

Technological Innovation and Industrial Evolution *- The Emergence of Industrial Networks*

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To Josefin and Amelie

FOREWORD

Two and a half years have passed and it is time to put down the pen or rather to save and quit. In the course of this inquiry into the nature of technological and social change, I have been through three technologies of writing: an ordinary ballpoint pen, an electric type-writer and finally I entered the micro-electronic age and shifted to a personal computer. If these technological shifts have had any significant, positive or negative, effect upon the quality of the work I cannot tell. They have certainly increased the cost of writing and the willingness to make changes. To a large extent I have changed my way of organizing the work. I have slowly adapted to the methods of word-processing and I have moved towards more and more sophisticated technology, yet when the writing gets difficult I sometimes go back to using the ballpoint pen. The outcome of the study would probably have been slightly different had I stayed with the original technology. I did however choose to wander in the garden of writing technologies and whatever route I would have taken, would have led me to a different end and there would be no path leading back.

The result of my endeavour to unravel the secrets of technological and social change has not only been affected by the technology used. A dissertation is a product of one doctoral student's struggle, which in its turn is a result of the social settings he or she is associated with. Or to use the words of Thomas Merton, "My successes are not my own. The way to them was prepared by others. The fruit of my labours is not my own: for I am preparing the way for the achievements of another. Nor are my failures my own. They may spring from the failures of another, but they are also compensated for by another's achievement."

A dissertation is not produced in a vacuum. And during the seven years of seemingly endless struggles a lot of help has been needed, which has been, generously, offered by friends and colleagues. My first thanks must naturally go to my family: my wife Gunilla without whom I would not have started the project in the first place, and my daughters Josefin and Amelie making all these years at least twice as dynamic. I am also deeply grateful to Lena Björklund and Staffan Hultén with whom I spent my first critical years as a doctoral student. Innumerable walks through Stockholm with Staffan have enabled

me to clarify the main points of my work and our continuous discussions have made it impossible to separate my own ideas from his.

My four advisors have enthusiastically guided me through the process, always encouraging me to proceed further. Professor Lars-Gunnar Mattsson, Stockholm School of Economics, prepared the road for me, provided good working conditions and has continuously been urging me to complete the work. Continuous discussions, debates and disputes with Docent Håkan Håkansson, Uppsala University, have taken me to a point well beyond what I thought possible. Professor Svante Lindqvist, Royal Institute for Technology, introduced me into the gardens of history of technology and he taught me the difference between being a doctoral student and writing the doctoral dissertation. Professor Bengt Stymne, Stockholm School of Economics, helped me clarify my thoughts by persistently raising the impertinent question: What, more specifically is your research question?

The Department of Marketing, Distribution and Industry Dynamics and the Economic Research Institute at the Stockholm School of Economics have provided an excellent environment for research and for writing a dissertation. Numerous research seminars and continuous private discussions have left me greatly indebted to several friends and fellow doctoral students: Per Andersson, Ann-Charlotte Edgren, Torbjörn Flink, Claes-Fredrik Helgesson, Susanne Hertz, Staffan Hultén, Dimitrios Ioannidis, Bengt Mölleryd, Anna Nyberg, Magnus Söderlund, Lena Wikström, Mats Vilgon, Susanne Östlund and other past and present colleagues at the department. The critique provided by Docent Bo Sellstedt is greatly appreciated. His comments has been most helpful in the completion of the thesis.

I have also had the pleasure of working intimately with the IM-group affiliated to Uppsala University and various discussions with past and present associates of the group, have provided many invaluable insights. I am especially grateful to Jens Laage-Hellman and Alexandra Waluszewski with whom I have had the opportunity to work more closely, in the field of technological change in industrial networks. My dear friend Jan Ottosson at the Department of Economic History at Uppsala University introduced me to social network analysis. The comments on my work provided by him and some of his fellow economic historians at seminar in Uppsala are greatly appreciated.

Parts of my work have been conducted at the Center for Economic Policy Research at Stanford University and I am deeply indebted to professor Nathan Rosenberg and professor Paul A. David for conveying the economic historian's view on technological

FOREWORD

change. The stay at Stanford University was made possible thanks to generous financial support from the Swedish National Board for Technical Development, L. Fränkels Stipendiefond and E. Hellströms Stipendiefond.

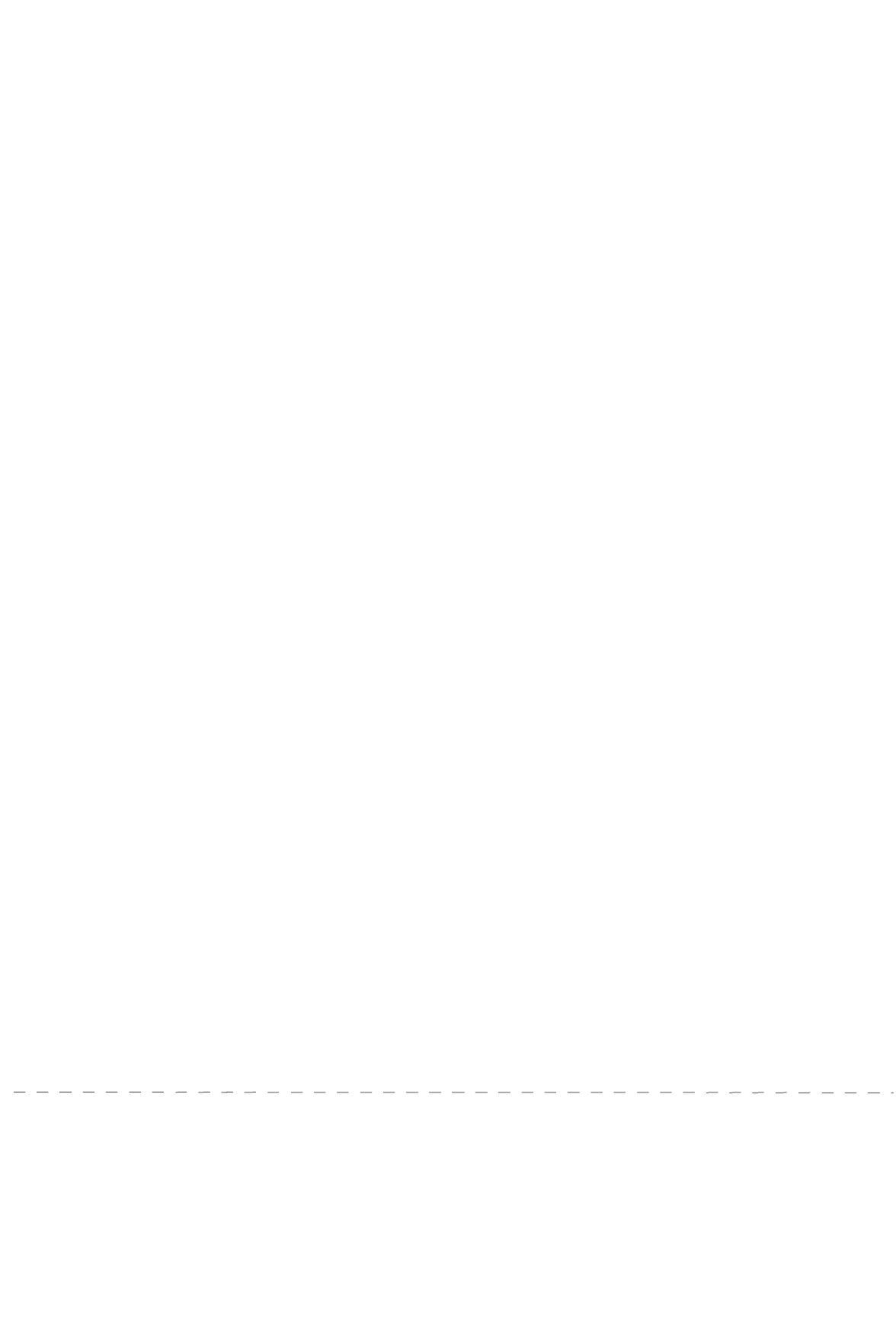
This thesis would not have been possible had it not been for all the scientists, researchers, public policy makers, and managers in Swedish image processing network generously supplying me with a wealth of information. Financial support from the Swedish National Board for Technical Development and the Swedish Council for Research in the Humanities and Social Sciences, have kept me alive and my study going for all these years.

Finally, I am greatly indebted to Rune Castenäs, the Director of the Economic Research Institute at Stockholm School of Economics for his incredible ability to identify and solve all kinds of problems and to Lennart Elg, the Swedish National Board for Technical Development, for always believing in me. Bill Harris of Professional Communications Skills at the Stockholm School of Economics helped me with my English. A very special last word of appreciation goes to Lena Wikström and Claes-Fredrik Helgesson for proof-reading the final manuscript and helping me with some of the figures and tables.

The technology used and the social context in which I have worked have led me down a specific path and in writing this thesis, this has made all the difference.

Anders Lundgren

Stockholm in November 1991



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Part I

SETTING THE STAGE

In this part the stage will be set for the study of the emergence of an image processing network in Sweden. We begin with stating the issues and continue with a brief introduction to digital image technology and the context in which it has been developed.

Chapter 1

INTRODUCTION

Every study can be conceived as a journey into the unknown. You start off somewhere and hope to end up somewhere else, having accumulated new knowledge along the way. I entered this specific journey intrigued by modern society's and Sweden's capacity of resurrection and change, constantly turning out new gadgets, carried by new technologies and new firms. Some extremely successful, such as cellular phones and automobiles, others less so, like picture phones and plastic bicycles. Yet, in all the dynamics and changes there was an apparent stability. We could all read about the paperless, electronic, office, but few of us if any had yet experienced it. In this paradox of change and stability, I set out to study technological and industrial change. What were the needs and possibilities in developing a high-technology industry in a small country like Sweden?

This study was embarked upon through the raising of one specific issue. How could we understand the birth of a new industrial network and what were the forces propelling the birth process. Research into the nature of corporate action in industrial networks had been under way for several years. Some reports had already been published¹, while others were yet to be completed². The main thrust of the work was that individual and corporate actions were perceived as being embedded in an economic, social and technical structure labeled industrial networks. The focus was thus upon the interrelationships between firms and between the actions undertaken by these firms. The successful completion of the first research ventures and the perceived potential of the new perspective on economic organization were transformed into a substantial research program - "Marketing and Competitiveness" - revolving around the general theme - industrial networks.

¹ Two of the first books on industrial networks were; Hammarkvist, K-O., Håkansson, H. and Mattsson, L-G., Marknadsföring för konkurrenskraft, Malmö: Liber Förlag, 1982 and Hägg, I. and Johanson, J., (eds.) Företag i nätverk, Stockholm: SNS, 1982.

² Two studies associated with the pioneering years in the development of the network perspective were; Benndorf, H., Marknadsföringsplanering och samordning mellan företag i industriella system, Stockholm: Stockholm School of Economics, 1987 and Liljegren, G., Interdependens och dynamik i långsiktiga kundrelationer - Industriell försäljning i ett nätverksperspektiv, Stockholm: Stockholm School of Economics, 1988.

The empirical focus in the research program as well as in the earlier studies was on traditional Swedish industries; mechanical engineering, steel, paper and pulp and construction. Within the group supervizing the program it was considered necessary to complement the studies of corporate action in existing networks with a study of the birth of a new network. Several possible arenas for the study were suggested. The final choice of the object of the study fell in favour of computerized image processing, which was the suggested arena least attached to traditional Swedish industries. The study of technological innovation and the birth of a new industrial network did not only fit excellently into the research program. It was also a continuation of a long tradition of inquiries into the nature of industries and into the nature of innovation or product development.³

Three Paths of Inquiry

A new industrial network, that is a new economic, social and technical structure in which corporate action is embedded, does not emerge in a vacuum. Already at the outset the birth of a network was associated with the development of new technologies. As scientific research seemed to be of increasing importance in the generation of new technologies the relationship between scientific research and industrial production was considered to be critical in the birth of a new network. Thus the birth of a new network was perceived as being comprised of three interrelated processes: the emergence of a new technology, the emergence of a new industrial network and the transformation of scientific discovery into industrial production. Consequently, the journey into the birth of a new network was pursued along three different paths of inquiry, asking three questions related to the development of image processing technology in Sweden: What was behind the emergence of a new technology? What was behind the emergence of new industries? What was the nature of the transformation of scientific discovery into industrial production? Let us now re-enter the journey onto the paths of inquiry into digital image processing in Sweden.

³ In the seventies three doctoral dissertations focusing differently on new products were presented at the Marketing department at the Stockholm School of Economics; Valdelin, J., Produktutveckling och marknadsföring, Stockholm: Stockholm School of Economics, 1974; Brodin, B., Produktutvecklingsprocesser, Stockholm: Stockholm School of Economics, 1976 and Hammarkvist, K-O., Köpprocessen för nya produkter på byggmarknaden, Stockholm: Stockholm School of Economics, 1976. The two first studies represent only minor deviations from the contemporary marketing view on product development. The third study is in this sense much more interesting in that it looks at new products in a larger context, where the adoption of new products is primarily explained by the product's degree of dependency on a system and the interdependencies of the social system of adopters.

Digital Image Processing - The Emergence of a New Technology

Can machines be brought to see? Vision is one of the distinctive marks of human intelligence. Can the capability of processing image information be mimicked in the development of the mechanized world? Apparently, this is the case: the development within optics and electronics, television and computer technology have prompted a development of machine vision and computers are increasingly being used to process information contained in natural images. The first tottering attempts, in the fifties and sixties, to use computers to analyze image data headed off a development of a new technology for computerized image processing. The new technology, machine vision, computerized image processing, digital image technology or whatever we choose to call it, unfolded alongside the development of television and computer technology and, in the eighties, artifacts of the new technology; general image processing computers, robotic vision systems, digital image transmitters and others, were increasingly becoming commercially available.

Machine vision is not yet, and will perhaps never become, as general as human vision. Digital image processing is, however, a multi-purpose technology in that it stretches over several applications, from industrial automation to radiology. On the supply side digital image technology is a combination of several interrelated technologies and on the user side it is applied in wide variety of fields. This suggests that instead of perceiving digital image technology, or any other technology for that matter, as an isolated well-defined entity, we should recognize that technologies are interrelated with other technologies into technological systems. Any inquiry into the emergence of new technologies should thus not be focused upon individual innovations, but on the origination and evolution of technological systems.

The pursuit of science, research and development undertaken by public institutions and private firms together with public policy concurred in the origination and establishing of digital image technology in Sweden. And Sweden have established a remarkably prominent position in the international research and development related digital image technology. Remarkably, in the light of the size of the Swedish economy and industry and in light of the fact that digital image processing was developed simultaneously as the Swedish national computer industry declined. The technological achievements in digital image processing have, however, not yet been transformed into an equally successful commercialization of the technology.

The emergence and evolution of new technologies is an intriguing issue. What are the forces behind the emergence of technologies? What are the the preconditions for

technological innovation and how are innovations interrelated? Why has Sweden been especially successful in the development of digital image technology and why has this technological success not been transformed into a commercial success? Behind these questions lies the more intricate problem of the emergence and establishment of new technologies and industries, specifically in small or mid-size economies.

The Swedish Image Processing Network - The Emergence of a New Industry Structure

Technologies or technological systems are not autonomous. Behind the development of any technology lies endless human endeavour of technological innovation and social and economic organization. Prevalent technologies have thus become embedded in and inseparable from the social and economic structures fostering and sustaining them. The prevalent order have evolved over decades: revealing complex sets of flows of resources and specialized capabilities and abilities. The emergence of a new technology requires the development of new capabilities and abilities and the reorganization of the pre-existing flow of resources. Technological change and social and economic reorganization are two sides of the same coin and we cannot have one without the other. In the emergence of a new technology not only innovators and manufacturers are required, but most often also suppliers, users, distributors and others combined in organized networks of functions, activities and actors. Transforming technological innovation into economic production requires the interconnection of several industrial activities encompassing a whole industrial network from the supply of inputs, necessary manufacturing or assembling facilities, distribution and marketing capabilities to the use or consumption of the new technology by the end-user. Some of these activities or functions can be facilitated by actors within the local market, but for other activities the network must be extended to distant markets. The emergence and evolution of a new technology must thus be accompanied or preceded by an emerging and evolving industrial network connecting the supply and the demand side facilitating the development, production and application of the new technology.

Swedish actors, acting and interacting to solve everyday problems spurred not only the emergence of digital image technology, but also the establishment of new relationships, connecting the proponents of the new technology: moulding a new industrial network. As the problems encountered by individual actors shifted, they developed relationships with other actors resulting in changes in the emergent network.

The rise of new industrial structures is most often associated with the emergence of new technologies. Yet, apart from Schumpeter's notion that new technologies would be pre-

dominantly fostered by new entrepreneurial firms we know little about the birth of new industries or industrial networks. What are the forces provoking the emergence of a new institutional structure, a new industrial network? To answer this question we must study the intricate relationships between the emergence of new technologies and new industrial structures and between the micro level acts of individual inventors and entrepreneurs and the macro level social, economic and/or technological development.

Digital Image Technology - Transforming Scientific Research into Industrial Production

The linkage between scientific research, technological development and industrial production is neither as straightforward as common logic might suggest nor as strong as it, perhaps, objectively should be.⁴ Science and technology as we know them today did not originate from the same set of circumstances. Technological development has primarily been motivated by the solving of problems of economic production, while the growth of scientific knowledge primarily have been motivated by non-economic factors. The linkage between science and technology has at best been weak and the evolving institutional structures for that of scientific research and technological development are markedly different. The relationship between science, technology and industrial innovation has, however, not remained static. Over time it has changed character, generally drifting towards increasing integration. And lately, from World War II and onwards, the emergence and development of computer technology and biotechnology and the revitalization within telecommunications reveals a closing of the gap between scientific discovery and industrial innovation. Science is increasingly at the service of economic production and the translation of scientific discovery into industrial innovation and economic production is a problem attracting more and more interest. Needless to say, the progress of scientific knowledge has not become solely dependent upon economic variables.

Digital image processing bears the marks of modern technology in that it predominantly emerged, at institutions of science all over the western world, as solutions to specific problems often unrelated to the economic sphere. Even though some well-established private firms took interest in the development of automatic image analysis, the quest for the new technology was primarily pursued within military research institutions and by university based researchers. In Sweden, university based research played a critical role in the fostering of digital image technology and by establishing new firms the scientists

⁴ For an excellent review of the relationship between science, technology and economic growth see, Mowery, D. C. & Rosenberg, N., Technology and the Pursuit of Economic Growth, Cambridge: Cambridge University Press, 1989.

attempted to realize the economic potential of the new technology. Translating the results from scientific research into viable industrial innovations proved, however, to be much more problematic and costly than what the proponents and supporters of digital image processing had anticipated when the first firms were established.

Transforming scientific discovery into economic productivity: bridging the gap between scientific research and industrial innovation, between two different institutional structures, seems to pose specific problems in the emergence and evolution of a new technology. Even though several authors dedicated their lives to unravelling the secrets behind technological development and economic change, much remains to be learned. Despite the number of studies in this field our knowledge is still limited. And the question we must put forward is: What is the nature of the relationship between scientific research, technological development and economic change? To begin to answer this question we must first address the complexity of evolutionary processes and thus attain a better understanding of the interdependencies of the relationships between science, technology and industry. Rich, historical and contextual, empirical studies of the evolution of emerging technologies and industries are necessary if we are to achieve this.

Stating the Issue

We have here outlined an agenda for the study of emerging technologies and industries. It is apparent that the emergence and evolution of image processing in Sweden is a complex process with many faces representing most aspects of social progress. The three parallel processes sketched above the emergence of a technology, the emergence of an industrial network and the transformation of scientific discovery into industrial production are, but some of the puzzles contained in the birth of a new network.

The three paths of inquiry into the emergence of computerized image processing in Sweden have generated three broad research questions;

- 1. What are the forces behind the emergence of technologies?*
- 2. What are the forces provoking the emergence of a new institutional structure, a new network?*
- 3. What is the nature of the relationship between scientific research, technological development and economic change?*

The questions put forward are both broad and far-reaching. It would thus seem logical to treat them in isolation: the answering of each question, in its own right, requiring a major inquiry. Yet, the questions are interrelated: they are really complementary verses of the

same song. To answer one of them we must at least have tentative answers to the other two.

The fact that we are dealing with a highly complex problem should not prevent us from venturing into the matter. And instead of trying to simplify the problem as far as we can, which would be the natural way of conducting scientific inquiry, we must acknowledge the fact that this is a complex issue and only by retaining some of the complexity will we be able to increase our understanding of the complex problem. This implicitly suggests that some of the more important insights might arise in the interface between different facets of the problem. Scientific inquiry is, however, all about simplification and abstraction, at least when we proceed beyond pure description, but even though this must be featured in the inquiry as a whole, it does not necessarily have to pertain to how we approach the problem.

Nevertheless, studying the development of image processing in Sweden we need to narrow down the perspective to more specific problems. Using non-neoclassical economic theory, predominantly theoretical economic history, history of technology and the growing field of network studies as focusing devices we are able to limit the analysis of emergence and evolution of digital image technology to a few more specific aspects of technological progress. And the three parallel lines of reasoning outlined above provide us with an intriguing set of interrelated research questions. Combined, they constitute the backbone on which this study is based.

The purpose of this study is twofold. Firstly we have an empirically oriented purpose to provide a comprehensive picture of the development of digital image processing in Sweden. Secondly, we have a theoretically oriented purpose to depict the complex interplay of the emergence of technologies and industrial networks in the transformation of scientific discovery into industrial production.

It is obvious from the above that we are addressing a complex set of interrelated issues. First of all we will depict the emergence of digital image technology in particular and secondly we will be interested in the emergence of technologies and industries in general. Given this context two basic problems of social progress are addressed. The main problem is the relationship between technological and industrial change: the relationship between the emergence and evolution of a new technological system and the emergence and evolution of a new industrial network. Enclosed in this problem is the enigma of translating scientific discovery into technological innovation and industrial production, a

theme characteristic of post-World War II industrial evolution, and the second problem addressed in this study.

The specific focus of the study is motivated partly by the potential implications for the formulation of theoretical propositions regarding technological development and industrial change and partly by its practical implications for the formulation of public and business policies towards the support and the pursuit of technological development. Despite numerous studies of technological change we are still surprised by the poor performance of research and development, when it comes to its impact upon the present state of affairs. It most often takes much longer and is much more costly to develop new technologies than expected. This gap between the stylized facts of our knowledge of technological and industrial change and the observed outcome suggests that we still have much more to learn regarding the process of technological development and industrial change

Knowledge of the relationship between technological and industrial change in the transformation of scientific discovery into economic production can be essential in the formulation of future public policy towards the support of technological development and commercialization of new technology. The study can produce insights into the crucial issue of the balance between the support of every venture into technology and only the most prosperous ones. And by relating technological innovation to industrial evolution it will possible to discuss, not only, who or what should be supported and when, but also to elaborate on the organization of the support. For business firms and other individual actors promoting or pursuing the development of new technologies this study provides a new perspective on research and business strategies in that it connects the acts of individual actors with changes in the overall industrial structure.

Structure of the Book

We have by now set the scope of this inquiry into the emergence of new technologies and new industrial structures. The structure of the remainder of the book is borrowed from the gestalt theory of invention suggested by Abbott Payson Usher in his delineation of the process of cumulative synthesis.⁵ The book is accordingly divided into four parts; Setting the Stage, Act of Insight, Novelty in Thought and Action - The Emergence of Digital Image Processing in Sweden and Critical Revision of the Emerging Pattern. In the remaining two chapters of Part One we set the stage for our inquiry into the emergence of

⁵ Usher delineates the process of cumulative synthesis as the sequential order of perception of an incomplete pattern, the setting of the stage, the act of insight and critical revision and full mastery of the new pattern. Usher, A., P., *A History of Mechanical Inventions*, Rev. Ed., New York: Dover Publ. Inc. 1982. pp. 57 - 83.

image processing in Sweden. In chapter 2 image processing and the preconditions from which it emerged is presented. The chapter continues with an overview of the relationship between research and development and industrial production in Sweden and it is concluded with some notes on data.

As we endure the hardship of our journeys we encounter others, travelling in similar directions gladly sharing their experiences. Part Two contains the act of theoretical insight, provided by the predecessors and contemporaries on the paths of inquiry into the nature of technological change and industrial evolution. Part Two consists of three chapters expressing the general perspectives underlying this study and the particular model generated by it. Chapter 3 exhibits perspectives on technology and industry and knowledge. In Chapter 4 I argue for the necessity of setting technological change and industrial evolution in the context of time and place. This chapter is closed with a discussion of the particular method of historical analysis employed in the study. Chapter 5, the final chapter of Part Two, outlines a network perspective on technological change and contains a framework for understanding the emergence of a new technology and a new industrial network.

Part Three is comprised of chapters 6 through 8 and it is an account of the emergence and evolution of digital image technology and of the rise of an image processing network in Sweden. In chapter 6 the genesis of digital image technology and the image processing network is presented. Chapter 7 presents the formation years and in chapter 8 the establishing of the new technology is presented. The conclusions of our journey and the knowledge we have accumulated along the way is presented in the final Part. Here chapter 9 features some concluding remarks on the emergence of digital image processing in Sweden and finally in chapter 10 we will take the study one step further, presenting some more general findings.

The overall structure of the book is depicted in figure 1 on the next page.

Digital Image Technology

Digital image technology is a multi-purpose technology emanating from the progress within a combination of technologies, especially, computer science and telecommunication. Image processing makes automatic processing of images possible. It differs from computer graphics in that it deals with natural images.¹ The technology originated in the early sixties in the shape of optical character recognition, computer tomography, picture phones, scientific instruments and remote sensing for military intelligence. The basic problem solved was the reading of images into the computer. In the seventies special image computers were developed capable of processing the huge amount of data contained in images. During the eighties commercial applications of digital image processing became more readily available. The most common areas where image processing is applied extensively are; remote sensing, especially for military intelligence; cartography and meteorology; industrial automation, inspection and control in automated production and robotic vision; desk top publishing, electronic darkrooms and image archives; medicine, radiology and cytology. Image processing computers are also used as general scientific instruments to analyze different kinds of images. Furthermore, the technology is becoming increasingly important in modern image transmission.

The basic components of digital image technology are depicted in figure 1 below. In general, an image processing system consists of an image reading instrument, a computer and an output unit. Within this general system we can observe a high degree of variation. The image reading instrument can be both analog and digital, varying from a video camera to nuclear magnetic resonance. The output can be produced as; a yes/no decision, an instruction to an industrial robot or as a digitally processed image. The computer, performing the actual image processing, connecting input and output can be anything from personal to specialized image processing computers. Four basic technological problems of digital image processing can be identified. Firstly, the images must be digital or converted from analog to digital. Secondly, the output must be adapted the specific application. Thirdly, as the information content in an image by far exceeds the information content in symbols, image processing requires much faster computers with larger memory than what is offered by ordinary computers. Fourthly, these three parts must be integrated into a well functioning system.

¹ For a thorough description of digital image technology see for instance, Dyring, E., Nolla etta bild - Den nya bildrevolutionen, Stockholm: Prisma, 1984. and Davies, D., Bathurst, D. & Bathurst, R., The Telling Image - The Changing Balance Between Pictures and Words in a Technological Age, Oxford: Clarendon Press, 1990. For a discussion of one specific application of the technology, machine vision, see, Zuech, N. & Miller, R. K., Machine Vision, New York: van Nostrand Reinhold, 1989.

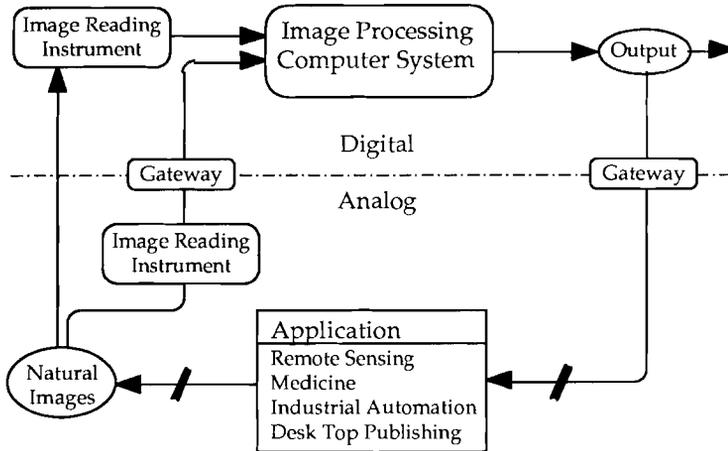


Figure 2: Schematic representation of digital image technology.

Around this general description of digital image technology we are likely to find a high degree of variation; from a general image processing system, to very specific applications of the technology.

Digital Image Technology - Characterization of the Innovation

How, then, can digital image technology be characterized as innovation? Christopher Freeman and Carlota Perez distinguish between four different types of innovation;²

1. Incremental innovations, which occur more or less continuously in any industry.
2. Radical innovations, which are discontinuous events unattainable through incremental adjustments of the pre-existing state of affairs.
3. New technological systems, which are far-reaching changes in technology affecting several branches of the economy.
4. New techno-economic paradigms, technological revolutions, which are so far-reaching in their effects that they have a major influence on the behaviour of the entire economy.

This taxonomy of innovation suggested by Freeman and Perez rests upon the characterization of innovation along two dimensions, the scale and scope of the technological change. In the scope of innovation they distinguish between minor and

² Freeman, C. and Perez, C., Structural Crises of Adjustment, Business Cycles and Investment Behaviour. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G. & Soete, L., (eds.) Technical Change and Economic Theory, London: Pinters Publishers, pp. 38 - 66, 1988. pp. 45 - 47.

major changes and in the scale of innovation they distinguish between single innovations and interrelated clusters of innovations. If we combine these two dimensions of innovations we end up with the following representation, figure 2, of the Freeman and Perez taxonomy of innovation.

		The Scope of Innovation	
		Minor Changes	Major Changes
The Scale of Innovation	Interrelated Clusters of Innovation	Changes of the Technological systems	Technological Revolutions
	Single Innovations	Incremental Innovations	Radical Innovations

Figure 3: Graphical representation of a taxonomy of innovation.

The classes of innovation are obviously neither independent nor mutually exclusive. An interdependence of minor and major changes can hardly be denied. Major changes are often induced through the accumulation of minor changes and minor adjustments following radical changes can often be necessary to increase the economic efficiency of the radical innovation. Furthermore, a hierarchical order of innovation can be detected: technological revolutions are made up by several new technological systems, which in their turn are made up of series of radical and incremental innovations. Nevertheless, the taxonomy can serve as a guide-line in the characterization of digital image technology.

Digital image processing is not confined to one isolated technology. It is comprised of a combination of technologies, computer technology, electronics, telecommunications, and others moulded into a technological system of interconnected technologies. The present state of the development of image processing does not result from the work of a single heroic inventor or from a single grand invention. True, some innovations and the deeds of some great men stand out as being pioneering contributions; the work at MIT on perceptrons and on parallel processor computer architecture; the development, at Bell Laboratories, of light sensitive semiconductors; the work of Godfrey Newbold Hounsfield on computer aided tomography and, finally, we can mention the development of magnetic resonance imaging technology. But, more importantly, behind these more spectacular contributions, we can find series of small interrelated innovations produced by individual actors in different countries and industries. As these actors extended the

frontiers of digital image processing, they paired with other proponents of the technology, not randomly or according to the pre-existing structures, but according to the emerging logic of the new technological system. This new technological system, digital image technology, is also reaching out towards other technological systems, such as radiology, industrial automation, graphic production and geographic information systems. Together the emergence of digital image technology, the furtherance of electronics and computer technology and the changes in traditional technological systems coincide in "the battle of the systems" between digital and analog technology.

In summing up we can, therefore, characterize the emergence of digital image technology as being a new technological system comprised of series of radical and incremental innovations. The new technological system is, however, also a significant part of a technological revolution - the battle of the systems between digital and analog image technology.

Examining some of Preconditions for the Development Digital Image Technology in Sweden

In the previous chapter it was argued that digital image technology bore the marks of modern technology in that it predominantly emerged as a result of the pursuit scientific research at public institutions. Here we will take a cursory view of the history of the Swedish national system of innovation from which digital image technology emerged.

Swedes with an interest in industrial progress often take pride in putting forward the frontline position in technology of Swedish industry. Axel F. Enström once wrote; "It is said, and it is true, that Swedes in general have a pronounced technical and mechanical bent. In other words, technical ability is one of the important natural resources upon which the nation can rely in its struggle for life. This gift for mechanics in the people is supposed to be the result of centuries of development, inasmuch as from ancient times the people have been accustomed to get their daily bread from tilling a poor soil. This bent is traditional, and traditional also is the endeavour to foster and train it"³

Enström based his admiration for the Swedish technical ability upon several observations and if we take them in chronological order they begin with the eighteenth century instigation of institutions - the Royal Academy of Science (1739) and the Ironmaster's Association (1747) - for the fostering of science, development and trade. The establishing of engineering schools and specialized laboratories in the beginning of the nineteenth

³ The Federation of Swedish Industry, Stockholm, *Industry in Sweden*, Uppsala: Almqvist & Wicksell Boktryckeri AB, 1928. p. 68.

century were taken as further evidence of the Swedish tradition to foster and train the technical ability. But the observation that probably stroke him as most important was the seemingly close relationship between inventive activities and industrial development at the turn of the century. Many of the current leaders⁴ in Swedish industry were established at or before the turn of the twentieth century. The establishment of the firms have to a large extent been associated with the eighteenth century Swedish inventors and their heroic deeds.⁵ These firms did not, however, thrive on a single innovation, but on continuous streams of radical and incremental innovation. Thus, the major source of innovation shifted from independent inventors to organized research and development. Lately in the history of western civilization the pursuit of scientific research has become of increasing importance in the generation of innovation.

The question is if Sweden's technical tradition is something unique and if so, if it have been able to sustain this alleged comparative advantage in technical ability. Does the pattern of industrial development in Sweden diverge from those of other similar countries? Probably not! The instigations of academies of science and engineering schools are parallel to many other countries and most western countries exhibit an industrial development, with a close relationship between innovation and entrepreneurial activity, equal to the Swedish case. Also the shift from independent inventors, to organized research development and scientific research as the sources of innovation seem to be a general phenomenon. Simon Kuznets has stated that; "The epochal innovation that distinguishes the modern economic epoch is the extended application of science to problems of economic production."⁶ Hence, the industrial development in Sweden is not unparalleled; other countries exhibits similar patterns.

Yet, compared to the size of the Swedish economy, the nation's industry has accrued a very strong position on the international scene. Maybe it is true that Sweden's most

⁴ Atlas Copco 1873, Ericsson 1876, ABB 1883, Alfa-Laval 1883, Stal-Laval 1893, AGA 1904 and SKF 1907 are some of the firms dominating Swedish industry established at the turn of the century. Hult, J., Lindkvist, S., Odelberg, W. and Rydberg, S., *Svensk teknikhistoria*, Hedemora: Gidlunds Bokförlag, 1989. p. 244.

⁵ Some of the inventors and the firms associated to their names are presented in the table below.

Gustaf Dalén	1869 - 1937	AGA
Gustaf de Laval	1845 - 1913	Stal-Laval
Lars Magnus Ericsson	1846 - 1926	Ericsson
Alfred Nobel	1833 - 1896	Nobel Industries
Jonas Wenström	1855 - 1893	ABB
Sven Wingquist	1876 - 1953	SKF

Source: Ibid, p. 245.

⁶ Kuznets, S., *Modern Economic Growth*, New Haven: Yale University Press, 1966. p 9.

important natural resource is technical ability. The current relationship between investments in research and development and productivity growth does, however, indicate some problems in the Swedish system. In the eighties Sweden was one of the leading countries with regard to expenditure on research and development, nonetheless Sweden's measured growth in productivity is one of the lowest among the OECD-countries. In tables 1 and 2, Swedish expenditure on research and development and its productivity is compared with some other countries. Note, however, that the tables cover different periods of time.

1975			1981			1985		
1	United States	2,3	1	United States	2,4	1	United States	2,8
2	Germany	2,2		Germany	2,4		Japan	2,8
	United Kingdom	2,2		United Kingdom	2,4		Sweden	2,8
4	Japan	2,0	4	Japan	2,3	4	Germany	2,7
	Netherlands	2,0	5	Sweden	2,2	5	France	2,3
6	France	1,8	6	France	2,0		United Kingdom	2,3
7	Sweden	1,7		Netherlands	2,0	7	Netherlands	2,1
8	Norway	1,3	8	Norway	1,3	8	Norway	1,6
	Belgium	1,3	9	Canada	1,2	9	Canada	1,4
10	Canada	1,1	10	Denmark	1,1	10	Denmark	1,2
11	Denmark	1,0	11	Italy	0,9	11	Italy	1,1
12	Italy	0,8	-	Belgium	n.a.	-	Belgium	n.a.

Table 1: Gross domestic expenditure on R&D as a percentage of Gross Domestic Product
Source: *OECD Science and Technology Indicators Report, no 3, 1989, R&D, Production and Diffusion of Technology, OECD, Paris*

1960-70			1970-80			1980-90		
1	Japan	10,8	1	Belgium	7,0	1	United Kingdom	5,4
2	Netherlands	7,1	2	Japan	6,6	2	Japan	5,3
3	Sweden	6,7	3	Netherlands	6,0	3	Belgium	4,9
	France	6,7	4	Italy	5,9	4	Netherlands	4,0
5	Italy	6,5	5	Denmark	5,6	5	Italy	3,9
6	Belgium	6,2	6	France	4,5	6	France	3,7
7	Germany	5,9	7	Germany	4,1	7	Norway	3,6
8	Denmark	5,8	8	Sweden	3,5	8	Sweden	3,2
9	Norway	4,1	9	Canada	2,7	9	United States	2,6
	Canada	4,1	10	Norway	2,6	10	Canada	2,5
11	United Kingdom	3,7	11	United Kingdom	2,5	11	Germany	2,3
12	United States	2,8	12	United States	2,4	12	Denmark	1,0

Table 2: Productivity in Swedish industry compared with other countries 1960-1989
Increase in production per labour hour, yearly average

Source: *SOU 1991:82, Produktivitetsdelegationens betänkande, Stockholm. Allmänna förlaget, 1991*

The only way by which the investments in research and development are reflected in foreign trade is an increase in Sweden's net exports of licences. In fact, Sweden exhibits

consistent signs of a problem in its ability to appropriate the investments in research and development in domestic production and exports of advanced products.⁷ Swedish industry's strength is in some traditional industries; metals/materials, forest products, transportation, power generation and distribution and telecommunications,⁸ while its position in fast-growing high technologies, like computer technology is declining.⁹ This implies that the export channels for advanced electronic products are deteriorating.

Lately, Swedish industry has, often been characterized as being immobile and incapable of entering high technology areas. The absence of a nationally based electronics and computer industry is often perceived as especially problematic and efforts have been made to overcome this problem. These efforts¹⁰ have so far not been successful in that they have neither been appropriated in terms of industrial production, nor have they had significant indirect effects on the dynamics of Swedish industry.¹¹

The problems of appropriating the investments in research and development, and technical ability, do, however, not necessarily suggest anything regarding the quality of the research and development or regarding the technical ability as such.

What was the nature of the technical capabilities in Sweden in the fields from which digital image technology emerged. Sweden held a strong position in the development and construction of mechanical calculators, predecessors to the first computers. In the pioneering years of the development of computer technology the strength in mechanical engineering was transformed to emerging capabilities in computer technology. When the news of the first electronic calculators reached Sweden a group was sent to the USA to study the development of computers. After this, the interest in computing machines was shortly formalized in an institution for the furtherance of Swedish computing capability, "Matematikmaskinnämnden" (the board for calculating machines). Attempts to acquire an

⁷ Ohlsson, L. and Vinell, L., Tillväxtens drivkrafter - En studie av industriens framtidsvillkor, Stockholm: Industriförbundets Förlag, 1987.

⁸ Sölvell, Ö., Zander, I. and Porter, M. E., Advantage Sweden, Stockholm: Norstedts Bokförlag, 1991. pp. 59 - 60. The authors also include heterogeneous cluster of civil engineering products, centrifugal pumps, gas related equipment etc., which they label multiple business.

⁹ Hultén, S., Vad bestämmer de svenska exportmarknadsandelarnas utveckling, Stockholm: Stockholm School of Economics, 1988. pp. 115 - 117.

¹⁰ Two major national efforts to enhance Sweden's position in high technology are the development of a Swedish fighter aeroplane and the information technology program, modelled after the Japanese national programs.

¹¹ See for instance; Ny Teknik, *Teknisk Tidskrift*, 1991:5, pp. 16 - 21 and Ny Teknik, *Teknisk Tidskrift*, 1991:6, pp. 14 - 17.

electronic calculator from the USA were futile; American export laws prohibited export of products of strategic importance. Consequently, machines had to be constructed in Sweden and Matematikmaskinnämnden supported and supervised the construction of several electronic calculators in Sweden. The most important of the first computers was a machine called BESK completed in 1953. For a short while BESK was the fastest electronic calculator in the world. BESK was used both in research and in the solving of practical industrial problems. BESK was followed by the construction of other machines at universities and in industry. Even though the first machines to a large extent were copies of their American ancestors, they also contained solutions and components developed through independent Swedish research.¹²

In the late fifties the ability to construct calculating machines was transformed to industrial production, two large Swedish corporations, Saab, at first primarily for internal needs and Facit AB ventured forth to exploit the emerging capabilities in computer technology commercially. Matematikmaskinnämnden had played its role well, and, now it was dissolving, the majority of the committee continued their work at Facit, some went to Ericsson and others followed the committee as it was transformed into another public institution. Alongside Saab and Facit a third firm, Standard Radio and Telefon AB - SRT AB, also struggled to exploit the emerging technology. The endeavours were not major victories but were not without their successes. The firms were, however, burdened by insufficient economic performance.

Gradually Swedish efforts in computer technology became concentrated to one firm, Datasaab. In 1971 Saab and the Swedish State acquired SRT AB and renamed the company Stansaab. In 1974 Saab acquired Facit's computer electronics division and, finally, in 1978 Saab's computer division and Stansaab were merged with Datasaab. In 1981 Datasaab was acquired by Ericsson and integrated with their efforts to build a position in integrated information systems. The effort proved to be a disaster and it threatened Ericsson's well established position in telecommunications. In January 1988 Ericsson sold the computer division to the Finnish conglomerate Nokia: the Swedish effort to establish a national computer industry had come to an end.

The indirect effects of the efforts in computer technology were also limited. No internationally competitive support industries, like electronics, emerged. A parallel story can be found in the development of television technology in Sweden. Initially, strong

¹² The section on computer technology in Sweden is primarily based upon; Lund, J., *Från kula till data*, Värnamo: Gidlunds Förlag, 1988. pp. 99 - 118.

technological positions for Swedish industry were not transformed into lasting commercial successes. Of the industries mentioned only in telecommunications has Sweden been able to hold and develop an internationally competitive position.

Computer Technology - An International Perspective

Even if the national Swedish computer industry was exhibiting problems and slowly dissolving, the international computer industry took automatic computation to new areas of application and to new technological heights. Electronic components, computers and other electronic products have become better, faster and cheaper. And apart from some defence motivated trade barriers, electronic components have been freely available on the international market. In digital image technology the critical factors are memory and processor capacity. Figure 4 below, depicts the development of these critical factors.

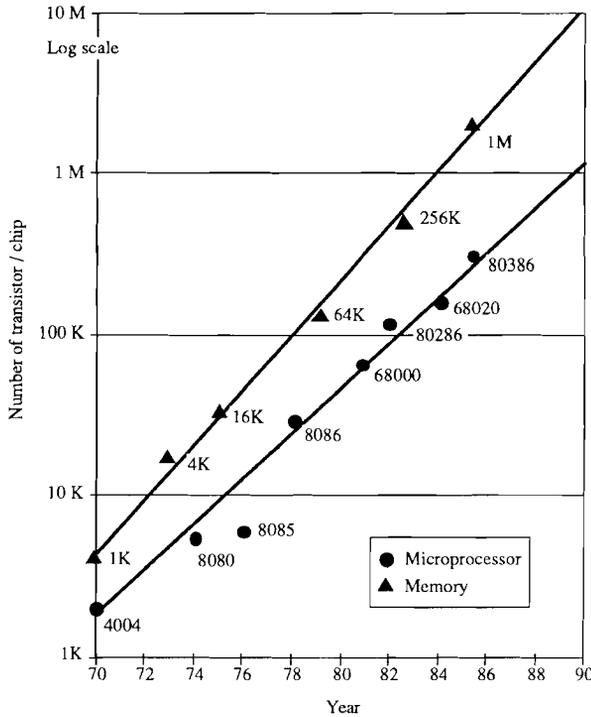


Figure 4: The evolution of memory and microprocessor capacity.
 Source: OECD. *Information Computer Communications Policy: 20, Major R&D Programmes for Information Technology*, Paris, 1989.

The evolution of memory and processor capacity have in their turn pushed the development of performance of computer technology and the cost of computation has

been lowered significantly. The decrease of computing cost is exhibited in figure 5 below.

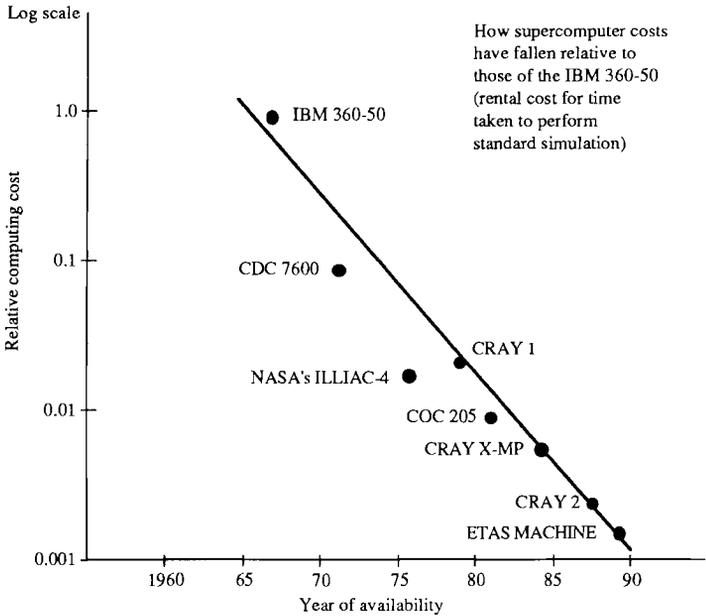


Figure 5: Relative computing cost.

Source: OECD. *Information Computer Communications Policy: 20, Major R&D Programmes for Information Technology*, Paris, 1989.

Finally, the performance of computer technology is to some extent contingent on the computer architecture applied. The traditional von Neumann architecture with sequential dataprocessing seem to be approaching its limit. But by shifting to a computer architecture¹³ involving parallel processing new avenues of performance will be opened. The performance of sequential and parallel dataprocessing architectures are compared in figure 6 on the next page.

¹³ In sense parallel dataprocessing does not signify a major break with respect to the computer architecture suggested by von Neumann. The only really non-von Neumann-architecture explored is neural networks.

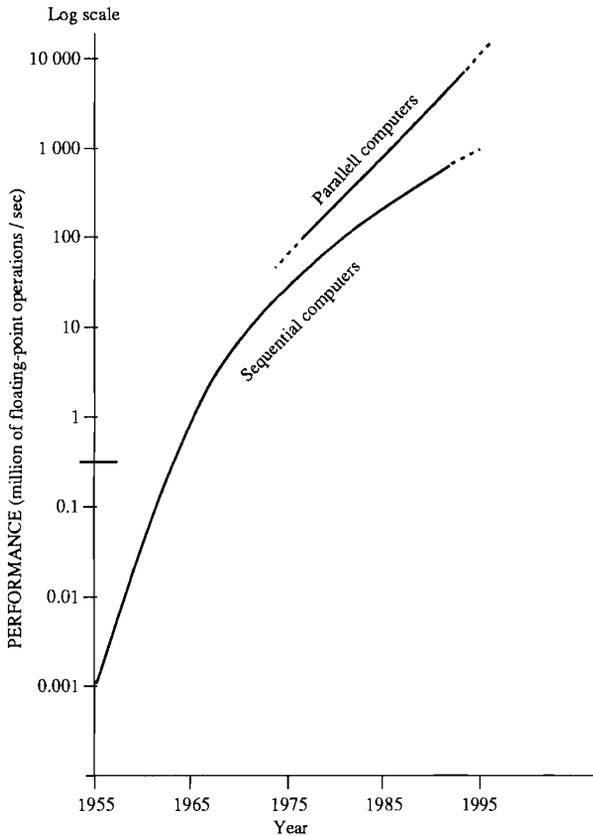


Figure 6: The performance of sequential and parallel dataprocessing compared.

Source: *OECD. Information Computer Communications Policy: 20, Major R&D Programmes for Information Technology, Paris, 1989.*

We have now in some way set the stage in which digital image technology emerged. We will continue depicting the emergence and evolution of image processing in Sweden in chapters 6 through 8. Before we proceed with a theoretical discussion of the relationship between technology and industry let us make some notes regarding data.

Some Notes on Data

A general problem in this kind of study is the scarcity of adequate data consistent with the perspective in focus. Another major problem is the absence of a congruent understanding of the field to be the object of research, here digital image processing. An initial effort had, therefore, to be made establishing an operational definition of the technology and identifying the participating actors.

The scarcity of consistent data implied that a major part of data had to be collected through personal interviews with the participating actors. History had to be invented. It was not just laying there ready to be explored. Interviews are always problematic: people tend to forget and to idealize. To some extent it has been possible to handle this problem by interviewing representatives of all the major actors. The fact that the evolution and development of image processing in Sweden has been followed from 1984 to 1990 has increased the possibilities of evaluating data. Data from interviews have also been compared with other sources research reports, travel reports, patent data, newspaper articles and corporate records and statements, when available. Remnants of the technological development blueprints and actual machines, have also been used to verify statements made in interviews.

The majority of the interviews were conducted during two periods; autumn 1984 and winter 1987/1988. As time wore on the availability of secondary sources increased, which enhanced the possibilities of evaluating the sources. From 1988 onwards the story of image processing in Sweden has predominantly been based upon secondary sources and contacts with the field through meetings.

Subjects for interviews were the directors of different research groups, predominantly university professors, presidents and research and development managers in image processing firms. In the first round, interviews were more unstructured consequently a tape-recorder was used. In the second round interviews were more structured and recording them was perceived as unnecessary. Protocols of the interviews were sent back to the interviewees for control and it is these controlled protocols that have been used as the major source to the case story presented in chapters 6 through 8. Interviewees and the interview guideline are exhibited in appendix 1.

The method of analysis is presented at the end of chapter 4. The description of the specific network analysis employed has been put in the footnotes. Appendix 2 to 4 reveal input data for the network analysis as well as the results from the analyses of individual actors and the analyses of the whole networks.

Part II

THE ACT OF INSIGHT

TECHNOLOGICAL AND INDUSTRIAL EVOLUTION - THEORETICAL PERSPECTIVES.

The aim of this part is twofolded. First of all the purpose is to lay the foundation upon which the study of the emergence of digital image technology in Sweden is based. Secondly and of equal importance, it provides the theoretical and methodological underpinnings of the work. Here we inquire into the nature of technological change and industrial dynamics. We head off by examining the nature of technology, industry and knowledge and continue arguing for the necessity of applying a contextual and historical perspective in studies of the relationship between technological and industrial evolution. The section is closed with a discussion of technological systems and industrial networks.

Chapter 3

PERSPECTIVES ON TECHNOLOGY AND INDUSTRY.

The predominant schools of thought in the social sciences are absorbed by the problem of how existing structures are administered. Whether or not we reviewed sociology, economics, business administration or other academic fields we would most certainly find that the majority of the studies are concerned with some aspect of the administration of the current state of affairs. Novelties, such as technological innovation, enter into these studies, primarily, in the shape of their impact on or consequences for pre-existing structures. Thus, social progress is primarily, viewed as a process of cumulative growth, where future structures are only extensions of the existing order. Yet, at least in hindsight, we are able to observe the existence of new structures; new technologies, new industries new social systems or new ideologies representing discontinuities in the evolution of the society. The origin and emergence of these new structures are rarely studied. This does not imply that an understanding of the emergence of new structures is unimportant in the study of progress. The general bias towards the study of the administration of older order and the implication of change upon pre-existing structures is not unwarranted. It is justified by its compelling importance in the progress of any system. But, the interdependence of the emergence of a new structure and its subsequent integration into the pre-existing structure justifies increased interest in the emergence of new structures, as a complement to more traditional perspectives.

After a discussion of the general relationship between technology and economics, the perspectives on technology and industry will be exposed, continuing on the three paths of inquiry set out in chapter one. We begin the search for insight by exploring the issues at hand, the forces behind the emergence of technologies, the forces provoking the emergence of new institutional structures and the nature of the link between science, technology and economics. Thus, the presentation will continue with a discussion of the nature of technological change. The focus of the discussion will then shift to the issue of industrial evolution and finally the relationship between science and technology will be discussed in terms of the nature of knowledge.

Technology and Economics.

In economics technological change is an obvious and significant novelty, shaping the future direction of economic production and consumption. Mainstream economics have,

however, shown very little interest in economic growth or its causes. Other problems were more pressing¹. The problem of economic growth had been at the heart of the thinking of the classical economists, but as time wore on, growth lost its grip on the attention and imagination of the growing body of mainstream economists². Yet some individuals and schools of thought gave close attention to some aspects of the problem. The German historians, the American institutionalists and the Marxists provided a critique of the economic performance under a capitalistic regime. Yet, others like Veblen, Weber and Schumpeter focused their efforts on explaining the forces behind industrial dynamics³.

The heritage of the classical economists was picked up much later by the early growth accountants of the fifties. They found that only a small fraction of measured productivity growth could be attributed to increased productivity of individual production factors or total input growth. Approximately 90 % was attributed to the advance of, the unidentified and unmeasured, total factor productivity⁴. Robert Solow labelled this unknown element, "technical change" and showed that it corresponded to shifts in the aggregate production function. In this way he generalized the neoclassical growth model. Moses Abramovitz called it "a measurement of our ignorance" and as it could not be measured it later became known as simply "the residual". The early growth accountants all carefully explained that the large unmeasured residual also included other components apart from technological change, such as education, economies of scale and better resource allocation⁵. Later studies have aimed at decomposing, attributing portions of total factor productivity to other measured components, and thus reducing the residual, but nonetheless approximately 50 % have remained unexplained and are attributed to the advance of knowledge or technological progress, an element still, very much, enclosed in ignorance.⁶

¹ Mainstream economics has very little to say with respect to economic growth or technological change, but on the other hand it has never purported to address these issues. The aim here is not to criticize mainstream economics, for an excellent review of the place of growth and change in mainstream economics see; Nelson, R. R., and Winter, S. G., An Evolutionary Theory of Economic Change. Cambridge, Mass.: Harvard University Press, 1982.

² Abramovitz, M., Thinking About Growth, New York: Cambridge University Press, 1989. p. 1.

³ Ibid, p. 80.

⁴ Two representatives for early growth accountants are; Abramovitz, M., Resource and Output Trends in the United States since 1870, American Economic Review, Papers and Proceedings, May 1956, pp. 5 - 23. and Solow, R., Technical Change and the Aggregate Production Function, Review of Economics and Statistics, Aug. 1957 pp. 312 - 320.

⁵ Abramovitz, Thinking About Growth, pp. 14 -15.

⁶ Ibid, p. 17.

Technology touches upon us all: We live in a mechanized world with complex interactions between man and the man-made world. Technological artifacts and methods of production have increasingly been applied to solve problems of everyday life and of economic production. Changes in the man-made world through technological development or innovation are considered as one of the most important dynamic forces behind the progress of our⁷ modern society.⁸ A quick look around will probably be sufficient to convince us that technology has an important role in shaping society. It was the perception of this importance of technology in industrial progress that rendered Torstein Veblen to state; "All industrial innovation and all aggressive economy in the conduct of industry not only presumes an insight into the technological details of the industrial process, but to any other than the technological experts, who know the facts intimately, any move of that kind will appear hazardous."⁹ Perhaps Veblen overstated the role of technological experts. But, nonetheless the impact of technology can hardly be denied in a society where automobiles, electric light, television, nuclear power stations, computers and other technological artifacts have become a dominating feature even of everyday life. And to lend the words of Abbot Payson Usher; "Broadly conceived, technology is an important part of the central core in the evolutionary process. It is an essential aspect of the accumulation of knowledge and the development of skills. It does not exhaust the field of the development of the mind, but it is a characteristic segment of the whole. ...In its own right, and as an aspect of the general process of innovation, technology has powerful claims upon our attention."¹⁰ The generation of technological change or innovation and the realization of these changes in the progress of society are some of the most intriguing issues in the study of economic growth. These issues are not addressed in the neoclassical growth model. The early growth accountants identified technical change as an important factor determining economic growth, but they, very much, left us in ignorance regarding the nature of this factor.

⁷ Our in this context refers to the western world.

⁸ Whether man is the master or slave of technology: whether technology is socially constructed or whether society is technologically determined is a complex issue of a philosophical nature. The issue will be addressed later, without any ambition to produce a conclusive answer. The perspective maintained throughout this work is, however, that technology evolves in interaction between social and technological systems.

⁹ Veblen, T., The Engineers and the Price System, New Brunswick: Transaction books, 1983. (Originally published in 1921) pp. 65 - 66.

¹⁰ Usher, A History of Mechanical Inventions, p. 2.

The critical issue has not been resolved. The advance of knowledge or technological change is a primary cause of long-term economic development¹¹ and our knowledge of the nature of technological change and its effect upon growth remains limited. The first modern economist to focus on the dynamics of economics was J. A. Schumpeter. He saw the capitalistic system as the engine of change and argued that population growth or technological change had a positive effect upon the interest rate and profits. If technology remained unchanged there would not be any profits encouraging entrepreneurial activities and in the circular flow of economic life the marginal product of capital would be driven down to zero. But this was not the circumstance that caught Schumpeter's attention. Unlike his contemporaries who mainly visualized the problem as how existing structures were administered,¹² Schumpeter saw the creation and destruction of structures as the relevant problem. As Marx had done before him, Schumpeter viewed the economy as an ever changing system. He introduced inventors and entrepreneurs, creating and realizing new combinations, threatening and eventually breaking pre-existing structures and thereby transforming the economy from one structure into another.¹³ According to Schumpeter social progress was not only a process of cumulative growth. It also embodied a fair number of revolutionary changes. He perceived the inventors and entrepreneurs as the engines of these revolutionary changes. The inventors and entrepreneurs were thought to be primarily but not solely motivated by and rewarded with extraordinary profits. The magnitude of these profits depends on the duration of the temporary monopoly created through the innovation. Perfect competition, on the other hand, excluded extraordinary profits and thus also the incentive to innovate. According to Schumpeter monopolistic competition is justified by its positive effect upon innovation. In Schumpeterian economics the process of creative destruction takes precedence over price competition. Technological competition is more compelling than price competition and the monopoly created by innovation is always temporary, constantly subject to the threat of creative destruction.

Another theorist who observed the close connection between technology and economy was the American institutionalist J. R. Commons. Discontent with contemporary economic theory, with the possible exception of the works of T. Veblen and H. D. Macleod, he set out to develop an economic theory of collective and individual activities,

¹¹ Rosenberg, N., Perspectives on Technology, Armonk, N.Y.: M. E. Sharpe Inc.,1976. p.61.

¹² Schumpeter, J. A., Capitalism, Socialism and Democracy, New York: Harper Torchbooks, 1975. p. 84

¹³ Schumpeter, J. A., The Theory of Economic Development, New Brunswick: Transaction Books,1983.

thus taking adequate account of the institutional elements of the economy¹⁴. Commons took a different stance than Schumpeter. His interest did not focus on the elements of the capitalistic regime, profits and rents, but on the elements of institutional regimes, collective and individual action, and their effects upon the course of economic life. Commons perceived the economy and economic change as a dynamic interplay between complementary and limiting factors. These are continually changing places. "What was the limiting factor becomes complementary when once it has come under control; then another factor is the limiting one. ... This is the meaning of efficiency - the control of the changeable limiting factors at the right time, right place, right amount, and right form in order to enlarge the total output by the expected operation of complementary factors."¹⁵ This is achieved through volitional processes of routine and strategic transactions, where the resolving of limiting factors are characterized as strategic transactions and the operation of complementary factors as routine transactions.

The doctrine of complementary and limiting factors has three different but inseparable applications; scarcity, efficiency and going concerns. "The technological economy is efficiency; the business economy is scarcity; the going concern economy is technology and business; the national economy is political economy. Each is a special case of strategic and routine transaction."¹⁶ Even though Commons did not particularly address the issues of technological change and economic change, he is very specific in his general framework regarding the relationship between technology and economy and regarding the forces behind change.

Individuals and schools of thought, here represented by Schumpeter, Commons, Veblen and to some extent also the growth accountants, studying the problems of economic growth have not focused our attention solely upon technological change, but also upon the close relationship between technology and business and upon how technological change is translated into economic performance. On the aggregated level economic performance is usually judged by growth of GNP, by distribution of wealth and by inflation and unemployment.¹⁷ On a disaggregated level economic performance can be

¹⁴ Rutherford, M. Introduction to the Transaction Edition. In: Commons J. R., Institutional Economics - Its Place in Political Economy, New Brunswick: Transaction Books, 1990. p. xxii.

¹⁵ Commons J. R., Institutional Economics - Its Place in Political Economy, New Brunswick: Transaction Books, 1990. p. 629.

¹⁶ Ibid, p.634.

¹⁷ Myrman, J., The Process of Economic Growth, Working Paper: Stockholm School of Economics, Jan 1990

determined by growth of turnover or by return on investment. The impact of technological change on aggregated economic performance will be the result of the sum, both positive and negative effects, of the impact on the disaggregated level. Thus the economic performance of technological innovation will be filtered through accompanying changes in the industrial structure, the creation of new structures and the destruction of obsolete structures. The economic impact of technological change can appear directly through cost reduction or the increase in sales resulting from an innovation or it can appear indirectly through cost reductions and increases in sales that it prompts in other related areas. The major impact can, furthermore, accrue from the subsequent adjustments prompted by the original innovation, in which case we would have a hard time tracing the benefits from innovation. Nevertheless, the economic impact of technological change will accrue through the changes in the industrial structure.

Schumpeter lived in a time of revolutionary technological and social change, comparable to our own time and his vision is as actual today as it was when he first published his works on economic development. And, lately, a group of economists have picked up the heritage of Schumpeter, combining it with the theories and findings of growth accountants and institutionalists, addressing the issue of technological change in economic theory. Some of the thoughts of the group are published in a recent book, "Technical Change and Economic Theory", edited by; Giovanni Dosi, Christopher Freeman, Richard Nelson, Gerald Silverberg and Luc Soete¹⁸. In the introductory chapter of the book Freeman summarizes the essence of the group's approach to the problem¹⁹;

- (1) Technological change is a primary cause of long-term economic development.
- (2) The dynamic mechanisms of economic development are radically different from those allocative mechanisms postulated by traditional theory.
- (3) The dynamic mechanisms have to do both with technical change and institutional change or the lack of it.
- (4) The socio-institutional framework always influences and may sometimes facilitate and sometimes retard processes of technical and structural change, coordination and dynamic adjustment.

¹⁸ Dosi, G., Freeman, C., Nelson, R., Silverberg, G. & Soete, L., (eds.) Technical Change and Economic Theory, London: Pinters Publishers, 1988.

¹⁹ Ibid, p. 2.

In many respects contemporary economic theories of technological change, here represented by the above mentioned book, are extensions of the work of Schumpeter, but by adding institutional elements they take us well beyond the scope of Schumpeter. What is perhaps missing from the general approach of his work is the significance he attributes to the acts of individual organizations, especially innovators and entrepreneurs.

Technology and Economics - A Short Summary.

We can now summarize the economists' approach to technological change. Technological change is one of the most compelling dynamic forces behind long term economic development. Growth accountants have identified the crucial link between technological change and economic progress, but they have left us in ignorance as to the nature of the link. Others, however, have shown that the relationship is neither symmetrical nor straightforward. On the one hand we have economic performance, economic growth, distribution of wealth, inflation or unemployment. On the other hand we have the reciprocal relationship between technology and business: between technological change and institutional change or changes in the industry structure. In this context we will concentrate on the relationship between technological and institutional change and the causal link to overall economic performance will not be explored.

As we have seen technological change and changes in the industry structure is a complex issue and as we will be preoccupied with the issue all through the book let us take a closer look at the two major components, technology and institutions. We will begin with the nature of technological change and proceed with technology and industrial evolution.

The Nature of Technological Change.

Technology is one of these infuriating words that can mean everything and nothing and it is almost impossible to decode the meaning of the word. The aim here is not to present a conclusive definition of technology, but rather a workable one. In a recent paper, the Swedish historian of technology, Svante Lindqvist discusses the meaning of technology. He presents different definitions of technology, from the use of machine and tools and applied science to all rational and efficient activities²⁰. Lindqvist ends up with a definition of technology that is also workable in this context: technology is human methods of satisfying needs and wants through the use of physical objects or all purposeful activities that change the material world²¹. In his dissertation Lindqvist discusses the three

²⁰ Lindqvist, S., Vad är teknik. In: Sundin, B., (ed) I teknikens backspegel, Stockholm: Carlsons Bokförlag, 1987. pp. 11 - 33.

²¹ Ibid, p.33

traditional functions of technology in society; productive, military and symbolic²². The first two roles are rather straightforward, technology is used for economic production and for military purposes. In the third role, technology is perceived as being used for symbolic reasons or to increase our social status, a role which perhaps is more debatable. But even though we often would like to think that technology results from rational behaviour, we cannot deny that also military and symbolic considerations will affect the direction and pace of technological development. So much about technology. What about technological innovation or change?

The evolution of our modern society is sometimes described as series of radical technological innovations, glorifying the heroic inventors and their spectacular innovations. Their names and achievements are for ever written in society's special "Halls of Fame" for technology; the patent system, the Nobel Prize and the history writings. Since long forgotten are their predecessors, their associates, their less successful contemporaries and the innumerable heirs of their achievements, collectively adapting their innovation to productive work. Who cannot accurately account for the achievements of James Watt, Thomas Alva Edison, Alexander Graham Bell or Charles Babbage, but who remember John Newcomen, Francis Upton, Elisha Gray or Per Georg Scheutz or other unsung heroes of technological change. But, truly is not every single inventor and every single innovation dispensable, will there not always be someone or something there to replace him or it? Here we are implicitly contrasting the heroic theory with the social theory of discovery, where the course of science and technology is regarded as a continuing process of cumulative growth, with discoveries tending to come in due time²³. But is this not a false disjunction? In the process of technological and economic change is it not only the totality that counts? Schumpeter would absolutely agree with this conjecture. The first sentence in his "Theory of Economic Development" is fittingly, "The social process is really one indivisible whole."²⁴

The progress of society is often described in terms of chains of technological breakthroughs each one replacing its antecedents. Animal power was replaced by wind and water mills, made obsolete by steam engines, replaced by electricity. We move from unsophisticated to sophisticated technology; from cave paintings, hand writings, mechanical and electrical type writers to electronic word processing. Older technology is

²² Lindqvist, S., Technology on Trial, Stockholm: Almqvist & Wiksell International, 1984. p. 14.

²³ Merton, R. K., Singletons and Multiples in Science, In: Merton, R. K., The Sociology of Science, Chicago, Ill.: Chicago University Press, pp. 343 - 370, 1973. p. 352.

²⁴ Schumpeter, J. A., 1983, p. 3.

successively being replaced by revolutionary innovations, disrupting the prevalent societal and industrial structure. New structures are created or pre-existing ones are altered making them more able to cope with the technological change. Radical innovations do not only embody a potential to replace obsolete technologies. They can also open new avenues of continuing technological and social change, where the new technology makes an entrance into a variety of related fields or industries. The computer replaced a mixture of methods of mathematical computation, but has since then, through continuous development, been applied in areas, such as word-processing and automatic tellers, unthought of by the inventors. And we presume that the new technology is superior to the old in that we assume that it contributes positively to the rate of productivity growth²⁵.

But, do these chains of isolated technological changes reveal more than the ABC of a complex historical process? The French historian Fernand Braudel encourages us to believe otherwise. In reviewing the history of furniture he writes; "But are the several histories of these items of furniture really the history of furnishing? However characteristic it may be, one piece of furniture does not reveal a whole picture; and the whole picture is what matters most. Museums, with their isolated objects, generally only teach the basic elements of a complex history. The essential is not contained within these pieces of furniture themselves but is in their arrangement, whether free or formal, in an atmosphere, an art of living both in the room containing them and outside it, in the house of which the room is a part. How, then, did people live, eat and sleep in these furnished interiors of the past - which were of course havens of luxury."²⁶ What Braudel says about furniture holds true also for the study of technological change, do the histories of pieces of technology reveal the history of technology? However characteristic one isolated innovation or technology might be, it does not reveal the whole picture; "and the whole picture is what matters most"²⁷. The essentials lies beyond particular technological innovations, in their relation to the context in which they occur and become a part of. The focus on radical innovations and heroic inventors has furnished important insights into the process of technological change, the nature of innovative activity and why some individuals and firms are willing to accept the inescapable uncertainty related to

²⁵ Kuznets, S., Economic Development, the Family, and Income Distribution, Cambridge: Cambridge University Press, 1989. pp. 8 - 9.

In general the proponents of technological development bring forth the positive economic effects, increased employment, increased wealth or improved competitiveness. The critics on the other hand often discusses the social consequences of new technology, alienation, unemployment or inequality.

²⁶ Braudel, F., Civilization and Capitalism 15th - 18th Century, Volume 1, The Structures of Everyday Life, London: William Collins Sons & Co Ltd., 1981. p.306.

²⁷ Ibid, p. 306

innovative activity. This focus does, however, deemphasize the subsequent adjustments and improvements in technology and economic structure. As these are often of higher or equal importance in the generation of performance this perspective ignores one of the most important aspects of economic development. The impact of radical innovations is often increased by subsequent technological development. Initially, this development will probably be dominated by product innovation nurturing the emergence of a new industrial structure. As process innovation increases, integrating the production process, reinforcing the emergent structure and obstructing the possibilities of further product development, the degree of product innovation will level off²⁸. Consequently, technological artifacts or innovations can never be understood in isolation. Technologies combine into technological systems of complementary components and pieces of knowledge. Technologies depend upon and interact with one another in intricate ways. The smallest unit of observation is therefore not single innovations but interrelated clusterings of innovations²⁹, technological systems.

We might conclude this section by asking ourselves if the observed economic performance of the western world and the changes in the social order are due to these streams of continuing innovation, revolutionizing the technological order. An unconditional positive answer to this question would be quite wrong leading us astray in the garden of technological determinism. Schumpeter made this observation, arguing that it would be quite wrong to say "that capitalistic enterprise was one and technological progress a second, distinct factor in the observed development of output; they were essentially one and the same thing"³⁰. The message conveyed by Braudel is that technological artifacts or innovation should be seen from both the technological and social context in which they are a part of or in which they occur. In the same way, pieces of furniture in Braudel's words have certain roles and positions in the room and in the house reflecting the social life of the inhabitants. Likewise, pieces of technology are interrelated, not randomly, but according to a specific logic and the essential lies beyond the individual pieces or innovations, in the totality, both in the relationship between the individual pieces and in the context of the society fostering and being captivated by them. If we continue to read Braudel, he becomes more specific regarding the role of technology in

²⁸ Utterback, J. M., *The Dynamics of Product and Process Innovation in Industry*. In: Hill, C. T. and Utterback, J. M., (eds.) *Technological Innovation for a Dynamic Economy*, New York: Pergamon Press, pp. 40 - 65, 1979.

²⁹ Rosenberg, N., *Technological Interdependence in the American Economy*. In: Rosenberg, N., *Inside the Black Box: Technology and Economics*, Cambridge: Cambridge University Press, pp. 55 - 80, 1982. p. 59.

³⁰ Schumpeter, *Capitalism, Socialism and Democracy*, p. 110. He finishes the sentence by stating that the former, the capitalistic enterprise, was the propelling force of the latter, the technological progress.

social progress. "Technology ultimately cover as wide a field as history and has, of necessity, history's slowness and ambiguities. Technology is explained by history and in turn explains history; but the correlation is in neither case fully satisfactory. In the realm of technology, co-extensive with the whole of history, there is no single onward movement, but many actions and reactions, many changes of gear. It is not a linear process."³¹ Technology most certainly possesses the capacity to shape society, but technology is not autonomous. It is the result of human endeavour: the researcher's search for a solution, the businessman's hunt for profit or the politician's quest for power. "And no innovation has any value except in relation to the social pressure which maintains and imposes it."³² Many examples show the same process. "The steam engine, for example, was invented a long time before it launched the industrial revolution - or should one say before being launched by it? The history of inventions, taken by itself, is therefore a misleading hall of mirrors. A splendid sentence by Henri Pirenne neatly sums up the question: America, when the Vikings, reached it, was lost as soon as it was discovered, because Europe did not yet need it."³³

The Nature of Technological Change - A Short Summary.

The most important finding in this section is definitely the definition of technology as clusters of interrelated technologies structured into technological systems. In summing up the nature of technological change we must, however, inevitably note that technology and technological change is an important part of society and human progress. "Technology is indeed a queen: it does change the world"³⁴, but it is also socially constructed ladened with the attitudes and values of the society that promotes it.³⁵ The role of technology in social progress can only be fully understood in the context of the society that promotes and maintains and is promoted and maintained by it.³⁶

³¹ Braudel, *Civilization and Capitalism 15th - 18th Century*, Volume 1, *The Structures of Everyday Life*, p. 334.

³² *Ibid*, p. 431.

³³ *Ibid*, p. 335.

³⁴ *Ibid*, 435.

³⁵ Hughes, T. P., *The Evolution of Large Technological Systems*. In: Bijker, W. B., Hughes, T. P. and Pinch, T. J.,(ed.) *The Social Construction of Technological Systems*, Cambridge, Mass.: MIT Press, pp. 51 - 82, 1987. p. 51.

³⁶ The perspective on innovation and technological change suggested here is not as novel as it might seem. Already Francis Bacon argued for the necessity of perceiving innovations as products of time and place. In his essay "Of Innovations" he stated that, "As the births of living creatures at first are ill-shapen, so are all innovations, which are the births of time. ...All this is true, if time stood still, which contrariwise moveth so round that a froward retention of custom is as turbulent a thing as an innovation; and they that reverence too much old times are but a scorn to the new. It were good therefore that men in their innovations would follow the example of time itself, which indeed innovateth greatly, but quietly and by degrees scarce to be perceived." Bacon, F., *Essays*, In: Robertson, J. M., (Ed.) *The Philosophical*

We will now leave this track for a short while and instead discuss technology and industrial evolution and hence the nature of industry. We will return to the contextuality of technological change and industrial evolution and how this process is influenced by its history in the next chapter.

Technology and Industrial Evolution.

The works of Schumpeter have many sides and if we look at the young and the old Schumpeter we can detect a slight shift in focus. The young Schumpeter elaborated on how new structures emerged from actors performing acts of innovation and entrepreneurship: creating extraordinary profits: attracting imitators pressing the profit level downwards. The older Schumpeter on the other hand was primarily interested in the impact of market structure on the level of innovation. Thus he elaborated on two distinct, but interrelated sets of problems. Maybe it is this shift in focus that have prompted the major differences among his successors. We have previously seen how the young Schumpeter have been taken up by economists studying technological change. Here we will take a quick glance at how the older Schumpeter has affected the field of industrial economics. Here the impact of market structure on technological development is the basic issue. In one of the more influential textbooks in industrial economics F. M. Scherer says; "Here we shall be concerned largely with a possible causal flow in the opposite direction: from market structure to technological innovation. Is progress faster or slower under monopolistic conditions, or does it make no difference?"³⁷ The same message is conveyed by a survey of the literature covering market structure and innovation by M. I. Kamien and N. L. Schwartz.³⁸ Here the heritage of Schumpeter is synthesized in two broad hypotheses. The first states, that there is a positive relationship between innovation and monopoly power and the second that, large firms are unproportionally more innovative than small firms.³⁹ Less attention is endowed the critical issues of how economic structures are created and destroyed: of how new industries emerge and the role of individual firms, inventors and entrepreneurs, in the advancement of this process.

Works of Francis Bacon, Ellis & Spedding, London: George Routledge and Sons Ltd., 733 - 814, 1905. pp. 764 - 765.

³⁷ Scherer, F. M., Industrial Market Structure and Economic Performance, 2nd ed., Boston, Mass.: Houghton Mifflin Comp., 1980. p. 408.

³⁸ Kamien, M. I. & Schwartz, N. L., Market Structure and Innovation, Cambridge: Cambridge University Press, 1982.

³⁹ Ibid, p. 22.

In mainstream industrial economics the primary interest is the study of the structure, conduct and performance of industries. Traditionally, an industry is defined as a group of producers of goods perceived as close substitutes, available to a common group of buyers. Producers of goods that are relatively distant substitutes are not included in the industry.⁴⁰ This theoretical, product oriented, definition of industry thrives on homogeneity. A homogeneous group of sellers produces a homogeneous set of products, to be sold to a homogeneous group of buyers. The nature of competition between the incumbents of the industry combined with the threat from potential entrants determines the overall economic performance of the industry. Increased competition drives down the profit level and thus the attractiveness to potential entrants. The economic performance of individual firms are determined by the relative success of their competitive behaviour. These industries are transformed through the seeking of differential advantage by the incumbent firms. Less successful firms will earn a less than sustainable return on investment and eventually they will exit the industry. When the overall profit level of the industry exceeds the sustainable return on investment and cost of entry, new entrants will be attracted, squeezing the profit level. The industry will transform through natural selection of the firms best adapted to the conditions of the industry. Individual firms will enter and exit, but the industry with its core technology will persist.

An industry is thus identified as a group of naturally selected competitors, where the performance of all others becomes the natural criteria for evaluating individual performance. Successful strategies will instantaneously be imitated, resulting in increased homogeneity in competitive behaviour of incumbent firms. A competitive symbiosis evolves where entry deterrence is given higher priority than intra-industry rivalry. The capacity of self-resurrection slowly deteriorates. Competition will no longer function as the propelling force behind development and industries cannot, as Schumpeter proclaims, incessantly be revolutionized from within.⁴¹ Sources of innovation, resurrection and revolution are increasingly to be found outside focal industries. Basic research at universities is of increasing importance in the generation of new technologies: computers, biotechnology and image processing are but a few examples of new technologies emanating from basic research. The inter-industry flow of technology is one of the major sources behind the resurrection of some industries: developments within computer technology have been instrumental in the recent revitalization within telecommunication. Suppliers and buyers are assuming more active roles in the innovative process.

⁴⁰ Bain, J. S., Industrial Organization, New York: Wiley, 1959. p. 6 - 7 and 110 - 112.

⁴¹ Schumpeter, Capitalism, Socialism and Democracy, p. 83.

Development and change is not a result of intra-industry rivalry, but of the interaction between complementary actors and the integration of complementary technologies.

Theories defining industry as a group of naturally selected producers of close substitutes are inherently static, in that they can neither explain the emergence of new industrial structures nor the major extensions of old structures that are brought on by technological change.⁴² Natural selection is a concept borrowed from biology. Biological theory of evolution is comprised of two basic mechanisms; one mechanism generating variety and one mechanism, natural selection, selecting and retaining the useful variety⁴³. Genes are the biological entities being subject to evolution. Variation and natural selection improves the fitness, the reproductive capacity, of individual genes in the gene pool and thus the organism evolves over time. Note that it is the genes and not the organism that are selected. Natural selection operates without foresight, without plans and without purpose and yet it is capable of producing the most complex organisms⁴⁴. Darwin ends his "The Origin of the Species" by pointing at this quality of the biological theory of evolution. He states: "There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."⁴⁵

Given this grandeur of the biological theory of evolution, how can it ever be stated that theories defining industry as a group of naturally selected producers of close substitutes are inherently static. We should perhaps not borrow metaphors as often as we do. They turn back on us as if they were explanations when they are meant to focus the attention on the unexplained⁴⁶. First of all social entities or their populations, companies, corporations or organizations can never be the basic unit of natural selection. They are too unstable to be the basic unit. They are too short-lived to be subject to natural selection and furthermore since they constantly merge or otherwise blend with each other natural

⁴² Van de Ven, A. H. & Garud R., A Framework for Understanding the Emergence of New Industries, Discussion paper #66, Strategic Management Research Center, University of Minnesota, Feb. 1987. p. 6.

⁴³ Elster, J., Nuts and Bolts for the Social Sciences, Cambridge: Cambridge University Press, 1989. pp. 75 - 77.

⁴⁴ Dawkins, R., The Blind Watchmaker. London: Penquin Books, 1986. p. 21.

⁴⁵ Darwin, C., The Origin of the Species. London: Penguin Books, 1968, pp. 459 - 460.

⁴⁶ Sandemose, A., Varulven, Stockholm: Forum, 1986. p. 102.

selection as it is known from the biological theory of evolution would be impossible⁴⁷. The firms or their competitors can thus never be the basic unit of industrial evolution. The question is, does there exist basic units of evolution, with stable qualities comparable to the biological gene, within the social sphere? In one of the more convincing applications of evolutionary theory in economics, "An evolutionary Theory of Economic Change", the authors Nelson & Winter resolve the problem of the basic unit of evolution in that they define routines as the genes of economic evolution⁴⁸.

A second and more important objection against the casual use of the metaphor of biological evolution in the studies of industrial change strikes at the heart, the definition of the industry. The position of an individual producer in an industry defined as a group of producers of close substitutes is totally different from the position of individual genes in the set of genes constituting a living organism. While firms are considered to be free agents, unattached to other firms, the genes exist in a highly complex system, "they collaborate and interact in inextricably complex ways, both with each other, and with their external environment."⁴⁹ Furthermore, it is often difficult to separate the social entities from the environment that constitutes the selection mechanism.⁵⁰

Technology and Industrial Evolution - A Short Summary.

Heterogeneity rather than homogeneity, interconnectedness rather than independence and mutual adaptation rather than one-sided selection are the relevant attributes of a definition of industrial structure that are required if we are to study the emergence of new industrial structures. This implies that substitutes are less suitable as a stratifying concept when it comes to analysis of the emergence of new industrial structures. A more relevant concept is complementaries focusing on the interconnectedness of industrial structures. In this study, as well as in many other studies of industrial dynamics, the industrial structure is perceived as an evolving system of interconnected parts: a network where the parts consist of actors interconnected through the activities they partake in and the resources they employ to perform these activities. The overall system is defined as an industrial network⁵¹ of interconnected exchange relationships. Any attempt to explain the evolution

⁴⁷ Dawkins, R., The Selfish Gene, Oxford: Oxford University Press, 1978. p. 36.

⁴⁸ Nelson and Winter, An Evolutionary Theory of Economic Change, pp. 134 - 136.

⁴⁹ Dawkins, The Selfish Gene, p. 39

⁵⁰ What we actually is arguing against is the population ecology perspective on the emergence and evolution of populations of firms, that is industries. See, Hannan, M. T. & Freeman, J., The Population Ecology of Organizations, American Journal of Sociology, Vol. 82, No. 5, pp. 929 - 964, 1977.

⁵¹ Later, in chapter 5, we will provide a more elaborated definition of industrial networks, but for now it is sufficient to perceive them as interconnected exchange relationships

of this system must be founded upon an understanding of the interaction over time between the evolution of the parts and the evolution of the whole system.

We are thus not refuting the grandeur of the biological theory of evolution, but basically focusing on other qualities of the metaphor: on the qualities of the webs of interlocking relationships underlying the process of evolution and on the path-dependent character of the evolution generated by problem-solving and adaptation and self-reinforcing mechanisms in complex contexts. What is suggested is a historical and contextual perspective on the emergence of new industrial structures, new industrial networks.

The Nature of Knowledge.

Advance of knowledge, most often expressed as growth of scientific knowledge is typically assumed to be one of the major causes behind the economic prosperity of the Western nations⁵². Technology is not only made up of artifacts; it also contains knowledge components and technological innovation is often assumed to result from progress of knowledge. But, what is knowledge? Is there one conclusive answer to this straightforward question? Probably not, but what we might agree on, is that knowledge is intangible and impossible to fully comprehend. What we also might agree on is the role of knowledge in society and the significance of the pursuit of knowledge in relationship to technological and industrial evolution. Håkan Håkansson states that "New knowledge in terms of new product or process ideas often emerges at the interface between different knowledge areas. In exchange situations different kinds of knowledge come together (are combined and confronted) to create innovative situations."⁵³ Knowledge is therefore a compelling constituent in the course of technological change and industrial evolution, but its true nature is, at best, secluded in the shadows of philosophy. The present inquiry into knowledge will not be as pretentious as the heading suggests and only a few features pertaining to the problem of technological change and industrial evolution will be discussed.

I would argue that assumptions regarding the nature of the state, and the growth of knowledge have an immediate impact on the issue at hand. In his classical article, "The Use of Knowledge in Society", F. A. von Hayek states that if we assume that we have perfect knowledge regarding the initial conditions, all remaining economic problems can be solved by pure logic. He continues by claiming that the peculiar character of economic

⁵² Rosenberg, N., and Birdzell, L. E., Jr., Science, Technology and the Western Miracle, Scientific American, Vol. 263, No. 5, pp. 18 - 25, November 1990.

⁵³ Håkansson, (ed.) Industrial Technological Development - A Network Approach, p. 4.

order "is determined by the fact that the knowledge of the circumstances of which we must make use never exists in concentrated or integrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess." He also claims that the solving of economic problems really are all about utilization of knowledge not given to anyone in its totality.⁵⁴ Knowledge is also to some extent contextual, and contingent upon particular circumstances of time and place. In this respect individuals accrue advantages over all others in that they have access to unique information that can be put to beneficial use, but only if the decisions depending on it are left to specific individuals or are made with their active cooperation⁵⁵. Decisions or innovations can be improved or ascend through interaction between individuals with access to pieces of knowledge predisposed by their particular circumstances of time and place. Von Hayek stated the proposition more specifically than Håkansson did above; solutions to economic problems are produced by the interaction of people, each of whom possesses only partial knowledge⁵⁶.

The issue addressed by von Hayek was the construction of a rational economic order. But like Schumpeter he perceived the problem as the administration of an ever-changing order and he stressed that economic problems arise always and only in consequence of change⁵⁷. We end this discussion by proposing that dynamic economics must be construed upon assumptions of imperfect and partial knowledge. The question is how to characterize the particular circumstances of time and place of knowledge and if we can specify the effects this will have upon the course of technological change and industrial evolution.

How, then has the idea of individualized, imperfect and partial knowledge, expressed by von Hayek, been articulated in more recent theories of technological change⁵⁸. The Italian economist Giovanni Dosi characterizes knowledge in three dimensions: articulated versus

⁵⁴ Hayek, F. A., von, *The Use of Knowledge in Society*, *American Economic Review*, Vol. 35, pp. 519 - 530, 1945. p. 519 - 520. The quotation from p. 519.

⁵⁵ *Ibid*, pp. 521 - 522.

⁵⁶ *Ibid*, p.530.

⁵⁷ *Ibid*, p. 523 - 524. In this context von Hayek also discusses the relationship between day-to-day adjustments and technological innovation, concluding that the growing interest in the role major changes was inappropriate; stating that the whole economic picture is made up by the constant number of small changes secluded in the statistical aggregates exhibiting a greater stability than the micro-dynamics.

⁵⁸ I here refer to the theoretical tradition introduced in; Nelson and Winter, *An Evolutionary Theory of Economic Change* and also represented by; Dosi, Freeman, Nelson, Silverberg & Soete (eds.) *Technical Change and Economic Theory*.

tacit, universal versus specific and public versus private knowledge⁵⁹. He paints a picture of knowledge as a continuum from perfect - articulated, universal and public, knowledge to imperfect and partial - tacit, specific and private knowledge. The three dimensions, proposed by Dosi are far from mutually exclusive and we might conclude that the latter two follow from the first; the distinction between tacit and articulated knowledge. In discussing knowledge assets, Sidney Winter adds some other taxonomic dimensions; observability in use, degree of complexity and whether it is independent or an element of a system⁶⁰. For the present purpose it is, however, sufficient to distinguish between tacit and articulable knowledge, bearing in mind that this articulation of imperfect and partial knowledge has further implications regarding the nature of knowledge.

Returning now to the initial question, what is knowledge? Let us here also include other enigmatic concepts, occasionally used synonymously, such as competence, skills, know-how and capability in the term knowledge. Knowledge consists of a tacit, implicit and non-codifiable, component as well as an articulable, explicit and codifiable, component. While some elements of knowledge can be well articulated and coherently coded in textbooks and manuals, thus enabling meaningful communication, knowledge transfer or teaching, of these particular elements. Yet some elements of knowledge can never, or at least not presently, be adequately expressed: "we know more than we can tell"⁶¹. Some elements of knowledge are tacit and they cannot be properly communicated. The tacit elements of knowledge are effective barriers to the transfer of knowledge and technology: the individual practising the knowledge does not even have to recognize or be aware of it. Tacit knowledge is commonly considered as resulting from learning processes; hands-on experience or trial-and-error experimenting. A collective of individuals, an organization, a business firm or simply a network actor, can be perceived as an agglomeration of elements of knowledge and competences, some tacit and some articulated.⁶²

⁵⁹ Dosi, G., The Nature of the Innovative Process. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G. & Soete, L., (eds.) Technical Change and Economic Theory, London: Pinters Publishers, pp. 221 - 238, 1988. pp. 223 - 224.

⁶⁰ Winter, S. G., Knowledge and Competence as Strategic Assets. In: Teece, D. J., (ed.) The Competitive Challenge: Strategies for Industrial Innovation and Renewal, New York: Harper & Row Publ., pp. 159 - 184, 1987.

⁶¹ Michael Polyani, quoted in Nelson and Winter, An Evolutionary Theory of Economic Change, p. 76.

⁶² A similar perspective on knowledge is conveyed by Karin D. Knorr-Cetina in her inquiry into the nature of the manufacture of knowledge. She argues that the manufacture of knowledge is a social process, marked by local, contextual, and social action, situated in time and space. She claims also that this scientific knowledge is manufactured and sustained in resource-relationships constituting the webs of social relationships in which the scientists acts. See, Knorr-Cetina, K. D., The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science, Oxford: Pergamon Press, 1981.

A historical example of the essence of tacit knowledge is provided by Svante Lindqvist in his study of the transfer of the Newcomen steam-engine to Sweden⁶³. By combining a number of well established complementary competences and without knowing or understanding the underlying theoretical principles Thomas Newcomen, later described as a common ironmonger, and his assistant John Calley constructed a very successful prime mover. Needless to say Newcomen and Calley were not without predecessors in their quest for converting thermal energy into mechanical energy, but in the first decade of the eighteenth century they succeeded in developing a practical working steam engine which proved to be of great benefit to the British mining industry.

The working principle of the Newcomen engine was fairly easy to understand from the available, published, prints of the early engines, even if these were more like advertisements than complete working instructions. But an elementary understanding of the basic working principle was quite different from the knowledge and hands-on experience needed in order to design and operate the engine. The Newcomen engine won immediate acceptance in the British mining industry. In the early eighteenth century practical experience of Newcomen engines was, however, rare, and the engines were constructed and operated by Newcomen and his associates. But as the stock of engines grew so did the knowledge and experience from designing and operating the engine and during the eighteenth century about 1700 Newcomen engines were erected in England.

In England an organization for the construction and operation of the Newcomen engine was established and with a growing installed base there followed a familiarity with the technology, favouring even more installments. The situation in Sweden was utterly different. The engine could not just be shipped to Sweden; it had to be constructed there and be adapted to the specific local context. In Sweden knowledge of designing steam engines was sparse and the necessary experience of practical operation was non-existent. And as was mentioned above a series of technical and social circumstances coincided, keeping the Newcomen engine from being widely spread in Sweden, thus, repressing the development of the practical experience, the tacit knowledge, necessary in order to construct and operate the engine. While the positive feedback loops in England led the Newcomen engine into a winning path the negative feedback in Sweden hampered

⁶³ The following illustration is solely based upon, Lindqvist, Technology on Trial.

learning, restricted the diffusion of the engine and preserved the barriers towards the development of steam technology⁶⁴.

The tacit elements of knowledge imply that knowledge cannot be universal, available to all. Knowledge is to some extent specific and access to it is restricted not only through the fact that its diffusion is deliberately avoided, a not too seldom occurring phenomenon in research and development. But also and perhaps more importantly from the fact that knowledge occasionally is impossible to communicate. Knowledge is contextual: it is unequally distributed and partial. The tacitness, contextuality and partiality of knowledge have significant implications on the theoretical propositions regarding the development, use and diffusion of knowledge. Even the codifiable knowledge is to some extent context specific.

First of all, knowledge is not equally available to all actors or all individuals. The notion that knowledge, once it is produced, is costlessly available to all others does not hold. The appropriation or utilization of knowledge "on the shelf" is not costless⁶⁵. The technological capability of firms differs and consequently also so does their ability to appropriate knowledge. The utilization of knowledge is not equally costly to all actors. Due to previous experience some actors can utilize specific elements of knowledge more economically than others⁶⁶. It is not even the case that the utilization of knowledge "on the shelf" necessarily has to be less costly than the original production of the knowledge. This observation sets the distinction between original innovation and subsequent imitation in a new perspective, implying, contra-intuitively, that imitation is more problematic and costly than what is commonly suggested. The distinction between innovation and imitation is thus an artificial one. The two processes are in many respects similar in nature and they are often only separated by the fact that one is, through different social institutions, primarily through the patent system, defined as being first and original and all others as being second and only imitations.

Continuing on this line of reasoning; the production of knowledge is contextual, burdened with the specific circumstances in which it occurs. The communication of

⁶⁴ It is interesting to note the contrast between the promptness to try the Newcomen engine in Sweden and the delay in the adopting of the subsequent and more efficient Watt engine.

⁶⁵ Rosenberg, N., Why Do Firms Do Basic Research (With Their Own Money)?, Research Policy, Vol. 19, No. 2, 1990.

⁶⁶ See for instance; Cantwell, J., The Technological Competence Theory of International Production and its Implications, Paper presented at the European International Business Association, 16th Annual Conference, Madrid, December 12 - 15, 1990.

knowledge from one context to another; from one individual, firm, industry or country to another, is not unproblematic. Transfer of knowledge requires due adaptation of both the knowledge subject to transfer and the knowledge possessed by the receiver. Some parts of the knowledge might be embodied in technology, yet some parts will inevitably be disembodied, represented by the tacit knowledge of the experienced constructor or operator. These assumptions concerning the nature of knowledge are not only suggestive when it comes to the transfer of technology, they also imply severe restrictions regarding the trading of technology. The notion of a perfect market for technology is inconceivable given that some tacit knowledge is required to reap economic benefits from technological innovation derived from advances in knowledge. This logical consequence of the contextuality of knowledge would have a significant impact upon the transformation of scientific discovery to economic production.

The Nature of Knowledge - A Short Summary.

We have here touched upon the intricate relationship between knowledge and technology and between advance of knowledge and technological change. This issue will probably never be fully resolved and here only some general features have been highlighted. The relationship between knowledge and technology is not symmetrical. Technology contains some elements of knowledge: some elements of knowledge are embodied in the artifacts of the technology. But not all the knowledge which is required to develop or operate a technology will be embodied in the products: some elements of knowledge will be disembodied. A special form of disembodied knowledge is associated with the interrelatedness of technologies into technological systems. This type of knowledge can of course also be embodied, which it is in what we most commonly refer to as network technologies; railways, telecommunication and electricity. But these are not the only technologies organized into systems. In other technological systems, like digital image technology, the interrelatedness is more subtle and disembodied. We have every reason to assume that knowledge concerning the interrelatedness of technology does not exist in concentrated and integrated forms. The pursuit of activities in technological systems thus requires the interaction of actors each of which possesses only partial knowledge regarding interrelatedness. It should be clear that knowledge can be embodied in technological systems, unknown or unattainable by actors in industrial networks. But, knowledge, explicit and implicit, is also embedded in industrial networks.

In general we might suspect that the accumulation of knowledge and the development of technology will converge. The relationship between the advance of knowledge and technological change is, however, also asymmetrical. We cannot simply state that technological change follows from advances in knowledge: the Newcomen engine was developed without a clear understanding of the underlying theoretical principles. The

opposite causality is not closer to the truth, though it is possible to observe several cases when advances in knowledge follow from technological change: the theoretical principles underlying steam engines were developed long after the technology had been established. Science owes probably more to technology than does technology to science. But the relationship between the two is more reciprocal than directed. We end this discussion with the general proposition that our assumptions regarding the nature of knowledge most certainly will affect how we perceive technological change.

Summary

Technology most certainly has the power to shape society, but it is not autonomous and it has no value except in relation to the social pressure which fosters it. Steam engines or computing machines were invented long before they launched the industrial or information revolution - or was it the other way around, were they launched by their revolutions? To become familiar with technology and technological change it is therefore necessary to proceed beyond the spectacular innovations and the great, heroic, men behind them. Society would probably be different if the telephone had never been invented, but would this have arrested progress? Would the removal of any innovation or any inventor halt progress? In the development of technology and progress of society no single innovation and inventor is indispensable. There will always exist alternative solutions to any problem addressed and there will always be humans attempting to solve perceived problems. Human ingenuity and changes in the man-made world are compelling ingredients in the progress of society, not in their singularity, but in their multiplicity, variety and ambiguity.⁶⁷

It was first suggested that the dynamics of technological and social evolution could be captured by focusing on two structures of society, technology and institutions. This basic model has since been significantly modified. The basic components and the relationships between them have been retained, but they have been defined differently. Technology has been defined as technological system and institutional structure as industrial network. In studying the emergence of new technologies and new industries, it is thus suggested that it is the emergence and evolution of technological systems and industrial networks that is the relevant issue. See also figure 7, on the next page.

⁶⁷ We can note that multiplicity, variety and ambiguity are prerequisites for evolutionary modelling of any kind. That is not only in models employing natural selection. For the evolution of society see Jantsch, E., *The Self-Organizing Universe*, Oxford: Pergamon Press, 1980, pp. 253 - 262. and for the evolution of technology see, Basalla, G., *The Evolution of Technology*, Cambridge: Cambridge University Press, 1988.

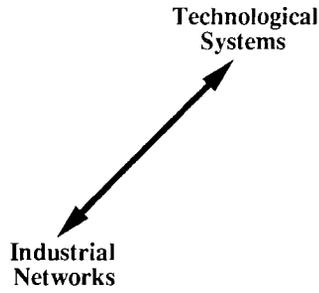


Figure 7: A basic model of the link between technological systems and industrial networks.

In the next chapter we will add two other dimensions to technological systems and industrial networks and take a closer look at contextual and historical perspectives and at the concept of technological systems. The concept of industrial networks and a framework for understanding the emergence and evolution of new technological systems and new industrial networks are then presented in chapter 5.

Chapter 4

A CONTEXTUAL AND HISTORICAL PERSPECTIVE

In a study of organizational development in the Imperial Chemical Industries, Andrew Pettigrew argues that to understand change we must study it as a continuing process in the context in which it appears and he encourages us to adopt a contextual and historical perspective on processes of change, whatever the content of change might be¹. Here we are concerned not with changes within individual organizations, but with the emergence of new technologies involving agglomerations of firms and organizations. This does not mean that the perspective suggested by Pettigrew is less valid on the contrary, and as has been argued above, the relationship between technological change and social progress is reciprocal: technology possesses the capacity to shape society, but it is neither autonomous nor neutral: it is the result of human effort and it is laden with the attitudes and values of the society that promotes it. Here the primary interest is not society as a whole, but a part of society - industry. It has been argued that technological innovation and business activities must be studied in the context of technological systems and industrial networks. As these structures are the results of the past, a contextual perspective necessitates a historical one.

¹ Pettigrew, A. M., The Awakening Giant - Continuity and Change in ICI. Oxford: Basil Blackwell, 1985.

No Man is an island, entire of itself;
 every man is a piece of the continent,
 a part of the main;
 if a clod be washed away by the sea,
 Europe is the less,
 as well as if a promontory were,
 as well as if a manor of thy friends
 or of thine own were;
 any man's death diminishes me,
 because I am involved in mankind;
 And therefore never send to know for whom
 the bell tolls; It tolls for thee.

John Donne (1572 - 1631)

In Context

Donne wrote this poem when, during a serious illness, he heard the death bell knolling for another², making him aware of the interdependence of men and women in the life of mankind as a whole. Ernest Hemingway cited it in his epichal story of human solidarity in the Spanish civil war. Mankind is one volume of many authors. The idea expressed by Donne has bearing also on our own field of study. No technology is an island, nor is any business an island³. They are all pieces of continents, parts of the main. Adam Smith realized it when he stated that the division of labour was limited by the extent of the market. Marx saw it when he derived the social structures and conditions from the economic relations of production. As we saw in our discussion above, neither the contextuality of technology nor the relationship between technology and society are novel findings of modern research. In contemporary research on technological change and social progress there is a growing consensus, even if this cannot always be detected in individual pieces of research, regarding the relationships within and between the two basic components. But when it comes to the nature and direction of these relationships we can find some general disagreements, all the way from pure technological determinism to pure social construction of technology. In the following we will trace different notions of technological systems and how they have been related to social progress.

Veblen did, as we saw above, identify the interdependency of technologies and his call for engineers as managers of industrial progress was the result of his perception of industrial systems. He defined these as "An inclusive organization of many and diverse

² Merton, T., No Man is an Island, Turnbridge Wells, UK: Burns & Oates, 1955. p. xxi.

³ Håkansson, H., and Snehota, I., No Business is an Island: The Network Concept of Business Strategy, Scandinavian Journal of Management, Vol. 5, No 3, pp. 187 - 200, 1989. This paper is an example of how the message conveyed by John Donne can be applied in business studies.

interlocking mechanical processes, interdependent and balanced among themselves in such a way that the due working of any part of it is conditioned on the due working of the rest."⁴ To Veblen only an engineer could understand the complexity of industrial systems and thus only an engineer could supervise this system efficiently. Today most of us are probably inclined to believe that Veblen was overly optimistic regarding the possibility of managing the industrial system. Nevertheless, men like Frederick W. Taylor and Henry Ford thrived on integrating the parts of the American system of manufacturing into an efficient system of mass-production⁵. His faith in engineers aside, the major contribution of Veblen was his identification of industrial systems as sets of interrelated technologies contingent upon human action. His "failure" in his trust in the engineer was to be compensated for by some of his many disciples.

We have seen how Commons, a great admirer of Veblen, addressed the problems of the industrial society. The specific ideas put forward by Commons can easily be regarded as generalizations of Veblen's thoughts on industrial systems. The idea of complementary and limiting factors is well in line with Veblen's observation that mechanical processes were interlocked, interdependent and balanced in such a way that the due working of any part of it was conditional on the due working of the rest. Commons did not share Veblen's strong belief in engineers, but he stressed the volitional side of economics in his routine and strategic transactions. To Commons the going concern economy consisted of one objective, technological, side of complementary and limiting factors and one volitional, managerial, side of routine and strategic transactions.

Before we continue with some of Veblen's many followers let us briefly examine the different systems approach suggested by the economic historian, Abbott Payson Usher. Contrary to Veblen and Commons whose primary interest was the going concern economy Usher set out to explain technological change and social progress. In his book "A History of Mechanical Inventions", first published in 1929, Usher presents his unique theory of social evolution, the particular system of events. Turning against the early concepts of social evolution, expressed as sequences of stages that were presumed to describe the entire social structure, Usher claimed that adequate historical analysis required concentration on particular sequences of events. Instead of maintaining that the

⁴ Veblen, *The Engineers and the Price System*, p. 72.

⁵ On the American system of mass-production see; Rosenberg, N., *Technological Change in the Machine Tool Industry, 1840 - 1910*. In Rosenberg, N., *Perspectives on Technology*, Armonk, N.Y.: M. E. Sharpe Inc., pp 9 - 31, 1976. or Hounshell, D. A., *From the American System to Mass Production: The Development of Manufacturing Technology in the United States*, Baltimore: John Hopkins University Press, 1984. On Veblen, Taylor and Ford and the American System see; Hughes, T. P., *American Genesis*, New York, N.Y.: Viking Penguin, 1989. pp. 184 - 294.

totality of the present was derived from the totality of the past, he formulated the proposition more specifically, that every event has its past. The analysis of social evolution required studies of processes of innovation and processes of diffusion through imitation. In the first chapters of the book Usher articulates a general theory of innovation, where he proposes an analysis of the processes of change with explicit reference to the place of individual effort in the general social process. Usher was not, as were Veblen and Commons, interested in the interrelatedness of the prevalent technological systems. His focus was on particular sequences of events and their place in larger systems of relationships⁶.

The next scholar on our list is Lewis Mumford. A basic communist, a student of Veblen and sympathetic towards Usher, Mumford studied how the Western civilization had been affected by the development of the machine⁷. Mumford, stating that technics and civilization as a whole, was a result of human choices, inclinations and aspirations, conscious as well as unconscious, was probably more inclined than Usher to perceive technology as a social construction⁸. Where Usher stressed technological innovation as the engine of social evolution, Mumford underscored social progress as the engine of technological change. A third scholar with a keen interest in the nature of invention is S. C. Gilfillan. He perceived the invention process as a whole and demonstrated the length of the process. Mainly concerned with the social aspects of the process, Gilfillan pointed out that inventions are changes in a system which necessitates further invention and he showed that technological change was made up of innumerable minor improvements, with only infrequent major inventions.⁹

Usher, Mumford and Gilfillan can be considered as classical forerunners to the contextual approach to the history of technology¹⁰. The contextual historians, Melvin Kranzberg,

⁶ Usher, *A History of Mechanical Inventions*, pp. 18 - 19.

⁷ Mumford, L., *Teknik och civilisation*, Göteborg: Vinga Press, 1984. The original, *Technics and Civilization*, was first published in 1934.

⁸ *Ibid*, p. 15.

⁹ Gilfillan, S., C., *Inventing the Ship*, Chicago: Follet Publishing, 1935, and Gilfillan, S., C., *The Sociology of Invention*, Chicago: Follet Publishing, 1935. See also, Rosenberg, N., *The Historiography of Technical Progress*. In: Rosenberg, N., *Inside the Black Box: Technology and Economics*, Cambridge: Cambridge University Press, pp. 3 - 33, 1982. pp. 7 and 13. and Kelly, P., Kranzberg, M., Rossini, F., Baker, N., Tarpley, F. & Mitzner, M. *The Individual Inventor - Entrepreneur*. In: Roy, R. & Wield, D., (Eds.) *Product Design and Technological Innovation*, Milton Keynes: Open University Press, pp. 76 - 85. 1986.

¹⁰ Staudenmaier, J. M., S.J., *Technology's Storyteller: Reweaving the Human Fabric*, Cambridge, Mass.: MIT Press, 1985. p. 12.

Lynn White Jr. and Thomas P. Hughes to mention but a few, aimed at historical synthesis of the dynamic interplay between the functional characteristics of technology or technological system and the complex social, cultural, political and economic context in which it prevailed. In closing his book on technology's storytellers John M. Staudenmaier describes contextual history as "a vulnerable process in which the historian is deeply affected by the humanity of the subject matter. To reject as ahistorical the ideology of autonomous progress is to recognize that technological designs are intimately woven into the human tapestry and that all of the actors in the drama, including the storyteller, are affected by the tensions between design and ambience. By telling the stories of technological developments while respecting the full humanity of the tale, the contextual scholar rescues technology from the abstractions of progress talk and, in the process, takes part in the very ancient and very contemporary calling of the historian, reweaving the human fabric."¹¹

In Sweden the economist Erik Dahmén influenced by Schumpeter, Veblen and the Swedish institutionalist Johan Åkerman, also observed the systemic nature of industrial development. Dahmén's particular interest was in entrepreneurial activities and industrial transformation and he has developed a theory of industrial dynamics where the two major constituents are development blocks and entrepreneurs. He combines the concepts in referring to development blocks as "a set of factors in industrial development which are closely interconnected and interdependent. Some of them are reflected in price and cost signals in markets which are noted by firms and may give rise to new techniques and new products. Some of them come about by firms creating new markets for their products via entrepreneurial activities in other industries. This, too, may include the creation of new techniques and new products. In both cases, incomplete development blocks generate both difficulties and opportunities for firms." Dahmén furthermore distinguishes between two extreme cases of transformation, positive transformation pressure characterized by opportunities and negative where the necessity to adapt and adjust is immediate.

Development blocks are construed upon complementaries of technological, economic and other related factors and upon the notion of structural tensions, that is the absence of particular complementary factors. Now the definition of the concept falls into place. The concept development blocks refers to sequences of complementaries which by way of series of structural tension, i.e., disequilibria, may result in a balanced system¹². The

¹¹ Ibid, p. 201.

¹² Erik Dahmén articulates the concept of development blocks in his dissertation published in Swedish 1950. Dahmén, E., *Entrepreneurial Activity and the Development of Swedish Industry 1919 - 1939*, American Economic Translation Series, Homewood, Ill.: Richard D. Irwin, 1970. And in his later work he has developed the concept. See; Dahmén, E., *Development Blocks in Industrial Economics*,

concept of development blocks is not only suggestive when it comes to industrial transformation. It also offers an alternative to traditional economic aggregates and it should be obvious from the discussion of technology and industrial evolution above, that the definition of industrial networks to a large extent has been influenced by the works of Dahmén. A final observation regarding development blocks, which is not immediately obvious from the definition, but ascends from some of the examples, is that transformation processes drift towards conclusive solutions.

Lately, we have observed an increasing interest in the interrelatedness of technologies and in the nature of technological systems. Nathan Rosenberg informs us that the "growing productivity of industrial economies is the complex outcome of large numbers of interlocking, mutually reinforcing technologies, the individual components of which are of very limited economic consequence by themselves."¹³ Paul A. David offers a very precise definition of technological systems when he states that they are characterized by technical interrelatedness and prospects of economic benefits from system integration.¹⁴ The network benefits or network externalities originate from two different circumstances. Firstly, and as is stated in the straightforward definition above, the benefits arise directly from the integration of the interrelated technologies. Secondly, and which is perhaps not equally obvious, network externalities, and thus potential benefits, are apparent when the overall economic performance of the system is dependent on the number of users and when the economic value for an individual user increases with increasing total number of users.

Hughes provides us with a more articulated, and less operational, definition of technological systems, where he combines the internal and functional technical interrelatedness with the social, political and economic context in which it prevails. He suggests that the nature of technological systems goes beyond the interrelatedness of physical artifacts, such as generators, transformers, transmission lines, consumption measuring devices, and light bulbs and electrical apparatus in the electric light and power system. "Technological systems also include organizations, such as manufacturing firms, utility companies, and investment banks, and they incorporate components usually

Scandinavian Economic History Review, 1988:1, pp. 3 - 14, 1988. also available in Carlsson, B. (ed.) Industrial Dynamics, Boston: Kluwer Academic Publishers, pp. 109 - 122, 1989. The quotation is from the latter p. 109.

¹³ Rosenberg, Technological Interdependence in the American Economy, p. 58 - 59.

¹⁴ David, P. A., Some New Standards for the Economics of Standardization in the Information Age, In: Dasgupta, P. and Stoneman P., (ed.) Economic Policy and Technological Performance, New York: Cambridge University Press, pp. 206 - 239, 1987. p. 208.

labeled scientific, such as books, articles, and university teaching and research programs. Legislative artifacts, such as regulatory laws, can also be part of technological systems. Because they are socially constructed and adapted in order to function in systems, natural resources, such as coal mines, also qualify as system artifacts."¹⁵

Let us make a halt here to see what we are up against. We have been through several different inquiries into the nature of technological change and social progress. The unifying theme has been the contextual approach to the issue. We have seen different definitions of technological systems ranging from straightforward, more mechanistic, definitions presented by Veblen or David, focusing primarily upon the interconnectedness of technologies to more complex definitions, by Mumford and Hughes setting the technical interconnectedness into a larger social, political and economic context. For our purpose it seems operational to maintain the distinction between the more mechanistic technological system on one hand and the social, political and economic context - the institutional structure, on the other. And, as we saw above, we will perceive the latter as industrial networks.

Technologies depend upon and interact with one another in intricate ways. Only in schools do technologies appear in their pure and simple forms. Technologies are interconnected into technological systems of complementary artifacts of different technologies and pieces of knowledge. Technologies are interconnected into systems, not randomly, but according to an internal logic, not ordained, but set by the historical development of the system. The logic of the system will at every moment in time embody the seeds for further development. Resolving imbalances in technological systems, Commons called them limiting factors, Dahmén structural tensions, Rosenberg bottlenecks and Hughes reverse salients, will lead to the development of the system, but also to new imbalances in other parts of the system. The dynamics of the sequential resolving of imbalances push the technological systems and what was once a limiting factor will in the next moment be a complementary. The resolution of imbalances require human action, Commons called it strategic transactions, Dahmén entrepreneurial activities, Schumpeter and many others innovations and entrepreneurial activities and Hughes system-building. Of course not all imbalances can be resolved and if not compensated for in other parts of the system they can threaten the whole system. Nor are all solutions to be found where the imbalances are perceived.

¹⁵ Hughes, *The Evolution of Large Technological Systems*, p. 59.

Technological systems are, however, not all about resolving imbalances through innovation. There is an everyday life also in technological systems, a going concern of complementary factors. Some have shown that day-to-day rationalization in going concerns contributed more to economic productivity than did radical innovation¹⁶. But on the other hand it is difficult to refute a strong relationships between radical innovation and day-to-day rationalization.

Technological change and social progress is not only about technical factors. Institutional factors might be of equal or even greater importance. In Sweden as well as in other places in the world, firms, organizations and even individuals are struggling to develop electric vehicles. There are some technological imbalances to be resolved, specifically with regard to battery technology and the relationship between effective power and volume and weight. But it is mainly an institutional problem. The prevailing automotive technology has been gaining momentum for a century and contemporary society is almost perfectly adapted to automobiles with combustion engines and to mass - automobile - transportation. Thus the prevailing institutions of automotive technology will favour conservative technological innovation and will penalize radical ones. A Swedish entrepreneur reports that it took him three months to develop his first electric car but it took him six months to have it registered and inspected according to Swedish law¹⁷.

In addition to institutional factors, geographical factors can play a significant role in shaping technology. In his account of the history of steamboat technology Louis Hunter elusively points to how a particular geographical factor, the shallow waters of the Mississippi river, shaped the technological design of steamboats. Consequently, the design was less viable in areas with deeper waters¹⁸. Hughes claims that different

¹⁶ In a study of cost reduction of process innovation in the petroleum industry John Enos, Enos, J., Petroleum, Progress and Profits, Cambridge, Mass: MIT University Press, 1967, divided the innovation process into two phases; the alpha-phase - cost reduction due to the introduction of the basic innovation and the beta-phase - cost reductions due to subsequent improvements. He found that the alpha-phase had much less impact on cost reduction than the beta-phase. Actually the basic innovation accounted for approximately 5 % of the cost reduction and subsequent improvements accounted for 95 %. Similar results are reported by Håkansson, H., Product Development in Networks. In: Håkansson, H., (ed.) Industrial Technological Development - A Network Approach, London: Croom Helm, pp. 84 - 127, 1987; Hollander, S., The Sources of Increased Efficiency: A Study of Du Pont Rayon Plants, Cambridge, Mass: MIT University Press, 1965 and Wibe, S., Change of Technology and Day-to-Day Improvements. Umeå Economic Studies, No. 78, Umeå University, 1978.

¹⁷ Hansi Kobes, statement made in the Swedish environmental TV-program, Miljöbilder, channel 2, Sunday, 3 Feb., 1991. See also Fridlund, H., Snabb elbil för 75 öre milen, Expressen, Sunday, 3 Feb., 1991.

¹⁸ Hunter, L., Steamboats on the Western Rivers: An Economic and Technological History, Cambridge, Mass.: Harvard University Press, 1949.

regional areas, exhibiting natural and human variations, will shape technology into different technological styles. He shows how locational characteristics such as climate and seasonal variations in daylight, the location and character of rivers, lakes and seas, the availability of mineral deposits, soil and vegetation, elevations, transportation, industry, and demography, decidedly shaped the character of electric power systems¹⁹.

Local or national, institutional and geographical characteristics shape the particular design of technological systems. These qualities are even more explicit if we turn to art and architecture. The art historian Nikolaus Pevsner writes; "In acknowledging the international unity of the new style, it ought not be forgotten that in Hoffmann's elegance, in Perret's clarity, in Wright's expansive broadness and comfortable solidity, or in Gropius's uncompromising directness, national qualities are represented at their best. But the art historian has to watch personal as well as national qualities. Only the interaction of these with an age produces the complete picture of the art of an epoch, as we see it."²⁰ Well, art is not technology: the degree of freedom is much higher in art than in technology. Nevertheless, technology, especially emerging technology, will also be laden with both local and personal qualities. In many ways technology grows out of local needs and social circumstances. And whatever the origins of a technology its impact upon industrial production will be contingent upon the ability to shape it according to the local needs of the users. The successful transfer of technology from one local context to another, from one nation, region or industry to another, requires that the people and institutions employing it must be able to understand it, experiment with it and evaluate the economic repercussions of its use²¹.

An excellent example of the local qualities of technology and the subsequent problems of technological transfer is the futile attempts to transfer the Newcomen steam engine, originating in eighteenth century Britain, to Sweden and the United States. The development of the Newcomen engine in Britain grew out of the problem of flooded mines, a favourable social organization, ample supply of strongly energized fuel and the use of iron for construction. The Swedish historian of technology Svante Lindqvist has shown that a functioning Newcomen engine could be constructed in Sweden and that the failure of transferring the engine to Sweden was due to a number of coinciding technical

¹⁹ Hughes, T. P., Networks of Power: Electrification in Western Society, 1880 - 1930, Baltimore: John Hopkins University Press, 1983. pp. 404 - 460.

²⁰ Pevsner, N., Pioneers of Modern Design: from William Morris to Walter Gropius, Hammondsworth, UK.: Penguin Books Ltd., 1960. pp. 198 - 199.

²¹ Rosenberg & Birdzell, Science, Technology and the Western Miracle.

and social circumstances. The problem of flooded mines was not critical; the particular organization of ownership did not favour experimenting with new technology; compared to Britain the energy content of Swedish fuel was lower and the supply of fuel was a critical problem and finally Sweden based its technology on wood rather than on iron, which made the construction less viable²². The attempts to transfer the engine to the United States also proved to be unsuccessful²³. The Newcomen engine with its extremely low fuel efficiency seems to have been adapted to peculiarities of the local British context, flooded coal mines and ample supply of inexpensive strongly energized fuel. This occurred more than 250 years ago and we might argue that the situation is different today and in many respects it is. The increasing globalization of modern industrial production might function as an institution facilitating technological transfer, leading to less accentuated differences between technologies emerging in different local contexts, but on the other hand the problem of transfer might also be amplified.

In Context - A Short Summary

To sum up; no man, technology nor business is an island, entire of itself. Each is a piece of the continent, a part of the main. Every innovation is embedded in a specific context, social as well as technological. The development of ploughs cannot be separated from, the technique of ploughing, the quality of the soil, the social organization of the community, the holding of draught animals, the nature and quality of available raw materials or the skills of the producers and users of ploughs. The processes by which man makes himself is, as A. P. Usher so vividly pointed out, doubly dynamic; "man and the geographic environment react upon each other, and both terms are transformed"²⁴.

Pre-existing technological systems result from the combined historical efforts of different actors acting, independently or jointly to solve locally defined problems. Each actor acts within historically defined boundaries. No actor can efficiently control the complexity of a full technological system. But, as the pay-off of collaborating with an actor controlling complementary technologies is often higher than abstaining from collaboration, the individual actors will form a community of interrelated actors, an industrial network. The combined efforts of the actors in the industrial network set the condition for future development of the technological system. Here again the process is doubly dynamic

²² Lindqvist, *Technology on Trial*.

²³ Hindle, B. and Lubar, S. *Engines of Change: The American Industrial Revolution*, Washington, D. C.: Smithsonian Institution Press, 1986. pp. 68 - 69.

²⁴ Usher, *A History of Mechanical Inventions*, p. 2.

industrial networks and technological systems react upon each other and both terms are transformed.²⁵

²⁵ The fruitfulness of applying a network perspective on technological development is shown in several studies; Håkansson, H., (ed.) Industrial Technological Development - A Network Approach, London: Croom Helm, 1987.; Håkansson, H., Corporate Technological Behaviour - Cooperation and Networks, London: Routledge, 1989.; Laage-Hellman, J., Technological Development in Industrial Networks, Department of Business Studies, Uppsala University, 1989. and Waluszewski, A., Framväxten av en ny massateknik - En utvecklingshistoria, Department of Business Studies, Uppsala University, 1989. None of these studies addresses the issue of the emergence of new technologies and new industrial networks.

The Road Not Taken

Two roads diverged in a yellow wood,
 And sorry I could not travel both
 And be one traveler, long I stood
 And looked down one as far as I could
 To where it bent in the undergrowth;

Then took the other, as just as fair,
 And having perhaps the better claim,
 Because it was grassy and wanted wear;
 Though as for that passing there
 Had worn them really about the same,

And both that morning equally lay
 In leaves no step had trodden black.
 Oh, I kept the first for another day!
 Yet knowing how way leads on to way,
 I doubted if I should ever come back.

I shall be telling this with a sigh
 Somewhere ages and ages hence:
 Two roads diverged in a wood, and I -
 I took the one less traveled by,
 And that have made all the difference.

Robert Frost (1874 - 1963)

History Matters

The technological and social embeddedness of innovation creates a decisive momentum, pushing the development of technological systems not towards an optimal, a conclusive nor a completely balanced state, but in accordance with the restrictions and opportunities set by the historic development. Veblen observed the power of the existing industrial systems and he attributed it to both technological and institutional factors. "The state of industry in America and in the other advanced industrial countries, will impose certain exacting conditions on any movement that aims to displace the Vested Interest. These conditions lie in the nature of things; that is to say, in the nature of the existing industrial system; and until they are met in some passable fashion, this industrial system can not be taken over in any effectual or enduring matter. And it is plain that whatever is found to be true in these respects for America will also hold true in much the same degree for the other countries that are dominated by the mechanical industry and the system of absentee ownership."²⁶

A path is laid by taking one rock at the time. Similarly, technology evolves by the solving of one problem at the time. In this way the past holds a stronger grip over

²⁶ Veblen, *The Engineers and the Price System*, p. 110.

progress than all the future opportunities combined²⁷. Technological development and social progress is not evolving towards any particular future state. It is evolving from the present state. New technologies are not enclosed in the shadows of the future, but in the ambiguity of the past. And we may trust ourselves to dream, to have visions, but dare we predict? This does not imply that the present is derived from the past and the future from the present: we are not slaves of the past, but we are its children. Progress is propelled by circumstances embodied in history and, regardless of whether we are historians or not, historical analysis is necessary if we are to acquire a better understanding of progress and the forces prompting it.

One very obvious way in which history matters in the study of technological change and social progress is the time lag between original invention and its successful implementation. The electronic computer can be said to have been invented in the mid forties and since the sixties have we heard the rumours of a computer revolution. Yet, it is only recently that we have witnessed the widespread use of computer technology and still there is no immediate evidence of the economic impact of the computer. On the contrary we are struck by the paradox of rapid technological innovation combined with disappointingly slow gains in economic productivity. The story of the computer is not without precedence. In a recent paper the economic historian Paul David reflects the development of computer technology in a not-too-distance mirror and compares it with the development of electricity²⁸. Even if he hesitates to take the analogy too far, he presents a striking similarity in the development of these two general purpose technologies, especially regarding the time lag between the establishing of the technologies and their economic impact.

Many examples tell similar stories: a long duration between technological change and its economic impact and a huge difference between frontier technology and technology in use. The future factory-concept have been the topic of manufacturing technology for decades, still surprisingly little has happened on the factory floors. Digital image technology is no different: the original ideas turned up nearly thirty years ago and it is, still, too early to say that the technology is successfully implemented in today's society. It began when some groups of researchers, independently, began to experiment using computers to analyze data contained in images. Since then the path to image processing technology of today has been filled with temporary successes and failures and enclosed

²⁷ Håkansson, *Corporate Technological Behaviour*, p. 37.

²⁸ David, P. A., *Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror*. Paper presented at the OECD International Seminar on Science, Technology and Economic Growth, Paris, France, June 5 -8, 1989.

by futile attempts and unexplored routes. And the digital image technology that stands before us is neither optimal nor conclusive. It plainly is and whatever is, is right²⁹.

As time wears on and individuals and organizations, with vested interests, put money and efforts into specific technological or social solutions, social and technological momentum is accumulated in the technological system and in the institutional structure, in this case the industrial network. Development becomes path-dependent and small historical events, such as investments in particular technological solutions or specific institutional circumstances, can lock the industrial evolution into different paths. And the particular path traveled by, can make all the difference.

A prevalent technological system is founded on the accumulated achievements of the past and the history of the system could have taken a number of different paths and the particular path followed does not necessarily lead towards an optimal solution. We do not have to go very far to find suboptimal technologies that have persisted despite the overtness of their inefficiency. Look only at the persistence of the Anglo-Saxon measures of distance or the three different standards for television broadcasting: it even seems likely that this difference will survive the development of High-Definition-Television. From the railways in Sweden comes another example. In the technological shift from steam to electricity: in the construction of the D-train, one of the most successful and long-lived Swedish designs of trains, manufactured from 1924 - 1957³⁰. Swedish Rail had decided that the back-and-forth movement characteristic of the dominant design of steam engines, should also be retained after the shift to electrical motors.³¹ The persistence of this peculiarity was of course not without rationale: it was argued that only a back-and-forth motion could produce the torsion necessary to get a train set started. ASEA argued unsuccessfully for bogies and motors on every axis, a technological solution more appropriate for an electric manufacturer³². This implied that the rotating motion from the electrical motor was transformed to a back-and-forth motion, which in its turn was transformed to a rotating motion to the wheels. It also implied a preservation of the structure of the locomotive industry, in that it did not prompt continued division of

²⁹ Gould, S. J., *The Panda's Thumb of Technology*. In: Tushman, M. L. and Moore, W. L., (eds) *Readings in the Management of Innovation*, 2nd. ed., Cambridge, Mass.: Ballinger Publishing Company, pp 37 - 44, 1988. p. 37.

³⁰ Glete, J., *ASEA under hundra År 1883 - 1983: En studie i ett storföretags organisatoriska, tekniska och ekonomiska utveckling*, Institutet för Ekonomisk Historisk Forskning vid Handelshögskolan i Stockholm, 1983. p. 168.

³¹ *Ibid*, p. 196.

³² *Ibid*, p. 196

labour and specialization. And the major Swedish manufacturer of steam locomotives, Nykvist & Holm AB, Motala Verkstäder and AB Svenska Järnverksverstäderna could - alongside ASEA, to whom the future of train technology belonged - continue to be significant suppliers.

David provides an illustrative example of the long stability of an obviously suboptimal technology - the persistence of the QWERTY-keyboard³³. In the development of the first typewriters the choice was free regarding the configuration of the keyboard. Ultimately it should be adapted to the mechanics of the typewriter and allow for efficient typing. The first typewriters to hit the American market had a keyboard known, today, as QWERTY, an up-stroke mechanism, and a flat paper carriage. With the up-stroke mechanism followed a risk for typebar clashes and the flat paper carriage, with a non-visible printing point, meant that an occurrence of a typebar clash was not immediately obvious to the typist and the clash would thus be reproduced. The QWERTY-keyboard was deliberately configured to hamper the speed of typing so as to minimize the risk for typebar clashes. The configuration also meant that the word TYPE WRITER, the brand name of the first typewriter, could rapidly be pecked out by sales representatives wanting to impress potential customers.

Truly, when it comes to efficient typing the QWERTY-keyboard makes no sense. It was deliberately constructed to reduce the speed of typing. Hence we might suspect that it would have been abandoned once it had been made obsolete through the development of new mechanics where the risk of typebar clashes, is reduced or totally aborted. Yet the QWERTY-keyboard has persisted even in the age of personal computers. We have a technological imperfection at our fingertips. QWERTY has not persisted due to lack of more efficient configuration: it has survived despite the existence of much more efficient alternatives. One alternative placed the sequence DIHATENSOR in the home row: ten letters from which more than 70 % of the words in the English language can be composed. Later, in the thirties, a serious contendent configuration, DSK - reportedly allowing for 20 - 40 % faster typing, challenged QWERTY. But despite several technological shifts since then QWERTY has persisted. Neither was it the case that the technological solution of up-stroke mechanism and flat paper carriage was specifically sticky. Well before the turn of the century alternative mechanical solutions reducing or eliminating the risk for typebar clash were developed and from 1890 typewriters with visible printing points, eliminating the reproduction effect of a single clash, were

³³ David, P. A., Clio and the Economics of QWERTY, *American Economic Review*, Vol. 75, pp. 332 - 337, 1985. See also; Arthur, W. B., Competing Technologies and Economic Prediction, IIASA, Options, No 2, pp. 10 - 13, 1984 and Gould, The Panda's Thumb of Technology.

available. Nor had QWERTY accumulated a strong installed base: by 1880 the entire stock of QWERTY-typewriters did not exceed 5000.

It is clear from a rational point of view that QWERTY should have been abandoned, but it has survived. What, then, are the basic forces behind the persistence of QWERTY? Why was the configuration of keyboards already locked in before we entered the twentieth century. Probably a number of circumstances coincided favouring QWERTY as the universal design of keyboards. The fact that QWERTY was first and that it was associated with the largest manufacturer certainly helped, but it was probably not sufficient. What was probably more decisive was the development of methods for fast typing, i.e. touch-typing, which required the memorizing of the configuration of the keyboard and thus created an idiosyncratic relationship between the keyboard and the typist. But why then QWERTY? There existed several different keyboards and schools of typing. A crucial event was perhaps a public competition between eight-finger and four-finger typing methods. Eight-finger typing was developed by Ms Longley, the founder of the Shorthand and Typewriter Institution in Cincinnati in 1882. She happened to teach with a QWERTY-keyboard although many of the competing configurations would have served equally well. The eight-finger method taught by Ms Longley was challenged by a four-finger method taught on a rival non-QWERTY typewriter. The eight-finger method won and even if the competition really did not concern the keyboard, it proved the superiority of QWERTY in the eyes of those running typing schools and those publishing manuals. QWERTY acquired momentum and the interconnectedness of keyboard and typing method and the installed base have made it persist even through a series of technological changes. The origin and survival of QWERTY is due to a series of events, some rational but most purely coincidental. And if it had not been for some of these events we might as well have been locked into a different path and maybe we would have ended up with a better configuration of our keyboards. But, as Stephen Gould ends his opus on QWERTY, "why fret over lost optimality. History always works this way. ... For if history were not so maddeningly quirky, we would not be here to enjoy it. Streamlined optimality contains no seeds for change. We need our odd little world, where QWERTY rules and the quick brown fox jumps over the lazy dog."³⁴

The case of the QWERTY-keyboard illustrates the contextuality of technology. The technological interrelatedness, not only between purely technical factors such as keyboard configuration and typebar mechanics, but also between technical and human factors; keyboard and methods of typing. In the case of the D-train the technological

³⁴ Gould, *The Panda's Thumb of Technology*, p. 44. The last quirky juxtaposition of uncongenial carnivores is held to be the shortest English sentence that contains all twenty-six letters.

interrelatedness between the back-and-forth motion and necessary torque was not equally entrenched and this peculiarity of steam locomotives was finally abandoned and the Swedish locomotive industry was restructured where ASEA became the major supplier of railway technology. Two other characteristics of technology in context are; system scale economics favouring the dominant solution and quasi-irreversibility of technological change immunizing inferior technology from the attacks of superior technology. It also illustrates the consequential fact that dynamic processes take on an essentially historical character and it suggests that the study of economic history is necessary in the making of an economist³⁵, the study of business history essential in the making of managers and researchers in business administration and the study of history of technology essential in the making of engineers. And if we are to reach a better understanding of the dynamics of industrial evolution we must combine all these related fields of history and also add some others, because history really matters in the making of tomorrow.

It is clear that history is an important factor begetting processes of technological and industrial change and in our everyday lives the role of history is undisputable. But how does history enter into the social sciences? What we have to observe first is, however, just the opposite, that is, that history rarely enters into the analysis, neither in orthodox economics nor in mainstream business administration³⁶. The role attributed to history in mainstream, non-historic, social sciences should be discouraging to any historian or anybody else with an interest in history. Nevertheless, history has not vanished completely from the research agendas and it is worth taking a short glimpse into how history has been taken into account in economic analysis.

In arguing for turning economics into a properly historical social science, Paul David, distinguishes between four classes of how history has entered into economic analysis; two, quite ordinary, which he labels mild to moderate history and two, perhaps more controversial, which he labels strong history³⁷. As we move through these classes we go from an economic analysis where history plays a minor part to those where history is subsumed to beget the course of actions and events. The mildest, and completely uncontroversial, way in which history enters into economic analysis is through time lags

³⁵ David, *Clio and the Economics of QWERTY*, p. 332.

³⁶ By orthodox economics I primarily mean neoclassical economics and with mainstream business administration I refer to the business administration, marketing, cost-benefit analysis, organizational theory or business strategy as these appear in the general textbooks or major journals.

³⁷ David, P. A., *Path-Dependence: Putting the Past into the Future*, Stanford University, [Institute for Mathematical Studies in the Social Sciences, Economic Series](#), Technical Report No 533, November 1988.

between cause and effect. The direction is always the same, effects follows from causes, not instantaneously, but with a slight delay in time³⁸.

A more significant, but still moderate, role for history is found in models where the outcome is derived from particular dynamic sequences of intervening events. These models are in general based upon a notion of generalized accumulation, where the presence of "A" is a precondition for attaining "B": specific conditions or sets of conditions must be present for dynamic processes to transcend from one state of development to another. A special class of models within this category is represented by random walk or state dependence with unique temporal sequences of moves. Unrestricted - where all moves are perfectly reversible - the dynamic process described by these models, will eventually shake loose from its past; "where the process is likely to end up eventually is independent of the place at which it started, or where it was at any specified intervening times."³⁹

If we now turn to the second category discussed by David - strong history, we will find models associated with path-dependent dynamics of economic systems, in which the role of history is substantially stronger. According to David path-dependence connotes the fact that, "the influences of past events and of the states they bring about must be communicated -- like the deepening of the wheel-ruts by each successive vehicle -- through some definite chain of intervening casual events, effects and resultant states -- down to the present state, whence they can be passed on to future events."⁴⁰ Path-dependence does not preach historical determinism, where the totality of the present is derived from the totality of the past. It simply suggests, as Usher pointed out above, that every event has its past, its present and its future, where irreversible events or activities effectively disconnect some regions of the state space from the rest. All roads do not lead to Rome and as way leads onto way, the particular path "chosen" will make all the difference.

David discusses two explicit forms of path-dependence; lock-in by small historical events and path-dependent transitions. The first refers to dynamical processes, which can be locked into particular evolutionary paths through seemingly insignificant and entirely random events. The economics of QWERTY discussed above is an excellent example of how a if not totally random at least, semi-random configuration of the typewriter

³⁸ Ibid, pp. 12 - 13.

³⁹ Ibid, p. 14.

⁴⁰ Ibid, p. 17.

keyboard locked in the development of typewriters and typing. The work of Brian Arthur shows that issues, like competing technologies and industry location, can be analyzed as processes locked in by small historical events⁴¹. And even if the event shaping the future is random and initially insignificant it is possible to make statements regarding the probability of the possible outcomes, one of which is sure to emerge⁴².

Path-dependence of transition probabilities refers to a class of models where history really matters in the sense that knowledge of the present is not sufficient when it comes to predicting the future: some knowledge of the past is also necessary. The dynamics of a system is not only governed by where it is, but also by where it is coming from. In path-dependent dynamics history is transmitted through a series of positive feedbacks, through which the system gains momentum: pushing it forward in a direction set by the past. Yet some forces - technological innovation, economic conditions or political ambitions function in the present inducing the system to drift. These forces do not affect the system directly, but through particular sequences of events. What, then, is the positive feedback: the carriers of history? This is a matter which explicitly as well as implicitly has been discussed above in relation to the contextuality of technology and the economics of QWERTY. And here only five major sources of feedback will be presented⁴³, some of which have already been discussed, but also some that, through their commonality, have been excluded from the discussion so far.

1. Economies of scale in production: as the cost of production falls with increasing numbers of units produced, past performance in production is transmitted to the economics of production of the future .

2. Learning processes: learning always favours the existing. Regardless of the mode of learning; "Learning by Doing"⁴⁴, which is more aligned with the concept of economies of scale or Learning by Using⁴⁵, which is more contingent upon technological interrelatedness, learning loads the dice on future development.

41 Arthur, W. B., *Competing Technologies: An Overview*. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G. & Soete, L., (eds.) *Technical Change and Economic Theory*, London: Pinters Publishers, pp. 590 - 607, 1988. and Arthur, W. B., *Industry Location and the Importance of History*, Center for Economic Policy Research, No. 84, Stanford University, 1986.

42 David, *Path-Dependence: Putting the Past into the Future*, p. 20.

43 The list presented here is to a large extent similar to the one presented in; Arthur, *Competing Technologies: An Overview*, p. 591.

44 David, P. A., *Learning by Doing and Tariff Protection*, Journal of Economic History, September 1970.

45 Rosenberg, N., *Learning by Using*. In: Rosenberg, N., Inside the Black Box: Technology and Economics, Cambridge: Cambridge University Press, pp. 120 - 140, 1982.

3. Technological interrelatedness: the interrelatedness of technological systems creates an indivisibility, where the functioning of the parts are contingent upon the functioning of the whole: endorsing development of prevalent systems: deterring from revolutionary changes of the parts.

4. Network externalities⁴⁶: refers to the notion that the user-value of a good or a service is dependent upon the total number of users. The user-value of the telephone is extremely low for the first adopters, but as the number of users increases, so does the user-value. Network externalities punish the early adopters and rewards the laggards.

5. Industrial networks: the industrial and institutional structure, here referred to as industrial network, is a carrier of history through rules and regulations, routine transactions, relationship-specific investments and through socialization of action.

These five sources of positive feedback are obviously not mutually exclusive. They influence and interact with each other in intricate and complex ways creating a decisive momentum pushing the dynamics of systems into path-dependent evolution. These mechanisms reinforcing past achievements do not only inform us about the evolution of prevalent technological systems and industrial networks. They also tell us something about the problems associated with the emergence of new technological systems and industrial networks and the obstacles that have to be overcome in order for novelties to become established. Such feedback mechanisms counteract novelties to the same extent as they preserve the pre-existing structures.

History Matters - A Short Summary

The notion that dynamic processes - technological change, economic growth, social progress or whatever, are path-dependent conveys the necessity of historical perspective. Current events cannot be fully understood without knowledge of how they have been shaped by past events, some - like QWERTY, situated in the remote past⁴⁷. In this sense every process is unique and it is in unique sequences of events we find the explanations to the outcome of dynamic processes, and where the particular path traveled by, with its uniqueness and dependency on chance, will make all the difference. Or as Benedetto Croce puts it: "The material of history is the singular in its singularity and contingency, that which is once and then is never again, the fleeting network of a human world which drifts like clouds before the wind and is often totally changed by unimportant events."⁴⁸

⁴⁶ Katz, M. and Shapiro, C., Network Externalities, Competition, and Compatibility, American Economic Review, Vol. 75, pp. 424 - 440, 1985.

⁴⁷ David, Path-Dependence: Putting the Past into the Future, p.16.

⁴⁸ This is an example of an unfortunate peculiarity that occasionally happens in the pursuit of social science, where you are obliged to quote a source in third hand. The words of Croce are quoted in Salvenni, G., Historian and Scientist, Cambridge, Mass.: Harvard University Press, 1939. p. 88. Quoted in; David, Path-Dependence: Putting the Past into the Future, p.15.

Against the uniqueness and dependency upon random events of history and dynamic processes we must set ambitions to reach generalizable knowledge. While history most often is preoccupied with the uniqueness of events and sequences of events, social sciences are all about theoretical abstractions and generalizations. Maybe it is futile to seek to integrate the two⁴⁹: unique processes and timeless generalizations are indeed contradictory. Nevertheless, timeless generalizations founded on a historical perspective are at least better than ahistorical generalizations⁵⁰.

Some Notes on Method

You might recall from an earlier discussion that Schumpeter introduced his Theory of Economic Development by stating that; "the social process is really one indivisible process". And it is out of this great stream, that the classifying hand of the investigator artificially extract facts⁵¹. It is the privilege of a scholar of any discipline or of any theoretical leaning to use his sensitive classifying hand to extract the relevant facts. Schumpeter was an economist and as such he was, without denying the significance of other factors, bound to extract the economic facts of social progress. This inquiry into technological change and industrial evolution is conducted within the realms of marketing, broadly defined. Marketing theory rests firmly upon the duality of economic and social theory and being a marketing scholar it is natural that I also seek to extract social facts from the great stream of events characterizing the social process.

Even so, our ontological starting point is that there is a reality, which exists independent of our own consciousness, of which it is possible to get objective knowledge⁵². The question is whether the study of this reality, the reconstruction of the past, can be conducted independent of our own consciousness, our own preconceptions and implicit

⁴⁹ Here a fair word of warning is at place. Criticizing historicism Karl Popper argued that the search for a general law of evolution would be futile and impossible. He saw the idea that society can move as a whole along one singular path as merely a holistic confusion. According to Popper social change is made up by innumerable independent or interdependent paths of development. Hence, "history is characterized by its interest in actual, singular, or specific events rather than in laws and generalizations." And Popper is suggesting an institutional and technological analysis of the conditions of progress. Popper, K., The Poverty of Historicism, London: Ark Paperbacks, 1986. (Originally published in 1957) pp. 105 - 144. Quotation from page 143.

⁵⁰ David, Path-Dependence: Putting the Past into the Future, p.16

⁵¹ Schumpeter, The Theory of Economic Development, p. 3.

⁵² Lindgren, H., Business History, Historical Economics and Economic Theory. The Bridge-Building Function of Business History. In: The Network of Financial Capital: Essays in Honour of Ragnhild Lundström, Uppsala Papers in Economic History, Working Paper No. 9, Uppsala University, pp 45 - 64, 1990. p. 53

or explicit theoretical propositions. Can a story be told as it really was, as Leopold von Ranke put it - "wie es eigentlich gewesen"?⁵³ The famous phrase of T. S. Ashton, "The facts do not wear their hearts on their sleeves", encourage us to think otherwise. The choice of theory or theoretical shifts will delineate the subset of facts that are deemed relevant and hence worth bothering to record or remember⁵⁴. Reality is complex and according to the business historian Håkan Lindgren it can be compared to "cobwebs of nodes and lines", categories and causal relationships, "being structured both horizontally and vertically and integrated with other complex cobwebs in an infinite tunnel of time."⁵⁵ Reality is and by itself it neither contains categories nor does it reveal causal relationships. The nodes and lines, the categories and casual relationships are theoretical constructs, abstractions founded on empirical observations or the theoretical inclination of the investigator or, as most often is the case, a combination of the two.

Consequently, even though we might assume that the past exists independent of our consciousness and firmly believe that we can obtain objective knowledge relating to it, we cannot deny that our knowledge of the past will be based upon our preconceptions and implicit or explicit theoretical propositions. "For undoubtedly there can be no history without a point of view; like the natural sciences, history must be selective unless it is to be choked by a flood of poor and unrelated material."⁵⁶ We cannot free ourselves of past experience and we enter into a new study with specific ambitions and preconceptions. The way out of this difficulty is to introduce a "preconceived selective point of view into one's history; that is, to write that history which interests us"⁵⁷. The initial purpose of this study was to explain the emergence of a new industrial network. I entered into the study with an ambition to combine two growing schools of thought; the network approach and dynamic economic theory, hence the interest in the dynamics of technological innovation and industrial change. It cannot be denied that this non-rational choice of theories has had an impact upon my understanding of the development of digital

⁵³ Quoted in Lewis, B., History - Remembered, Recovered, Invented, New York: Touchstone Books, 1975, p. 71.

⁵⁴ The whole passage including the quote attributed to T. S. Ashton from; David, *Path-Dependence: Putting the Past into the Future*, p. 23.

⁵⁵ Lindgren, *Business History, Historical Economics and Economic Theory. The Bridge-Building Function of Business History*, p.53.

⁵⁶ Popper, *The Poverty of Historicism*, p. 150.

⁵⁷ *Ibid*, p. 150.

image technology in Sweden. The "choice"⁵⁸ of theory locked me into a particular path of theoretical reasoning.

The choice of theory determines what facts or subset of facts that are worth recording and remembering. The present study of technological innovation and industrial change in the emergence of digital image processing in Sweden is not an exception. The perspective that has been laid before you in this chapter suggests one possible delineation of the relevant facts pertaining to the study of the issue at hand. In this case it implies that relatively higher importance has been attributed to context and time related facts regarding the interconnectedness of technologies and the relationships between firms over time. Other, perhaps more traditional, perspectives would inevitably extract different subsets of facts from the same reality: probably emphasizing the role of individual inventors or particular innovations in the course of industrial change. The underlying frame of reference does not only affect what we will see it also indirectly determines the results. While I am destined to put forward conclusions regarding technological systems and industrial networks others are bound to give priority to the support of individual inventors and innovations.

We have here discussed how our knowledge of social processes is determined by our explicit or implicit theoretical propositions. So far we have not touched upon the contradiction between the study of unique processes, in this case the emergence of image processing in Sweden and the ambition to generate more general knowledge about these, in this case about technological change and industrial evolution. In the following I will continue to argue for theory laden studies of historical processes and to discuss the characteristics of the particular method of historical analysis employed in this study. Finally, some methods of generalization will be discussed.

Lindgren informs us that; "the hard core of the historical method is the linking-up of the thing to be explained to more abstract concepts in a dynamic analysis."⁵⁹ The latter part of this statement is far from being controversial: history is all about processual analysis of long-term change. The first part should neither be surprising nor ought it be controversial. If we do not agree with the general notion that the totality of the present is

⁵⁸ The word choice have been put within quotation marks to indicate that the choice is not a choice in traditional meaning. We do rarely, objectively, set alternative theories against each other choosing the one best fitted to solve the actual problem. We are rather socialized into schools of thought, focusing our attention to specific problems and segments of the reality and the theory adapted is more or less given by the context within which the investigator works.

⁵⁹ Lindgren, *Business History, Historical Economics and Economic Theory. The Bridge-Building Function of Business History*, p. 60.

derived from the totality of the past and instead formulate the role of history more specifically that every event has its past. We must have a method to move from particular events, or rather sequences of events, to higher levels of aggregation and abstraction. Historical analysis implies the move from unique observations, through successive abstraction, to the phenomenon to be explained, unifying the particular sequences of events in their particularity with the general trends of an ever-changing reality. What we are opting for is historical interpretations rather than general laws of social evolution. The task of historical interpretation is to disentangle causal threads of development and to describe the accidental manner in which these are interwoven.⁶⁰ And as Carlo M. Cipolla suggests the aim of a study "... is not to twist facts to prove a theory, but rather to adapt the theory to provide a better account of the facts." In the process of scientific inquiries into unique historical events, it must therefore "... be perpetual feedback between the formulation of problems and the process of gathering evidence."⁶¹

John R. Commons describes the method of analysis as the phases of analysis, genesis and synthesis or insight. Where analysis refers to the process of classification, genesis to the analysis of the changes that are continually going on in all factors and finally synthesis, or the concept preferred by Commons insight, refers to the uniting of the changing parts into a changing whole.⁶² To put the process of thinking proposed by Commons into our context we can interpret analysis as the classification, based upon the present state of knowledge, of the unique observations. Genesis, then, is the analysis of the particular sequences of events and finally insight is the unification of particular sequences of events into a changing whole.

The scheme through which we generate knowledge from historical processes is a complex activity of analysis, genesis and insight, actively constructed by the mind of the investigator in order to understand, predict or control the complex social processes of reality. The process is never finished. New insights set the scene for re-classification of observations: calling for re-analysis of the changing parts: producing opportunities for more insight. And there is always plenty of room for new insight. "The older insights have been wonderful and important for their time and place - never to be forgotten or set aside. The new insights are needed and in turn they need the aid of the old, because 'the world's economic dilemma' is more puzzling than ever before, and yet similar dilemmas

⁶⁰ Popper, *The Poverty of Historicism*, pp. 146 - 151.

⁶¹ Both quotations are from, Cipolla, C. M., *Between History and Economics - An Introduction to Economic History*, Oxford: Basil Blackwell, 1991, p. 17.

⁶² Commons, *Institutional Economics - Its Place in Political Economy*, pp. 98 - 102.

have occurred in the past."⁶³ The suggested constant reiteration of the process in no way suggests that the growth of knowledge is purely accumulative. New insights might contradict as well as corroborate old insights. I do not only know more about technological innovation and industrial evolution now than I did before I started to study the emergence of digital image processing. The acquired knowledge is also more specified and better articulated.

Neither is the process necessarily moving only in one direction. New insights can, as the social psychologist Karl E. Weick has so vividly pointed out, antedate the categorization of observed events⁶⁴. The process of acquiring new knowledge could work the other way around; from insight and genesis to analysis. An example of this could be the development of the Newcomen-engine discussed above. Where insights in the form of a new engine were produced without analysis and genesis, that is without knowledge of the underlying theoretical principles. These were developed much later, after the innovation of the second generation steam-engines.

Method of analysis as a complex activity of analysis, genesis and insight suggests that theorizing - the process of thinking, is more implicit in this case than in most other studies. It is a process of uniting empirical observation with theoretical insights: combining inductive and deductive reasoning: integrating unique observations, classification of hard data or articulated knowledge with theoretical insights, higher levels of understanding or expressions of tacit knowledge. The process of theorizing around dynamic processes, characterized as they are by multiple change and multiple causation, calls for true pluralism. In the successive abstraction of unique observation, in the pursuit of insight through analysis and genesis, anything goes. In the sequential reiteration of analysis, genesis and insight, pluralism is essential: poems, prayers or promises, theoretical reasoning, anecdotal evidence or quantitative methods of analysis, anything goes in the pursuit of insight. The only action that would be totally wrong would be to refrain from trying additional methods or alternative modes of reasoning, that is to refrain from pluralism. Note here that what I am advocating is not an extreme form of pluralism, but a pluralism within the realms of existing observations and within the actual line of reasoning. The basic scientific criterion employed is that of internal consistency: the consistency of the theoretical reasoning and the consistency between the empirical findings and the theoretical reasoning.

⁶³ Ibid, p. 102.

⁶⁴ Weick, K. E., The Social Psychology of Organizing, 2nd ed., Reading, Mass.: Addison Wesley Publishing Co., 1979.

The result of the study of the emergence of image processing in Sweden lying before you is far from being an accurate representation of the often tedious efforts and the seemingly endless endeavour of the underlying work. Only a minor part of the analytical effort put into the study is presented here. The story of the emergence of image processing in Sweden could have been, and has been, told in many different ways. In the first attempt to portray the process⁶⁵, each and every research and development project was presented as a separate process, as a particular sequence of events. The story based upon several different case stories revealed some interesting properties. First of all, it revealed a surprising stability of the individual efforts of technological development. Even though many of the projects went through major institutional changes, primarily in the transfer of the projects from scientific institutions to business firms, these changes were only to a lesser extent reflected in changes in the course of technological development. Secondly, and more importantly, it revealed an interrelatedness between the different stories. A general pattern was disclosed where the different projects were initiated in different contexts, seemingly moving towards each other forming an apparent network structure around the emerging technology, only to be attracted to other technologies and other actors dissolving the emerging network structure. Had I been interested in a different question, for instance economic performance and the organization of research and development in digital image processing, this structure of the story would have been perfectly adequate. But since the interest was focused towards the whole picture of industry dynamics and the relationship between technological change and industrial innovation, the structure of the story was deemed inadequate.

The observation of different phases in the development of image processing was the point of departure in the second attempt to depict the story⁶⁶. Here the different sequences of events were divided into three periods, and the development within the different periods were lumped together. The development of digital image technology in Sweden was therefore divided into three distinct phases. Each and every phase followed logically from the preceding ones and was a precondition for the succeeding ones. This was a first attempt to unite the unique observations of changes of the parts with the changes of the whole. This exercise confirmed the observation that the story could be told as three distinct periods, but the story as such was insufficiently integrated. And major rewritings

⁶⁵ Lundgren, A., Computerized Image Processing in Sweden - A Case Report, Working Paper, Stockholm: Stockholm School of Economics, 1985. (In Swedish)

⁶⁶ Lundgren, A., Computerized Image Processing - Analysis of the Development of a New Technology, Stockholm: Thesis Proposal presented at the Stockholm School of Economics, 1986. (In Swedish)

were still needed. Some attempts at integration were made, focusing on specific problems in the development of new technologies and industrial change⁶⁷.

A third attempt of total revision of the case story was discontinued half way through due to perceived lack of insight into the underlying theoretical principles. Combining new theoretical insights with the existing empirical observations resulted in, as you will see in chapter 5, the abstraction of the particular systems of events into three sequences of technological development and industrial evolution: genesis, coalescence and dissemination, where the different processes dominate the course of events in different periods of time. To confirm the general pattern of evolution quantitative methods of network analysis were employed. It is only this last analytical effort that is reported in the present survey.

So far so good. Up to now we have discussed the proposed method of historical analysis and what we might call the internal validation of the theorizing based upon a single case story - a unique process. A question still untouched upon is how general the findings of studies of unique processes are. First, we should observe that the purpose of applying methods of successive abstraction is to produce testable theoretical propositions. The purpose is to find the general pattern behind the observed changes in the reality. The results could thus ideally be generalized through subsequent scientific tests, confirming or contradicting the present results. We can also argue for a more general applicability of the findings by comparing them with other studies of unique processes of technological change and industrial evolution. We should, however, be careful in our use of other studies and employ at least some rudimentary source criticisms before we use them as an external validation of our studies. In this study I take the results one step further, arguing for the generality of the findings by comparing them with other similar studies.

Some Concluding Notes on Method

The pursuit of knowledge in the social sciences can in agreement with the pursuit of technological change be treated as processes of particular systems of events subject to lock-in by small historical events, that is, as path-dependent evolutionary processes. What we end up with are not conclusive, eternal, everlasting truths. The accumulated knowledge does not even necessarily have to converge towards the truth. We are only adding to the huge bulk of research reports, providing yet another statement, posing

⁶⁷ These attempts have been reported in; Lundgren, A. and Björklund L., *Economic Changes in Industrial Networks - Coordination of Activities and Mobilization of Resources*. In: Axelsson, B. and Easton, G., (ed.) *Industrial Networks - A New View of Reality*, London: Routledge, 1991. and in; Easton, G. and Lundgren, A., *Changes in Industrial Networks as Flow Through Nodes*. In: Axelsson, B. and Easton, G., (ed.) *Industrial Networks - A New View of Reality*, London: Routledge, 1991.

different arguments in a continuing scientific dialogue. Hopefully our studies will be read and understood and, where history shows that we were on to something, others will be there to reproduce our findings and our successors can also compensate for our mistakes. The particular method of analysis and theorizing advocated here suggests that the results are embodied in the path pursued. In consequence, I am more inclined to argue for the plausibility of the findings rather than to present conclusive results. Some of the major findings of this study are embedded in the structure of the story: in the presentation of the emergence of image processing in Sweden as sequences of genesis, coalescence and dissemination.

Technological System and Industrial Network in their Particular Context of Time and Place

All through this chapter it has been argued that events must be seen in their particular context of time and place. Adding these arguments to the basic model presented in the previous chapter, provides an extended abstraction of the interdependence between technological system and industrial network. See figure 8 below.

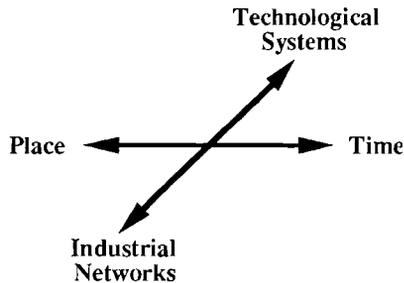


Figure 8: Technological systems and industrial networks in their particular contexts of time and place.⁶⁸

A remaining problem is, however, that by adding new dimensions, clarity is not automatically brought to the initial dimensions. This is especially enigmatic in the present study since the basic components, technological systems and industrial networks, are generic concepts covering the same ground. The concepts are not mutually exclusive and in many cases they are interchangeable. In the following we will very much fall back to a

⁶⁸ This basic model has many similarities with some of the theories proposed by the sociologist Anthony Giddens, encompassing a materialistic and a social system put in their particular context of time and place. See, Giddens, A., *The Constitution of Society*, Cambridge: Polity Press, 1984. See also Sellstedt, B., *Samhällsteorier - Vad har Giddens, Habermas m fl att säga ekonomer*, Lund: Studentlitteratur, forthcoming.

more mechanistic definition of technological systems, like the one presented by Paul David, that they are characterized by technical interrelatedness and prospects of economic benefits from system integration. Industrial networks on the other hand will be perceived more as a social system of interconnected exchange relationships.

The story of technological change and industrial evolution in the emergence of digital image technology in Sweden will be presented in chapters 6, 7 and 8. But before we dive into image processing we will first make an inquiry into the character of the network approach and elaborate on a framework for understanding the emergence of a new technology and a new industrial network.

Chapter 5

TECHNOLOGICAL SYSTEMS AND INDUSTRIAL NETWORKS

In the previous chapters it has been argued for the necessity of studying change in the context of time and place. From a general model of the relationship between technology and institutional structure, a more specific model of the reciprocal relationship between technological systems and industrial networks was derived. The nature of technological systems has already been discussed, so in this chapter we will focus on the nature of industrial networks and specify the nature of the link between technological innovation and the evolution of networks. We will begin by looking at some antecedents of the network theory and then quickly move to an inquiry into technological change, followed by a discussion of the relationship between technological systems and industrial networks. The chapter is closed by the presentation of a framework for the understanding of the emergence of new technological systems and new industrial networks.

Industrial Networks Some Antecedents

Network theories are becoming increasingly recognized as analytical tools applicable to the analysis of the nature of industrial production and consumption. The purpose here is to provide the antecedents of the specific theory of industrial networks developed by some groups of European marketing researchers. Being firmly rooted in industrial organization, interorganizational theory and system analysis, the theory rests upon the layers of the function of organized behaviour systems, the behavioural theory of the firm and the interdependence of firm behaviour and environment. Here a path to industrial networks will be laid by relating the accumulation of theoretical knowledge to the changing conditions of industrial production.

The Rise of Modern Capitalism and the Organization of Industry

The giant corporation, mass-production technology and the dominant schools of thought in industrial economics emerged almost simultaneously. The shift from craft technology to mass-production both necessitated and facilitated corporate growth. Many of the rising giants were organized so as to encompass the greater part of the underlying technology. The Edison Electric Light Company did not only manufacture incandescent-lamps and electric dynamos, it also constructed, operated and maintained electric service stations¹.

¹ Hughes, T. P., Networks of Power: Electrification in Western Society 1880 - 1930, Baltimore: John Hopkins University Press, 1983, pp. 38 - 42.

The Ford Motor Company exhibits a similar organization: centred around manufacturing of automobiles, Ford also controlled tool manufacturing, steel-works, gas stations and automobile outlets.² The pattern was to strive for maximum internal control. So, when Ford Motor Company discovered a growing production of car radios that could be fitted into Ford automobiles, thus competing with internally manufactured radios. The interior of the car was changed in such a way that only Ford's own radios could be installed³. Specialization and division of labour was primarily perceived as being effectuated within the rising corporations. It gave rise to increased productivity through the capitalization on the enhancement of the skills of the work force and the division of labour between men and machines. Altogether it gave rise to economies of scale prompting internal corporate growth.

The emerging industrial structures with a limited number of large corporations were far from the idealistic dichotomy of monopolistic and perfect competition. The complete theoretical distinction between monopoly and perfect or pure competition, impaired by assumptions of homogeneous inputs and output and perfect information, was negated by the facts of intermixture in real life. Edward Chamberlin addressed the discrepancy between theory and reality in his pioneering work "The Theory of Monopolistic Competition" presenting a synthesis of monopoly and perfect competition⁴. By introducing the concept of product differentiation⁵, Chamberlin brought heterogeneity to the theory of competition. He observed that; "when products are differentiated, buyers are given a basis for preference, and will therefore be paired with sellers, not in random fashion (as under pure competition), but according to these preferences. Under pure competition, the market of each seller is perfectly merged with those of his rivals; now it is to be recognized that each is in some measure isolated, so that the whole is not a single large market of many sellers, but a network of related markets, one for each seller."⁶

² Hughes, American Genesis, pp. 203 - 220.

³ Greenstein, S. & Ramey, G., Product Inertia and the Incentive to Innovate, Center for Economic Policy Research, No. 149, Stanford University, 1988.

⁴ Chamberlin, E. H., The Theory of Monopolistic Competition, 3:rd ed, Cambridge, Mass.: Harvard University Press, 1938. He was not the only economist searching for new expressions of competition. It seems that the early thirties was a ripe period in the field of imperfect competition. Several economists approached the problem independently of each other and among Chamberlin's contemporaries we find; Robinson, J., The Economics of Imperfect Competition, London: Macmillan, 1933. and Sraffa, P., The Laws of Returns under Competitive Conditions, Economic Journal, Vol. XXXIX, pp. 41 - 57, 1929.

⁵ Products were differentiated through certain characteristics of themselves and through conditions concerning the sale of these products. The sales of an individual seller was limited and defined by; the price of the product, the nature of the product and the advertising outlays.

⁶ Chamberlin, The Theory of Monopolistic Competition, p. 69.

Chamberlin only used the concept of network in an everyday sense. His main interest, and those of his contemporaries and successors, were in the nature of industrial competition. They handled the observed heterogeneity by grouping firms into industries according to the substitutability of their products. The notion of industries or trades was of course not new and the major contribution was rather the formulation of theoretical propositions regarding the relationship between the characteristics of industries and industrial competition. This product-oriented definition of industries and the relationship between the characteristics of industries and competition have permeated the preponderance of the studies of industrial economics and its impact on western thinking is indisputable: national statistics and anti-trust regulations are irrefutable evidence of its predominance⁷.

Industrial Systems and Organized Behaviour

Others responded differently towards the observed increase in heterogeneity of inputs and outputs: primarily by focusing on the complementarities rather than on the substitutes and on industrial systems rather than on industries. This did not merely represent a shift in focus, it also represented a shift in interest. The main issue was not intra-industry competition, but the functioning of total market or industrial systems, where the functioning of the parts was considered to be contingent upon the due functioning of the whole. R. F. Harrod and J. A. Hobson described the forces of production and consumption as; "forming common funds of industrial energy pulsing through the whole framework of industry, as the blood course through the various organs and cells of the body, giving organic unity to the entire system."⁸ This analogy between the course of economic action and the blood system was also put forward by Schumpeter in his discussion of the circular flow of economic life. He used the analogy in setting up the general perspective but abandoned it, referring to its inaptness to reveal processes of discontinuous change, when he came to the dynamics of economic life.⁹

Wroe Alderson, one of the founding fathers of modern marketing theory¹⁰, went one step further. Assuming perfect heterogeneity Alderson's functionalistic approach to

⁷ This has of course created a decisive momentum favouring the orthodox view in the pursuit of research in industrial economics.

⁸ Harrod, R. F. and Hobson, J. A., The Science of Wealth, 4th ed., London: Oxford University Press, 1950, first published in 1911, p. 25.

⁹ Schumpeter, The Theory of Economic Development, p. 61.

¹⁰ Alderson was not alone. He represented a strong tradition in the early theory of marketing and he had many predecessors, contemporaries and successors. See: Cox, R. & Alderson, W. (Eds), Theory in Marketing, Chicago Ill.: Richard D. Irwin Inc., 1950. See also: Grether, E. T., A Theoretical Approach

marketing was a total commitment to a systems approach of organized behavior systems in heterogeneous markets. In his analysis of heterogeneous markets Alderson employed the concepts of transaction and transvection stating that "The function of exchange is accomplished at successive levels by means of transactions, but the process of bringing any given item to the ultimate consumer is accomplished through a series of sorts and transformations called a transvection."¹¹ Through the concept of transvection Alderson accentuated the interdependencies of transactions and hence the complementarities of the market system. By focusing on transactions and transvections Alderson emphasized the importance of horizontal and vertical interdependencies to the functioning of organized behavior systems. Alderson was, like Schumpeter, preoccupied with the dynamics of economic life. Like Schumpeter, he stressed the importance of technological change, stating that "The treatment of technological change occupies a key position in a theory that attempts to show the dynamic character of marketing behavior. the fundamental basis of market dynamics is located in the fact that markets are both heterogeneous and discrepant. A (heterogeneous) market which is discrepant in the short run will display a long-run tendency toward equilibrium but will never actually achieve this steady state."¹² We recognize this commitment to disequilibrium from our previous discussions of dynamic analysis. What was perhaps new was the recognition of heterogeneity as a major force, driving dynamic processes.¹³

Depending on the issue at hand, approaches towards the observed heterogeneity followed two different routes. Either as Chamberlin and his adjuncts did, addressing issues of industrial competition by grouping the heterogeneous commodities into more

to the *Analysis of Marketing*, In: Cox, R. & Alderson, W. (Eds), *Theory in Marketing*, Chicago, Ill.: Richard D. Irwin Inc., pp. 113-124, 1950 and Grether, E. T., *Pioneers in Marketing: Edwin Griswold Nourse*, *Journal of Marketing*, Vol. XXII, 1958. A representative of alderson's successors is, Clewett, R. L., *Integrating Science, Technology, and Marketing: an Overview*. In: Haas, R. M. (Ed), *Science, Technology & Marketing*, *American Marketing Association, 1966 Fall Conference Proceedings*, Indiana University, Bloomington, Indiana, pp. 3 - 20.

¹¹ Alderson, W., *Dynamic Marketing Behavior*, Homewood, Ill.: Richard D. Irwin Inc., 1965, p. 278

¹² *Ibid*, p. 259.

¹³ Since this is a study of technological and industrial change I cannot abstain from a further inquiry into Alderson's views on technology. Alderson's perspective on technology was as holistic as his approach to marketing theory. Technology constituted a sub-system completely integrated in the organized behavior system. He expressed the changing technology in terms of the evolution of transactions as a part of the transactional network embraced by a transvection. Technological change was an inductor of changes in transactions that, through the transvection, would necessitate complementary changes to balance the system: a primary interest was how changes travelled through the system. His analysis of technology included the influence of technology in matching heterogeneous supply and demand as well as the sources, characters and dynamic effects of technological change. For a further discussion of how technology has entered into marketing theory see: Lundgren, A., *Technology and Marketing Theory*, Working Paper, Stockholm: Stockholm School of Economics, 1990

homogeneous groups, or by focusing on the complementarities of industrial systems: addressing issues of the nature of industrial activity in the context of interconnected market or industrial systems. As Alderson inquiring into the function of organized behaviour systems by introducing the vertical interconnectedness of sorts and transformations in transvections. The difference between the two routes pursued is more than the difference of micro and macro perspectives on industrial production: the different general methods of aggregation used in the two approaches are totally irreconcilable.¹⁴ To combine the two schools of thought, addressing both the nature of competition and the function of industrial systems, a synthesis of intra- and inter-industry competition and co-operation is required.

Taking the virtues of economies of scale to the extreme would lead us to believe that one single or a few corporations eventually would dominate the industrial reality of the world. Specialization and division of labour and the extent to which economies of scale can be realized are not unlimited. Even if Adam Smith's famous conjecture that the division of labour is limited by the extent of the market, suggests that, in the present times of globalization and integration of markets, there would be opportunities for even more specialization. Economies of scale are subject to diminishing returns: unit costs will not continue to decline indefinitely with increases in production volume or size of the corporation. Technological as well as market and managerial factors check the realization of economies of scale and industrial production appears to be a trade-off between production volume and adaptability to changing conditions: between economics of production and economics of organization and marketing.

The organization of economic activity has become increasingly problematic. Advantages of firm size and mass-production can be, and have been, set off by a continuous stream of technological innovation, crises of control of the heightened flow through production and consumer preferences for individuality and choice. The supposedly ever increasing flow through the systems of mass-production and mass-consumption invoked friction and problems of control of production, inventory, distribution or consumption. The resolving of these problems some social; like organization and rationalization of bureaucracies and routinization of decisions and transactions, and some technological; like the development of means of communication and means of handling information, sometimes called a control revolution,¹⁵ highlights the highly problematic nature of

¹⁴ We can note, however, that Alderson analyzed both horizontal competition and vertical transformation.

¹⁵ Beninger, J. R., The Control Revolution: Technological and Economic Origins of the Information Society, Cambridge, Mass.: Harvard University Press, 1986. Also quoted in: Hughes, *American Genesis*, pp. 298 - 299.

organization and administration of large firms in complex industrial systems. The advantages of mass-production were set off by the complexity of the whole system. Investments in production capacity had to be matched with corresponding investments in the markets for inputs and outputs. But neither the suppliers of inputs nor the buyers of output remained passive. They actively sought to improve their utility, thus the economic performance of an investment made by one corporation is to some extent subject to elements in other parts of the industrial system, on which the corporation in question has less or no control.

As the industrial systems of mass-production have matured the components have become increasingly standardized, opening avenues for specialization and division of labour beyond the scope of manufacturer of finished goods. In many industries we can observe the exploitation economies of scale in the production of components. This development is perhaps most obvious in the computer industry, where the exploitation of economies of scale have primarily been located within the semi-conductor industry, but where computer industry represents the bulk of the value added. Other industries, like the manufacturing of automobiles, exhibit similar patterns¹⁶. Hence, by division of labour between different firms within the industrial system, specialization could be taken to new heights. Economies of scale unexploitable by a single firm could be realized by a series of consecutive firms. This should have positive effects on the overall economic performance, but it will also make the performance of an individual firm subject to the performance of adjacent firms. The present tendencies, combined with new production technologies and changing consumer preferences have increased the possibilities for flexible specialization¹⁷ Where the development of interchangeable parts once was instrumental in the emergence of mass-production and mass-consumption it now seem to foster a new phase in the industrial development with exploitation of economies of scale with flexible manufacturing and individuality in consumption.

Consumers preferring alternatives of choice is nothing new. One of the major crisis facing Ford Motor Company, centred on the fact that the consumer preferred the choice and style offered by General Motors before the low priced, standard automobile offered by Ford. The resurrection of the Swedish automobile industry in the nineteneighties was

¹⁶ The development of integrated steel-mills is an example of division of labour within in an industrial system, moving in the opposite direction. That is from division of labour to integration. The problem for an individual firm is however the same, interaction with adjacent firms to increase the performance of the firms and the system.

¹⁷ The concept of flexible specialization is suggested by; Piore, M. J. and Sabel, C. F. The Second Industrial Divide: Possibilities for Prosperity, New York: Basic Books Inc. Publisher, 1984, pp. 258 - 308, as a path for economic recovery.

to a large extent also due to consumer preferences for alternatives. In the seventies the Swedish automobile manufacturers, Saab and Volvo, were doomed: they were considered to be much smaller than the assumed optimal scale. But changing consumer preferences in terms of choice of size enabled Saab and Volvo to survive and prosper in well defined market niches. In flexible manufacturing, the lately ascending outgrowth of the factory of the future, the final user is bestowed with a greater discretion over production decisions. Ultimately, the decisions of what and when to produce would be made by the user, while the producers only would decide on how to produce. Realizing flexible specialization would thus require efficient flows of information and goods from production to consumption.

The industrial systems of mass-production have grown larger and more complex, constantly appending and uncoupling components, changing the interrelationships of the systems. And when further growth of the rising giants of production seemed hampered by the limitations of the market, they extended their reach by setting up multinational operations and their scope by becoming multi-product firms.¹⁸ This added to the already problematic situation of economic organization. Internally, the visible hand of managerial hierarchy was falling apart: the rising giants were reaching or going beyond the limits of organization. Advantages of large size was set off by worker dissatisfaction and ineptness to act upon anything but very large changes. The quest for worker motivation and flexibility, presumed virtues of small organizations, encouraged corporations to try new forms of internal organization. Simultaneously the giants' access to resources; markets for inputs and outputs have become increasingly critical and too dire to be left to the whims of the market.

A new reality is in the making: with a wide variety of firms from very small to extremely large, far from the perfect competitive conditions of smallness and similarity, where only loosely organized firms strive for their existence in a complex environment: disclosing market arrangements, which in consecutive order connect systems of production and systems of consumption. There is a new reality where multi-product firms cross industrial borders and multinationals cross national borders, craving new theoretical insights into the problems at hand.

Maybe the industrial reality actually did not change and maybe did neither the world view of the theorists. But at least theorists focusing on the economic organization within and between firms were becoming increasingly recognized. In general they addressed the

¹⁸ Ibid, pp. 194 - 200.

failure of the economic organizations of pure hierarchy or pure market. They perceived firms and organizations as social entities rather than as production functions. They focused on the behaviour of firms and organizations in changing environments, setting internal organization in the perspective of external organization.

The Behaviour of the Firm

As we proceed down a path of alternative views on economic organization we slowly pull away from the rationalistic view. A major step in this direction was taken by the now classic work of Richard M. Cyert and James G. March on a revised theory of firm decision making.¹⁹ To them firms were social entities and, as an alternative to the predominant economic theory, they formulated a behavioral theory of the firm. The theory outlined specified an alternative framework "for dealing with the modern 'representative firm' - the large, multi-product firm operating under uncertainty in an imperfect market."²⁰

The basic constituent of the revised theory was an alternative perspective on organizational goals, expectations and choice. Where the organizational goal was survival rather than profit maximization and the outcome of a social bargaining process based upon existing coalitions of organizational participants. The aspiration level was perceived to be set by the combination of past goals, past performance and the past performance of others. Organizational expectations refers to the process through which information is made available. They described the formulation of expectations as search processes, where the direction of the search was affected by the nature of the problem stimulating search. The intensity and success of the search was on the other hand affected by the extent to which goals were achieved and the amount of available resources, organizational slack. Here we can notice that the firms were striving for satisfactory rather than optimal results. Finally, organizational choice was perceived as taking place in response to a problem, invoking and identifying alternatives consistent with prevailing goals and using standard operating rules in making the final choice. From here Cyert and March continued to discuss decision making of firms as quasi resolution of conflict, uncertainty avoidance, problemistic search and organizational learning.²¹

¹⁹ Cyert, R. M. and March, J. G., A Behavioral Theory of the Firm, Englewood Cliffs: Prentice-Hall Inc., 1963.

²⁰ Ibid, p. 115.

²¹ Ibid, pp. 114 - 125.

It should be obvious from this discussion that the behaviour of firms portrayed by Cyert and March, characterized by sub-optimization, local rationality and limited search is far from the rationalistic assumptions regarding firm behaviour, reacting optimally towards the stimulus of price, suggested by economic theory. Most of the modern thinking regarding decision making within firms is firmly based on this path-breaking work of Cyert and March

Firms' Dependence on the Environment

The next rock to be laid in making a path towards industrial networks, is to more specifically relate the decision making within firms to their environment. The action of complex organizations was exposed by James D. Thompson, whose interest was in the effects of the basic sources of uncertainty, technologies and environments, on how organizations designed and structured themselves.²² He focused on the interface between internal organization and external environment where he suggested that the organizations, through buffering, smoothing adaptation and rationing, would seek to seal off their core technologies from environmental influences. Technological requirements produced interdependencies within the organizations and as organizations were, always embedded in a larger system he also argued that organizations must be interdependent with entities in the environment, not subordinated to authoritative control. The internal interdependencies within the technical core were to be handled through coordination while the interdependence with the environment should be handled through boundary-spanning activities of adjustments to uncontrollable constraints and contingencies.²³ Note here the significance Thompson attributed to technology. Not only would it shape the internal organization of organizations but also the larger system within which the organization was embedded.

Thompson concluded his inquiry into complex organizations by suggesting that; "there is no one best way, no single evolutionary continuum through which organizations pass; hence, no single set of activities which constitute administration." Yet he maintained that under norms of rationality the design of organization would be contingent upon the requirements of technologies and environments: following through by stating that; "(a)ppropriateness of design, structure and assessments (of complex organizations) can be judged only in the light of the conditions, variables and uncertainties present for the organization",²⁴

²² Thompson J. D., Organizations in Action, New York: McGraw-Hill Book Co., 1967, p. 1.

²³ Ibid, pp. 14 - 24 and 51 - 82.

²⁴ Both quotations from, *ibid*, p. 162.

Jeffrey Pfeffer and Gerald R. Salancik went one step further in the direction pointed out by Thompson, purporting that no organizations are completely self-contained or in complete control of the conditions of their existence. Organizations are, to a greater or lesser extent, always subject to external control. Organizations depend on their environment through the fact that they must inevitably acquire resources by interacting with their social environment.²⁵ In accordance with the reasoning of Thompson, Pfeffer and Salancik perceived the environment as the basic source of uncertainty. The concentration of power, the scarcity of critical resources and the pattern of interconnectedness between organizations, determine the degree of conflict and interdependence in the relationship between organizations which in its turn determines the degree of uncertainty facing an individual organization.²⁶

Problems do not only arise because organizations are dependent on their environment, but also because this environment is not dependable. Neither can it be fully comprehended or predicted by the organization. Does an objectively defined environment exist? This question points at a compelling problem: is organized action resulting from actual or perceived properties of the environment? The social psychologist Karl E. Weick goes one step further, in suggesting that the environment is created, enacted, through organized action.²⁷ Hence, relating internal organization to external environment is problematic. Yet, the survival of organizations is dependent, not only on the efficiency of internal adjustments, but also on the ability to cope with and adjust to ever-changing environments.²⁸

Systems for production and consumption of goods and services are being extended over national and industrial borders. Industrial activities have become increasingly interconnected. Firms engaged in industrial production are gradually becoming dependent upon each other in their pursuit of interconnected industrial activities. In the study of social or industrial change researchers are increasingly becoming inclined to address

²⁵ Pfeffer, J. and Salancik, G. R., The External Control of Organizations: A Resource Dependence Perspective, New York: Harper & Row Publ., 1978, p. 19.

²⁶ Ibid, p. 72. Technology, the other basic source of uncertainty suggested by Thompson, is however treated as an integrated part of environment.

²⁷ Weick, K. E., The Social Psychology of Organizing, 2nd ed., Reading, Mass.: Addison Wesley Publishing Co., 1979, pp. 164 - 166.

²⁸ Pfeffer and Salancik, The External Control of Organizations, p. 3.

issues of the interrelatedness of firms and organizations in industrial markets. And inter-organizational issues are increasingly taking precedence over intra-organizational ones.

Industrial Networks - A Response to the Observed Changing Conditions of Industrial Production

Observing the changing conditions of industrial production a group of researchers, primarily Swedish, found industrial structures of firms and organizations, transforming and transacting economic resources through interconnected industrial activities resembling cobwebs of lines and nodes. Organized action was found to be embedded in a structure, in a network.²⁹ They found that the major part of the exchange in industrial markets took place within the realms of relationships between firms characterized by long-term stability. Where these exchange relationships were established through evolutionary processes, the relationships evolved slowly through the interaction between the firms, but once established they were rarely broken. The character of the relationships was found to be affected by the internal organization of the two parties and by product and production technology. Within the relationship, logistic and technical problems seemed to dominate over price considerations: exchange in industrial market seemed to be regulated by problems rather than by price.³⁰

Perhaps most importantly, it was concluded that the individual relationship was affected by the two firms other relationships. The exchange relationships formed a network pattern, where individual relationships were affected by the properties of the whole network. Industrial markets were observed to be coordinated, not only by the visible hands of the managers or the invisible hands of price mechanisms, but also through the adjustments and adaptations within long-term relationships. Networks represented a coordinative mechanism, a governance structure separated from the traditional dichotomy of markets and hierarchies.³¹

Firmly rooted in the traditions of industrial economics, system analysis and inter-organizational theory the group conceptualized a network perspective on the behaviour of

²⁹ For a comprehensive overview of studies related to interactions, relationships and networks see; Ford, D., Understanding Business Markets: Interaction, Relationships and Networks, London: Academic Press, 1990. For an overview of contemporary network theory see; Axelsson, B. and Easton, G., (eds.) Industrial Networks - A New View of Reality, London: Routledge, 1991.

³⁰ Hägg, I and Johansson J. (eds.), Företag i nätverk - Ny syn på konkurrenskraft, Stockholm: Studieförbundet Näringsliv och Samhälle, 1982, pp. 18 - 22.

³¹ Ibid, pp. 14 - 15. See also the path-breaking work of; Williamson, O. E. Markets and Hierarchies: Analysis and Antitrust Implications, New York: Free Press, 1975. Note that even if we can perceive exchange relationships as being on a continuum between price and authoritative control, this does not imply that the aggregates markets, networks and hierarchies are on same continuum.

firms in, and the function of, industrial markets. Inductive reasoning based on empirical research of industrial markets suggested that firms were linked together into industrial networks, through the fact that they produced or used complementary or competitive products. Empirical findings combined with theoretical insights provided; by Cyert and March regarding decision-making within firms; by Thompson and Pfeffer and Salancik setting the behaviour of firms into the context of environment and by Alderson regarding the function of organized behaviour systems, resulted in the articulation of a theoretical model of industrial networks.³²

Resting on the assumption of perfect heterogeneity, industrial networks were defined as consisting of actors linked together by their performance of complementary or competitive industrial activities, employing or consuming economic resources to process other resources.³³ Here we have the basic constituents of the most well articulated network model, that is; actors, activities and resources, all three defined as being perfectly heterogeneous. Actors differs in respect to purpose, scope and scale, which means that business firms, social organizations and public institutions at different levels of aggregation could be considered as actors. A general condition, however, is that the actor should have the capacity to retain at least some degree of autonomy. Activities are comprised of acts of transformation and transaction interconnected into activity cycles and transaction chains. Resources are heterogeneous and both tangible like capital and land, and intangible such as worker skills and goodwill. Heterogeneous resources are employed to transform or to transact, other heterogeneous resources, hence one dimension of resources is that they are complementary.

Actors control resources and perform activities. But no actor controls all the necessary resources or performs all the complementary activities of activity cycles and transaction chains. Technological change and industrial evolution have driven forth specialization and division of labour between actors, leaving the individual actors mutually dependent upon other actors in their performance of activities and production and use of resources. The interconnectedness of activities and resources creates interdependencies between actors, which are too critical to be left to the whims of the market . Hence, actors handle these interdependencies by establishing long-term relationships, where they give up some of their independence and freedom to act, in return for decreased uncertainty. The economic performance of actors is thus contingent on the performance of the whole network. Actors are embedded in industrial networks functioning as constraints on individual

³² Håkansson, *Corporate Technological Behaviour*, pp. 16 and 27

³³ *Ibid*, p.16.

action, but also as an instrument and medium for interactions and counteractions between actors and other entities in their world pushing further technological change and industrial evolution.³⁴

Industrial networks at every point in time exhibit specific structures of relationships based on specific combinations of interconnected activities and resources, where the future of the network, new relationships and new activities and resources, is enclosed in past relationships, and in past combinations of activities and resources. In the real world an industrial network could through continuing chains of relationships be extended infinitely, until it, ultimately, would embrace the whole world. This definition of network is, however, far from operational. Even if we probably will never be able to conclusively set boundaries for industrial networks, we need some tools to delimit them. The pragmatic solution is to let the delimitation of networks be dependent on the specific questions to be answered. The boundaries are, then, set where mutually dependencies transcend into one-way dependencies. Boundary spanning activities will nevertheless be the ones most propelling in the evolution of networks and thus delimitations must always be considered as temporal.

What, then, are the issues raised by the proponents of industrial networks? Well, basically network studies are performed along two lines of inquiries. First of all we have inquiries into the nature and evolution of organized action embedded in industrial networks. It is here that we find the absolute majority of the network studies.³⁵ A second line of studies pertains to the nature and evolution of whole industrial networks. Here we are likely to find only a limited number of studies: total network studies have been utterly rare in the pursuit of network research.³⁶ Few, if any, have studied the formation years

³⁴ *Ibid*, p. 25.

³⁵ Three themes seem to dominate this line of research in industrial networks. 1. Strategic action in industrial networks. See for instance Mattsson, L-G., Management of Strategic Change in a "Market - as - Networks" Perspective. In: Pettigrew, A. (ed.) The Management of Strategic Change, Oxford: Basil Blackwell, pp. 234 - 256, 1987. 2. Internationalization in industrial networks. See for instance; Johansson, J. and Mattsson, L-G., Internationalization in Industrial Systems - A Network Approach. In: Hood, N. and Vahlne, J-E., (eds.) Strategies in Global Competition, London: Croom Helm, pp. 287 - 314, 1988. 3. Technological development in industrial network. See for instance; Waluszewski, Framväxten av en ny massateknik - En utvecklingshistoria.

³⁶ A few examples do however exist. Håkan Håkansson has studied product development in the wood saw and metall drill network. See; Håkansson, H., Product Development in Networks. In: Håkansson, H., (ed.) Industrial Technological Development, London: Croom Helm, pp. 84 - 127, 1987. Phil Smith has studied the industrial network within a geographic area, the Morecambe Gasfield. See Easton G. and Smith, P., The Formation of Interorganizational Relationships in a Major Gasfield Development, Proceedings of the International Research Seminar on Industrial Marketing, Stockholm School of Economics, Aug. 29 - 31, 1984. Jens Laage Hellman has studied the pattern of cooperation in R&D networks. See Laage-Hellman, J. and Axelsson, B., Biotechnological R&D in Sweden - Research

of industrial networks. Before we continue our discussion on the nature of industrial networks, combining them with technological systems, let us briefly take a look at the nature of technological change in industrial networks.

Technological Change in Industrial Networks - Three Propositions

Actions or rather sequences of actions, organized, chaotic or unconscious, are undertaken by actors embedded in the social and technological contexts of industrial networks.³⁷ Technological innovation is one sequence of actions pursued in industrial networks. Technological change in industrial networks is affected by the existing structure of the network, the actors involved and their inter-organizational relationships, and the specific combinations of activities and resources. But it is also one of the propelling forces determining the future structure of the network. Hence, technology and technological change are fundamental aspects, reflected in several network studies, of the evolution of industrial networks. The results of more than ten years of study of technological change in industrial networks can be summarized in three general propositions; technological development is an interactive process; technological innovation results from local search processes elicited by locally perceived problems and the evolution of technology is a process of accumulation.

Technological Change as an Interactive Process

The first proposition is that technological development in industrial network is an interactive process. A significant part of the development takes place in the form of technical exchange between different actors; individuals, companies and research organizations. Håkansson argues accordingly that "interest should be focused as much on the interaction between different actors as on what happens within the actors. An innovation, therefore, should not be seen as the product of only one actor but as the result of an interplay between two or more actors; in other words as a product of a 'network' of actors."³⁸ No actor is in complete control of the system of production and consumption

Volume, Direction of Research, Pattern of Cooperation. A Study of the Biotechnological R&D Network 1970 - 1985, STU - Information 563 - 1986, Stockholm: Styrelsen för Teknisk Utveckling, 1986.

³⁷ This metaphor regarding change processes is well in line with the 5 footnotes to organizational change suggested by James March:

Footnote 1: "Organizations are continually changing, routinely, easily and responsively."

Footnote 2: "Changes in organizations depend on a few stable processes."

Footnote 3: "Theories of change in organizations are primarily different ways of describing theories in action in organizations, not different theories."

Footnote 4: "Although organizational response to environmental event is broadly adaptive and mostly routine, the response take place in a confusing world."

Footnote 5: "Adaptation to a changing environment involves an interplay of rationality and foolishness". See, March, J. G., Footnotes to Organizational Change, Administrative Science Quarterly, Vol 26, pp. 563 - 577, 1981. p. 563.

³⁸ Håkansson, (ed.) *Industrial Technological Development*, p. 3.

in which he to a varying degree participates, performing activities and controlling resources. He can neither incorporate the factors underlying the supply side of innovation nor can he completely control the factors underlying the demand side. Suppliers, users and competitors can make significant contributions to the innovation process, both by inducing innovation and by contributing, with their specific competence, to the problem-solving. The innovation process can be improved through the interaction between different actors: combining complementary competences, coordinating existing resources and mobilizing new resources, thus increasing the probability of success and reducing the risk and cost of failure.³⁹

The rate of technical exchange and the subsequent theoretical interest in innovation as an interactive process seem to be increasing.⁴⁰ The observed increase in technological cooperation between firms can be attributed to two properties of industrial development. Firstly, the highly developed vertical division of labour being the stylized fact of modern industrial societies, suggesting that a substantial part of the innovative activities take place in units separated from the potential manufacturers and users of the final innovations.⁴¹ Secondly, increasing volumes of production leading to the massive increase in the costs of research and development experienced by most actors.⁴²

The accentuation of the interactive facets of the innovation process does not suggest that the deeds of individual inventors, or internal research and development departments, are completely insignificant in the pursuit of technological development in modern industrial

³⁹ Ibid, pp. 4 - 6.

⁴⁰ Three other representatives of the increasing interest in innovation as interactive processes are; Lundvall, B-Å., *Innovation as an Interactive Process: From User-Producer Interaction to the National System of Innovation*. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G. & Soete, L., (eds.) *Technical Change and Economic Theory*, London: Pinters Publishers, pp. 348 - 369, 1988; Hippel, E., von, *The Sources of Innovation*, New York: Oxford University Press, 1988. and Carlson, B and Jacobsson, S., *What Makes the Automation Industry Strategic?*, Paper presented at the European Association for Research in Industrial Economics, 17th Annual Conference, Lisbon, Portugal, September 2 - 4, 1991.

⁴¹ Lundvall, *Innovation as an Interactive Process: From User-Producer Interaction to the National System of Innovation*, p. 349. and Laage-Hellman, *Technological Development in Industrial Networks*, pp. 34 - 35. Laage-Hellman also suggests a third process underlying the increasing needs for technological cooperation: increasing technological complexity leading to the fact that the nature of research and development is becoming increasingly multidisciplinary.

⁴² Laage-Hellman, *Technological Development in Industrial Networks*, p. 35. Boeing reports the cost of developing new wings to existing aeroplanes to exceed 3 billion US dollars. Volvo reports the cost to develop their latest car model to be slightly less than 3 billion US dollars. Finally, Gillette reports the cost of development of their new razor to be 500 million US dollars.

societies. It only suggests that whatever takes place within a firm must be set into the context of the cooperation between firms in an industrial network.

Technological Change as Local Search Processes Stimulated by Local Problems

The next proposition regarding technological development in industrial networks is that it is characterized by local search processes stimulated by locally experienced problems or opportunities. Actors are exposed to constant streams of events emanating from the technologically changing environments. And technological development unfolds as actors act, react, interact and counteract, responding to the streams of events facing them.⁴³ Which problem or opportunity to act upon and in what direction the solution or exploitation is to be searched is determined by the outcome of political processes, as much as it is determined by economic and technological rationality. This proposition regarding technological development stands in contrast to the heroic theory of development. It focuses on the everyday life of innovation. Note that this does not necessarily preclude major technological breakthroughs. There is also an everyday life behind major innovations.

The direction of the search processes and the rate of innovation will be governed by the underlying stream of technological problems and opportunities, which in its turn is determined by the prevailing state of technology in the network, the technological base of past developments.⁴⁴ The implication of this contextual proposition on the nature of technological change is that technology will be differentiated between firms and networks. Technology is specific to the problems and opportunities spurring the local search processes; both the stream of problems and opportunities and the direction of the search processes are governed by the specific contexts of industrial networks. The network specificity of technologies creates particular problems when it comes to the diffusion or transfer of technology from one network to another, requiring costly adaptations to or adjustments by the recipient network.

The problems or opportunities cannot always be sufficiently resolved or exploited where they are ascending. Not seldom are the solutions to be found outside the control of the actor experiencing the problems,⁴⁵ which brings us back to the first proposition:

⁴³ Håkansson, *Corporate Technological Behaviour*, p. 3.

An excellent example of this is provided by Alexandra Waluszewski in her study of the emergence of a new mechanical pulping technique. Waluszewski, *Framväxten av en Ny Mekanisk Massateknik*.

⁴⁴ Håkansson, *Corporate Technological Behaviour*, p. 37. Compare also with; Cantwell, *The Technological Competence Theory of International Production and its Implications*, p. 11 - 12.

⁴⁵ Håkansson, *Corporate Technological Behaviour*, p. 4.

innovation is an interactive process. Mutual adaptation and adjustments, rather than the deeds of heroic inventors, engineers and scientists, are the distinctiveness of technological development in industrial networks, regardless if it pertains to original innovation or diffusion or transfer of innovation within and between networks.

Technological Change as a Process of Accumulation.

Knowing how way leads onto way and how the solving of problems excites new problems triggering new search processes, bring us forth to the next proposition: technological change in industrial network is a process of accumulation.⁴⁶ It is a cumulative process in the traditional sense in that it is a consequence of incremental technological change and gradual learning and it is as much a question of retaining previous experience combining it with the prevailing circumstances, as it is a question of developing novel solutions.⁴⁷ But it is not a process of general accumulation, new knowledge or innovation is, even after it is once produced, not costlessly available to others.⁴⁸ Technological development unfolds in sequences of problem-solving, where problems lead onto problems, the solutions of which pushes the technological frontier forward along a particular path. This does not proceed according to a master plan, nor through the invisible hand of the market, but through the accomplishments of many actors, all acting in their self-interest.⁴⁹

The particular path of technological development is constrained by the interconnectedness of activities and resources in the industrial networks. Technological change in industrial networks is irreversible or quasi-irreversible. Innovation is created by adaptations and adjustments necessitating adaptation and adjustment of interconnected activities and resources, locking the development into specific fields of development, locking it out from others. The network creates limitations and opportunities, a momentum, pushing the future technological development in the direction set by the past.⁵⁰ The network and the technology evolve through specific paths of accumulation.

⁴⁶ The sequential accumulation in industrial networks can be compared with the particular systems of events proposed by Abbot Payson Usher in; Usher, A History of Mechanical Inventions.

⁴⁷ Waluszewski, Framväxten av en ny mekanisk massateknik, p. 249.

⁴⁸ Rosenberg, N., Why Do Firms Do Basic Research (With Their Own Money)?, Research Policy, Vol 19, No. 2, 1990.

⁴⁹ Håkansson, Corporate Technological Behaviour, p. 89.

⁵⁰ Ibid, pp. 88 - 89. Compare also with previous discussion of the nature of technological change and with; Cantwell, The Technological Competence Theory of International Production and its Implications, p. 10 - 11.

Technology is a significant part of industrial networks.⁵¹ Technological development is a compelling force driving the evolution of industrial networks, but this statement only covers half the story. The evolution of the industrial network is a compelling force driving technological change.

So far we have dwelled within the prevalent descriptive model of industrial networks, construed upon actors, activities and resources. Yet, before we entered this chapter we had established that technological change and industrial evolution unfolded in the dynamic interplay between technological systems and institutional structures. Given this particular interest we will in the next section make some qualifications to the contemporary network model, even though we will still use the concepts, actors, activities and resources, and return to the basic idea of technological systems and industrial networks.

Industrial Networks Defined

We will now follow a route suggested in a paper by Jan Johansson and Lars-Gunnar Mattsson, two proponents of network theory, where they consider industrial systems as consisting of two levels: two basic sets of interconnections. One institutional set, still labeled industrial networks and defined as interconnected exchange relationships. The institutional set is perceived as a governance structure, through which the exchanges in the system of production and consumption are coordinated. The other level is construed upon a technological set, labeled production system, exhibiting an industrial logic of interconnected activities and resources. In this way the authors accentuate the interconnectedness and interdependency of industrial networks and they move from stressing the individual elements of actors, activities and resources to emphasizing the interconnectedness and interdependencies of activity cycles, transaction chains and networks of relationships. The interconnectedness of the production system is handled by actors through internal organization and through relationships to other actors producing the interdependencies of the governance structure of industrial networks. Combined

⁵¹ The above mentioned texts on technological development in industrial networks, are not the only ones studying this phenomenon. There is a strong tradition in this line of inquiry also in the Netherlands. On product innovation and development in industrial networks see, Biemans, W.G., Developing Innovations within Networks - With an Application to the Dutch Medical Equipment Industry, Doctoral Dissertation, University of Groningen, Groningen, 1989. For a discussion of technical co-operation in industrial networks see, Hagedoorn, J. & Schot, J., Co-operation between Companies and Technological Development, Working Paper, University of Groningen, Groningen, 1988. Two studies under way stating issues similar to those stated in this work are, Blauwhof, G., Rossum, van, W., & Zeldenrust, S., The Development of Technologies / Towards a Network Analysis, Paper prepared for the Dutch Workshop on Technology Research, Groningen, May 31 - June 1, 1990. and Hicks, E. K. & Rossum, van, W., The Developmental Process of Technologies: Combined Insights from Network and Systems Theory, Paper prepared for the Dutch Workshop on Technology Research, Groningen, May 31 - June 1, 1990.

production systems and industrial networks constitute the higher order concept, industrial systems.⁵²

From Hobson and Harrod we obtain a comprehensive picture of an industrial system "in which many clusters of businesses are grouped into trades, while these trades are arranged in order by series to carry on the work of converting the raw materials and forces of Nature into commodities and services for the use of man."⁵³ Given the embeddedness of technology and social action we would here be primarily interested in the dynamics of production systems and industrial networks in the emergence of an industrial system for digital image technology in Sweden. This perspective on industrial networks is well in line with the view advocated in the present study, but some minor adaptations are necessary.

Industrial Networks - Technological Systems and Networks of Exchange Relationships

Accepting the content of the concept used and the general perspective on the linkages between them, what remains to be done is adapting the concepts to the present perspective. First of all, the concept industrial network is used to encompass the holistic level. Secondly, the institutional set is labelled networks of exchange relationships and the technological set is labeled technological systems. Industrial networks are therefore viewed as sets of interrelated actors performing interconnected activities, by transforming and transacting heterogeneous and interdependent resources.⁵⁴ The industrial network is hence the union of network of exchange relationships and technological systems. To avoid confusion in the future, the word network will be used to denote a network of exchange relationships and industrial network will be used to denote the totality, the union of a technological system and a network. See also figure 9 below.

⁵² Johansson, J. and Mattsson, L-G. Network Positions and Strategic Action - An Analytical Framework, In: Axelsson, B. and Easton, G., (ed.) Industrial Networks - A New View of Reality, London: Routledge, 1991.

⁵³ Harrod and Hobson, *The Science of Wealth*, p. 26.

⁵⁴ This use of industrial network is not different from the dominant use of the concept. What is different is how this superior layer is represented in lower layers of analysis.

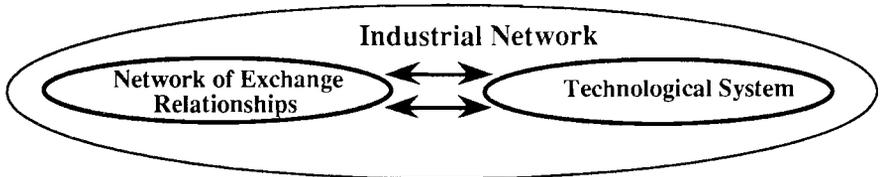


Figure 9: Industrial Networks - Technological Systems and Networks of Exchange Relationships.

The technological system is globally defined and characterized by technical connectedness and prospects of economic benefits from system integration.⁵⁵ Network benefits or network externalities originate from two different circumstances. Firstly, and as is stated in the straightforward definition above, the benefits arise directly from the integration of the interconnected technologies. Secondly, and what is perhaps not equally obvious, network externalities, and thus potential benefits, are apparent when the overall economic performance of the system is dependent on the number of users and when the economic value for an individual user differs as the total number of users differs.

The nature of technological systems goes beyond the interconnectedness of physical artifacts, such as generators, transformers, transmission lines, consumption measuring devices, and light bulbs and electrical apparatus in the electric light and power system. An industrial logic of the nature of the production and consumption activities of the system; knowledge of product technology, production methods and of natural resources, is embodied in the technological systems. Technological systems are then reflected in locally defined networks of exchange relationships. Over time networks of relationships become increasingly institutionalized as institutional structures of government agencies, laws and regulations and common rules of behaviour accumulate.

Due to the historical pattern of interaction within local networks the technological system is reflected differently in different local networks. Local in this context does not suggest that networks are primarily demarcated by geographical boundaries. Local networks can extend over several different countries and several local networks can co-exist within the same country. That networks of exchange relationships are locally defined simply implies that they can be separated from other networks reflected by the same technological system.

⁵⁵ David, *Some New Standards for the Economics of Standardization in the Information Age*, p. 208.

Technological systems can be used to set the boundaries for the industrial network in focus. Actors, especially large multi-product firms, are often engaged in several different networks of exchange relationships, the concept of technological system enable us to delimit industrial networks to focus on particular networks. But the concept is also essential when it comes to the understanding of the complex interplay between technological innovation and changes in the pattern of interaction in networks. Actors perform acts of innovation to resolve perceived imbalances in the technological system or in their network of relationships. If reproduced the innovation will be preserved in the technological system, functioning as a driving force for further changes in other parts of the network in focus and in other local networks.

The development and subsequent implementation of radical technological innovation and the emergence and evolution of new industrial networks, thus, embodies two sets of interrelated issues; the emergence of a new technological system, adapting and integrating the parts of the system to one another and the emergence of a new network of exchange relationships, coordinating specialization and division of labour between actors, routinizing transactions and distributing the economic surplus, setting the scene for further integration within the technological system.

Starting out with what he labelled Wieser's principle of continuity, Schumpeter wrote that; "the economic system will not change capriciously on its own initiative but will be at all times connected with the preceding state of affairs."⁵⁶ Yet, as he entered the path of industrial dynamics he asserted that the new structures would emerge beside the old. He wrote; "new combinations are, as a rule embodied, as it were, in new firms which generally do not arise out of the old ones but start producing beside them".⁵⁷ Hence, his emphasis was on the capitalistic system capable of allocating resources for new ventures. In his later works, as we have seen above, he more willingly admitted that new structures could emerge from within pre-existing structures.

The economic structure in the western world of today is in many respects different from the structure experienced by Schumpeter. As we saw above; technological systems have grown larger and become more integrated; industrial networks have been extended globally and specialization and division of labour have become more apparent and distinct. Almost every economic field has become dominated by a few large multi-product firms. As a consequence economic activity has increasingly become embedded in socio-

⁵⁶ Schumpeter, *The Theory of Economic Development*, p. 9.

⁵⁷ *Ibid*, p. 66.

technical structures. And the semi-autonomous actors of industrial networks are dependent upon the support of other actors to realize changes in the network. The cost of research and development and market introduction have increased tremendously and firms are increasingly seeking partnership in the development of new businesses.

A more potent social and technological momentum has been accumulated causing the emergence of new industrial structures to be better aligned with the pre-existing structure than Schumpeter had reason to anticipate. Changes emerge from pre-existing structures and if viable, they will eventually be re-integrated with the structures from which they originated. The emergence of new industrial networks will neither be purely cumulative nor purely revolutionary. It will most likely be the result of a combination of change and accumulation, where previously independent technological systems and networks are being linked into one unity, one whole, a new industrial network.

New technologies, new technological systems, originate from innovative activities located within established technologies. Radical innovations represent discontinuities disrupting the established economic structure. Thus, new technologies will primarily be embodied within research and development departments of universities, national defence organizations and business firms and within newly established firms. As new technological systems diverge, through different acts of innovation, from the paths of the established technologies and networks, the innovators, the newly established firms and the different research and development departments will attempt to accumulate resources to transform the innovations into self-sustaining economic enterprises.⁵⁸ Simultaneously, new infra-structures, new industrial networks, connecting the interrelated parts of the emerging technological systems must evolve. The performance of individual actors will to some extent be contingent upon the performance of the whole, positive networks externalities are present. A new industrial network cannot function in isolation. It must eventually be integrated with the structure from which it emanated. The emergence of a new industrial network can thus be perceived as a continuous evolutionary process transforming industrial production and consumption from one structure to another, conveying new technological systems and new networks of exchange relationships.

Our primary interest here is the emergence of one specific industrial network, digital image processing, in one specific country, Sweden. In the next section a framework for the understanding of the emergence of a new industrial network as the dynamic interplay between a technological system and a network of exchange relationships, is presented.

⁵⁸ Van de Ven and Garud, *A Framework for Understanding the Emergence of New Industries*, p. 10.

A Framework for an Understanding of the Emergence of a New Industrial Network

Evolutionary processes in industrial networks are the subject of several recent studies.⁵⁹ Being slightly different in scope, these studies still share a common view, in that they present industrial networks as living, ever-changing, organisms. From these studies it can be concluded that the evolution of industrial networks is composed of two complementary, but contradictory processes, the generating of variety and the organization of everyday life. Both processes are embedded in the pre-existing industrial network and are therefore bounded by historical evolution. The organization of everyday life refers to the process through which the activities and components of everyday life are coordinated, integrated or adapted to one another. The organization of everyday life is constantly disrupted by the generating of variety; the inducing of innovation or the establishment of new network relationships, motivated by perceived problems. The organization of everyday life primarily increases the degree of integration within the network while the generating of variety induces heterogenization and disintegration. A specific evolutionary pattern therefore results from these two parallel processes. As the processes are likely to dominate in different periods of time we can expect the evolution of an industrial network to move from integrative to disintegrative back to integrative, carrying a transforming structure.

Two different metaphors would be conceivable in the study of the emergence of new industrial networks. First of all we could perceive it as a biological life-cycle⁶⁰, where the condition and interconnectedness of the complex system is set from the beginning⁶¹. And where the technological system and industrial network properly fostered and nurtured

⁵⁹ See for instance, Håkansson, Corporate Technological Behaviour - Cooperation and Networks., Håkansson, H., Evolution Processes in Industrial Networks. In: Axelsson, B. and Easton, G., (Eds.) Industrial Networks - A New View of Reality, London: Routledge, 1991., Hertz, S., Towards More Integrated Industrial Systems. In: Axelsson, B. and Easton, G., (Eds.) Industrial Networks - A New View of Reality, London: Routledge, 1991. and Lundgren, Economic Changes in Industrial Networks - Coordination of Activities and Mobilization of Resources.

⁶⁰ The product life-cycle is one of the most widespread models for the study of product innovation. An excellent inquiry into the nature of the product life-cycle can be found in, Duijn, van, J. J. The Long Wave in Economic Life, London: George Allen & Unwin, 1983. pp. 20 - 32.

⁶¹ This specific aspect of the life-cycle metaphor is criticized in, Gherardi, S., Development and Decline in Organizational Analogies - A Critical Review, Working Paper, Dipartimento di Politica Sociale, Università' Degli Studi Di Trento. Svante Lindqvist is criticizing it from another perspective, from the fact that it has focused our interest towards the early phases of the development. Lindqvist, S., Changes in the Technological Landscape - The Temporal Dimension in the Growth and Decline of Large Technological Systems. Paper presented at the conference The Development of Large Technical Systems, at the Max-Planck- Institut für Gesellschaftsforschung, Cologne FRG, November 25 - 28, 1987

will move through the stages of birth, adolescence, growth, maturity, declining years bent with age and eventually death, bringing prosperity to society. On an aggregated level this metaphor suggests that periods of evolutionary growth will be nullified by revolutionary change⁶². The policy implications are rather obvious, the state should provide support during birth and adolescence, tax it during growth, maturity and declining years and facilitate and balance the death. The individual actor should strive to decrease the time span and cost of birth and adolescence, extend the time and increase the profits of growth and maturity, managing decline, exhausting final profits and timing the dismantling of the dying system.

We can set another, more action oriented, metaphor against the biological life-cycle, where we do not assume that the condition and interconnectedness of the complex system are set from the beginning. We assume, in fact that this is what the existence of technological systems and networks really is all about, the continuing formation, establishing, adaptation of the interconnectedness of the technological system and of the interdependencies of the network of exchange relationships. Not in consecutive order, but simultaneously, constantly expanding and contracting the industrial network, changing, integrating or disintegrating, the interdependencies of the network and the interconnectedness of the technological system. The emergence of a new industrial network is thus not characterized by a sequence of life, but of life itself: with ascending, growing, maturing, declining and dying elements constantly co-existing within the system. Here the policy implications do not come as easily and we have to postpone an inquiry into this issue until later. The study of the emergence of an image processing network in Sweden seems to be supporting the second action oriented metaphor. Even though this metaphor does not seem to allow for new industrial networks to emerge, the evolutionary process studied, will be interpret as life itself rather than as a sequence of life.

New Networks of Exchange Relationships

We can, however, assume that new industrial networks really do emerge carrying new technological systems and new networks of exchange relationships. New here does not necessarily mean new in an absolute sense. New can also mean a re-organization of the pre-existing state, but normally this would include at least some novel elements. Industrial networks do not ascend instantaneously in a once and for all shape. They rather unfold through parallel and continuous processes of formation, establishment and

⁶² A recent and elaborated model of the basic life-cycle metaphor employed on an aggregated level, that is for industries or technologies, can be found in, Dosi, G., *Technological Paradigms and Technological Trajectories*, Research Policy, Vol. 11, No. 3, pp. 147 - 162, 1982

adaptation. It is likely that, even if the processes are parallel, different processes can dominate in different periods of time and it is plausible that, formation precedes establishment and that establishment precedes adaptation. Focusing on changes in the network of exchange relationships, the study of the development of digital image processing in Sweden suggests that the emergence of a new industrial network can be divided into three distinct processes; genesis, coalescence and dissemination. And even though the processes are omnipresent they tend to dominate in different periods of time. Genesis represents the creation of variety and the ascending of a new pattern of interaction. Coalescence represents the integration of variety into an emerging community of actors. Finally, dissemination represents the adaptation to the pre-existing structures and the dissolving of the network.

New Technological Systems

The evolution of the institutional structure will of course be contingent upon the evolution of the technological one. The move from individual innovations to technological systems implies a move away from the dominant model of technological development, stating that technical change is brought about through the sequence of invention - innovation - diffusion/imitation. The undertaking of inventive activities is a salient feature of mankind, what transforms the single invention to the development of a new technological system, is the identification of the interconnectedness of a cluster of inventions. The identification of a technological system as something new and different from the prevalent technologies, represents the origination of the new system. The fact that a system is something novel does not, however, imply that resources automatically will be devoted to its establishment. To establish the new system, this development must be legitimated. Finally, whence a new technological system has been identified and legitimated, it must be adapted to the prevalent technological systems. Thus, the other side of the evolution of industrial networks can be treated as the continuous processes of identification, legitimation and adaptation. And as was the case with genesis, coalescence and dissemination, these processes do not necessarily unfold in a sequential order, they are rather omnipresent continuously altering the structure of the industrial network.

Summary

Combining the emergence of a network of exchange relationships with that of technological systems, the genesis of the network corresponds to the identification of the technological system. Coalescence has its counterpart in legitimation and dissemination corresponds to adaptation.⁶³ A graphical representation of the framework for the

⁶³ The suggested model is thus slightly different from the perspective on the dynamic interplay between industrial innovation and industrial change purported by James Utterback in, Utterback, *The Dynamics of Product and Process Innovation in Industry*. The difference basically pertains to the shift in focus from

understanding of the emergence and evolution of technological systems and industrial networks is presented in figure 10 below. Note that the diagonal line represents the main focus in this study.

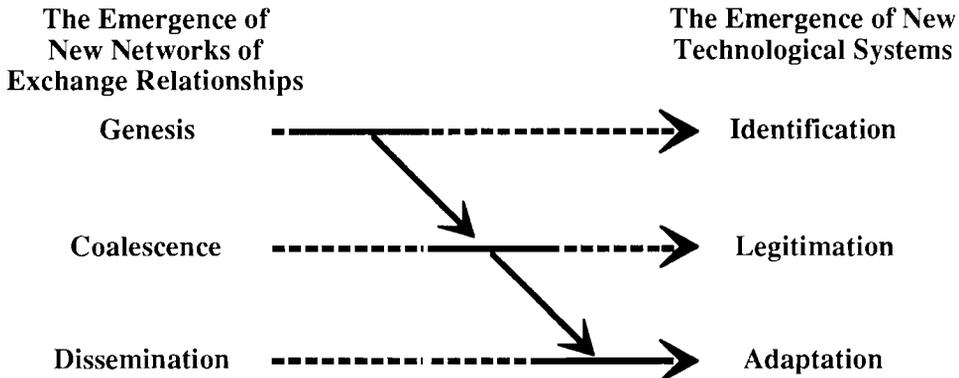


Figure 10: A framework for the understanding of the emergence of a new industrial network.

Genesis - Identification

Genesis is marked by the independent initiation of several different research and development projects and the origination of the new technological system. These projects were initiated within different technological systems and in different industrial networks and the actors of the emerging network were scattered geographically, functionally and technologically. As the projects deviated from their origins the proponents of image processing had to initiate search processes for support and complementary resources outside their original networks.

Coalescence - Legitimation

As the emerging technological system was identified the proponents of image processing began to interact with one another, and the emerging network coalesced into a closeknit community of complementary and competing image processing firms developing image processing into a multi-purpose technology. As the network coalesced the parts of the new technological system were adapted to one another, the technological system of digital image processing was integrated and the network produced several different image processing systems.

viewing the innovation and industrial change as a sequence of change processes, to perceiving them as a number of parallel processes. This does not, however, imply that the work of Utterback is fully appreciated. Any similarity with population ecology is, however, purely accidental and unintended.

Dissemination - Adaptation

In adapting the technology to the specific needs of different users, inducing processes of learning by using and exploiting complementary investments made outside the close community of image processing firms, the image processing network disseminated. Dissemination refers to the extension of the network, backwards connecting it with supplier networks, and forwards, connecting it with user networks.

These processes are omnipresent. They do not unfold in a sequential manner, but will each become dominant in different periods of time. We have not yet seen the end of the emergence of digital image processing in Sweden and the evolutionary processes will continue to govern the development of the industrial network for digital image technology. A remaining question is: What determines the shift from the domination of one to the domination of another?

The genesis - identification, coalescence - legitimation and dissemination adaptation of the emergence and evolution of a new industrial network is based upon the empirical observation of the development of digital image processing in Sweden. It does not imply that this is an optimal route, nor that all emergent networks will follow similar paths. But it is suggested that the evolutionary pattern observed is of a more general character and it is thus held to be plausible that most cases of the emergence of new industrial networks will unfold in a manner similar to that of digital image processing in Sweden. The emergence and evolution of digital image technology and the image processing network in Sweden will be more carefully analyzed in the next section.

Part III

NOVELTY IN THOUGHT AND ACTION

THE EMERGENCE OF DIGITAL IMAGE PROCESSING IN SWEDEN

The emergence of an image processing network in Sweden, will as has been suggested before, be presented as the three different, but interrelated, processes of genesis - identification, coalescence - legitimation and dissemination - adaptation. We have previously concluded that these processes do not follow from each other in a consecutive order: They are rather parallel processes continually changing the technological system and the network of exchange relationships. We can, however, also see how different processes dominate in different periods of time and in the emergence of a network of exchange relationships. Genesis is likely to dominate earlier on in the process, followed by the domination of coalescence and finally dissemination is likely to dominate closer to the end of the emerging years. Consequently, it is possible to treat the processes in a consecutive order of domination.

Before the analysis of the emergence of the digital image processing network in Sweden is presented, we must briefly re-examine some of the underlying principles governing the selection of information. What information is included and what is excluded? The issues involved are the emergence of industrial networks and the transformation of scientific research into industrial production. The focus has therefore been on the evolution of the cooperation between firms and other organizations and on changes in technology. Less attention has been given to the individual inventors and entrepreneurs. This is not because these have been absent in the emergence of digital image processing, nor that their role

has been insignificant. The rise of image processing is filled with heroic individuals performing heroic deeds: Sixten Abrahamsson developing a drum-scanner; Torleiv Orhaug making pioneering contributions in the development of image processing and remote sensing; Nils Åslund continually developing image-reading instrument systems; Per-Erik Danielsson and Björn Kruse developing parallel computer architecture and spinning off the first image processing company; Gösta Granlund constructing one of the more exciting image processing computers; Ingemar Ingemarsson and Robert Forchheimer taking the Swedish tradition in image transmission to new heights; Rolf Johansson making pioneering contributions in industrial automation; Lars Dahlström developing the first Swedish system dedicated for robotic vision; Björn Stenkvist and Ewert Bengtsson developing image processing systems for cytology. To a large extent these and other pioneers have taken Sweden to its technologically leading position in digital image processing. But these individuals are only the tip of the iceberg, behind them we are likely to find larger and smaller groups of fellow workers and researchers. Furthermore, it has been argued that human ingenuity is more interesting as a phenomenon than are the individuals representing this skill. Our focus is thus on networks of exchange relationships and technological systems and not on individual inventors and entrepreneurs.

Chapter 6

GENESIS

Digital image processing is an extension of computer technology and consequently the existence of and availability of computers is a necessary condition for the emergence of image processing technology. The development of computing machines made it possible to mechanize solutions to old problems. It also made it possible to solve new sets of problems, whose emergence coincided with the development of the computer. Telecommunication and television technology, broadly defined were important auxiliary sources in the emergence of image processing. Combining two of the high technologies of the post war time: television and computer technology, connecting a television camera to a computer and thus enabling machine vision was not a far fetched idea.

In 1948, only a few years after the erection of the first computers, John von Neumann holds a presentation on the general and logical theory of automata at the Hixon Symposium where he discusses the possibility of mechanized image interpretation. He not only mentions it. He also indicates in which direction to search to solve the problem.¹ Von Neumann says; "Nobody would attempt to describe and define within any practical amount of space the general concept of analogy which dominates our interpretation of vision. There is no basis for saying whether such an enterprise would require thousands or millions or altogether impractical numbers of volumes. ... It is therefore not at all unlikely that it is futile to look for a precise logical concept, that is, for a precise verbal description, of 'visual analogy'. It is possible that the connection pattern of the visual brain itself is the simplest logical expression or definition of this principle."² Von

¹ This presentation with the title, "The General and Logical Theory of Automata", has been published in John von Neumann's Collected Works, pp. 288-328, 1963. The General and Logical Theory of Automata is an inquiry into the possibilities of artificial intelligence: into the possibilities of constructing a machine with self-regulating mechanisms. In his work on the theory of automata he suggests a construction of the automata similar to that of the human brain. Curiously enough not until lately has his ideas on the automata bore fruit. Neural networks can be viewed as an extension of von Neumann's theory of automata. For the achievements of John von Neumann see, Aspray, W., John von Neumann and the Origins of Modern Computing, Cambridge, Mass.: MIT University Press, 1990. In the mid sixties, Bengt Wedelin and a small group of researchers at the department of Electric Circuits at Chalmers Tekniska Högskola worked on the construction of models of the human brain. The work of this group was to some extent explored in the construction of image processing computers. (Personal interview, Prof. Gösta Granlund)

² Neumann, von, The General and Logical Theory of Automata, p. 311.

Neumann's statement should be seen as accounting for the fact that prospects of mechanized vision were not only a distant dream and not as the starting point of digital image processing. As a matter of fact not until lately has the route pointed out by von Neumann been intensively explored.

Initially, the primary problem was the reading of images into the computer. As solutions to this problem were developed, a new problem became critical, namely the huge amount of data embodied in images. An ordinary colour photograph contains the same amount of data as 25 books of approximately 400 pages. Conventional computers could very well be used to process image information, but it was extremely time consuming and in almost every respect inferior to every other method of image processing. If image processing were to become technologically and commercially viable, special image processing computers capable of processing and storing huge amounts of data would have to be developed. In the late sixties and early seventies parallel data processing was developed, which still remains the dominant solution to the demand of high speed processing capacity.

Another important problem was the interrelatedness of input processing and output suggesting that it could not be handled through the separation of the whole into distinct problems. As the technology developed and became more standardized the process could be broken down into parts. Thus the possibilities for specialization and division of labour increased. This and the problems mentioned above appeared and were resolved within the realms of emergent networks and the developed solutions modified future technological development and the evolution of the networks.

Five Centres of Origin

Five centres of origin of the technological concept of digital image processing can be identified: 1. optical character recognition related to the development of techniques to read data into computers, 2. remote sensing related to the development of air and satellite reconnaissance of early warning systems, 3. radiology and the development of methods and instruments for the registration of soft tissue, 4. mechanization of previously manual analysis of images in research laboratories and 5. image transmission, and the development of picture phones. The common denominator of these remotely connected fields of interest was the increase in the degree of mechanization in the analysis or processing of natural images. As the capabilities within these technologies had developed differently in different countries, digital image processing emerged in different clothing in different countries. Sweden did not exhibit equal strength in the five centres of origin of

digital image processing and all problems propelling the acts of innovation were not equally immediate.

Optical Character Recognition

In the development of the computer, man - machine interaction soon became problematic. This was particularly the case with input procedure. To develop a more functional way of feeding data into the computer several research and development activities were initiated. One of these was to develop a device that could read written or printed characters and transform them into computable units. This gave rise to a technological field labelled optical character recognition and the spread of this technology followed the spread of the early computer industry. The basic problem of converting an image of a symbol to digital information proved to be extremely difficult to solve efficiently, given the state of computer technology. When the computer terminal, keyboard and monitor, became the standard solution to the man - machine communication, one tension compelling the development of optical character recognition disappeared. Consequently, the computer industry slowly lost interest in this field. The further development of optical character recognition was pursued outside the computer industry and the major impact of the technology has so far been in the development of faxmachines.

Picture Phones and Image Transmission

Another field of interest of importance in the emergence of image processing, of significance also in the development of fax-machines, was image transmission. The major difference between image processing and image transmission is that the latter seldom involves elements of processing or analysis. In the adolescence of television technology image transmission surfaced in actual tests and in the science fiction literature as interpersonal communication over television. Before television became a technology for mass-communication, it was tested for interpersonal communication. The more futuristic ideas were materialized much later in AT&T's Picturephone, first presented at the New York World's Fair in April, 1964.³ Besides AT&T several other telephone companies were making progress with picture phones. To the Swedish company L. M. Ericsson the picture phone was one of the most promising research and development projects from 1968 to 1971 and they performed the first transatlantic transmission of sound and image between two picture phones in 1970. L. M. Ericsson tested picture phone systems internally and in their collaboration with Swedish Telecom. A system was also installed at one of the largest Swedish commercial banks. The picture phone, however, captured more imaginations than it did business. Nonetheless, companies have

³ Forester, T., High-Tech Society, Cambridge, Mass: MIT Press, 1987. p 124.

persistently clutched to the concept of transmitting images over telephone and picture phones are still presented as the future mode of telecommunication. The concept of picture phones has been expanded into image transmission but the basic idea of a widespread picture phone system persists and it is still being evaluated by the telecommunication operators all over the western world.

The development of picture phones is an excellent example of the interrelatedness of technology. Why could the scientific and technological achievements of image transmission not be transformed into useful products of economic significance in the 1970's? After all, the capability of transmitting sound and images simultaneously had been established, and functioning prototypes were developed and tested. There is, however, a huge distance between achieving something under favourable conditions and the production of profitable products and services. The picture phone functioned well in isolation, but it could not be implemented in the existing system of telecommunication. The economic benefits of any communication system relies upon the availability of a substantial amount of nodes. Image transmission requires a much higher transmission capacity than ordinary transmission of sound and the limitations of the existing communication channels of the time only allowed small scale use of picture phones. Large scale use of picture phones required a substantial increase in transmission capacity and at the time this could only be achieved by employing expensive satellite-technology. By itself this was a sufficient cause for the delay in implementing picture phones. Additional, supply-side, barriers to the development of picture phones were the unavailability of low cost components, cameras and monitors, on which the picture phone system was based. On the demand side tests of picture phones eventually showed that the primary need for the system was to communicate documents, not the ability to see the interlocutor. Compared to other modes of communication, picture phones were a most inefficient technology for transmission of documents. The development of the picture phone was therefore, locked into a situation where no evolutionary paths of development were open. Further development and implementation of picture phones required a giant leap in technology and the demand for picture phones did not motivate the commitment of resources necessary to make this leap. Picture phones remained a remote vision of a distant future, but they accentuated the need for improvements in the system of telecommunication, especially regarding the cost and capacity of transmission.

Research Laboratories

Automatic analysis of images was also developed in numerous research laboratories basing their research on the analysis of images. Some of these laboratories had already began to make extensive use of computing machines feeding manually interpreted image

data into the first generation of computers, thus performing a rude form of computerized image processing. To enhance the capability to process images an instrument capable of interpreting image data and reading them into the computer was needed. Two examples of fields of research spurring the development of image reading systems are spectrography and x-ray crystallography. In spectrography two-dimensional information is measured and processed. A manually operated mechanical instrument was the standard procedure for reading spectral recordings.⁴ The obtained image data was read into the computer via punch cards. In the beginning of the sixties a group of Swedish physicists, within Physics IV at the Royal Institute of Technology, set out to develop a machine for reading spectral recordings into a computer. By employing an electro-optical technique they were able to construct a spectral reader capable of performing the specified operations. The spectral reader was used in combination with one of the first Swedish computers.⁵ This pioneering work, in image reading, later led to the development of a scanner, IRIS for the reading of two-dimensional star plates.

In crystallography, x-ray diffraction of substances is used to describe and analyze the three-dimensional structure of a substance. In x-ray diffraction a substance is irradiated with electromagnetic radiation. The three-dimensional structure of this substance is revealed in the diffraction pattern of this radiation. The diffraction pattern is registered on photographic film and by measuring the position and intensity of the diffracted radiation it is possible to reconstruct the structure of a substance. Initially, the positions of the diffractions were measured with an ordinary ruler and the intensity was estimated by comparing the diffraction with a library of reference points. The problems associated with these measurements limited the size of the structure possible to analyze using this method. A Swedish crystallographer saw the possibility to mechanize the measuring of diffraction patterns and thus overcoming the tedious work of measuring and enhancing the scope of the method. In the beginning of the sixties he initiated a development of an automatic drum densitometer, a film scanner. The availability of this scanner made it "possible to make fast routine determinations of interplanar spacings and diffraction intensities from X-ray powder photographs".⁶ This scanner resembled the above mentioned spectral reader in that it was based upon electro-optical technology. The film scanner and IRIS was manufactured by two different divisions of the emerging Swedish

⁴ Åslund, N., *Digital bildteknik*, *Kosmos*, Svenska Fysikersamfundet, Stockholm, pp. 73 - 82, 1984. pp. 81 - 82.

⁵ Personal interview, Professor Nils Åslund 1984-12-10

⁶ Malmros, G. & Werner, P-E., *Automatic Densitometer Measurements of Powder Diffraction Photographs*, *Acta Chemica Scandinavica*, vol. 27, p. 493 - 502, 1973. p. 493.

computer corporation, DataSaab, who perceived the instruments as interesting applications of computer technology. The film scanner was introduced in 1965 and IRIS in 1972, none of them became a commercial success.

Other laboratories conducting research, to some extent, based on the analysis of natural images had not yet commenced making use of computers to process the information embodied in images. Laboratories of this kind could be found within different applications of science ranging from quality control of steel to cytology. The images to be analyzed were often very complex and difficult to stratify, thus the delay in the mechanization of the analysis. Across applications the variation of images was almost unlimited, but within a particular application or laboratory the variation was limited. The dominant method of image analysis involved humans, basing their analysis on past experience or on the comparance of specific images with reference images. The developments within computer and television technology in combination with the homogeneity of the images within specific applications spurred an interest in the computerization of image analysis. A company that early envisioned the possibility of computerized image analysis was the British company Metals Research Ltd.

Metals Research developed and marketed research metals and scientific instruments, primarily for the research laboratories of the steel industry. In the early sixties a small group within the company began to develop an image analysis computer and in 1963 Metals Research presented a computer system for analysis of microscope images. The system consisted of one television camera and two monitors connected to a relay-computer⁷. The introduction of the second generation of image-analyzing computers, Quantimet B, in 1964 was followed by a commercial breakthrough. In 1965 the research laboratory at the Swedish steel producer Fagersta AB acquired Quantimet B and before 1970 twelve systems were installed at other research laboratories within the steel industry.⁸ Quantimet B was primarily used in the analysis of non-metallic inclusions in steel. The Swedish steel industry initiated a cooperative project regarding the usage of computerized image analysis in the steel industry. The commercial success of Quantimet B motivated Metals Research to change name to Imanco Ltd, an acronym for Image Analyzing Computers, and business was concentrated to computerized image analysis. The success continued and they acquired the more well known producer of scientific

⁷ Braggins, D. W., The Evolution of Quantitative Image Analysers 1963 - 1981. Proceedings of the Indian Statistical Institute Golden Jubilee International Conference on: Advances in Information Science and Technology, Vol 1: Pattern Recognition and Digital Technique, Calcutta January, pp. 298 - 315, 1982, p. 298 - 299.

⁸ Unpublished list of Quantimet installations Kjellbergs Successors AB.

instruments, Cambridge Instruments Ltd., a company whose name it adopted. The success of Metals Research, Imanco and Cambridge Instruments also propelled other producers of scientific instruments, such as Zeiss, Leitz and Bausch & Lomb to initiate the development of image processing systems⁹.

Radiology

Radiology represents a fourth origin from which electronic image processing emerged. X-ray technology is certainly one of the most important innovations in medicine, in that it enables physicians to examine interior parts of the human body. X-ray is a form of electromagnetic radiation capable of penetrating solids. The penetration capability is higher in soft tissue than in hard and this difference can be registered on photographic film. This basic method of X-ray was quite sufficient for the examination of broken bones or punctuated lungs, but had its limitations when it came to the examination of soft parts. This gave rise to extensive experimentation aimed at increasing the usage of X-ray as a diagnostic instrument. The easiest way was to alter the penetration regarding the soft tissue in question by injecting or otherwise inserting contrast liquid. The use of contrast liquid sometimes proved to be dangerous, as in the case of the examination of the spinal cord and sometimes impossible, as in the case of the examination of an unborn child. Furthermore, even if we should not exaggerate the awareness, at that time, of the risk associated with exposure to radiation, X-rays could be detrimental to human health. These problems induced further experimentation regarding alternative methods of penetrating the human body and of alternative methods of registering this penetration.

The use of X-ray as a diagnostic instrument was increased by the replacing of the photographic film with a light sensitive electronic device combined with a capability for amplifying the signals. We can call this device an image amplifier. Through this development it became possible to convert the X-ray beam to analog electronic signals, that could be presented on a television screen. In many respects the technology of image amplifying resembled television technology. By employing electronics it became possible to decrease the energy in the X-ray beam and thus to reduce the exposure to radiation. The shift to electronic technology increased the possibilities to discriminate between different levels of penetration and it also made it possible to examine moving parts. The energy required by the electromagnetic radiation was also reduced by the development of new more light sensitive photographic film.

⁹ Braggins, *The Evolution of Quantitative Image Analysers 1963 - 1981*, p. 300.

Electromagnetic radiation was, however, not the only radiation capable of penetrating solid materials or human bodies. Ultra-high frequency sound exhibited similar qualities and all around the western world experiments were conducted using ultra-high frequency sound to penetrate human tissue. In the early fifties Dr. D. Howry and R. Bliss, an electronics engineer, constructed a system for scanning soft tissue involving the moving of a beam of ultra-high frequency sound through an arc. By timing the echoes electronically they were able to construct a representation of slices of insonated objects. Howry and Bliss claimed that their equipment was capable of revealing details of soft tissue of a kind unavailable from X-ray examinations.¹⁰

The basic technique employed by Howry and Bliss was not unavailable in the further development of X-ray technology. By using a similar technique, moving the electromagnetic beam through an arc and registering it electronically, slices of human tissue could be reconstructed. This technique often called tomography was improved by A. M. Cormack and G. N. Hounsfield in their development of computer aided tomography. In computer aided tomography series of exposures are combined in a computer into a reconstruction of slices of human bodies or objects.

Remote Sensing

Satellite reconnaissance and remote sensing represents the fifth center of origin of digital image processing. The early development of remote sensing was primarily aligned with the military need for analysis of reconnaissance images. Due to strong military interest remote sensing represents the single centre that perhaps has attracted most resources. The Cold War and the race for supremacy in space and nuclear technology between East and West and the development of equipment and methods to unravel the other side's progress was one of the most compelling driving forces behind the development of remote sensing and digital image processing in the USA and the Sovjet Union.

Many modern technologies had their real breakthrough during the Second World War. One of these technologies was the use of air reconnaissance, which came to provide essential information for military intelligence. In the USA the development of satellite reconnaissance was initiated in 1946 through the presentation of the RAND-project: a study of the possibilities of satellite technology for scientific and military purposes¹¹. In

¹⁰ Yoxen, E., *Seeing with Sound: A study of the Development of Medical Images*. In: Bijker, W. B., Hughes, T. P. and Pinch, T. J.,(ed.) The Social Construction of Technological Systems, Cambridge, Mass: MIT Press, pp. 281 - 303, 1987. p. 292.

¹¹ The official name of the report was; *Preliminary Design of an Experimental World Circling Space Ship*. KJass, P. J., Secret Sentries in Space. New York: Random House, 1971. pp 71 -72

1956, the US Airforce's high flying airplane U-2 began surveillance over the Soviet Union. In 1957 the Soviet stunned the world by announcing the successful launching of the first satellite. The USA was deeply shaken, it had lost its supremacy in space technology. Consequently space and satellite technology was accorded highest priority and two years later, in 1959, the USA succeeded in placing a satellite in orbit around the world. The shooting down of U-2, in 1960, brought an abrupt end to air reconnaissance. As the development of satellite reconnaissance by then was gaining headway, the U-2 incident did not constitute a major setback for the military intelligence.

Testing of satellite reconnaissance showed that the result exceeded prior expectations¹². But it also showed that some critical problems remained to be solved. One of these problems was associated with the high altitude from which the reconnaissance was effected. To be able to detect anything of interest the satellites had to be equipped with special cameras with extremely high resolution. Another critical problem was how to recover the photographs from the satellite. Initially this problem was solved by detaching the film cassette from the satellite and recapturing it with an aeroplane. This procedure of high altitude fishing, was never considered as an ideal solution and research was spurred in the field of television technology and in the transformation of the photographs to series of electronic pulses. The development of satellite reconnaissance constituted a major driving force compelling the development of image reading and generating instruments and of image transmission. As the volume of photographs generated from satellite reconnaissance increased the analysis of these photographs became problematic and the need to routinize the interpretation of satellite photographs became apparent. In the USA experiments were conducted in order to teach pigeons how to analyze photographs, but even if some of these experiments were successful the developments within computer technology conveyed prospects of mechanized image processing. In the long run a development of computerized image processing appeared to be more productive than pigeons¹³. Even if the prospects were good, outcomes were often disappointing. Through the years the amount of resources employed in the development of remote sensing was allowed to vary with the variation of research and development results.

The most significant pioneering endeavour in the emergence of image processing in Sweden was undertaken by the National Defence Research Institute (FOA). In 1965 a

¹² It proved to be possible to circle on lower altitudes and to produce images of higher quality, than had initially been expected. Ibid, pp. 79 - 80.

¹³ Orhaug, T., Eklundh, J-O & Strand, L., Dator kan förvandla bilder till siffror, FOA-Tidningen, Vol. 7, No. 2, pp. 12 - 14, Oct. 1969. p. 12.

newly appointed researcher, Torleiv Orhaug, with a background in radio astronomy and ionosphere physics, suggested a research activity related to remote sensing. There was no immediate military need for remote sensing,¹⁴ as in some other countries, but the field was regarded as promising for both civilian and military purposes. After some tentative efforts involving holography¹⁵ FOA initiated a research project in computerized image processing related to remote sensing and since no pressing military problem existed they began by addressing more general problems of machine vision and commenced work on problems of a more civilian nature.¹⁶

At this time FOA was one of the more important research institutes in Sweden, not only for military purposes but also in general, and they had no problems in attracting a sufficient number of researchers with relevant competence in computer science and mathematics. To enable the feeding of image data into the computer FOA acquired one of the drum scanners mentioned above.¹⁷ To learn more about the specific problem they cooperated with a group of geographers from Stockholm University. FOA also collaborated with one of the major Swedish suppliers of defence electronics on thermovision using IR-technology. FOA was also represented in the Remote Sensing Committee initiated in 1969. This committee was closely related to the Swedish Space Technology Group and its primary purpose was to motivate Swedish industry to participate in the development of remote sensing. When the Swedish Space Technology Group was transformed into the Swedish Space Corporation, remote sensing complemented the space activities of the company.

Apart from developing image processing FOA also made pioneering efforts in diffusing knowledge about image processing and remote sensing through seminars and different publications. To keep informed about the international developments within image processing they conducted several visits around the world. FOA not only developed

¹⁴ The fact that Sweden is a neutral country restricts the possibilities of military intelligence directed towards other countries. This does not, however, mean that Sweden is not spying on other countries. A recent book on the history of Swedish military intelligence, reveals both an interest in spying on other countries and a willingness to employ the latest technology in doing so. Ottosson, J. & Magnusson, L., *Hemliga makter - svensk militär underrättelsetjänst från unionskrisen till det kalla kriget*, Stockholm: Tidens Förlag, 1991.

¹⁵ Orhaug, T., Nyberg, S. & Granberg, E., Optisk "restaurering" gör suddig bild skarp. *FOA-Tidningen*, Vol. 6, No. 1, pp. 13 -15, May 1968

¹⁶ Personal Interview, Torleiv Orhaug 1985-01-10.

¹⁷ Orhaug, Eklundh and Strand, Dator kan förvandla bilder till siffror, pp. 13 - 14.

remote sensing. They demonstrated for the Swedish research community that computerized image processing was possible.¹⁸

At this time the use of computers was centralized and the processing of images was extremely complicated, especially since FOA was not allowed to connect the drum scanner to a computer at the major computer centre in Stockholm. FOA had first to digitalize the image using the drum scanner in connection with an analog/digital computer. The image was then stored on magnetic tape and handed over to the computer centre together with the processing instruction. Some time later FOA received the results from the computer centre. This way the simplest image analysis could take several weeks to complete. This was sufficient for the theoretical work at FOA, but to be of practical use, image processing technology had to be developed. The input and output units and the processing unit had to be integrated and the processing capacity had to be increased immensely.

In the late sixties and the early seventies the now established computer industry presented two technological breakthroughs: the mini-computer and the micro-processor. The mini-computer offered higher processing capacity but still far from enough for image processing operations. More importantly, the introduction of the mini-computer was accompanied by an organizational innovation. The concept of centralized computer processing was abandoned and research organizations obtained direct access to computer systems. Direct access to computers and thus control of the computer operations was a necessary condition for profound experimentation in computer science and related fields such as image processing. The introduction of micro-processors meant that industrial applications of computer technology became more feasible. Another important landmark in the development of image processing technology was the launching of the first dedicated remote sensing satellite, ERTS 1 (later called Landsat 1). ERTS 1 produced digitally stored images and made digital images widely available.

As sufficient solutions to the problem of feeding image data into the computer were presented, the problem of insufficient data processing capacity became critical. The computer industry had been instrumental in the earliest development of image processing, especially regarding optical character recognition and other input medias such as the

¹⁸ The group conducted and reported the results of several international study trips to France, Great Britain, the USA and Japan. In 1967 they gave a course in optical signal processing and among the participants in the course we find some of the researchers that were to become pioneers in Swedish image processing: Per-Erik Danielsson, Sten Ahlbom and Gunnar Brodin. Source: List of participants course 161, *Optisk signalbehandling (Optical Signal Processing)*, April 5 - 7 1967. Orhaug also published a textbook on image processing see, Orhaug, T., *Bilder, bildinformation, bildbehandling*, *FOA 2 Rapport A2538 - 51*, March 1971.

image reading system and the drum scanner mentioned above. But as the computer terminal became the standard solution to the man - machine communication problem the computer industry lost interest in image processing. The data processing capacity offered by the mini-computer was more than sufficient for almost every possible application of computer technology and the computer industry saw absolutely no need for faster computers. If faster computers were needed they had to be developed outside the computer industry. The barriers to developing image processing technology portrayed by the computer industry are perhaps one of the most pressing reasons behind the genesis of image processing networks.

A Second Wave of New Ventures

In 1972, knowledge regarding the possibilities and prospects of image processing together with the introduction of mini-computers and micro-processors incited the establishment of several research ventures in Sweden. They came independently from different directions; computer science, computer graphics, telecommunication, optics, electrical measurement, geography, geology, cytology and radiology and they all initiated research of different aim and scope in image processing. They combined their specific experience and different technologies, but they shared the same purpose, to develop the technology and methods of digital image processing. Instrumental in the spurring of research in image processing in Sweden was the establishment of a new university, the University of Linköping. In Linköping three of the more radical research groups, the Picap-group, the Image Coding Group and the Gop-group, were established. Together they formed an impressive community of image processing researchers.¹⁹

Most of the research was financed through public funding. The major sources of funding were FOA, the Swedish space program and the Swedish National Board for Technical Development (STU). The public institutions assumed a passive role in the early progress of image processing. Apart from the forming of the Remote Sensing Committee in 1969 the public institutions reacted more to the proposals of individual researchers and groups of researchers than acting on their own initiative to spur a specific development. Research and development was, however, also undertaken within private firms unable to receive public funding. The introduction of the micro-processor increased the possibilities to apply computer technology to problems of industrial production. And in the development of industrial automation two of the largest Swedish companies, Saab and ASEA, initiated development of image processing technology. Spurred by a proposal from an independent inventor Saab in Jönköping, who previously had manufactured the image

¹⁹ Personal interviews, Per-Erik Danielsson, 1984-09-17, Gösta Granlund, 1984-09-19 and Ingemar Ingemarsson, 1984-12-12.

reading system mentioned above, initiated a project concerning the development of machine vision optimizing the outcome of sawing. As Saab had no previous experience of working within forest industry they acquired a company possessing this experience.²⁰ ASEA had recently initiated the development of industrial robots and as a parallel activity they initiated a project regarding the adaptivity of industrial robots. Robotic vision was one ingredient in the adaptivity project. To get a fresh start in image processing ASEA acquired an experimental system developed by the Department for Electrical Measurement at the Royal Institute of Technology.²¹

Recapitulating the Genesis of The Swedish Image Processing Network

The independent initiation of a cluster of related research projects combining new technologies with previous experience slowly departing from their source of origin describes the genesis of the Swedish image processing network. The fact that image processing emerged from multiple centers of origin should not come as a surprise. After all, the social and technological momentum accumulated in different countries and in different industries is often significantly similar and it would be more surprising if we were to find only a single center of origin of a new technology²². The genesis can neither be associated with a single point in time nor with isolated activities of technological change. The genesis of a new network and the identification of a new technological system are processes over time involving complex sets of transfer of technology, innovation, diffusion of innovation and adaptation of innovation to local settings. And as we can see from the developments within FOA transfer of a problem can be as important to the generation of new technology as is the transfer of a technology. From this surge of inventive activities, and not from the deeds of one particular heroic inventor, the new technological system was identified. Digital image technology arose from the ashes of television and computer technology and an image processing network was born. Instrumental in the identification of digital image technology was FOA, who not only constructed new machines, but primarily worked with the whole set of interconnected technologies, and who diffused this knowledge to others.

The development of image processing in Sweden is clearly related to changes in the social structure. The causality, however, does not necessarily run from technological to social change. The case story reveals processes pointing in an opposite direction. The

²⁰ Personal interview, Lars Olsson, 1984-10-02

²¹ Personal interview, Lars Dahlström, 1984-10-25

²² Merton, R. K., Singletons and Multiples in Science, In: Merton, R. K., *The Sociology of Science*, Chicago, Ill.: Chicago University Press, pp. 343 - 370, 1973. p. 356.

employment of new researchers, the establishment of a new university and the decentralization of data processing were instrumental in the initiation of research related to image processing. Simultaneously, the impact of innovation on social structure cannot be denied. The genesis of the image processing network in Sweden was partly a result of the dynamic interplay between the emerging new technology and the emerging new network. It was partly the result of the barriers to develop image processing found within the computer industry. The identification of digital image technology as a new technological system was a necessary, but not sufficient condition in the genesis of the network. The fact that the new technological system was identified as being different from the pre-existing ones was instrumental in the genesis of the new network.

One important facet of the genesis process is the existence of a local structure capable of supporting the emergent new structure. In Sweden the defence industry and the emerging computer industry were important sources of local support. Both were instrumental in the establishing of an infrastructure for computer manufacturing and the computer industry was also important during the first years in that they manufactured the first image processing instruments. The Space Technology Group was another construction, instrumental in the support of emerging new structures and in general it can be claimed that these years were characterized by immense technological and social experimentation. It is possible that an experimental structure is more effective in supporting emerging networks than would directed public policy efforts have been.

The Swedish Image Processing Network in 1975

The emergence of image processing technology follows a recent developed pattern in that basic research, often conducted at universities, is becoming increasingly important in the generation of new technologies. The genesis of the image processing network is characterized by the initiation of a cluster of research undertakings related to the development of image processing technology. The major actors in the emergence of the new network had by the end of 1972 embarked on the path of the development of digital image processing technology. These actors were later to form the core of the image processing network. Figure 11 below depicts the emerging Swedish image processing network in 1975²³.

²³ The figure is based on an EBLOC analysis of relationships between actors active in research and development of digital image processing. In EBLOC analysis actors are blocked according to their relationships to other actors. Actors within a block are more closely connected to each other than to actors outside the block. Note that the spatial position of individual actors in the figures is not meant to depict the centrality of their specific network positions. For a description of the procedure and the underlying algorithm see; Everett, M., EBLOC: A Graph-Theoretic Blocking Algorithm, *Social Networks*, 5, pp. 323 - 346, 1983.

Relational data is collected through personal interviews with the leading individuals within actors pursuing research and development in image processing in Sweden. The relationships are primarily research and development collaborations, but also the transfer of technology and the origin of some of the leading researchers are considered to constitute relationships. Later, in the evolution of the Swedish image processing networks, spin-offs, commercial relationships and ownership have also entered as relationships. The relationships have been coded binary, but the output of the EBLOC analysis has occasionally been complemented with additional information regarding the nature of activities performed and of the relationships. Data have been collected for three points in time 1975, 1983 and 1989. And network analysis has been performed for all three years. The analyses for 1983 and 1989 will be presented at the end of the respective passages.

The years have not been selected arbitrarily. 1975 is chosen because it demarcates the year when all of the major actors in Swedish image processing had been established: it demarcates the ending of the genesis phase. 1983 is selected because it covers the major spin-offs from the university research and it demarcates the ending of the coalescence phase. 1989 is the last year in the study. The number of actors and relationships entered into the network analysis for the three years are shown in the table below.

Year	No of Actors	No of Relationships
1975	40	46
1983	57	93
1989	80	107

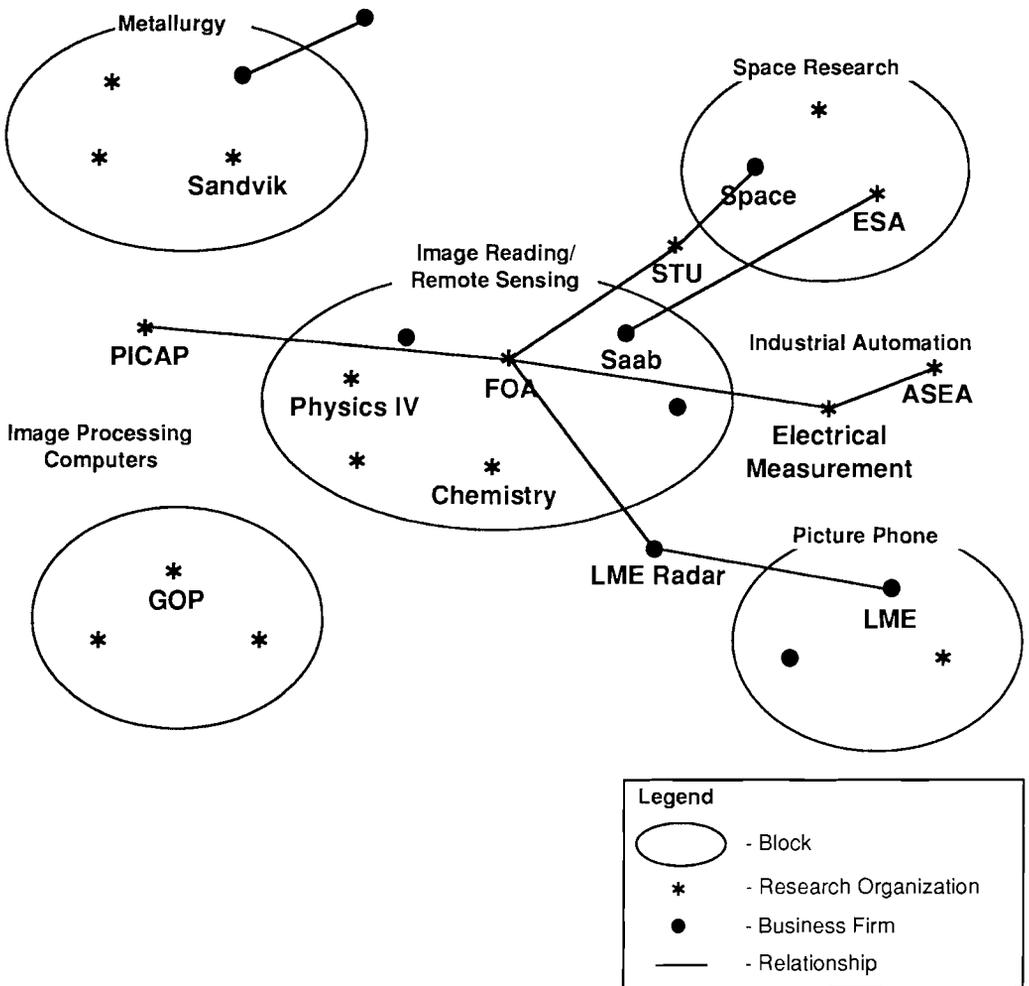


Figure 11: The image processing network in 1975. (Note that the graphical representation is not intended to depict the centrality of individual actors.)

The figure shows a number of actors, some of which have been grouped, these groups are called blocks and actors within a block is more connected to each other than to actors outside the block. It is obvious from the graphical representation above that the image processing network generated under the genesis phase consists of five remotely connected blocks of actors and of some unblocked actors. A closer look at the different blocks reveals that they are to some extent technology specific and that, in general, they consist of both research and development organizations and business firms. There is a high degree of heterogeneity between the blocks. Jointly, the five blocks and the unblocked actors portray capabilities in the complementary components of digital image

technology: image reading systems, image processing systems, image transmission and different applications of digital image technology.

The most central actor in the network is FOA²⁴, acting both as a "Merchant of Light" scanning the international research in image processing and as a "Preacher" preaching the gospel of digital image technology to other researchers in Sweden. Apart from FOA the emerging Swedish computer industry also holds strong positions in the network. In general the emerging image processing network is dominated by traditional firms and research organizations.

It is interesting to note that even if the emergent network transcends over geographical borders it is basically a local network of Swedish actors pursuing research and development in image processing. The applications of digital image technology developed in Sweden are all related to areas where Sweden has a long tradition; picture phone,

²⁴ The most common measure of the position of individual actors in networks is different centrality measures. The Katz index is only one of many measures of centrality in network analysis. The Katz index is chosen mainly for two reasons. Firstly, it is one of the few complex centrality measures that is independent of the total number of actors in the network, which means that it can be used comparing the centrality of actors in different networks. Secondly, the Katz index is chosen because it is based upon the notion that both direct and indirect relationships affects an actors position. The Katz index is computed from the adjacency matrix, where:

$$S_i = bA_{i+} + b^2(A^2)_{i+} + b^3(A^3)_{i+} + \dots \quad (i = 1, 2, 3, \dots, n)$$

Here A is the adjacency matrix, $(A^k)_{i+}$ denotes the i-th row sum of the k-th power of A and b is an attenuation factor. Other centrality measures, degree, bavelas and beauchamp, have also been computed they reveal a similar pattern, but also some minor difference. Sprenger, C. A. J. and Stokman, F. N., (eds.) GRADAP, Manual, version 2.0, Groningen: iec ProGAMMA, 1989. pp.327 - 375

The Katz index for the image processing network in 1975 is presented in the table below.

Year	Min	Max	Mean	Median	Var.	Spread	b
1975	0,139	1,284	0,386	0,341	0,061	0,898	0,1111

The Katz index of the 8 most central actors in the image processing network in 1975 are presented in the table below.

Ranking	Actor	Katz Index	Ranking 1989
1	FOA	1,284	26
2	Saab in Jönköping	1,025	12
3	Saab in Linköping	0,832	15
4	Physics IV	0,797	27
5	Saab in Gothenburg	0,594	19
6	Chemistry Gothenburg	0,588	- ¹
7	ESA	0,488	25
8	Sandvik	0,473	- ¹

¹ Deviated away from the image processing network.

industrial automation and metallurgy or where Sweden has a geographical comparative advantage; in this case space research²⁵.

²⁵ Northern Sweden presents specific advantages in space research, especially with regard to the reception of satellite information.

Chapter 7

COALESCENCE.

As we saw in the previous chapter, image processing emerged almost simultaneously at different locations through actors engaging in highly specialized problem-solving. Only a few, if any, perceived themselves as proponents of digital image processing. They rather entered evolutionary paths through research and development motivated by the solving of everyday problems. Some solutions shepherded the future problem-solving along paths directed towards the transmutation of computer and electronic image technology into digital image processing. These can ex post be identified as origins of Swedish digital image processing technology and as such they have entered this study. The evolutionary path of digital image processing in Sweden is comprised of the paths of several individual paths. Yet, we must remain open to the fact that similar problems in slightly different contexts might have induced other actors, using different or similar techniques, to produce solutions leading to different paths. If these actors had instead addressed their problems differently, the emergence of digital image processing in Sweden would probably have followed a different path. And by no means can we determine if the paths pursued produced a superior outcome than the paths never entered, taken or less often taken would have done. This suggests that the emergence and evolution of new technologies and new industrial structures to some extent are accidental. The process is, however, not purely accidental. Fortune favours the prepared mind and under favourable conditions fortune and the prepared mind can act together to produce change¹. Thus, to induce innovations prepared minds must encounter and perceive problems and opportunities in contexts favouring novel solutions.

Establishing the Technological System of Digital Image Processing

Just as the pioneers of computer technology a few years before them had made reference to the human brain, the pioneers of image processing technology were captured by the analogy of human vision.² Human vision is, quite naturally, a more narrow concept than

¹ Morison, E., *Men, Machines and Modern Times*, Cambridge: MIT University Press, 1966.

² See for instance, Fischler, M. A. & Firschein, O., *Intelligence: The Eye, The Brain and The Computer*, Reading, Mass.: Addison Wesley Publishing Company, 1987. How this was represented in Sweden is shown in, Orhaug, Bilder, bildinformation, bildbehandling and in Danielsson, P-E., Bildbehandling som disciplin och teknik. In: Bildbehandling inom forskningen, *FRN Rapport, 83:10*, Stockholm: Forskningsrådsnämnden, pp 7 - 28, 1983.

the human brain and contrary to computer technology future applications of image processing were more obvious. The function and capacity of human vision offered an important ground for comparison and the prophecy of the researchers was that machine vision in the future would be as general and as functional as human vision. To fulfil this vision it was necessary to connect previously only loosely interconnected series of artifacts and pieces of knowledge into complete systems of image processing. That is, into a system connecting image reading, image analysis and output. One problem was the development of systems with sufficient capacities to process the large amount of data contained in images. The major problem was, however, to adapt the different auxiliary components of image processing to each other, moulding them into a functioning system. Even to perform the simplest image analysis, the availability of a complete system was essential. Not only was it necessary to have access to the sets of functions of which the systems were made, but the functions had also to be performed in specific sequences, where every single function was dependent on all the preceding and succeeding functions.

Technological systems of image processing were developed by actors, in Sweden and elsewhere, motivated by the possibilities of computerizing the analysis of image data. In general, however, digital image processing was not a sufficiently significant application to push the development of electronics and computer technology. Consequently, none of the actors dedicated to the development of mechanized vision could control or even beget the flow of technology ancillary to digital image processing. Thus, they were compelled to adapt to the underlying technologies; combining them into a novel system; adapting and integrating the complementary parts of the system, artifacts and knowledge, to each other. This is not to downgrade the development of digital image processing achieved through research and development. The application of novel findings and artifacts to new situations might be as tedious as the production of the original finding or artifact. But given the status of our knowledge of innovation and industrial evolution it is of greater use to place the development of image processing in its particular context.

Different Problems and Different Resource Bases

Digital image processing did not emerge from a single centre of origin. Neither was its emergence conditioned by the solving of a single set of problems. Actors of different origin, bounded by different historical paths, addressing everyday problems, produced a variety of novelties related to the possibilities of machine processing of image information. The paths pursued by different actors not only defined the sets of problems

to be solved, but also the methods and techniques to be used, solving perceived problems.

The actors of the emergent image processing network had through their historical paths developed different resource bases on which the future development were to be founded. Different knowledge bases had evolved, some had acquired knowledge in radio astronomy, optics or spectroscopy and others in military intelligence, industrial automation or cytology. Furthermore, the actors employed technological practice of different levels of sophistication. As these actors commenced to develop image processing, their initial work became, quite naturally, laden by their past experiences. Not only did the actors differ in terms of knowledge and technology in use. The availability of and their access to complementary resources, such as complementary technologies and user experience, also varied. The established companies could at least potentially make use of the resource base of the company, and they could also test the new technology in more realistic settings. The university researchers on the other hand had more limited access to resources and unless they themselves were the prime users of the novel piece of technology they had only limited access to information about user needs. Even among the university institutes we can detect some differences, especially with respect to their access to user experience, in that some development projects were primarily motivated by the researchers' own need for image processing capabilities. Finally, the actors' access to financial resources differed, some of the research and development was pursued within the realms of established corporations, such as ASEA and Saab-Scania, or within rich research institutes, such as FOA, other research activities were pursued within universities, in both well established and recently formed institutes. The former group had access to larger amounts of financial resources, but on the other hand the researchers within these organizations were less free to choose problems. This last remark is equally valid for the researchers within established university institutes³. As some of the initiation of research ventures coincided with changes in the social and institutional structure, the employment of young researchers in established organizations and the establishment of a new university, some of the actors were bestowed with a larger degree of freedom in choosing problems and methods of problem-solving. Thus they were able to create history in the sense that they could bring their historical paths and prepared minds into contexts favouring new problems or new solutions.

³ Hughes, *American Genesis*, p. 53 -54, points out that a salient characteristic of the great inventors of the turn of the century was their freedom to choose problems.

Converging and Diverging Historical Paths in the Establishing of the New Technology

The focus of the individual research groups differed. Some groups focused on the development of image processing computer systems, some on the development of computer software for image processing, some on specific applications of image processing, some on the image reading systems and some on image transmission. Thus, both corresponding and complementary research and development activities were undertaken. Initially the research and development was, primarily, motivated by solving specific problems. The technological solutions to many of the specific problems did, however, not prove to be, sufficiently, viable in economic terms, or scientifically intriguing. The computer terminal was a more viable solution than optical character recognition to feed data into computers. Other solutions, such as the picture phone, did not correspond to pressing problems. Consequently, digital image processing was either abandoned or extended to encompass sets of more general image processing problems. The computer and telecommunication industry abandoned image processing. But others continued and the aim of most of the growing research groups became directed towards the fruition of general computerized vision. As the aim of the different groups converged so did their historical paths.

The Significance of Local Context in Technological Development

Not all paths led to the evolution of image processing technology. As we mentioned before the paths of both the computer and telecommunication industry deviated away from image processing. Another path that wandered astray was the development of the drum-scanner. Professor Sixten Abrahamsson of University of Gothenburg pioneered the image scanner technology by developing a drum-scanner.⁴ The scanner was used in two contexts; by FOA as their main image reading instrument and at the Arrhenius-laboratories to read data from X-ray crystallography into a computer.⁵ The drum-scanner was an important piece of equipment at both these institutes, but neither of them continued to develop image scanner technology. At FOA the focus was towards the development of methods of image processing and they were not particularly keen on developing the instruments as such. At the Arrhenius-laboratories the problem was to analyze molecular structures using X-ray crystallography and not image analysis in general. They continued to adapt the drum-scanner to their specific needs and eventually they developed a different instrument better adapted to their specific problem. Professor

⁴ Abrahamsson, S., Från kristall till molekylstruktur, Datasaab, undated. This paper by the inventor of the drum-scanner is an introduction to the usage of it in X-ray crystallography. The paper also hints how the scanner can be connected to Datasaab's D21 computer and the available software on this computer

⁵ Personal interviews, Torleiv Orhaug, 1985-01-10 and Per-Erik Werner, 1987-09-11

Abrahamsson himself continued to develop scientific instruments but his death put an end to further achievements. And the development of image scanners, a field in which Swedish researchers pioneered, decayed.

The drum-scanner, applied in two different local contexts, gave rise to two different paths of development. The users of the technology adapted it, to their specific needs according to the problems they were addressing. The nature of the local context in which the new technological system, or components thereof, are applied will have a significant impact upon the future development. Another example of this is provided by, a spin-off from the robotic vision development at ASEA. In 1980 when ASEA decided to halt the development of robotic vision pending the availability of more forceful micro-processors, the leading researchers behind the development decided to leave. As a group they continued the development of computer vision at Kockumation AB. But now the image problem was stated differently. Kockumation was active in the forest industry and the image problem they perceived was related to the analysis of natural objects, measuring and quality control of lumber. The shift from man-made to natural objects required even higher resolution and processing capacity. As a consequence the group brought the ASEA-system to new heights, with better resolution and much higher processing capacity; making it a more general image processing system.⁶

What If?

If the evolutionary paths of computer and telecommunication industries had converged towards or coincided with the path of image processing, the evolution of the three would have followed another path. Still, in no way can we determine if alternative paths would have produced a more desirable outcome than the path pursued. We can only suggest that if some paths, that did not converge, had converged, the outcome would have been different. If the development and usage of the drum-scanner in Sweden had spurred the development of scanner technology, rather than image processing and X-ray crystallography, Sweden might, for better or for worse, have acquired technological leadership in image scanners rather than in image processing.

Adaptation of the Components of the New Technology to a Functional System

To fulfil the future vision of a machine, with as general and functional vision as humans, the research groups in general extended their activities to embrace the total technological system of image processing. A quest for technological solutions for sets of general image processing problems was initiated. The first image processing systems developed were

⁶ Personal interview, Lars Dahlström, 1984-10-25.

predominantly binary, that is they only distinguished between the two pure colours, black and white. All images to be analyzed had to be registered as a combination of black and white. A basic problem was the definition of the colour in the border area between black and white. Exactly when should white be turned into black? The solution to the problem was contingent upon circumstances related to the specific application and every set of rules would only have limited validity if applied to any other application. The binary character of early image processing reinforced the problem specificity of the technical solutions. To actuate more general solutions it was necessary to go beyond the possibilities of binary images and develop image processing for grey-scale and colour pictures. The shift from binary to grey-scale and colour images accentuated the need for specialized image processing computers

Digital image processing had emerged as the combination of previously unconnected pieces of knowledge and artifacts; electronics and optics were combined into optoelectronics and computers and video-cameras were connected to enable processing of image information. The development of the parts, constituting image processing technology, was primarily motivated by circumstances unrelated to image processing. The technological system was therefore characterized by a low degree of standardization and a major problem facing the researchers was related to the adaptation of parts of the technologies to each other forming complete technological systems. Hence the basic problem was the establishing of the technological system itself.

The Coalescence of the Swedish Image Processing Network

The situation in Sweden in the early seventies was, such that a variety of specialized research and development, related to what later were to be known as digital image processing, had emerged. Collectively the emerging research and development activities in Sweden represented the essential parts of the technological system of image processing: image reading, computer systems and software for image processing, image transmission and application specific experience. The individual research groups, however, could neither control or beget the development of the underlying technologies, nor were they able to incorporate and stay on the scientific and technological frontier in all of the essential parts of image processing.

The technological system of a country is forged by the accomplishments of the individual actors. Simultaneously, the outcome of each individual research and development endeavour is to a large extent dependent on the overall development of the technological system. The outcome of different development activities is thus interdependent and each actor can increase the probability of success or decrease the risk for or consequences of

failure by cooperating with other actors active within the same technological system. Cooperation between actors undertaking complementary research and development induces increased integration within the system. As actors within the technological system begin cooperating to get access to complementary research and development and to adapt the parts of the technology to each other, the emergent network will coalesce.

The Significance of a Critical Mass

For the genesis process to transcend into coalescence an existence of a critical mass of similar and complementary research and development is a necessary condition. Critical mass in this context do not only refer to sheer numbers, but also to the degree of variation and complementarity of the going concern and research and development. Sheer numbers are important in that an increased number of actors engaging in specific research and development is accompanied by increased probability for every actor to encounter a peer with whom he can cooperate. Numbers are also essential when it comes to the legitimacy of specific development activities. Variation and complementary is critical in the sense that it denotes the systemic nature of technology and that it thus promotes cooperation.

We have seen that a number of actors in Sweden had initiated a variety of research and development activities related to image processing: a critical mass of similar and complementary change activities was present. Other fields, such as image scanner technology, did not accumulate a critical mass. The presence of a critical mass suggests an availability of potential partners and that actors could benefit from cooperating with other actors. As some of the actors of digital image processing commenced their cooperation the emerging network began to coalesce. The actors deviated from their origins, attracted by a common set of solutions, digital image processing, to a variety of problems, coalescing into a recognizable network of exchange relationships resembling the technological system of digital image processing.

As the image processing network coalesced the actors grew closer to other actors engaged in the development of digital image processing and further away from their origins. The coalescence process implies contraction and contains a tendency towards isolationism. This process is to some extent reflected in the fact that more image processing systems were sold in Sweden between 1960 - 1970 than between 1970 - 1980⁷. For the network to coalesce and the actors to deviate from their origins, the actors must attract new

⁷ Between 1960 - 1970 Imanco Ltd supplied the Swedish market with rudimentary image processing computers and Saab sold a few drum-scanners. Between 1970 - 1980 The systems sold were Saab selling an image reading instrument system to the original inventor, the Department of Electrical Measurement selling one experimental system to ASEA and Saab beginning to market an image processing system for saw mills.

resources: the pursued research and development must be legitimated to ensure continuing evolution of the network. Coalescence is thus a dual process of forming a new industrial network, a new community, and legitimating the activities of the network to the outside world.

Legitimizing the New Technology

In Sweden, image processing research and development did not fit into the traditional structure of research funding. The research and development was primarily multi-disciplinary and did not correspond directly to any of the existing research funding institutions, which mainly were intra-disciplinary. Instead, it was STU, whose societal role had traditionally been to encourage technological development and support innovators outside the industrial community, who assumed a somewhat modified position by funding both basic research and technological development of digital image processing. Others who assumed the role of funding the emergent new technology were the newly established institutions, such as the new university in Linköping and the Swedish Space Corporation. Within these institutions the fact that the technology was new, was by itself legitimating research and development in the field. Another new institution with the specific purpose to legitimate image processing was the Swedish Association for Automatic Image Processing, instigated in 1976 by five leading individuals, representing five different research groups⁸. Apart from legitimating digital image processing the association was an important mediator of social contact between researchers, in industry and at universities. An often discussed subject within the association was what were to be included within or excluded from the concept of digital image processing. Quite naturally, given the nature of the association, the concept was defined from a technological and not from a problem-oriented perspective and lower levels of technological sophistication were most often excluded from the definition or belittled. The standard set by the Swedish Association for Automatic Image Processing and by the coalescing network of digital image processing was that more technology was better.

STU Issues a Special Initiative for the Commercialization of Digital Image Processing

As digital image processing technology was legitimated and the industrial network coalesced an increasing amount of resources was devoted to continued development. And where public policy had previously assumed a passive role it now actively supported the rise of what was assumed to have the capacity to become a new Swedish frontline

⁸ The initiative to establish the Swedish Association for Automatic Image Processing came from Torleiv Orhaug, FOA. The other founding members were, Per-Erik Danielsson, the PICAP-group, Nils Åslund, Physics IV and Björn Stenqvist, the Image Laboratory in Uppsala.

technology. In 1979 STU initiated a five year special initiative concerning the development of image processing technology in Sweden. Special initiatives was a newly launched policy instrument to initiate concentrated efforts in specific technological fields. The purpose of this specific initiative was to generate a competitive development and production of digital image processing in Sweden, by combining the available resources for research and development with the capabilities of Swedish industry, to produce and market high-technology products. Ideally, the initiative was to bridge the gap between scientific research and industrial production. The special initiative arrangement was chosen in order to reach a sufficient volume of market-oriented development projects, relative competing nations, which means other industrialized Western countries. The special initiative was a natural continuance of STU's previous engagement in image processing. Less than 5 % of the total sum was allocated to projects with no pre-history of STU-grants.⁹ Nevertheless, the special program for image processing was more in line with the traditional role of STU, than the antecedent support for basic research had been.

STU did not, however, cut back on their support for basic research in image processing. They continued to promote university research and to back most of the university institutions engaged in the production of knowledge related to digital image processing. Thus, the mission of the university researchers did not solely become confined to product development. They also conducted basic research and developed educational programs, first in the doctoral program and later for graduate students, and they also gave courses to the industry, on theories and methods of image processing.¹⁰

In total, the program was comprised of SEK 18.5 M, a fairly large sum of money from a Swedish perspective. But compared only to General Motors support for research and development in industrial automation and machine vision during the same period it was less than 20 %. The SEK 18.5 M was distributed among 6 different actors pursuing 9 defined projects, representing the state of the art of image processing technology in

⁹ Chronhjört, B., Datoriserad bildbehandling, kort presentation av insatsområdet, STU-internal memo, Feb. 13, 1980.

¹⁰ Åsell, P. & Backström, B., Industrirelevanta effekter av STUs långsiktiga insatser för kunskapsutveckling, Preliminär utvärdering, STU, Oct. 1, 1985. This is an evaluation of the effects of STU's special initiatives. It looks at the effects of the special initiative on different areas such as, education, diffusion of knowledge, commercial applications, international networking and development of resources.

Sweden¹¹. All projects, except two minor ones, concerned the development of computer systems specialized for image processing. The basic idea behind STU's initiative was that STU and different industrial partners should share the cost of development in every individual project. This ambition could not, however, be realized in every single case; the major part of the available funds was still allotted to university research for which no industrial partner existed, at least not initially; only a few projects were directly related to concrete industrial applications and only two projects, the OSIRIS and the automatic inspection of PC-boards, seemed to satisfy the intent of the special program.

The OSIRIS project was a joint effort by Physics IV, Saab-Scania in Gothenburg, the Swedish Space Corporation and the camera manufacturer, Hasselblad AB to develop a mid-size image processing computer. Nils Åslund and his group at Physics IV had previously developed an image scanner, manufactured by Saab-Scania¹². The scanner and the complementary research and development regarding image processing at Physics IV were moulded into the concepts of OSIRIS, a low cost computer with sufficient capacity for image processing. The image processing technology of Physics IV, the production capacity of Saab-Scania, the user experience of the Swedish Space

¹¹ The following groups received grants from STU's special program for digital image processing;

Group	Responsible	Content	Amount	Partner
The GOP-group	Gösta Granlund	Development of image processing computer	5 229 000 SEK	No industrial partner
The PICAP-group	Per-Erik Danielsson Björn Kruse	Development of image processing computer Seed-control	5 219 000 SEK	Initially no industrial partner, later partly IMTEC AB
Image Analysis Laboratory, Uppsala	Björn Stenkvist Ewert Bengtsson	Automatic cell analysis with TV and computer technology	2 691 000 SEK	Privately held, small, medical company
Semyre Electronics AB	Göran Åsemyr	Automatic inspection of PC-boards	2 463 000 SEK	PICAP-group
Physics IV	Nils Åslund Sonny Lundin	Development of a smaller image processing computer, OSIRIS	2 348 000 SEK	Swedish Space Corporation, Saab-Scania, Gbg, and Hasselblad AB
Swedish Forest Products Research Laboratory	Staffan Rydefalk	Image analysis of paper fiber	311 000 SEK	

A tenth project, Lars Dahlström, Kockumation AB, concerning robotic vision received 250 000 SEK. But as Dahlström firmly believed that this was far from enough he did not accept the grant. Source: Chronhjort, Datoriserad bildbehandling, kort presentation av insatsområdet.

¹² The scanner did not become a commercial success. It was only sold to the Image Laboratory at the University of Uppsala and to Lund's Medical Hospital. Personal interview, Nils Åslund, 1984-12-10.

Corporation and the marketing capability of Hasselblad were combined into the OSIRIS-project. It looked perfect. The OSIRIS-project bridged the gap between scientific research and industrial production, or at least did the preconditions for bridging exist. What then were the goals of the collaborating actors? The goal of Nils Åslund and Physics IV was undoubtedly to promote the development of OSIRIS. Saab-Scania, probably, perceived the project as an interesting complement to their engagement in the space program. Hasselblad was primarily motivated by an interest in electronic image technology. The Swedish Space Corporation needed an image processing computer in their development of remote sensing technology. They were, however, dragged into the project in a rather late stage, when the concepts of OSIRIS were already defined and specified and when it was difficult to adapt the system to user specified needs.¹³

If we take a closer look at which the projects were that received funds from the special initiative, we can see that 7 of the 9 projects were related to some of the founding members of the Swedish Association for Automatic Image Processing. The project leader of the 8th project, who in 1982 was appointed professor in image processing, was thought to be one of the leading image processing researchers in Sweden. The selection mechanism applied in the special program was technological innovativeness rather than industrial applicability. The projects supported within the program were all perceived as being at the cutting edge of Swedish image processing technology. The projects were selected, not because of their applicability to immediate industrial problems, but rather because of their technological innovativeness. This does not signify a total lack of projects with a shorter distance to commercially viable applications. Companies like ASEA and Saab-Scania were well on their way to developing image processing for industrial automation and robotic vision. Since 1976 Saab-Scania had been selling image processing systems for edge detection in automatic sawing. Furthermore, the Department for Electrical Measurement at the Royal Institute for Technology (SYDAT) had successfully installed several image processing systems in different industries.

The projects funded within the special program can be lumped together into 5 dominating research and development ventures, receiving 18 of the SEK 18,5 M. And if the contributions from industrial partners are taken into account, the funds were equally distributed among the 5 projects. Thus, each project received approximately 5 MSEK over a 5 year period. Three of the five ventures were highly linked. A triad consisting of the Picap-group, the Image Analysis Laboratory in Uppsala and Semyre Electronics can be detected. The image processing computer used at the Image Analysis Laboratory in

¹³ Personal interview, Claes-Göran Borg, 1984-11-28.

Uppsala was the predecessor to the image processing computer developed by the Picap-group. The laboratory had previously also made use of a predecessor to OSIRIS. The automatic inspection of PC-boards developed by Semyre Electronics was a spin-off from research at the Picap-group. And the patent rights to the original invention was held by three members of the Picap-group.¹⁴ The development of automatic cell analysis and automatic inspection of PC-boards can be regarded as being specific applications of the development of a general image processing computer pursued by the Picap-group. The special initiative disclose three cores of the development of image processing in Sweden, the Picap-group, the Gop-group and Physics IV. Two of these, Picap and Gop, were based at the University of Linköping and apart from these two groups the university also harboured a prominent research group in image transmission. Linköping had grown into a local centre for Swedish image processing technology. This was further accentuated in 1978 when a part of FOA including the image processing research group was relocated to Linköping. It is true that FOA had abandoned the civilian side of remote sensing and image processing research, but it retained its leading position in the development of methods and software for image processing.

Aiming for General Solutions and Total Control

In STU's special program we can detect a bias towards the development of image processing computer systems. In three cases, the Gop-group, the Picap-group and Physics IV, the focus was on the development of general image processing computers and in two instances, the Image Analysis Laboratory in Uppsala and Semyre Electronics, the focus was on the adaptation of image processing computers to specific applications. This bias towards image processing computer systems was not confined to the sphere of STU. Almost every actor in Sweden interested in the processing of image information also developed, potentially multi-purpose, image processing computer systems. ASEA Robotics, Saab-Scania, Kockumation and SYDAT developed image processing systems for robotic vision and industrial automation. The Swedish Space Corporation developed a low cost image processing computer for remote sensing. Like many others, the Swedish Space Corporation was not particularly interested in developing the hardware of image processing.¹⁵ Its competitive advantage was in the methods of image processing related to remote sensing. Its development of image processing computers was primarily motivated by the non-availability of image processing computers. Not all research groups

¹⁴ Danielsson, P-E., Pääbo, M. & Kruse, B., Automatisk avsyning av mönsterkort - Förslag till prototyp konstruktion, Internal Memo, Linköping University Lith-ISY-I-0111, Linköping, Sept. 27, 1976. See also Danielsson, P-E. & Kruse, B., Distance Checking Algorithms, Computer Graphics and Image Processing, Vol. 9, No. 12, Dec. 1979.

¹⁵ Personal interview, Claes-Göran Borg, 1984-11-28.

developed computer systems. Others, such as FOA and the image transmission groups at the University of Linköping and the Royal Institute of Technology concentrated their efforts on the development of methods and software for image processing and transmission.

Bridging the Gap Between Scientific Research and Industrial Innovation

The special program of STU was successful in that it enforced Sweden's technological position in digital image processing. It was also successful in the sense that it spurred entrepreneurial activities. The gap between scientific research and industrial production was, unintentionally, bridged through the university researchers establishing business firms. Image processing companies started as spin-offs from the universities and the researchers leaped from being scientists to becoming business leaders. First out was IMTEC AB, a spin-off from the Picap-group, established in 1981. Followed, in 1983, by Innovativ Vision AB, another spin-off from the Picap-group, and Context Vision, a spin-off from the Gop-group. The availability of research and development funds directed towards the commercial application of image processing under market conditions was of course instrumental in the entrepreneurial process. To some extent STU demanded that commercial partners should be involved in the finance and the development of each and every project.¹⁶ In some cases this required the research groups to establish a business of their own. The argument that public support lured the actors to become commercial too early, can therefore to some extent be validated. Note, though, that Innovativ Vision AB was not established with direct public support.

The entrepreneurial activities of the early eighties were not, however, entirely dependent on the availability of financial resources from STU. The underlying computer technology had progressed producing faster and faster computers with bigger and bigger memories. In 1981 Motorola launched a 32-bits microprocessor: the first in their 68 000 series. Intel was not late to follow. The availability of more forceful microprocessors increased the economic potential of image processing. More forceful image processing computers could be developed and produced at lower cost. Increased accuracy and speed of computerized image analysis could be achieved at lower cost. Compelling breakthroughs had also been made in the field of opto-electronics, especially with respect to the conversion of light into electronic signals. In 1969 the CCD (Charge-Coupled Device) - semiconductor was developed at Bell Laboratories. CCD is a light sensitive semiconductor, through which light from an image directly could be converted to

¹⁶ It was labelled as barriers and difficulties that the initiative seemed to require a continuous support of University based research. Chronhjort, Datoriserad bildbehandling, kort presentation av insatsområdet.

electronic signals. In 1981 Sony presented Sony Mavica, the world's first fully digital camera, built upon CCD-technology. The Sony Mavica was only one of many newly developed instruments producing and storing images in digital form. The CAT-scanner, magnetic resonance technology and ultra-sound technology are but a few examples of others. Digital technology was gaining headway in the battle of systems between analog and digital image technology.

Digital image processing was reaching a stage of technological maturity. The research and development had started more than 20 years ago, searching for solutions to very specific problems. Now, in the early eighties, new image processing firms were established all over the world, advocating different technological solutions for more general sets of image processing problems. In Sweden, all of the groups in question had actively pursued research and development in digital image processing for more than 10 years. Taken together, the conducted research and development represented both similar and complementary components of the technological system of digital image processing.

Apart from an absence of manufacturers of electronic components and the fact that the Swedish computer industry was struggling for its survival, the necessary components of the technological system of digital image processing were present in Sweden. Through the collaboration between different proponents of image processing the emerging Swedish network had coalesced, exhibiting a structure and rudimentary division of labour resembling that of the technological system. As one proponent of a component of this system established a business firm, proponents of complementary parts were motivated either to merge with the new venture or to continue to collaborate, either in the previous institutional form or by following a similar evolutionary path, establishing another new business firm. Thus, in the establishment of IMTEC, prompted by the interest of a publicly owned development company, the complementary research of FOA played a critical role. It would be safe to say that IMTEC was established through the combination of the evolutionary path of the Picap-group, focusing on computer systems and the path of FOA, pursuing computer software development.¹⁷ The establishing of IMTEC opened commercial opportunities for other image processing endeavours and in 1983 the automatic cell analysis project of the Image Analysis Laboratory, accompanied by the leading researcher, was transferred to IMTEC for further commercial development.¹⁸ In the Picap-group The founders of IMTEC had worked together with the founders of Innovativ Vision. The latter had also been collaborating extensively with

¹⁷ Personal interviews, Björn Kruse, 1984-09-28 and Torleiv Orhaug, 1985-01-10.

¹⁸ Personal interviews, Ewert Bengtsson, 1984-12-06 and Sven Olofsson, 1984-09-26.

the Image Analysis Laboratory and the timing of the start up of Innovativ Vision was prompted by a development assignment from IMTEC.¹⁹

IMTEC, Context Vision and Innovativ Vision was, if not the top of the iceberg, at least only part of the story. The department of Electrical Measurement had formed Sydat Automation AB; the image coding group at the University of Linköping had established Sectra AB; at Saab-Scania research and development was intensified and broadened to be comprised of industrial automation in general; the Swedish Space Corporation established a subsidiary for the receiving and processing of satellite images and in 1981 ASEA reopened its mummified project concerning robotic vision.²⁰

The research and development ventures that, independently of each other, had been initiated 10 years earlier had evolved to become interdependent. Critical in the establishment of new companies were the complementary resources and competences evolving within the network of image processing. The newly established firms were often comprised of mixtures of resources; researchers, students, knowledge and equipment, originating from different research groups. And the entrepreneurial activities of the early eighties were not activated independently of each other.

The newly established firms continued in the pace set during the research years. The aim was to develop general image processing technology. The developed computer systems were to be able to process images of different origin, depicting different scenes generated by different methods. The computer systems were to be equally equipped for remote sensing as for industrial automation. Moreover, many of the new firms aimed to fulfil all functions of developing, manufacturing and marketing of image processing equipment. They strived for maximum control of their activities. Here, the newly established firms differed from the established ones. The established firms were directed more towards specific applications and they had better opportunities to utilize the existing organization to develop business related to image processing.

Recapitulating the Coalescence of the Swedish Image Processing Network

The genesis phase induced a number of competing and complementary ventures into research and development of digital image technology. The existence of a critical mass of research and development facilitated the legitimation of the new technology and as the

¹⁹ Personal interview, Lars-Erik Nordell, 1984-09-17 and Sven Olofsson, 1984-09-26.

²⁰ Personal interview, Hans Skoogh, 1984-09-27

paths of development converged to, or diverged from digital image processing the network coalesced, forming a closely knit core of proponents of image processing. The core towards which the network of exchange relationships coalesced was STU, the major source of public funding. The special initiative issued by STU was not, however, institutionalized independently from the research and development activities. The progress made in the establishment of the new technological system and the legitimation of it by the central actors was instrumental in the issuing of the initiative. This special initiative in its turn enabled the proponents of image processing to proceed with the establishment of the technological system. Hence, the emergence of an image processing network in Sweden exhibits a strong link between the coalescence of the network of exchange relationships and the legitimation and establishment of the new technological system. A crucial element for the evolutionary process to transcend from the domination of genesis to that of coalescence was the existence of a critical mass of competing and complementary research and development activities.

The state of the art of image processing technology as a system of loosely connected components and the nature of the STU-program ushered the actors into the adaptation of the components of digital image technology into functional systems, developing general image processing systems capable of processing almost any kind of images. The period 1976 - 1983 was concluded with the spinning-off of firms from university research and from established firms, thus bridging the gap between scientific research and industrial innovation.

From 1976 image processing equipment was sold on a regular basis. It was primarily the established firms and the firms employing lower levels of technological sophistication that were able to market image processing equipment successfully. The first highly sophisticated systems to be sold, were bought by actors in the focal network or by research organizations outside the focal network. Image processing technology had emerged through the needs of military intelligence and research laboratories for improved and automated analysis of image information. These institutions were also among the first to acquire image processing equipment. Unfortunately, these early adopters seldom contributed significantly to the development of image processing. The problems they addressed were often highly specialized and they were often capable of adapting the equipment to their specific needs and their experience of this adaptation was seldom communicated back to the seller. Furthermore they often used the equipment in isolation and did not integrate it in the technological context in which the image processing technology was applied. The first sales were critical, however, to the survival of the development projects.

The Swedish Image Processing Network in 1983

The coalescence of the Swedish image processing network is characterized by the legitimation and establishment of a technological system for digital image processing, integrating the separate components of the technology into a system: transforming the specific solutions for specific problems to general solutions for general sets of problems. The proponents of the different components of the technological system coalesced into a closely-knit community of actors representing the necessary components and competences to pursue the development of the technology. The coalesced Swedish image processing network in 1983 is depicted in figure 12 on the next page.²¹

²¹ For a discussion of the procedure used to generate the image of the network see footnote 23 in chapter 6.

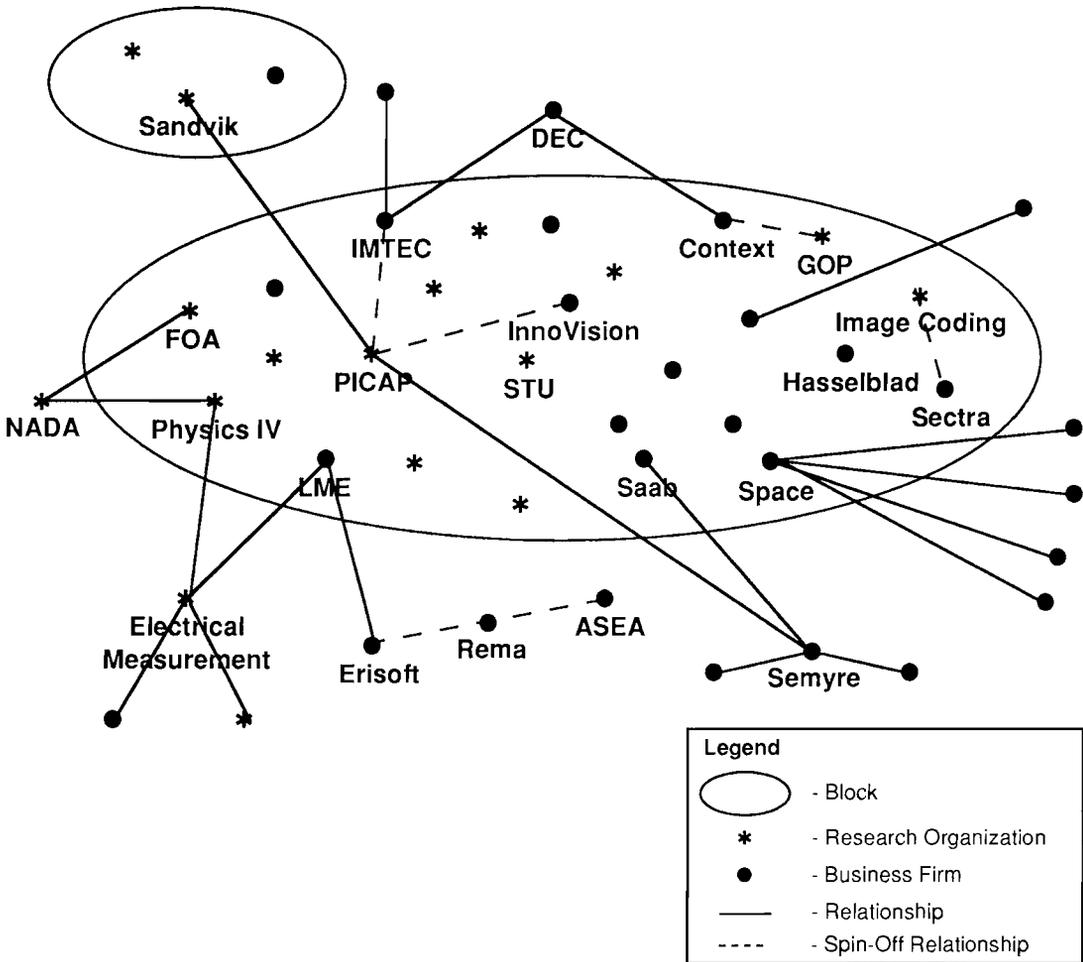


Figure 12: The image processing network in 1983. (Note that the graphical representation is not intended to depict the centrality of individual actors.)

The image processing network in 1983 was comprised of a large block of proponents of digital image technology, a peripheral block - the metallurgy block from the genesis phase not accompanying the others as the network coalesced - and some unblocked actors. The heterogeneous blocks found in 1975 had basically coalesced into one homogeneous block of actors striving to establish the technological system of digital image processing.

During the coalescence phase public policy supported the research groups at the universities and the Space Corp. accumulating strength and ascending as the most central

actors²² in the coalescing network. FOA lost its central position as it abstained from pursuing the development of civilian oriented remote sensing. The Swedish computer industry also lost its position in the development of digital image technology. The core of the network consisted of almost an equal number of research organizations and business firms.

It is interesting to note that the core of the image processing network is still dominated by actors based in Sweden. These actors all worked under the threat of liquidation or the dismantling of the development project. Most of the actors survived only through reconstructions. To reach a more stable state, digital image processing had to be integrated with other technological systems. Strategically, individual actors had to establish positions in the emergent network. At the same time they had to participate in the strengthening of the total network.

²² The Katz index for the image processing network in 1975 and 1983 is presented in the table below. For a discussion of the measure of centrality see; footnote 24 in chapter 6.

Year	Min	Max	Mean	Median	Var.	Spread	b
1975	0,139	1,284	0,386	0,341	0,061	0,898	0,11111
1983	0,084	1,383	0,374	0,249	0,099	1,009	0,07143

The Katz index of the 8 most central actors in the image processing network in 1983 and there ranking for 1975 are presented in the table below.

Ranking	Actor	Katz Index	Ranking 1975
1	Space Corp.	1,383	10
2	Imtec	1,243	1
3	Picap-Group	1,117	19
4	STU	1,054	15
5	Physics IV	0,958	4
6	Innovativ Vision	0,877	1
7	Context Vision	0,831	2
8	Image Coding Group	0,830	33

¹ A spin-off from the Picap-Group

² A spin-off from the GOP-Group

³ A spin-off from the Image Analysis Laboratory and Teragon System

Chapter 8

DISSEMINATION

The coalescence phase saw the formation of the technological system of digital image processing. All over the world, new ventures were established and old firms extended their activities to develop, produce and apply image processing technology.¹ In Sweden the proponents of image processing technology coalesced into a tightly-knit homogenous network. Sweden was on the cutting edge of the technology. All together by 1985, different Swedish organizations had developed at least ten more or less technologically sophisticated general image processing computer systems. The outcome of the development of image processing in Sweden was technologically successful. Commercially, the results were more disappointing.

Integrating the New Technological System with Pre-Existing Technologies

In digital image processing computer technology and opto-electronics had been transformed to produce technological solutions to the problems associated with the analysis of data contained in images or with computerized production or communication of images.

The computer systems for image processing produced in Sweden functioned well according to prior specifications, but sales were slow. The potential user's problems were rarely as well defined as they had been in the specification and development of the computers. The systems were, moreover, extremely expensive. The development cost had been higher than expected and the subsystems and components used were on the cutting edge of existing technology. The price of a general image processing computer therefore ranged from 200.000 to 2.000.000 SEK. An additional problem was the man-machine interface. Image processing computers represented the latest developments in computer related technologies, while most of the potential users still struggled to become friendly with personal computers. In most applications the machine had to be adapted to

¹ Braggins, D. and Hollingum, J., *The Machine Vision Sourcebook*, Springer-Verlag: Berlin, 1986., reports 268 firms and research organizations in 13 countries only in machine vision, a subcategory of image processing. The concept of machine vision primarily includes image processing for industrial automation. Two of the major applications, radiology and remote sensing, are therefore excluded from these numbers.

the environment in which it was to be used. And in some cases user friendliness proved to be even more important than technological power.²

The largest user groups predominantly prevailed in an analog technological environment and the application of digital image technology thus required effective gateways between digital and analog technology. In some areas of application cartography, graphic production and industrial automation investments had already been made in the transformation from analog to digital technology. The basic problem facing the proponents of image processing technology was thus to adapt the technology to preexisting technologies integrating the system of image processing with the technological systems of the users.

Circumstances Favouring Early Application of New Technology

The development of image processing technology, from 1960 to the present day, is filled with examples of how image processing computers are used in different settings remote sensing for military surveillance in the sixties, analysis of non-metallic inclusions in steel in the metallurgy laboratories in the seventies and robotic vision in modern manufacturing in the eighties. New technologies are often first adopted in contexts where economic performance is difficult to measure or of minor importance; new technologies are consequently often embodied in medical equipment or in military weapons. Another circumstance which favours early adoption is when the new technology can be applied in isolation: unrelated to existing technologies or patterns of behaviour; the first micro-chips were used in modern, high-technology, toys. Finally, the application of new technologies is favoured in contexts characterized by highly sophisticated users capable of and interested in further development of the new technology; research laboratories and scientific institutions are thus not only important as generators of new technologies.³ They also represent a considerable market for new technologies.

No Technology can Persist in Isolation

No technology can persist in isolation, the value of any technology is not determined by its static internal characteristics, but by its dynamic relationship to other technologies. A

² In one evaluation between three Swedish, Context Vision/Gop 300A, Imtec/Epsilon and Teragon 4000 and one American, Gould/IP 9.000, image processing computers Terragon 4.000 was ranked first on the basis of user friendliness and technological completeness even though some systems were ranked higher in technological power. Gustavsson, T., Upphandling av Bildanalyssystem för Medicinska Fakulteten vid Göteborgs Universitet, Ärendenummer 3103-06 nr 1/23, Göteborgs Universitet, februari 1987.

³ The outcome of basic research as the development of new scientific instruments is discussed in; Rosenberg, N., Scientific Instrumentation and University Research, Paper presented at the annual meetings of American Economic Association in New York City, December 30, 1988.

given technology is only an intermediary between other technologies. Its existence is based on its capacity to transform inputs from other technologies to produce solutions to problems in yet other technologies. A major theme in the advancement of bridge building is the recurrent changes in the materials used wood, stone, iron, steel and concrete. The progress of the early chemical industry was closely connected to progress within ancillary industries; first to the textile industry in the development of bleaching and dyeing techniques and later to the prospering mining industry in the development of new explosives⁴. The economic value of a technology is thus determined by its relative efficiency in the transformation of inputs and the scope of the solution it produces.

The history of a technology can never solely be construed upon single and isolated events and activities, on the heroic inventors of pieces of that technology or on the more spectacular utilization of the technology. The significance of technology in social and economic evolution is determined by how it affects other technologies. A technology cannot be said to be established until it has reached a stage of widespread use. The *raison d'être* of a new technology typically lies far beyond its initial application. Flying today is quite different from the first attempt with Kitty Hawk. The Wright brothers' major contribution was that they showed the world that flying was also possible with objects heavier than air. But it was the huge number of minor improvements, the development or adoption of new technologies and foremost the evolution of systems combining aerodynamics, engine technology and petrochemistry with military and civilian systems of flying, that brought flying to what it is today. The genesis and continuance of a novelty are motivated by different sets of circumstances and require the solving of entirely different sets of problems. This suggests that genesis is one process propagated by certain factors and bred by a different set of factors coalescence and dissemination, can be perceived as being separate from the genesis process.

The origination of a new technology is typically motivated by the solving of specific problems. Radio technology was first expressed as wireless telegraphy and used as a mean of communication between ships. The continuance of the technology was motivated, however, by the opportunity of broadcasting news and entertainment of the general public, generating new sets of problems in the establishing of total systems for radio broadcasting⁵. The original invention; the Kitty Hawk of Orville and Wilbur Wright, the wireless telegraph of Marconi or the ENIAC of J. Presper Eckert Jr and John

⁴ Bernal, J., D., *Science and Industry in the Nineteenth Century*, Indiana University Press: Bloomington, 1970. p. 31 - 33

⁵ In recent years the vision of wireless telegraphy has been fulfilled in the guise of cellular phones.

W. Mauchly⁶, did not induce much more than promises of a different future. Essential in the fulfillment of the promises made by original inventions was the composition and evolution of the huge technological systems, a prerequisite in bringing the new technology to the bulk of users and applications.

The revolutions promised by the initial inventions were set off by the need to connect the novel technology with other technologies into interconnected technological systems. But since the system was instigated, self-reinforcing mechanisms often have taken the technology well beyond the scope of the original invention. Neither steam technology, electricity nor computer technology had an immediate impact on the society that spurred them. But as the technological systems of steam and electrical power and electronic computing evolved, the social and economic consequences went far beyond even the wildest dreams of the pioneers.⁷

Bridging Gaps

The scope of a new technology must be extended, reaching towards other technologies and social structures; creating new interconnected technological systems, carrying the new technology from the research laboratories and development departments, bringing it into everyday life. In digital image processing the extension of the technology into other fields most typically implied that the gap between digital and analog technology had to be bridged. Image processing is only one of many new technologies focusing interest on overcoming or resolving the difference between analog and digital technology. The final chapter in the battle of systems⁸ between digital and analog technology began as the proponents of digital image processing extended their activities to encompass other technologies.

In 1984 STU's special initiative towards the development of digital image processing ended. The aim of the program had been to support the transition of image processing from scientific research to industrial innovation. The development had taken a somewhat

⁶ Here only a few pioneers are mentioned keeping in mind that they all had their predecessors, contemporaries and progenies

⁷ See for instance, Bernal, *Science and Industry in the Nineteenth Century*, pp. 31 - 33, Hughes, *Networks of Power*, and David, *Computer and Dynamo - The Modern Productivity Paradox in a Not-Too-Distant Mirror*.

⁸ Battle of systems seem to be a recurring phenomenon in the progress of society and many lessons are to be found in history. See for instance, David P., A. & Bunn, J., A., "The Battle of the Systems" and the Evolutionary Dynamics of Network Technology Rivalries, High Technology Impact Program, Working Paper No 15, Center for Economic Policy Research, Stanford University, 1987. and David P., A., *The Hero and the Herd in Technological History: Reflections on Thomas Edison and the "Battle of Systems"*, Center for Economic Policy Research, Technical Paper No. 100, Stanford University, 1987.

unexpected turn in that image processing technology predominantly had been transferred from science to industry through the migration of scientists from university research to newly established firms. The path followed by the image processing researchers was not unprecedented. Ever since Schumpeter the general notion has been that new technologies will primarily be embodied in new firms. The rise and development of the computer technology is a striking example of how scientific research, industrial innovation and public policy coincided to foster the emergence of one of the most compelling technologies of our time.⁹

Research Parks Bridging the Gap Between Science and Industry

With the growth of the computer industry a new institutional form, the research park, ascended connecting scientific research and industrial innovation. Stanford University Research Park in what were to be known to the world as Silicon Valley and MIT research laboratories promoting the materialization of Route 128 were the pioneering research parks setting the standards for the rest of the world. In these research parks resources slowly accumulated creating favourable conditions for entrepreneurial activities. Silicon Valley in particular evolved to become the single most important geographical location in the development of computer technology¹⁰. It attracted investments from established computer and electronic firms, capital investments and researchers and students from various fields enthusiastically seeking to reap the benefits from years of research or studies by establishing new ventures or by participating in the efforts of others. There are many stories of the heroic inventors and entrepreneurs of Silicon Valley; the Shockley Eight, William R. Hewlett and David Packard and the Stevens; Wozniak and Jobs carving their names in the history of computer industry, making fortunes by turning their ideas into industrial realities. Silicon Valley represented an increasing pool of resources and it functioned like an experimental economy with an excess of freely flowing resources. When perceived as agglomerations of resources for the development of new technologies, the institution of research parks is not a salient feature of the post-war era. The concentration of specific resources to specific geographical areas have been the normal case all through the industrialization process and the progress of society. The question is to what extent these agglomeration of resources purposefully can be created.¹¹

⁹ For an overview over the emergence of computer technology see Flamm, K., Creating the Computer - Government Industry and High Technology, Washington D.C.: The Brookings Institution, 1988. The development of computer technology in Sweden is described in: Lund, Från Kula till Data.

¹⁰ The culture in the growing Silicon Valley is excellently depicted in Everett, R. M. and Larsen J., K., Silicon Valley Fever: Growth of High Technology Culture, London: George Allen & Unwin, 1984

¹¹ Håkansson, Corporate Technological Behaviour, pp. 8-9.

Silicon Valley: a Self-Organizing System

The emergence and evolution of Silicon Valley was primarily unplanned. A number of necessary preconditions were at hand, however. The presence of Stanford University, providing a steady flow of research based technologies and graduate students and the access to skilled manual workers, to mention a few. But these conditions were also present elsewhere. The fact that Silicon Valley happened to emerge where it did was probably purely accidental and unplanned. Unplanned as it might have been, however, the making of Silicon Valley was filled with intentions. Stanford University intended to convert land to money when they in 1951 established the Stanford Research Park where companies were welcome to lease land. Hewlett and Packard intended to exploit the results of their research, a low cost variable frequency oscillator, when they formed a partnership in 1938.¹² Frank G. Chambers, one of the pioneering venture capitalists intended to increase the return on investment by investing in new ventures¹³. The actions of private firms, venture capitalists and entrepreneurs, generated by their specific intentions, moulded the evolutionary path of Silicon Valley. But neither the officials of Stanford University, Hewlett and Packard nor Frank Chambers had Silicon Valley in mind when they formed their intentions.

The making of Silicon Valley is probably best described as a self-reinforcing process locked in by small historical events¹⁴. What if William Shockley had not returned to his hometown or if it had been in Texas? The self-reinforcing growth of Silicon Valley as the center of microelectronics is comprised of two sets of interrelated processes. Firstly, we have the technological development of microelectronics and the rise of a mass-market for microelectronic gadgets. Where highly sophisticated technology could be embodied in low cost consumer products; digital watches, pocket calculators and home computers. The consumers were effectively protected from the complexity of the underlying technology of these products and if a gadget broke repair costs were often much higher than the price of a new and better product. Thus a huge market could be served even though most buyers did not know the difference between a transistor and micro-chip and without the need to set up systems for repair and service. The electronics firms also produced more complicated products such as lasers and microprocessors. The cost of these was reduced through the existence of the mass-market for electronic products and

¹² Everett and Larsen, *Ibid*, pp. 32-36

¹³ Everett and Larsen, *Ibid*, pp.73-74

¹⁴ A theoretical discussion of the evolution of Silicon Valley as a self-reinforcing process is found in Arthur, *Industry Location and the Importance of History*.

the high-technology end of electronics fed back to the development of consumer products, thus, the microprocessor was first used commercially in toys. Secondly, if we turn closer to Silicon Valley, the settings were favourable and the success of the pioneering entrepreneurs served as an example for others. It also attracted resources enabling the would-be entrepreneurs to set up businesses on their own. Their success attracted more resources prompting even more entrepreneurial activity, making Silicon Valley the birthplace of microelectronics. The achievements of scientific researchers and graduate students setting up business in Silicon Valley and by Route 128 also served as role models for university researchers in Europe. Commercial exploitation of the fruits of years of scientific research appeared to be a financially rewarding alternative to continued research. From this perspective it should not have come as a surprise that the Swedish image processing researchers chose to bridge the gap between scientific research and industrial innovation by setting up businesses of their own. As in Silicon Valley, the pioneering entrepreneurs in Swedish image processing served as examples for the others, still striving at different universities. Contrary to actors in Silicon Valley and by Route 128 the Swedish image processing entrepreneurs did not meet an infrastructure for high technology entrepreneurship.

Can the success story of Silicon Valley be repeated? Probably, but even if we were able to recreate all the circumstances giving rise to Silicon Valley it is not certain that we would end up with the same outcome. Nevertheless, the success story of Silicon Valley and Route 128 have echoed all over the world and policy makers not only in the USA but also in Europe have attempted to reproduce the making of Silicon Valley and Route 128, by setting up research parks in close proximity to major universities and institutes of technology.

Research Parks in Sweden

In the midst of the eighties research parks were institutionalized at most of the major universities in Sweden; Ideon at the University of Lund, Technology Village at the University of Linköping, Technology Hill and Kista Valley at the Royal Institute of Technology and "Glutten" at the University of Uppsala. Many of the recently established image processing firms were located or relocated to these research parks¹⁵. The

¹⁵ The following image processing firms were located within a research park:

Technology Village at the University of Linköping in particular, became dominated by competing and complementary image processing firms. The University of Linköping had been dominating scientific research in image processing so it was only natural that it also dominated the entrepreneurial activities in the field. Linköping, furthermore, had a prehistory as a center of Swedish high technology in that a major part of the Swedish computer industry had its roots in Saab-Scania in Linköping.

Technology Village in Linköping

A very special culture evolved at the technology village in Linköping. The village was comprised of individual firms mainly spin-offs from the university but also of more traditional Swedish firms. Also evolving was an invisible pool of personnel resources consisting of researchers from the individual firms and from the university. Whenever a specific actor had a problem or was at a critical point in the development process requiring more research personnel it could draw on the pool of available personnel. When the problem was solved the personnel called in, returned to their normal duties. In this way the firms within the Technology Village were able to expand and contract depending on the phases of development of specific projects. Not all firms participated in this sharing of resources. Some firms, especially the traditional ones, but also some of the spin-offs, did not participate in the sharing of resources.¹⁶

The research parks in Sweden have not yet prompted industrial progress in the surrounding area. Most parks reports problems in attracting investments from established firms. The evolving image processing network in Sweden was never supported by an ever-expanding computer industry. On the contrary, the emergence of image processing coincided with the decline of the Swedish computer industry. On the other hand this also implied that the infant image processing industry never had to compete with the computer industry for resources. If the Swedish computer industry had been prosperous perhaps

Company	Scientific Origin	Research Park
Teragon Systems	Picap-Group	Technology Village at the University of Linköping
Innovativ Vision	Picap-Group	Technology Village
Sectra	Image Coding Group	Technology Village
Integrated Vision Products	Image Coding Group	Technology Village
Context Vision	Gop-Group	Technology Village
Sarastro	Physics IV	Technology Hill at The Royal Institute for Technology
Imtec	Image Analysis Laboratory	"Gluten" at the University of Uppsala

¹⁶ Personal interview, Robert Forchheimer, 1987-11-17.

problems other than the analysis of images would have been more pressing and challenging, generating a totally different technological development.

The Dissemination of the Image Processing Network

Institutionalized mainly for other reasons, the research parks indirectly prolonged the public support for the furtherance of digital image processing technology, when STU's special initiative ended in 1984. Image processing had been legitimated scientifically and the evolving network was turning out technologically functional image processing computer systems. The Swedish image processing firms were, however, still struggling for their survival. Contrary to the development of microelectronics in Silicon Valley a mass-market for image processing gadgets was neither available nor accessible to the Swedish actors. The dominant design and shape of the image processing equipment primarily satisfied the needs of men and women of science dressed in white robes working in clean laboratories. The market represented by scientific laboratories was neither large enough nor sufficiently affluent to foster self-sustained growth for the large number of emerging image processing firms.

The Actors Outside the Special Initiative for the Development of Image Processing

The development of image processing technology in Sweden and elsewhere had predominantly been financed through public funds or by publicly held companies: STU, the Department of Defence, the Swedish Space Program, different regional development funds or State controlled companies. Private firms like Saab-Scania and ASEA also invested in the technology but, at least initially, they were exceptions from the overall pattern. When STU's special initiative came to an end the progress of image processing network became increasingly dependent upon the actors' ability to attract resources from sources outside the system for support of technological development. The emerging image processing firms had not been equally dependent on the availability of public funds. The growth of actors outside STU's special initiative and the Swedish space program were to a greater extent contingent upon their ability to attract resources from the private sphere. Some spin-offs from university research, especially Sectra and Innovativ Vision both with their roots in the University of Linköping, were not directly included in the public policy programs towards the development of image processing.

Indirectly, both Sectra and Innovativ Vision could benefit as subcontractors from the overall progress of the technology but their activities were more directly subject to a market evaluation. Innovativ Vision undertook development assignments on order. All development activities were thus directly connected with a user and they were also fully financed. When the assignments had been fulfilled Innovativ Vision retained the rights to

further development of the instruments or systems in question and in these cases they naturally assumed a more independent role in the technological development.¹⁷ Sectra was established to develop systems for computer and transmission security as the requests for the development of systems and components for image transmission increased the mission of the company shifted and development of image transmission and image coding became the central activity. Like Innovativ Vision, Sectra undertook technological development on direct order.¹⁸ The first image-related project was to develop the image transmission component of Hasselblad's image transmitter. The commercial success of the transmitter secured the growth of both companies and the relationship between them became mutually beneficial. Sectra was not solely confined to the role of subcontractor to Hasselblad, other lines of development were also pursued and in one case, the development of image archives they contributed substantially to the further progress of Hasselblad's development of digital image technology. And in 1988 Hasselblad and Sectra established a jointly owned company, Image Server AB, to develop, produce and market digital image archives.¹⁹

The development projects within Innovativ Vision and Sectra were to a greater extent self-financed and both firms exhibited a smoother growth process than the actors involved in STU's special initiative. Other emerging proponents of image processing, actors within established firms competing for internally generated resources with other development projects and spin-offs from established actors in quest for new sources of resources were also more directly subject to the evaluation of their potential suppliers and users in their accumulation of resources.

Legitimizing Digital Image Processing Outside the Public Institutions for the Fostering of New Technologies

When the flow of public policy motivated resources, basically development capital, tapered off, all actors became increasingly dependent upon their ability to attract resources from other sources. Some argued that STU should assume a greater responsibility, they had been instrumental in the emergence of the image processing network, now they ought to take the boat ashore. STU also continued to support the furtherance of digital image processing, particularly the research end of the development. They also followed the evolution of the image processing network with a keen interest but they did not,

¹⁷ Personal interview, Lars-Erik Nordell, 1987-11-17.

¹⁸ Personal interview, Jan-Olof Brüer, 1987-11-17.

¹⁹ SIND 1988: 1, Sverige - Drivhus för internationell konkurrenskraft?, p. 108.

immediately, issue a continued program directed towards the commercialization of image processing technology.

Many of the image processing firms were bleeding. The development had taken longer than projected and they needed more resources to realize the expectations of the new technology. The most urgent problem was the shortage of development capital. Naturally, other institutions, supporting the development of new technology apart from STU, were also accessible to the image processing firms. Image processing technology had been legitimated in the support system for technological development and it was comparatively easy to attract investments from other public sources different Pan-European, national and regional development funds. But increasingly the firms had to attract private investors. The future prospects of digital image processing were still promising and most firms were able to acquire new development capital.

The Public Side of Image Processing

The need to attract new resources to the development of image processing required that the technology was also legitimated outside the institutions for the development of new technologies. The proponents of image processing attempted to establish that they had the capacity to solve a number of societal and individual problems, and image processing was increasingly presented in the press. One side of the publicity of the technology focused on how the digital image technology was invading the production of newspapers. Another side was more spectacular presenting, the technology in the most beguiling contexts. In the investigation of the assassination of the Swedish Prime Minister Olof Palme different modes of image processing were presented. First of all, computer generated images played a crucial role in the generation of phantom pictures of the alleged assassins. Secondly, the Swedish Airforce performed air surveillance in order to locate the murder weapon and Context Vision analyzed the images produced. Other events also gave publicity to image processing. The Swedish Space Corporation and Satellite Image AB were the first ones in the world showing pictures of the nuclear catastrophe at Tjernobyli and lately, due to the Gulf War, Spotimage, partly owned by Satellite Image AB announced that it was no longer providing Iraq with satellite images.²⁰ A more quaint circumstance in which image processing was presented was in a late night, erotic, Swedish television production, where Innovativ Vision presented a system for generating phantom pictures of faces based on natural images. The system was used to produce artificial portraits of a man and a woman. Look-a-Like viewers were encouraged to send in pictures of themselves and the two with the highest resemblance to

²⁰ Expressen, Thursday, January 31, 1991.

the phantom faces were brought together in the next program. It seemed that spectacular problems called for spectacular technological solutions.

A more serious side of the legitimation of image processing in the business and public sphere has been the annual industry outlooks supplied by more or less scrupulous consultants. The general feature of these reports was that next year the market for image processing would be boosted. The reports were more aimed at encouraging potential financiers, than at being a foundation for the everyday activities of the different proponents of image processing.²¹

The Fundamental Problem - The Integration of Image Processing with the Technologies of the Users

The need to attract additional capital resources was in many cases urgent but yet only symptomatic of a more fundamental problem. The isolation of digital image technology had to be broken: the gap between the technological system of digital image processing and the technological systems employing the new technology had to be bridged. The proponents of image processing had to attract resources to integrate the new technological system with preexisting ones and in this way connect the investments in the development of digital image technology with complementary investments in other systems. In many industrial systems graphic production, map production, industrial automation and radiology investments had already been made in the conversion to digital technology. The next challenge for the image processing actors was to connect their development activities to the development activities within these systems. Like most other network technologies; electricity, computers and others, the performance of the components of digital image technology; image reading instruments and image processing computers were contingent upon the performance of the whole system. A total industrial system for development, production and consumption of image processing systems and of computer processed images were yet to be established.

The experiences from the first installations of image processing equipment prompted the proponents of the technology to work more directly with some users: adapting the technology to the particular image analysis problems and preconditions of specific users. The focus gradually shifted from serving a generally defined market to serving specific user groups sharing common characteristics. The problem of insufficient capital

²¹ An example of the annual optimism regarding the prospects of image processing is provided by Jonathan B. Tucker stating that, "growing at a fast-paced 90% annual rate, the vision market was worth \$42 million last year (1983) and is expected to exceed \$342 million by '87." By 1987 as many as half of all the industrial robots would be sold with vision capabilities. Tucker, J. B., Business Outlook: Robot Applications Enhance Vision Sales, *High Technology*, June 1984. p. 61.

prompted the image processing firms to cut costs and to establish a more viable resource structure. Many activities of development and production not vital to the existence of the emerging firms, that had previously been performed within the firms were shifted backwards to suppliers of components and subsystems. The specialization and division of labor emerging from the image processing firms addressing urgent problems resulted in the dissemination of the coalesced image processing network.

The Turning of OSIRIS from a Blatant Failure in Image Processing to a Splendid Success in Image Transmission

The first project within the special initiative to be abandoned was the development of OSIRIS, a low cost image processing system. OSIRIS was developed by Physics IV, the Swedish Space Corporation, Saab-Scania in Gothenburg and the famous camera manufacturer Hasselblad, in collaboration. The OSIRIS-project satisfied the aim of the special initiative and it was also in line with the ambition of STU to promote the formation of industrial networks. Nevertheless, the collaboration between the four crashlanded and the OSIRIS-project was abandoned. The reasons behind the collapse of the project were many; the technological design of the system proved to be less prospectful than had been anticipated; the market to be served proved hard to reach and the fact that OSIRIS never was used the way it had been intended. More important, however, was probably the incommensurability of the goals of the four actors. None of the actors, except Physics IV, the original inventor, had vested interests in the development of OSIRIS. The others participated in the project mainly for reasons other than the promotion of OSIRIS. Hasselblad was determined to follow the development of electronic image technology²² and the Swedish Space Corporation needed equipment to analyze satellite images.²³

The project collapsed in 1982 but the actors continued on the path of digital image technology; Physics IV was determined to make a success out of OSIRIS; The Swedish Space Corporation initiated the internal development of a mid-size image processing computer and Hasselblad continued to strive towards electronic image technology with the long term goal set towards the development of a still-video camera.

Connecting Frontline Users with Frontline Development

Hasselblad had been in contact with Agence France Presse, AFP, which had initiated a development of a digital picture-net for the newspaper industry. The basic components of

²² Personal interview, Lennart Stålfors, 1984-09-11.

²³ Personal interview, Claes-Göran Borg, 1984-11-28.

this system were a digital image switchboard, image terminals and image transmitters. AFP had not yet commenced the development of image transmitters and they communicated the need for an instrument capable of transmitting digital images to Hasselblad. In 1982 Hasselblad initiated a development of a digital image transmitter. A former associate of the Picap-group was appointed to lead the new venture. The transmitter was developed in collaboration with Expressen one of the largest newspapers in Sweden and a subsidiary of Expressen adapted the existing system for receiving images to digital technology. Sectra was engaged in the development of the transmission components and Hasselblad was also able to capitalize on their existing supplier structure: Carl Zeiss delivered the objective to the image transmitter. Technologically, the first image transmitter shared some common characteristics with the abandoned OSIRIS - image processing computer. They both used a ccd-array, but the transmitter was a totally different instrument,²⁴ where OSIRIS had been intended to be used to analyze images, the transmitter was intended to be used only to transmit digital images.

The first phase of the development of the digital image transmitter was completed in time for the Summer Olympics in Los Angeles in 1984. Hasselblad measured up to the first challenge and at the Olympics the transmitter reached a grand exposure to the assembled press. The primary advantage of the digital transmitter compared to the preexisting analog system of image transmission was that it could transmit negative images. The photographer could thus develop the film at the sports arena and send the pictures directly to the newspaper using an ordinary telephone and without first having to produce a paper copy of the pictures. Important hours were saved, the deadline could be met and furthermore the editor was also given more discretion in selecting the final picture.

In order to further specify the image transmitter according to the needs of the users Hasselblad continued to discuss with AFP and other representatives of the global press. One element that was changed in the second generation of the transmitter was the film format. The transmitter was specified for the use of 35 mm film only. This meant that the transmitter could not transmit photographs taken with Hasselblad cameras. But more importantly, it also meant that the transmitter could be made portable and easier to operate. A "dummy" of the new transmitter was presented to AFP and Hasselblad declared themselves willing to perform the development within a certain time if AFP signed a letter of intent to acquire a specified number of transmitters at a fixed price. AFP agreed and Hasselblad had taken on a new challenge. Not only had they promised to complete the development in time, they also set out to do it at a specified cost.²⁵

²⁴ Personal interview, Lennart Stålfors, 1984-09-11.

²⁵ Personal interview, Lennart Stålfors, 1987-11-23.

Internal Reorganization

To develop, produce and market the image transmitter Hasselblad established a subsidiary, Hasselblad Electronic Imaging AB. The new company could not meet all the promises made in 1984. The project was delayed but so was also the development within AFP and the time schedule for the transmitter was still sufficiently close to the original plan. For the development of the optics, mechanics and electronics of the image transmitter Hasselblad drew upon the experience of around 25 subcontractors. Most important was the image coding and transmission expert, Sectra. Sectra also produced the image compression elements of the final transmitter. Production of the image transmitter was organized internally through employing resources in the mother company and by using a network of subcontractors, the most important besides Sectra being Carl Zeiss, producing the objective for the transmitter as well as for the Hasselblad cameras.

The first transmitter was delivered to AFP on February 7, 1986 and before the end of the year Hasselblad managed to turn out 28 systems, mainly to AFP but also to two Swedish newspaper actors and to the car manufacturer, Fiat. It was still too early to order champagne. The transmitter, marketed under the name "Dixel 2000", was rarely used in active service. Dixel was impaired by some unsolved technical problems. But they were not only able to solve the problems, together with Sectra they moreover took Dixel well beyond the specified performance levels. The delivered systems were called back for revision and up-grading. Hasselblad was gaining a solid reputation as producer of digital image transmission systems. Compared to its major competitor, Dixel was a real bargain. In 1987 the price of Dixel 2000 ranging from SEK 180.000 was less than half the price of the Nikon transmitter, at SEK 450 000.²⁶ Dixel is sold through AFP and through the existing channels of the mother company.

Connecting Digital and Analog Technology

Dixel 2000 was developed for digital image transmission, but apart from actors acquiring the AFP-system, the newspaper production system of Teragon Systems or some of the few other existing systems accepting digital signals, Dixel 2000 was useless. The orders from AFP for digital image transmitters, close to 200 systems up til 1989, were of course vital for the growth of Hasselblad Electronic Imaging AB and, through them, also for the growth of Sectra. But the bulk of the market was still within analog transmission. To make it possible to use Dixel 2000 without first having to invest heavily in digital technology, Hasselblad, in collaboration with Sectra, developed an analog transmission

²⁶ Personal interview, Lennart Stålfors, 1987-11-23.

module. In 1987 Dixel for analog transmission was presented, representatives of the Swedish press were enthusiastic. The analog module also made it possible to use Dixel in active service outside the AFP-sphere. The possibilities of analog transmission, have through the use of Dixel by Swedish newspapers substantially increased interest in the system. The first analog transmitter was developed according to the European telephoto standard. The next step in the development process was to adapt it to the American standard.

Spin-Off Effects

To further promote digital image transmission Hasselblad and Sectra have developed a total system for digital transmission consisting of Dixel and a receiver-interface.²⁷ A digital system have certain advantages compared to analog transmission. It is safer, faster and the outcome is of higher quality. It has also proved to have certain qualities when it comes to the handling of colour pictures. A colour picture must be transmitted several times, one colour at a time. Before the editor can inspect the final result, the picture must be reproduced, a costly process. In the digital system the picture could be recreated in the receiver-interface and displayed by connecting the receiver to a monitor. Colour separation could, of course, be performed directly with Dixel.

The growing number of colour pictures in the newspapers of today revealed a hidden potential of Dixel. Newspapers found that the system could be used as a low cost colour separation system. By transmitting colour pictures locally to the internal receiver Dixel functioned as a colour separator affordable to almost every newspaper, especially since it also could be used for long distance transmission. A large Swedish press organization has initiated tests of Dixel for colour separation.

An Effective Network for the Development, Production and Application of Digital Image Transmission

The successful collaboration between Hasselblad and Sectra has continued and in 1988 they began to develop a digital image archive. Together AFP, Hasselblad and Sectra have forged a network connecting traditional photography and digital image technology with the production of newspapers. What began as the development of a low cost image processing computer has, through different critical events and through the establishment of a few critical relationships, evolved to become an effective system for the development, production and use of digital image transmission.

²⁷ Personal interview, Jan-Olof Bråter, 1987-11-17

Physics IV - Back to Basics

Meanwhile, Physics IV did not rest ashore. The department had initially been developing scientific instrument for the measuring of data contained in images. Slowly their activities had grown closer to the processing of images. Both systems developed at Physics IV, the spectral reader, IRIS, and the OSIRIS, had originally been designed for the reading of images. Gradually the instruments were adapted to the processing of images through the addition of computing capacity. Knowledge of computer technology was, however, never the base on which the department motivated its activities.²⁸ Their specific competence was more in the field of spectroscopy, image physics and optics and in the scientific endeavour succeeding the OSIRIS-project they turned back to basic, developing scientific instruments for extracting information contained in images. By combining laser and fluorescence technology Physics IV was able to extract new information previously concealed. Among other things it was found that the technology could be used for generating three-dimensional volumes from microscope slides, an observation that resulted in a collaborative research project between Physics IV and the Picap-group.²⁹ This scientific venture was also manifested in the development of a scientific instrument, an opto-electronic microscope, PHOIBOS, patented in 1986. In the development of PHOIBOS Physics IV was able to establish a fruitful cooperation with several research groups at the major medical research institutes in Sweden. And in 1984 the first prototype was installed at one of the groups.³⁰

While Physics IV wanted to exploit PHOIBOS commercially, they also firmly believed that OSIRIS deserved a different faith. The experiences from the previous attempts to transfer the projects to industrial partners combined with the examples set by other university spin-offs encouraged Physics IV to try on their own. In April 1985, Physics IV and a Swedish development company joined forces and established Sarastro AB. The mission of Sarastro was to develop, produce and market microscope-scanners, primarily PHOIBOS but also OSIRIS, to scientific institutes. The marketing of OSIRIS still proved problematic, apart from a few systems installed at the image analysis laboratory at the Royal Institute of Technology, Sarastro did not manage to sell the system and eventually even Sarastro abandoned OSIRIS. The prospects for PHOIBOS were much more promising. The microscope was adapted to conventional personal computers. A complete

²⁸ This was also pointed out in an international evaluation of the group. See, STU Information no 544-1986, Report of Visiting Committee on Swedish Research in Image Processing and Analysis. This principal weakness has, however been compensated for by the collaboration with the Computer Vision and Associative Laboratory (NADA) also at the Royal Institute of Technology.

²⁹ Personal interviews, Nils Åslund, 1984-12-10 and Per-Erik Danielsson, 1984-09-17

³⁰ Personal interviews, Nils Åslund, 1987-11-25.

PHOIBOS-system was, thus, comprised of the microscope, any Intel-based personal computer and application software developed by Physics IV and Sarastro. For the production of PHOIBOS a number of suppliers were contracted. To foster use of PHOIBOS Sarastro established an application laboratory where users were welcome to come and test the instruments. Collaboration with a group of users at the University of Philadelphia has resulted in the establishment of a sales subsidiary in the U.S.

Neither of the instruments developed by Physics IV were motivated by market needs. IRIS, OSIRIS and PHOIBOS were all developed to satisfy the internal scientific needs of Physics IV. Contrary to the two previous instruments, PHOIBOS, apparently had the capacity to solve more general sets of problems. In the development of PHOIBOS, Physics IV and Sarastro managed to establish a closer relationship to users than had been the case with the other instruments. The most significant difference, however, might have been the level of engagement devoted to the three projects. IRIS and OSIRIS never became more than minor undertakings in huge companies, while the development of PHOIBOS was the sole purpose of Sarastro.

A Network in Space

Another participant of the OSIRIS project, The Swedish Space Corporation, needed an image processing computer to analyze satellite images. They had participated in the development of OSIRIS and had also developed a sea surveillance system for the Swedish Coastal Guard, containing digital image technology. The absence of functional image processing systems motivated the Space Corp. to develop a system internally.

The Swedish Space Corporation is a state owned company and the spider in the web of actors constituting the Swedish Space Program. Apart from remote sensing and digital image processing they are also active in every space-related activity in Sweden. They run the rocket station Esrange in northern Sweden and they coordinate the Swedish satellite ventures. The Space Corp. coordinates the Swedish space effort and controls, directly or indirectly, the resources devoted to space activities.

Internal Needs Urging the Swedish Space Corporation to Develop Image Processing Computers

At the same time as the Space Corp. became involved in the OSIRIS-project they developed their own low cost image processing computer. In 1981 they launched "EBBA" a micro-computer based image processing system in the price range 100.000 - 150.000 SEK. EBBA was founded on their knowledge of remote sensing and on the image memory developed in the sea surveillance project. 15 - 20 EBBA-systems were

produced and subsequently sold or leased mainly to research institutions, government authorities and companies active in the fields of remote sensing and cartography. EBBA was successively developed and upgraded and in 1984 EBBA II was launched. EBBA II was an internally financed development of EBBA, representing an adaption to the requirements of the potential users. Later EBBA II was complemented with a larger, faster and more interactive image memory forming the basis for the third generation of low cost image processing computer systems, named EBBA-GIS, developed by the Space Corp. The sea surveillance system was later upgraded with the new image memory. EBBA-GIS was adapted specifically to the processing of geographical information, hence the name GIS - an abbreviation of Geographical Information System. EBBA-GIS was developed to be used together with a host computer from digital equipment but it could also be used as a stand-alone system. In connection to the development of EBBA-GIS the Space Corp. acquired the rights to a PC-based cartographic software package, Strings, developed by GeoBased Systems Inc. Strings was adapted to EBBA-GIS which provided the Space Corp. with access to two computer systems, of different complexity, for the processing of geographical information.³¹

The line of EBBA-systems and the PC-based Strings -system represented a development of mid-size and low cost image processing computer systems. The range of remote sensing activities performed within the Space Corp., however, also called for an image processing computer system with an even higher capacity than the EBBA-GIS. To satisfy the need for a high capacity image processing computer system the Space Corp. had outlined a new system, MIMA. To fulfil the specifications for MIMA a higher image processing capacity was required. And the Space Corp. acquired the computer Teragon 4000 from Teragon Systems, one of two suppliers of general image processing computers in Sweden at that time. Teragon Systems and Context Vision had each developed a highly sophisticated computer system for image processing.

Teragon Systems and the Development of a Total Digital Production System for Newspapers

Teragon Systems, originally a spin-off from the Picap-group at the University of Linköping established in 1981 under the name of Imtec and one of the pioneering image processing firms, was the largest new venture into digital image technology. Teragon Systems developed the Picap II-project to a commercially viable image processing computer system and they had anticipated serving all four major segments of image processing technology: industrial automation, graphic production, medicine and

³¹ Personal interviews, Claes-Göran Borg, 1984-11-28 and 1987-11-10

cartography.³² They had started out with a project within industrial automation concerning automatic seed control and with a digital total production system for large newspapers. The medical segment was covered through the continuance of the collaboration with the Image Laboratory of Uppsala University, something that had been initiated earlier between the Picap-group and the Laboratory. The relationship with Space Corp. could be Teragon's entrance ticket to the cartographic and remote sensing market.

The development of the total digital production system, labelled the TIPS-system soon became the dominant project. It was financed by the state owned publisher Liber AB who considered the project as a means to catch up with their competitors technologically. The TIPS-system was a desk top publishing system developed long before this concept was coined in the development of personal computing. But the TIPS-system was not intended for infatuated amateurs, it was supposed to satisfy the market for professional production of large newspapers. Like a young cuckoo the TIPS-system swallowed all the resources the striving company could attract and in 1982 a subsidiary of Liber AB, Liber Systems Text and Image AB acquired 91% of the shares in Imtec. The remaining 9% was still held by the original founding company, a state owned development company, SUAB. It still proved difficult to pursuit development outside the TIPS-project and they soon realized that they had to give up the aim of adapting the computer system to all four of the major applications. In 1984 Imtec was split into two parts according to the ownership structure. The major part of Imtec was transferred to Liber Systems Text and Image AB, who was to concentrate its efforts on developing digital image technology for newspaper production and for cartography and remote sensing. The two remaining segments industrial automation and medicine were to be served by the remainder of the company, initially under the control of SUAB. The spin-off consisting of one of the original founders and the leading researcher within the Image Laboratory retained the original name of the company, Imtec, and moved to Uppsala.³³

Liber systems continued to develop the TIPS-system and the general image processing computer system, then called Imtec 4000. The TIPS-project was developed in collaboration with a Finnish company, OY Typplan a subsidiary of Nokia, producing computerized text-systems for newspapers. Liber systems and Typplan were technologically compatible in that they both used the same host computer, a VAX from Digital Equipment. Others had also been involved in the project, especially related to the development of the man - machine interface of the TIPS-system. The TIPS-system was

³² Personal interview, Sven Olofsson, 1984-09-26.

³³ Personal interviews, Björn Kruse, 1984-09-28 and Sven Olofsson, 1984-09-26.

developed to become a total digital system for the production of newspapers integrating images, graphics and texts. An "Application Support Package" with an open architecture, around which different application modules could be organized, was the heart of the interface between the hardware and specific applications of digital processing. The original image and text modules were complemented by others to fit the needs and the specific technological vintage of the potential users. Some of these modules were supplied by different manufacturers, e.g. the type-setting equipment was supplied by Monotype, Crossfield or Chemco three, traditional original equipment manufacturers in the graphic industry.

Altogether three TIPS-systems were installed; at a small Finnish newspaper; at an American newspaper and at a Swedish newspaper. The first complete TIPS-system was installed at the Swedish evening paper "Aftonbladet" in 1985. With support from STU, Aftonbladet leased a TIPS-system for 2.5 years. The system was tested during the time of the lease and Liber Systems continually upgraded the systems according to the experience of the use of the system at the newspaper. At Aftonbladet the TIPS-system was used in a laboratory setting. The system was installed in a separate room and five typographers were specially trained by Liber Systems to operate the system. Apart from operating the TIPS-system these were also available if problems arose in normal production. The system was basically used to produce the images for the Sunday supplement of the Gothenburg edition and to compose one page containing the letters to the editor in the main edition. Why was the system not used to produce images for the other editions? Well, the main reason was incompatible technology: the image technology of Aftonbladet in general was old and about to be replaced, while the Gothenburg edition was produced with a more modern technology. There were no technological barriers to producing all the images with the system, but the quality of the outcome was not deemed to be satisfactory for the main edition. Why, then, was only one page composed in the TIPS-system and why was it the letters to the editor? First of all, letters to the editor were never an effective test of the capacity of the TIPS-system: it offered few possibilities to use the "goodies" incorporated in the system and it contained only a few, if any, images. In a newspaper production failure is a catastrophe and the letters to the editor were probably considered to be unimportant enough to be experimented with. The TIPS-system could probably have been used to produce the whole newspaper or at least one of the supplements, but that would have required a total modification of production routines. As it is, all pages of a newspaper are produced simultaneously and they are all completed at the same time, just before deadline. The cost of the TIPS-system and additional work-

stations³⁴ suggested a more sequential completion of the pages in the paper. The newspaper industry was not yet ready to take the giant leap into digital desk top publishing technology. It was not possible to change the routines of production and it could not afford to use the new technology in the traditional way. But it was slowly converting to digital image technology. Aftonbladet decided against acquiring the TIPS-system, but they have acquired both the AFP digital image system and Dixel 2000.³⁵

New Technology vs. Traditional Routines of Production

The failure of the TIPS-system was a setback in the growth of Liber Systems. The American paper also returned their system and the Finnish paper was the only remaining paper which continued to use the TIPS-system. The system had performed well technologically and the man - machine interface had proven to be well adapted to the preconditions and needs of the final users. The problems was that the TIPS-system challenged the traditional production routines within the newspaper industry. Liber Systems, still an emerging firm, neither controlled nor could they attract the necessary resources to be the missionary of desk top publishing technology for the newspaper industry. Furthermore OY Typplan had for different reasons left the collaborative venture. The difficulties encountered in the final stage of the development of the TIPS-system resulted in financial problems and the mother company announced an unwillingness to make up for the deficiency. Liber Systems was for sale and subsequently acquired by the independent venture capital firm, Connova Invest. The development of digital image processing systems continued, now under the name of Teragon Systems.

The restructured Teragon dismantled the TIPS-project and gave up or at least postponed the realization of a totally integrated production system for newspapers. Instead, they concentrated their efforts on developing one of the modules of TIPS, an electronic darkroom and on the development of the image processing computer, now called Teragon 4000.

The Major Competitors Following Different Paths

The pursuit of the development of the automatic seed control system and the TIPS-system guided Imtec, Liber Systems and Teragon Systems into a specific path of development of

³⁴ The cost of a complete TIPS-system, with work-stations was SEK 2 - 3 million. Additional work-stations would cost SEK 100 000 - 200 000. The total cost would thus beyond the means of any newspaper. Personal interview, Roger Cederberg, 1988-04-05.

³⁵ Personal interviews, Ingvar Hall, 1987-01-28, Björn Sporsén, 1987-01-28 and Lennart Berg, 1987-01-28

digital technology: the evolutionary path of digital image technology for production systems. The major Swedish competitor, Context Vision, was ushered into a different path of development. Context Vision established relationships with research institutions and consequently the GOP image processing computer system was primarily adapted to the needs of the scientists. They also established a collaborative venture with the French company, Télécommunication Radioélectriques et Téléphoniques (TRT), to realize the processor architecture in VLSI-circuits.³⁶ Compared to Teragon Systems, Context Vision had a more pronounced European focus and it gave priority to the development of its European market organization. Context Vision followed the path of development of general image processing systems for research institutes and laboratories in Europe. In the entrepreneurial stage of the evolution of the image processing network, the antagonism between Teragon and Context Vision was fierce. They drew on the same resources; they competed for the same research and development capital; they used the same components and subsystem and finally they aimed to serve the same needs of the same customers. As they encountered and solved everyday problems of developing and producing image processing systems and of adapting them to the needs of the buyers they established different relationships to other actors. Through the interaction within these relationships, Teragon with Liber and Aftonbladet and Context Vision with research laboratories, the two ventures were led into different evolutionary paths: drifting apart competitively, but remained next door neighbours geographically. The two firms had in a few years gone from being relentless competitors to becoming potential partners.³⁷

Connecting the Space Effort and the Development of Image Processing Computer Systems

The Swedish Space Corp. had initiated discussions regarding the possibilities of joint development of cartographic systems already with Imtec in 1982. They also ordered an image processing computer system from Imtec. The discussions continued with Liber Systems when they were in the midst of the TIPS-project. The possibility of a collaboration with the Space Corp. was considered highly interesting, but as the TIPS-system was at a critical point of development and it swallowed all the resources Liber Systems could attract the Space Corp. attained lower priority, when it came both to the installation of the computer system and to the plans of joint development.

³⁶ Télécommunication Radioélectriques et Téléphoniques is a company within the Philips sphere and the collaborative venture was supported through the Pan-European project for technological development, EUREKA. SIND 1988: 1, *Sverige - Drivhus för internationell konkurrenskraft?*, pp. 110 and 122.

³⁷ Personal interview, Roger Cederberg, 1988-04-05.

The efforts to develop digital cartography and remote sensing in Sweden was to a large extent compounded within the Space Corp. They controlled, directly or indirectly, the resources allocated to development of space technology and remote sensing and as a consequence they became regarded as an interesting partner in the development of digital cartographic technology and remote sensing and thus they attracted even more resources. In 1982 the Swedish Space Corp. established a subsidiary, Satellite Image AB, to receive and process satellite images. This was a natural extension of the Space Corporation's commitment to the development of European space technology and remote sensing capabilities. In 1978 the Space Corp., in collaboration with the European Space Agency, ESA, erected a data acquisition station for the Landsat-satellite at Esrange. The establishing and operating of satellite data acquisition stations and networks for dissemination of satellite data was considered an appropriate role for ESA promoting the development of remote sensing.³⁸ In 1978 the negotiations regarding participation in the SPOT-satellite, a European remote sensing satellite, were concluded and the Swedish part was set to 4%. The SPOT-satellite was in contrast to Landsat not experimental. SPOT was to be developed for commercially oriented remote sensing. The Swedish participation in the SPOT-project constituted the basis on which the Space Corp.'s endeavour into commercial exploitation of remote sensing was founded.

Approaching the launch of the SPOT-satellite, additional investments in resources for remote sensing were required modernization of the data acquisition stations, development of image processing capacity and enlargement of the networks for the dissemination of satellite data. The Satellite Image AB was one part of the European investment in commercial remote sensing. The French board for space activity, CNES, had an equal interest in investing in an infrastructure for remote sensing and Spot Image, the French equivalent of Satellite Image, acquired 9% of the stocks in Satellite Image. The remaining 91% was held by The Swedish Space Corporation. Satellite Image were to be equipped for advanced acquisition, processing and refining of satellite data and fully functional by the time of the launching of the SPOT-satellite.³⁹

Connecting the Space Effort and the Production of Maps

To be productive the raw satellite data had to be converted into geographic information and it also often had to be combined with other sources of information. To adapt the processing and refining of satellite images to the requirements of the users of geographic

³⁸ Grahn, S., and Borg, C-G., *The Sky is Not the Limit - SSC and the Swedish Space Effort*, The Swedish Space Corporation: Stockholm, 1982. p. 41.

³⁹ Alstermo, S., *Satellitbild - Ett Företag i Rymdbolagskoncernen*, *Fjärranalys*, no 10, November 1983.

information the Space Corp. initiated collaboration and joint projects with different actors active in the field of cartography: national, regional and local authorities, mineral prospectors and land survey institutes. The most consequential collaborative venture being that with the National Land Survey of Sweden, SLS. Who has the primary responsibility for the survey of the Swedish landscape and the subsequent production of maps, while the local authorities are responsible for more detailed surveying. Overall, a huge number of public and private organizations have a stake in the production and use of geographic information. The total cost for land surveying and map production in Sweden was in 1979 estimated to amount to SEK 1.5 billion and 10.000 - 12.000 men and women were estimated to be engaged in surveying Sweden⁴⁰. The position of SLS in the Swedish cartography industry can be compared to the position of the Space Corp. in the Swedish space effort.

Following the development of computer graphics a widespread conversion to digital technology was initiated decades ago in the field of cartography. Computer systems for digital map production became increasingly available. In 1984 one third of the Swedish 284 local authorities had acquired or had direct access to computer systems for map production⁴¹. The digital technology was primarily employed in the production process and rarely used to produce new information, nor were new sources of data, satellite images, employed. The conversion to digital technology signified that an increasing amount of geographic information would be stored digitally and would thus be accessible for further computer processing. The absolute dominant part of the geographic information, accumulated during centuries, was of course still stored with analog technology.

Combining Satellites, Digital Image Technology and Cartography

We have previously seen that image processing systems were also available at this time. They were, however, not yet used extensively outside the research institutions or the experimental units of the producing actors. The production of maps was still dominated by analog technology, but digital technology had broken through the technological barrier and a few local authorities were dominantly using digital technology in the production of primary maps. As remote sensing was reaching maturity, functional systems for remote sensing were being established. The mission of the collaboration between the Space Corp. and SLS was to develop and promote the development of digital geographic

⁴⁰ Status i Norden, Nordisk Kvantif: Delrapport 1, Ekonomiska Forskningsinstitutet vid Handelshögskolan i Stockholm, 1986.

⁴¹ Status i Norden, Nordisk Kvantif: Delrapport 1, Ekonomiska Forskningsinstitutet vid Handelshögskolan i Stockholm, 1986.

information systems, thus interconnecting the emerging system for remote sensing and image processing with the emerging system for the digital production of maps.

The Space Corp. commenced the development of MIMA in 1982, but the failure of Liber systems to deliver the computer system on time and the internal development of EBBA-GIS produced substantial delays of the MIMA-project. Certainly, the Teragon 4000 was not the only image processing computer on the market in Sweden, but Teragon was especially suited to be a partner in the development of MIMA. They used the same host computer as the Space Corp. and they had specialized in the development of image processing for production systems. The closest competitor, Context Vision, used another host computer and they were becoming specialized in image processing for scientific purposes. Several GOP-systems were sold to organizations pursuing research in remote sensing and geographic information systems. When the development of the TIPS-system reached the final stage, Liber Systems was able to devote more resources to the joint development of MIMA and after the shift of ownership and name MIMA was considered to be the most important project. In MIMA the computer and image processing technology of Teragon systems was combined with the knowledge and experience of remote sensing and geographic information systems accumulated at the Space Corp. and SLS.

The first phase of the development of MIMA was completed in 1986 and the first system was installed at Satellite Image. The characteristics of Teragon high interactive image processing capacity and extremely high user friendliness were incorporated in the system. At the same time the experience of the Space Corp. was reflected in the software for geographic information. Not only was it possible to analyze single satellite scenes, it was also possible to process multi-satellite images and combine these with data from several other sources. Teragon and the Space Corp. have also continued to develop the MIMA-system also after the first installation. The next challenge was to integrate the matrix based image processing with the vector based computer graphics.

Spin-Off Effects

The first installation was followed by others. MIMA was marketed internationally by Teragon but naturally the basic market consisted of the Nordic countries and SLS and its corresponding organizations in the other Nordic countries acquired MIMA-systems. The successful completion of the MIMA-system also proved to be an entrance ticket to another similar project. Ericsson Radio Systems had received an order for a processing system for meteorological satellite data, PROSAT, from the Swedish Meteorological and Hydrological Institute, SMHI. When the British supplier of the image processing

computer of PROSAT had problems to fulfil their part of the project, the order went to Teragon, who delivered. Teragon 4000 became the main feature of PROSAT. In connection with the MIMA and PROSAT projects Teragon also made some minor adjustments of the ccd-flatbed scanner developed for the TIPS-system.⁴²

Success fostered even more success and Teragon also found a new opening into newspaper industry. The TIPS-system was converted into a electronic darkroom and together with the flatbed scanner it constituted an effective system for digital production of both black and white and colour images. The electronic darkroom was further adapted to accept images sent by Dixel 2000 and Teragon was also granted the rights to sell Dixel. One of the former potential suppliers to the TIPS-system, Chemco, Europe will market the electronic darkroom in Europe. For the production of Teragon 4000 and the electronics of the flatbed scanner Teragon have established a relationship with Saab Combitech. The systems are tested and connected to the host computer at Teragon.⁴³

For the Space Corp. the collaboration with Teragon meant that they could abstain from further development of the hardware for image processing. The development of the line of EBBA-systems had primarily been motivated by the absence of reliable computer systems for remote sensing. Through the relationship with Teragon the Space Corp. now had access to an image processing computer system adapted to remote sensing and cartography and consequently the Space Corp. could concentrate on the development of methods for using satellite images as one component of geographic information systems and on the establishment and maintenance of infrastructures for connecting the acquisition, dissemination and processing of satellite images with the users of geographic information.

The Space Corp. and Satellite Image intensified the collaboration with SLS, who also located a branch office in Kiruna, in the vicinity of Satellite Image. Satellite Image alone or together with SLS sold satellite data of a varying degree of refinement in Sweden and all over the world. In the western world the systems for geographic information is well established and satellite data can at the most be a complement to the existing amount of information. Consequently satellite data are of less value. Here the basic problem is to adapt the digital image technology to the existing digital and analog production technology. In the underdeveloped world the situation is different, an insignificant base of geographic information and systems for production of information have been

⁴² Personal interview, Roger Cederberg, 1988-04-05.

⁴³ Personal interview, Roger Cederberg, 1988-04-05.

accumulated. Here satellite data can constitute the sole base on which geographic information is construed. The economic value of satellite data is in this case relatively higher. Together with Swedsurvey, a subsidiary of SLS, the Space Corp. have undertaken several projects regarding resource mapping in the third world. A survey of the Phillipines and an inventory of fire woods in Tanzania are two examples of undertakings of the Swedish Space Corporation and Swedsurvey. Naturally, most projects concerning the third world, including the two mentioned, are financed by different international aid organizations.

The Network in Space Connecting Complementary Technologies

The sequel Imtec, Liber Systems and Teragon were too lonely to establish a digital system for integrated production of newspapers. The new venture did neither have the financial resources nor the endurance to be the pioneering firm in the development of desk top publishing systems for newspapers. The necessary resources could not be attracted, neither through the establishment of relationships controlling critical resources nor through internal growth. Together, Teragon, with its relationships to the emerging image processing network and to the computer industry, the Space Corp., with its position in the European space program and SLS, with its position in Swedish cartography, successfully connected the complementary technologies of digital image processing, space and satellite technology and cartography into a digital system for civilian land survey and production of maps. Through this collaboration the three firms established positions consistent with self-sustained growth in the development of remote sensing and cartography. But the system as such can probably not survive without public support for years to come. Already before the transformation to digital technology was initiated, two thirds of the total costs for land survey and map production in Sweden was paid for through government spending. The immense investments in an infrastructure for digital geographic information systems satellites, ground stations, image processing computers and distribution networks, will take decades to recoup. And the volume of demand for satellite images is not yet substantial enough to sustain the system without public support⁴⁴. But a digital system for land survey and map production has an economic advantage over the analog system in that once geographical information is produced it can be reproduced and used in other contexts at a much lower cost⁴⁵.

⁴⁴ The privatization of Landsat 4 and 5 would not have been able to be sustained without additional support from the American government.

⁴⁵ Kylén, B., Digital Kartans Ekonomi, *Nordisk Kvantif: Delrapport 2*, Ekonomiska Forskningsinstitutet vid Handelshögskolan i Stockholm, 1987.

Other Chains of User - Producer Interactions in the Dissemination Process

The above constellations Hasselblad, Sectra and AFP and Teragon, the Space Corp. and SLS, were not the only ones capable of transforming the general solution of digital image technology to a specific solution to a generalizable set of problems.

The Established Companies

The established firms, Saab in Jönköping and ASEA, had an advantage in that they could embrace and control a relatively larger part of the underlying technological system. The chains of producers and users connecting digital image technology with the application could therefore be organized internally to a larger extent. Both Saab and ASEA could benefit from being both users and producers which rendered them at an advantage in the commercialization of digital image technology. Saab in Jönköping had already in 1976 successfully completed the development of an edge detector for sawmills. To attract the necessary resources for the venture they acquired a firm active in the forest industry. The ambitions of Saab in digital image technology went beyond systems for efficient sawing. After some attempts at developing general systems for image processing in industrial automation they specialized in systems for identification in logistic systems. On the order from the Swedish Postal Authorities they developed a total system for sorting of mail. Through this and other projects Saab has developed strengths in digital image technology for identification in industrial automation systems. Lately, in 1988, they also acquired the image processing department at C. E. Johansson AB, a remnant from a spin-off from ASEA,⁴⁶ specializing in digital image technology for inspection and control in industrial automation systems.

ASEA developed a vision system for industrial robotics. As ASEA was establishing itself as one of the largest manufacturers of industrial robots in the world it benefited from the accumulated experience of the application of robotics and from the fact that its vision system could be perfectly integrated with the general guidance system for the ASEA-robot. The robotic vision system was taken to the international market through the marketing of the industrial robot. Like most other actors in the image processing network, ASEA also went for general image processing systems, but after an internal reorganization they once again focused on the development of robotic vision.

This does not signify that huge firms with immense financial strength can overcome all the problems associated with the development of new technologies. The new technology must compete for resources with the other activities of the firms and few firms can devote

⁴⁶ SIND 1988: 1, Sverige - Drivhus för internationell konkurrenskraft?, p. 108.

more than a minor part of their resources to the development of new technologies. Naturally, Saab and ASEA encountered ample sets of problems in their promotion of digital image technology. But both firms have a long industrial tradition and they have accumulated experience in industrial automation for decades. For both companies digital image processing was only a minor component in a larger system and as they embraced the major part of the whole system, the new component could be well integrated with the overall system. And the technological solution of image processing could be adapted to the problems. Contrary to the emerging firms ASEA and Saab opted for less sophisticated technology.⁴⁷

Innovativ Vision - A Winning Spin-Off

Another firm that successfully adapted digital image technology to the users was Innovativ Vision. Originally a spin-off from the Picap-group they went to business to solve the image processing problems of potential users. Contrary to Imtec and Context Vision they were not established to develop a specific image processing computer system. They developed solutions to specific problems and as their clients increased in number so did the number of technological solutions and their primary problem became to discriminate between the projects and choose solutions suitable for further development. As they solved specific users' problems, a line of general image processing computers systems evolved and they set out to market these outside the initial producer - user relationship. In general they encountered similar problems as Hasselblad, Imtec and Context Vision. The image processing technology was not readily generalized to solve common sets of problems. They still had the advantage of not being tied down to one specific solution and together with a few users they continued to develop the systems on user specifications. One such system was a document reader reading the document part of tipping coupons for the Swedish Tipstjänst. Systems for automatic correction of gambling coupons had been in service for some years. To fully automatize the correction process the system had to be complemented with a capability of reading the names and addresses on the coupons. Innovativ Vision adapted one of their computer systems to this application and connected it to the existing system for automatic correction. The first document reader was delivered to Tipstjänst in 1986 and it has been followed by other orders. Initially the document reader was sold and installed by Innovativ Vision, but they also entered into agreements with the producers of the systems for automatic correction and through them they got access to a much larger market. The development of the document reader were typical for the projects pursued by Innovativ Vision. The other projects show similar patterns of intensive collaboration with users. To secure production

⁴⁷ Personal Interviews, Hans Skoogh, 1984-09-27, Jörgen Lindgren, 1984-12-05, Gösta Erikson, 1987-11-16 and Johan Halling, 1988-04-18

capacity Innovativ Vision acquired holdings in an electronic assembling firm, together with one of their major clients.⁴⁸

The cases cited above are some obvious examples of how the development and production of image processing capability were connected and adapted to the use of this capability. Through chains of intense user and producer collaborations digital image technology was extended backward towards the producers of computers and electronic components and forward towards the users of image processing. Through this collaboration a distinct specialization and division of labor evolved and the coalesced image processing network was disseminated.

Connecting the Swedish Image Processing Network to the International Market

Not only did the image processing network disseminate to connect production and usage of digital image technology. The dissemination was also an extension of the Swedish network to an international market. The Swedish market for image processing technology was far too small to sustain most individual applications of digital image technology and the relatively large image processing network. Here, the Swedish image processing network had a relative geographical disadvantage and a complicating fact was probably also the dismantling of the Swedish computer industry implying the dismantling of the distribution channels for general computers from Sweden to an international market. In the absence of a functioning infrastructure for connecting the Swedish image processing network with users internationally, the Swedish image processing firms did not only have to develop the technology, they also had to establish functioning international distribution channels. The Swedish image processing network primarily disseminated towards international users through the primary users' international relationships.

Failures to Connect Image Processing with the User Technology

Not all Swedish ventures into digital image technology were as successful as those reported above. We have previously seen the collapse of the TIPS-system due to the incompatibility of the system in the preexisting routines of newspaper production. The other failures exhibit a similar pattern of inadequate connection between the system of image processing and the system where it is to be applied.

The Measuring of Non-Metallic Inclusions in Steel

One of the first applications of digital image analysis was for the measuring of non-metallic inclusions in steel. A highly standardized problem with high market potential for

⁴⁸ Personal Interview, Lars-Erik Nordell, 1987-11-17

the technological solution. The proponents of an image processing solution to the problem in Sweden, mainly the research laboratories of two ironworks Sandviken and Avesta and their English supplier of image processing equipment Cambridge Instruments, did not follow the core of Swedish image processing actors as they coalesced into a tightly knit network. They remained on the periphery of the evolving Swedish digital image technology and as they struggled to solve the problem of measuring the non-metallic inclusions in steel the development of the steel quality ran ahead of them. In a few years the quality of steel, regarding the non-metallic inclusions, was improved 50 times. This implied that with the existing image processing equipment the errors would be greater than the factual inclusions. The linkages between digital image technology and the measuring of non-metallic inclusions in steel could not be upheld and the proponents of the image processing solution to the problem had to turn elsewhere in the search for a solution. What they did was to turn back to the preexisting manual method, complement it with the experience from image processing and come up with a new standard for the measuring of non-metallic inclusions in steel.⁴⁹

Automatic Inspection of Printed Circuit Boards

The story was repeated in the development of a system for automatic inspection of PC-boards. The development venture into the production of PC-boards for electronic components originated within the Picap-group as an application of their first image processing computer system. The system was specified by a group of actors in the electronics industry and the Picap-group developed a prototype for which they were later granted patent rights. In 1980 the project was transferred to Semyre Electronics in Gothenburg for commercial development and, as we saw above, the project was granted funds from the special initiative for the commercialization of image processing technology. The system for automatic inspection of PC-boards, named Cavis 8500, was a combination of several technologies; electronics, image processing, laser technology, optics and mechanics. The first problem was to integrate the different technologies to a functional systems. Especially problematic was the development of the laser scanner component. The resolution and accuracy specified was on the edge of what could be achieved with the existing laser scanner technology and Semyre devoted a tremendous amount of work to developing the scanner and to building up relationships with actors capable of producing it. Semyre maintained a general discussion with representatives of the electronic industry, but due to problems, primarily with the scanner, no system was tested in existing production lines. Finally, in 1986, all the problems with the scanner appeared to be solved and the future seemed bright and clear. Some additional

⁴⁹ Personal interviews, Stig Johansson, 1987-03-11 and Lars Svensson, 1987-01-26.

development was still required but the system was close to completion and ready to be marketed. But a new stroke hit the project, due to the delay in the completion of the project the window for the technology used in Cavis was closed. The potential buyers had chosen competing systems and it seemed impossible even to have a reference system installed. What had happened during the development of Cavis? The Cavis system was specified for error detection for unitary conductor widths down to 0,25 mm. Meanwhile the technology for production of PC-boards had developed and the production of PC-boards with conductor widths down to 0,25 mm was relatively unproblematic. Quality problems arose primarily for conductor widths down to 0,1 - 0,05 mm. Furthermore, the PC-boards were increasingly made up of varying conductor widths. The new specification hit Semyre hard. The laser scanner technology used could not be taken further and at the end of 1986 Semyre halted further development of Cavis.⁵⁰

During the development of Cavis, Semyre accumulated knowledge and experience regarding the development of image processing technology and the integration of the technology with other technologies. The halting of the Cavis-project left a whole in the business of Semyre. They did not have other image processing projects to replace Cavis. Instead of pursuing internal development of image processing systems Semyre became a subcontractor to other firms in the image processing network.

ASEA Deemphasising Robotic Vision

ASEA's venture into image processing was neither a complete success. The vision system developed for the ASEA robot was functioning perfectly technologically and it was well integrated with the overall robotic system. But while the availability of the ASEA robotic system was 99% the availability of the vision system was approximately 75%. Thus the vision system severely lowered the overall economic performance of the robotic system and for most applications suitable for robotic vision alternative solutions often proved more profitable. The market for robotic vision did not grow as projected and to maintain the level of resources devoted to the development of image processing systems ASEA considered it necessary to take the technology beyond robotic vision, and to cover industrial automation in general. Since the strength of ASEA was in industrial robotics and not in industrial automation in general they decided to decrease the amount of resources devoted for the development of image processing for industrial automation and to focus only on robotic vision. The leading manufacturer of industrial robots could not abstain from the possibilities of providing its robots with vision systems, but it did not necessarily have to lead the development of robotic vision.⁵¹ ASEA continued to

⁵⁰ Personal interviews, Göran Åsemyr, 1984-09-11 and 1987-11-11

⁵¹ Personal interviews, Hans Skoogh, 1984-09-27 and Johan Halling, 1988-04-18.

dissolve the development of robotic vision and in 1988 the team responsible for vision was encouraged to set up operation on its own. Consequently, the robotic vision department was spun off from ASEA and a new image processing firm, Sensor Control AB, was established in Sweden. Naturally, ASEA will, for many years to come, remain the most important buyer of Sensor Control's vision systems.

Competency Entrapment - A Common Feature of the Abandoned Ventures

The common feature of the abandoned ventures into the development of image processing was the failure to integrate the systems for digital image technology and the preexisting technological systems, unifying the previously separated systems into one whole. This inability to integrate into one whole a system, can be considered as competence entrapment,⁵² which in turn can be characterized as three different processes. Firstly, the problems of TIPS-system and ASEA's robotic vision exhibits a situation where the individual systems could be adapted to the needs of the users, but where further learning and adaptation were disabled through the incompatibility of the different technological systems. This is a more general type of competency trap, which has a similar effect on all proponents of the technology in question. These traps can also be dissolved through other development processes. Secondly, another type of competency trap, is exhibited by development of the Cavis-system and the system for the measurement of non-metallic inclusions in steel. Here, the paths of development pursued by the firms diverged from the development of the application area. Changes in the technological systems of the potential users made the development of image processing systems obsolete. Finally, a third type of competency trap is exhibited by ASEA, where the path pursued in research and development, diverged from the development path of the company in general.

The surviving and prospering ventures exhibited a different pattern of evolution, where the image processing systems were adapted to and integrated with other technological systems. Through chains of producer - user relationships complementary investments in the development of new technological systems were interconnected. A new technological system slowly evolved, reinforcing emerging relationships into mutual interdependencies. The coalesced network of the proponents of digital image technology was disseminated, exhibiting an explicit pattern of specialization and division of labour.

⁵² For a discussion of competency traps see, Levitt, B. & March, J. G., Organizational Learning, *Annual Review of Sociology*, Vol 14, pp. 319 - 340, 1988. and Blichner, L., Competency Traps and Successful Experimentation, Working paper, LOS-Senteret, Bergen, Norway, 1990.

A Horizontal Merger Counteracting the Dissemination Process

The credibility of the Swedish image processing network for the development, production and application of digital image technology was stricken a hard blow when it was announced in 1988 that Context Vision had fallen into an acute financial crisis. Image processing firms had balanced on the verge of bankruptcy before, but they had always managed to find last minute solutions, this was the first time someone had cancelled payments. The event was especially traumatic since it hit Context Vision, the figurehead of Swedish image processing.

Context Vision was a spin-off from the Gop-group, one of the most prestigious research groups in Sweden. And when the company was established the founders raised more working capital than any of the other image processing firms. Already these facts boosted expectations. Context Vision was also the image processing firm mentioned most often in the Swedish press. To a large extent Context Vision represented the public face of Swedish image processing. The expectations raised by the firm was not without substance. The technology of the Gop - image processing computer system was on the cutting edge of digital image technology. Furthermore, Context Vision had the most professional management and board of directors of all the image processing firms.

Context Vision did not fail to come through. As was the case with most of the new ventures it took more efforts to realize the image processing system than had initially been expected. But technologically, Context Vision was facing up to the expectations. Several systems were installed at research institutes all over Europe. They had also established development collaboration with the French company TRT to realise the processor architecture of GOP in VLSI-circuits.

The market for image processing computers in Europe, however, did not grow at the expected pace and problems arose in serving the European market. The situation in Germany was especially problematic. Context Vision was beginning to have problems in meeting the cost of the European expansion and as the problems were piling up it fell into an acute financial crisis.⁵³ The problems of Context Vision induced possibilities of horizontal cooperation in the image processing network. Negotiations regarding a horizontal merger with the major competitors, Teragon Systems and Imtec, were initiated. All three firms were heavily supported by the Swedish Industrial Development Fund, who recommended a concentration of the development of general image processing computers to one firm. The Swedish Industrial Development Fund had taken over the role of STU in supporting the commercialization of Swedish image technology

⁵³ SIND 1988: 1, Sverige - Drivhus för internationell konkurrenskraft?, pp. 123 - 124.

and it now participated in the structuring of the image processing network. The creditors in general were positive towards a reconstruction of Context Vision and they offered a 25% composition if the company was restructured. Both Teragon Systems and Imtec participated in the bidding on Context Vision. The final choice fell in favour of Teragon Systems and in the autumn of 1988 the two competitors were merged. The merger involved a changeover of the activities of the firms, towards a specialization, and the number of employees was cut down from 110 to 70. The merger did not, however, put an end to the discussions with Imtec. Negotiations regarding the possibility of establishing a trinity of Swedish image processing firms were continued, under the assumption that together they could establish a leading position on the European market. These thoughts were not totally without precedence. The emergence of the Swedish computer industry exhibited a similar pattern, where some major problems in the development resulted in the concentration of the emerging industry into one larger company.

The Separation of Science and Industry

The Swedish digital image technology had emerged from scientific research, mainly performed at the universities. University research was also instrumental in the early phases of the commercialization of the technology, in that most of the entrepreneurial ventures were spin-offs from the universities. The dissemination process of the image processing network was spurred by the business firms primarily addressing the problems of adapting the new technology to or integrating it with complementary technologies. Meanwhile, the research organizations continued to address some of the basic problems of machine vision: three-dimensional vision and the processing of moving images. Thus, the dissemination of the image processing network also contained the separation of the scientific research performed at universities from the technological development performed by business firms. The separation of science and technology was reinforced by the new program for the support of digital image technology issued by STU in 1987.⁵⁴ The previous special initiative had been designed to promote the commercialization of image processing and it had unintendedly resulted in the impoverishing of the scientific institutions. In the renewed initiative the scope is different in that it primarily is designated to promote basic research. One effect of the ambition was that the development of scientific instruments, the activity on which the first wave of

⁵⁴ Wasell, B., Ramprogram i datoriserad bildbehandling, STU Internal Memo 1987-04-23. In this memo the new 6 year initiative is outlined. The budget for the initiative is presented in the table below:

Year	87/88	88/89	89/90	90/91	91/92	92/93
Million SEK	7	10	11,5	12,5	13,2	14

commercialization rested, should no longer be supported. STU also conducted an international evaluation of Swedish research in digital image technology. The evaluation reconfirmed the prominence of Sweden's scientific position. It specifically identified the Image Coding Group at the University of Linköping as being on the scientific frontier. But it also pointed at some deficiencies in the Swedish system of scientific research in the field of digital image processing, suggesting collaboration and concentration of efforts⁵⁵.

One consequence of the reorientation of the public support was that new research organizations entered as winners in the competition for public funds. The Image Coding Groups at the University of Linköping and the Royal Institute of Technology and the Computer Vision and Associative Laboratory at the Royal Institute of Technology became the main beneficiaries in the new STU-program. None of these had previously been supported within the realms of STU's support of image processing. Image coding was not even considered as being a part of digital image processing prior to the launching of the new program. The main beneficiaries in the special program, Physics IV, the Image Analysis Laboratory in Uppsala and the Picap group, received relatively less support in the new program. The support of the GOP group was maintained at the same level.⁵⁶ The beneficiaries within the new initiative were urged to abstain from the development of scientific instruments. As a consequence, the new STU program could function as a barrier to a constant flow of new technologies from scientific research to industrial innovation. The new directions in the development of digital image technology were not to be founded in scientific research but in the industrial application of the technology. As the network of exchange relationships disseminated and the problems in commercializing digital image technology became more apparent some of the former scientists migrated back to the universities, which further underscored the separation of science and industry.

The separation of scientific research and industrial innovation was not absolute. Informal relationships were maintained between the researchers at the University of Linköping and the firms in the Technology Village. The Image Coding Group in Linköping maintained a strong working relationship with the two spin-offs from the group; Sectra and Integrated Vision Products. The relationship between the department of Electrical Measurement and its spin-off also remained intact, but then they were never supported through the STU-programs for digital image technology. The separation of scientific research and industrial

⁵⁵ STU Information no 544-1986, Report of Visiting Committee on Swedish Research in Image Processing and Analysis.

⁵⁶ STU information no. 769-1990, Datoriserad bildbehandling, projektkatalog 1990.

innovation in image processing accentuated the dissemination of the image processing network.

The Reentrance of the Computer Industry

The image processing firms do no longer stand alone in the fostering of digital image technology. Many technologies previously dominated by analog technology are converted to digital technology: television, telecommunication, synthetic speech etc are increasingly becoming transformed to complete digital systems. As was shown in chapter two computer technology has been developed into new heights, continuously turning out cheaper but better gadgets. The cost of electronic components has decreased tremendously, which has propelled the computer industry to reenter into digital image technology. For reasons other than the processing of images the computer industry in general has increased the processing capacity and memories of ordinary computers. The development of user friendly computer software applications increased the demands for higher processing capacity. Simultaneously, the development of super-computers and image processing systems has shown that it is also possible to achieve much higher processing capacity also in ordinary computers. Today, even personal computers are often equipped with co-processors. The increased capacity of personal computers has made them available for high capacity demanding operations such as image analysis and an industry supplying image processing components for the consumer market has emerged.

The reentrance of the computer industry into image processing has completely altered the conditions for the image processing firms. The competition has stiffened especially on the low-end fast growing consumer market, for instance desk top publishing, where the computer industry is capturing the major part of the business. But on the other hand the total amount of resources devoted to the development of digital image technology has also increased, creating new opportunities for the image processing firms as specialized firms in an ever expanding digital technology. So far, only one of the Swedish image processing firms, Sectra, has developed image processing components for the growing consumer market.

Recapitulating the Dissemination of the Swedish Image Processing network

The dissemination process has been characterized by the establishing of chains of user - producer interactions aiming at, and resulting in, the adaptation of digital image technology with preexisting technological systems. In this process the previously coalesced Swedish image processing network was disseminated. When the directed

support of digital image technology petered out the proponents of the technology increasingly had to go elsewhere to attract the necessary resources. The development had to be re-legitimated in a different context. Interconnecting the network to international networks of producing electronic components and sub-systems and those applying digital image technology seems to be of increasing importance in lowering the cost of production and in reaching applications sufficiently large to motivate further investments in the fine tuning of the computer systems and the development of application software.

In the successful ventures the actors were able to interconnect investments in complementary technologies and the image processing component was adapted to and integrated within a larger technological system. The abandoned projects disclose an opposite pattern, where the actors became entrapped by their inability to attract sufficient resources to connect the development of image processing technology with technological developments in the field of application.

The Swedish Image Processing Network in 1989

The dissemination of the Swedish image processing network is characterized by the interconnection of the technological system for image analysis with the technological systems in which it was to be applied and with systems for the production of the new technology. As the actors committed themselves to specific user - producer interactions or dismantled projects the focus shifted from the development of image processing as a general solution to all image problems, to the development of specific solutions to generalizable sets of problems. The functions performed by individual actors were shifted backwards and forwards resulting in increasing specialization and division of labour in the industrial network developing, producing and applying digital image technology. The proponents of digital image technology could not transform the world on their own and the existence of a critical mass of investments in complementary technologies was a necessary pre-condition for the evolution to transcend from the domination of coalescence to dissemination. The structure of the disseminated image processing network in 1989 is exhibited in figure 13 on the next page.⁵⁷

⁵⁷ For a discussion of the procedure used to generate the image of the network see footnote 23 in chapter 6.

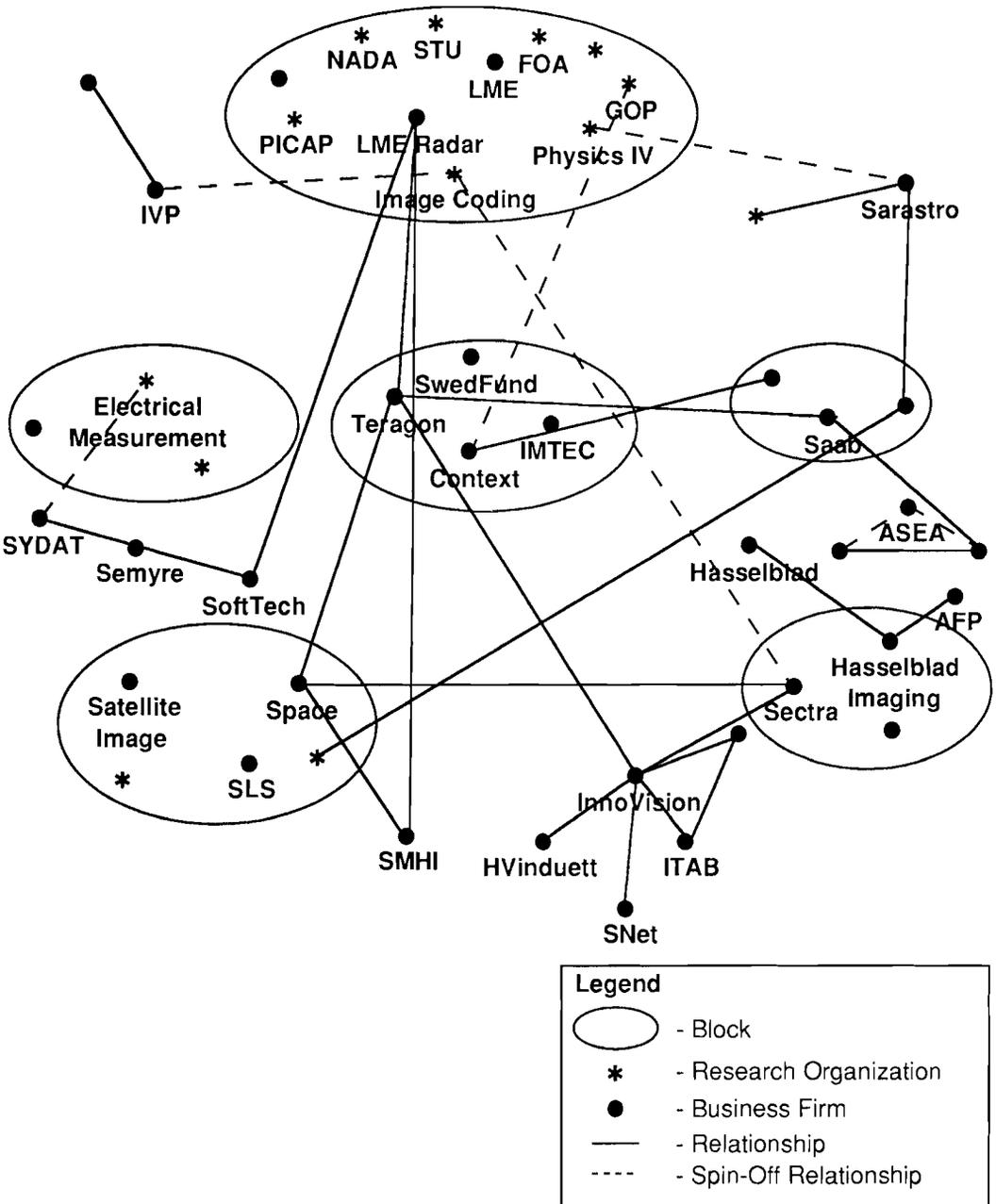


Figure 13: The image processing network in 1989. (Note that the graphical representation is not intended to depict the centrality of individual actors.)

The image processing network of 1989 exhibits a structure totally different from the network of 1983, but with some resemblances to the network of 1975. The disseminated image processing network is comprised of six relatively homogeneous blocks of actors and several strongly interrelated but unblocked sets of actors. The last observation suggests that these actors are becoming increasingly sequentially interrelated. The actors within each of the six, identified, blocks, share some common characteristics. The largest block consists mainly of actors of science; two of the blocks are composed of actors belonging to the same corporate structure; one block contains the pride of Swedish image processing and the remaining two block represent the successful venture into digital image transmission and the Swedish effort in space. Contrary to the structure in 1975 the blocks are now notably interconnected. The blocks are primarily complementary, representing different components or functions in the network developing, producing and applying digital image technology. This pattern is even more apparent when the unblocked actors are taken into consideration. To some extent the dissemination process was contradicted by coalescence tendencies and the pattern from the earlier time period was repeated. Parts of the network of exchange relationships coalesced and they coalesced towards financial resources. This time, however, these resources were controlled by the Swedish Industrial Development Fund.

The dissemination process has only produced minor changes in the positions of the most central actors. The actors accumulating strength during the coalescence phase also retained their position over the dissemination process. The Space Corp. is still the most central actor, but behind them we can detect some minor changes. Those include the declining importance of STU and the Picap-group and the increasing centrality of Innovativ Vision and the Image Coding Groups, two of the more anonymous actors in the image processing network.⁵⁸

⁵⁸ The Katz index for the image processing network in 1975, 1983 and 1989 is presented in the table below. For a discussion of the measure of centrality see; footnote 24 in chapter 6.

Year	Min	Max	Mean	Median	Var.	Spread	b
1975	0,139	1,284	0,386	0,341	0,061	0,898	0,11111
1983	0,084	1,383	0,374	0,249	0,099	1,009	0,07143
1989	0,100	1,285	0,347	0,236	0,075	0,938	0,08333

The Katz index of the 8 most central actors in the image processing network in 1989 and their ranking for 1975 and 1983 are presented in the table below.

Digital image processing is not yet fully established in our society and not all actors in the Swedish network have yet reached a position where self-sustained growth can be taken for granted. This study, however, shows that even in a small country like Sweden high technology can emerge. If this new technology can be transformed to viable economic structures that can persist in the international competition remains to be seen. The once so promising Swedish computer industry did not survive increased international competition, will the Swedish ventures into image processing prove to be more viable?

The Emergence of the Swedish Image Processing Network - An Epilogue

The case study was introduced by suggesting that digital image technology is slowly invading the prevalent structures of western technology. This observation was further emphasized later in the text, where there were claims that the integration of digital image technology with other technological systems and the dissemination of the Swedish image processing network signify the beginning of the final battle of the systems between digital and analog image technology. Eventually the digital technology will probably dominate the analog but for centuries to come the systems will coexist. For the foreseeable future they will, side by side, constitute the predominant technological systems for image processing. And even after digital technology has won the battle, pockets will remain where analog technology can prevail, just as direct current is still used for some applications, even though alternating current won the battle of electrical systems several decades ago. The development of efficient interfaces and gateways between digital and analog technology will still be a major problem in the future.

Ranking	Actor	Katz Index	Ranking 1983	Ranking 1975
1	Space Corp.	1,285	1	10
2	Teragon Systems	1,118	2 ⁴	· ¹
3	Innovativ Vision	1,117	6	· ¹
4	Image Coding Group	1,072	8	33
5	Context Vision	0,943	5	· ²
6	Imtec	0,855	2 ⁴	· ³
7	Sectra	0,775	10	· ⁵
8	Picap-Group	0,718	3	19
9	STU	0,699	4	15

¹ A spin-off from the Picap-Group

² A spin-off from the GOP-Group

³ A spin-off from the Image Analysis Laboratory and Teragon System

⁴ In 1983 Teragon Systems and Imtec was one company under the name of Imtec

⁵ A

spin-off from the Image Coding Group.

The emergence of an industrial network for image processing in Sweden was the result of the interaction between the emerging new digital image technology and the emerging image processing network. This process, however, reflected the barriers to developing image processing within the computer industry. As these are now being dissolved we might suspect that the image processing network will continue to be restructured. And this is certainly what has happened. At the end of 1989 it became obvious that the merger between Teragon Systems and Context Vision, and the plans to integrate also Imtec in this constellation, failed to come through. A new crisis in Swedish image processing surfaced. This time the outcome had more of a restructuring character. The Context Vision part of the merger was acquired by a Danish firm, with a Finnish firm holding a minority interest and the name was changed to Struers Vision. The Teragon Systems part was taken over by Innovativ Vision. Imtec has also been restructured but not to the same extent. Sarastro, the spin-off from Physics IV, has been acquired by the American firm Molecular Dynamics. Thus, the pride of Swedish image processing has either been reduced to peripheral positions or are now controlled by foreigners.

Part IV

CRITICAL REVISION OF THE EMERGING PATTERN

It should be obvious from the story of Swedish image processing that the development of new technologies and the emergence of a new industrial network is a complex and messy process well deserving the epithet; "doubly dynamic".

In closing this analysis of the development of digital image technology and the emergence of the Swedish image processing network we will first recapitulate the basic ideas underlying this study, and continue with a discussion of three themes generated by the study. These themes are 1. the significance of network technologies, 2. system-building without system-builders, and finally, 3. how public policy and strategic action matter.

Chapter 9

IN CONCLUSION

Recapitulating the Basic Ideas

The basic idea has been to treat the emergence of new industrial structures as a path-dependent process of accumulation, driven by technological as well as social factors. It was argued that the traditional definition of industry as a group of naturally selected producers was insufficient when it came to the analysis of the embryonic phases of the development of new industries. Instead a historic and contextual perspective was suggested, defining the industry on the basis of complementary activities rather than from competitive ones. The industrial structure was perceived as industrial networks and divided into two interrelated systems: technological systems and networks of exchange relationships. The emergence and evolution of the Swedish image processing network was moreover studied as an interaction between the emergence of a new network and the establishment of a new technological system. Before we proceed with the issue of the emergence of industrial networks the questions raised in chapter one will briefly be recapitulated. The questions will, however, be discussed in opposite order and we will begin with the third question.

3. What is the nature of the relationship between scientific research, technological development and economic change?

It has been shown that digital image technology bears the marks of a modern technology in that it pre-dominantly originated within the realms of scientific research. A critical issue has thus been the transfer of knowledge and technology from science to industry. In Swedish image processing the gap between science and industry was bridged through the migration of researchers from science to industry. But, as is most often the case when it comes to new technologies, the incumbents of the pre-existing industry showed very little direct interest in pursuing development of digital image technology and the proponents of image processing were to a large extent spurred to establish business on their own. University research, technological development in both university spin-offs and traditional firms and public policy coincided and brought Swedish digital image technology to a world leading position. The technological capabilities has not, however, been transformed to economic growth, at least not yet. In this study it has been suggested

that science, technology and industry are linked through institutional and technological structures. This was also the focus of the two other questions.

2. What are the forces provoking the emergence of a new institutional structure, a new network?

In this study the institutional structure of Swedish image processing has been perceived as a network of exchange relationships between the proponents of the new technology. The study of the development in Sweden indicated that the evolution of the network could be perceived as three interrelated and parallel processes - genesis, coalescence and dissemination - each dominating in different periods of time. Genesis was marked by the creation of variety; the emergence of novelty. Coalescence was characterized by the establishment of a community of proponents of image processing. Finally, dissemination represented the integration of this community with the rest of society. Moreover, it has been argued, that these processes could not be isolated from the development of digital image technology which, incidentally, was the focus of the last question.

1. What are the forces behind the emergence of technologies?

In moving from the study of individual innovations to that of interrelated clusters of innovations, technological systems, it was suggested that the common view of technological development as - innovation, development and adoption/diffusion - needed to be modified. It has, therefore, been suggested that the emergence of a new technological system can be perceived as the three parallel, social, processes of - identification, legitimation and adaptation. Identification represented the identification of digital image processing as a new technological system: as being different from the prevailing systems. Legitimation involved the legitimation of the new technological system in order to attract resources for its establishment. Finally, adaptation was suggested to describe the integration of the novel technological system, with the pre-existing.

The tentative answers to these three questions were combined into a framework for the understanding of a new industrial network, which will be re-examined in the next section.

The Emergence of Industrial Networks

The study of digital image technology in Sweden suggests that the emergence of a new industrial network is a doubly dynamic process of creation of the environment, which can

be understood as an interplay between networks of acting and interacting actors and technological systems. We have seen how digital image technology and the Swedish image processing network have emerged and evolved through actors working to solve locally defined problems. Some, not all, of these problems prompted the actors to search for new technological solutions. The solutions produced and problems solved opened new technological avenues, motivating the actors to search for more general technological solutions to image problems, thereby establishing a new technological system. The establishment of the technological system ushered the actors into fine tuning of the technology. Through actors interacting with leading users of image processing equipment the digital image technology was integrated with the preexisting technological systems.

The emergence of a new industrial network has been treated as three distinct processes; genesis - identification, coalescence - legitimation and dissemination - adaptation. 'Genesis - identification' was characterized by the ascendance of interrelated clusters of innovations emerging from actors, independently, striving to solve everyday problems. The identification of a new technological system was instrumental in genesis rising from the normal surge of innovative activities. In 'coalescence - legitimation' the emerging development activities diverged from their origins or converged towards a core of digital image technology, establishing a closely knit network of proponents of the technology, legitimating it and further pushing it towards the establishing of the technological system. The network coalesced and it did so, around the Swedish National Board for Technical Development. 'Dissemination - adaptation' was characterized by the establishment of different chains of user - producer interactions adapting and integrating the new technology with the preexisting technological systems. The primary chains of user - producer relationships developing Swedish image technology, predominantly consisted of Swedish actors. But the extension of the Swedish network towards international users as well as the separation of science and industrial innovation were other salient features of the dissemination process. Ventures characterized by insufficient connections between the development of digital image technology and the development within the field of application were eventually abandoned. The actors involved in these ventures did not vanish: they most often scaled down the venture focusing on particular components of it or they otherwise benefited from the competences developed through assuming a more peripheral role in the image processing network. Through these processes the dissemination resulted in increased specialization and division of labour in the evolving Swedish image processing network.

The three different processes were initiated and prompted by different sets of circumstances. 'Genesis - identification' was initiated by the development of

complementary technologies, in this case primarily computer and television technology, enabling the actors to solve old problems with new, and hopefully more efficient solutions and to focus on new problems. Instrumental in the 'genesis - identification' process were changes in the social structure encouraging the search for new solutions and the addressing of new problems. The genesis of the Swedish image processing network produced a heterogeneous cluster of interrelated innovations around the use of computer technology for image analysis. One important precondition for the outcome of the 'genesis - identification' phase was the heterogeneous Swedish industrial and research structure. Another fact stimulating the emergence of an image processing network was the barriers to developing the technology exhibited by the computer industry.

The move from 'genesis - identification' to 'coalescence - legitimation' was propelled by the existence of a critical mass of actors pursuing both similar and complementary research and development. The existence of a critical mass was, however, only a necessary condition, not a sufficient one. To attract the necessary resources to pursue research and development in image processing and thus to usher the evolutionary process into coalescence, the technology had to be legitimated. The legitimation of technology is a politic process and its outcome will most certainly affect the future development. In Sweden the legitimation of digital image technology favoured the development of the scientific end of image processing. The resources attracted to the development of digital image processing prompted the researchers to move out from the scientific institutes and to establish new business ventures. The coalescence phase produced a closely knit core of actors striving to establish the technological system of image processing.

The transition to dissemination - adaptation was facilitated by the existence of a critical mass of investments in the development of complementary technological systems. Investments in the development of complementary technologies created opportunities for the establishing of user - producer relationships integrating previously separated technologies, bridging the gap between image processing and the preexisting technological systems. So far the dissemination process has resulted in increased specialization and division of labour and the Swedish image processing network having integrated the new technology with the preexisting industrial structure in some applications. But since the barriers to developing digital image technology within the computer industry have been dissolved we can expect further restructuring of the Swedish image processing network.

To sum up: the emergence of industrial networks are made up of the three evolutionary processes of 'genesis - identification', 'coalescence - legitimation' and 'dissemination -

adaptation'. Even if it was stressed that these processes were parallel, we could observe how they dominated the evolution in consecutive order. If not the technological system would be continuously identified or legitimated there would be no force holding the industrial network together in the adaptation of the technological system to complementary technological systems and the industrial network would be dissolved or abandoned. We suggested that critical masses of similar and complementary R & D ventures and of investments in complementary industrial networks, were necessary conditions for the domination of one process to transcend into the domination of another. For a summary of the suggested framework, see figure 14 below.

The Emergence of New Industrial Networks

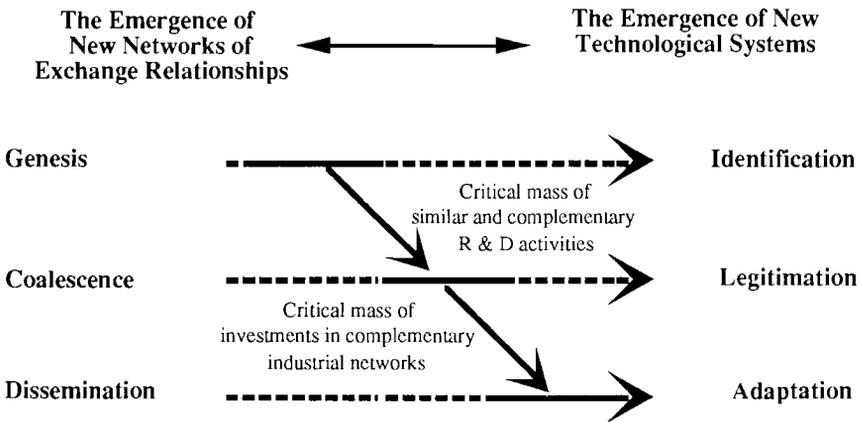


Figure 14: A framework for the understanding of the emergence of new industrial networks and technological systems.

The digital image technology that stands before us is neither optimal nor conclusive. Other solutions to the problem of analyzing data contained in images might, if they had been legitimated, have guided the evolution of the technology into different paths. If the computer industry had also continued to develop image processing it would probably have affected the design of both the digital image technology and of the computer technology. Technological development is path-dependent, the future development will be shaped by the past. In the evolution of the Swedish image processing network, it is interesting to note the fact that the technology emerged from technologies where Swedish industry was traditionally strong combined with the fact that the image processing network has been unable to catch up in other fields. This can be attributed to the path-dependence of technological change.

The notion of path-dependence is closely aligned with the notion that technologies are interrelated in technological systems or networks. Network technologies and image processing will be discussed in the next, final, chapter.

Chapter 10

TAKING IT ONE STEP FURTHER

Network Technologies

The roots of digital image processing can be traced back at least 30 years and yet the technology is still not fully established in the western world. The impact of the new technology is far less than expected. The transfer of image processing from science to industry has taken much longer and it has been much more problematic than what the proponents of the technology had reason to anticipate. The commercial development of digital image technology has advanced at a much slower pace than projected and the economic outcome in most cases has been extremely disappointing. Furthermore, the evolution of digital image technology has not advanced equally in all segments; the development in industrial automation has advanced at a much slower pace than the development of remote sensing and the number of scientific instruments produced has far outnumbered the production systems installed.

The network quality of digital image technology is suggested as the basic cause of the observed problems in the development of the technology. The concept of network technologies is most often associated with technologies where the network features are obvious, that is with electricity, telecommunication and railroads. Here it has been suggested that all technologies, to a varying degree, embody network characteristics in that technological interrelatedness and network integration benefits are present. In digital image technology we have been discussing two sources of the network externalities or effects. First of all, we have internal network effects in the interrelatedness of the components constituting the basic technological system of image processing and, secondly, we have external effects associated with the interrelatedness of the basic technological system and the surrounding technologies.

History has shown us that a common feature in the emergence of all technologies is the flourishing of rival systems¹, where the potential, primarily the external but also the internal, integration benefits have been difficult or impossible to exploit. The network effects or externalities can function both as a driving force for further integration and as a

¹ Foray, D., Exploitation of Networks Externalities vs. Evolution of Standards: Markets, Committees and the Dilemma of Efficiency, Paper presented at the ITS-conference, Venice, Italy, March 1990.

barrier to the development of the new technology². In this respect the emergence of image processing technology in Sweden reveals a similar pattern of development. The coalescence phase saw the development of several rival and incompatible image processing systems. The systems were internally consistent, the components of the systems were adapted to each other and they functioned according to specifications. The choice of components was, however, determined by functionality of the total system rather than by the cost or performance of the components. Internal integration benefits were difficult to realise. The difficulties were even worse when it came to exploiting the external network effects. The individual users could hardly benefit from the use of other systems. In cartography one system was employed in the production of maps and another system was installed at the research institutes. The problems of exploiting the network effects encouraged some actors to collaborate to standardize image processing technology. AFP, Hasselblad and Sectra on one hand and Teragon, Space Corp. and SLS on the other were two constellations standardizing image processing in certain segments.

The existence of network technologies not only has an impact on how we should approach the study of the complex and messy problem of the emergence of new technologies. It also has a significant effect upon the nature of the emergence of new technological systems and upon the behaviour of individual actors. In the next section we will focus our attention on system-building without system-builders. But before we continue, we will briefly discuss the nature of competition and co-operation in the presence of network externalities. It is often assumed that competition is a necessary prerequisite for change and development. And certainly it is important, primarily since it indicates the existence of several alternative solutions. Under the presence of network technologies there is, however, the question of how free the choice between existing alternatives can be. In nascent network technologies, freedom of choice is usually restricted by the non-existence of standards or at least is the risk for lock-in greater than with standards. All existing alternative solutions are not equally suited to solve all existing problems. And competition could function both as a selection mechanism: selecting the most efficient solutions and as a driving force: driving competitors to improving their solutions. The problem is, however, that in the presence of network technologies with no standards, the alternative solutions are not interchangeable. Hence, even though alternative solutions might exist, competition does neither function as a

² This is in the same line of thought as the proposition made by the Swedish economic historian Erik Dahmén that structural tensions in development blocks work as driving forces to overcome the tension, but on the other hand if the tension cannot be resolved it can lead to the collapse of the whole development block.

selection mechanism, nor as a driving force. To increase interchangeability among the alternative solutions, some form of collective action is necessary: standards must be established so that a potential user freely can choose among the existing alternatives. Hence, given that we believe that competition has a significant effect upon the pace of development, collective action enabling it, should be supported.

System-Building without System-Builders

The notion that technologies or industrial activities are interconnected into systems is not a novel finding of contemporary research. Throughout history different authors have identified this specific quality of technologies and discussed its effect upon technological change. Thorstein Veblen, taking the systems for granted, wrote "In more than one respect the industrial system of today is notably different from anything that has gone before. It is eminently a system, self-balanced and comprehensive; and it is a system of interlocking mechanical processes, rather than of skilful manipulation."³ The nature and complexity of the systems rendered Veblen and others such as Frederick W. Taylor and Henry Ford to believe that the systems could effectively be managed, but only by engineers, familiar with the intricacy of the systems.

Others, recognizing the existence of technological systems, have approached the issue differently and focused on the emergence of new systems. Two prominent authors studying industrial dynamics from the perspective of technological systems, Erik Dahmén and Thomas P. Hughes, present converging views on the nature of the emergence of new systems; they both challenge the view of Veblen and they refute the importance of the engineers as managers of technological systems and put forward the entrepreneurs or the system-builders as the propelling human force behind economic and technological progress⁴.

A third perspective on the emergence of technological systems more aligned with the biological theory of evolution is that they emerge and evolve, without entrepreneurs, system-builders or designers, as self-organizing systems. In biology this would be achieved by the mechanism of natural selection. In industrial economics a similar process could be reproduced through mutual adaptation and self-reinforcement. This would imply that technological systems could emerge without foresight and grand design through actors acting individually to satisfy internally determined objectives. We have previously

³ Veblen, *The Engineer and the Price System*, p.72.

⁴ Dahmén, *Development Blocks in Industrial Economics*, underscores the importance of entrepreneurs and Hughes, *American Genesis*, discusses the significance of system-builders.

argued that the agglomeration of resources around growth poles, like Silicon Valley, in essence was a self-organizing process without foresight and grand design.

Digital image technology in Sweden emerged through actors acting individually to solve locally defined problems and the technological system was established through trial and error and mutual adaptation in the relationships between proponents of complementary components of the system. Some actors assumed the role of system-builders or coordinators and in some cases their activities had a significant impact upon development. One such actor was FOA which, from the late sixties and onwards, coordinated the diverse components of the emerging technology. Other system-builders can be found in specific segments of the technology: the Swedish Space Corp. coordinating the efforts to combine satellite technology, image processing and map production and Hasselblad coordinating efforts to develop digital image transmission. The special initiative of STU to commercialize image processing also qualifies as a system-building activity. Despite these activities, the general conclusion must still be that digital image technology and the Swedish image processing network evolved without foresight and grand design. This is not the same, however, as stating that neither public policy nor the acts of individual actors matter, an issue that will be discussed in the next section.

Public Policy and Strategic Action Matters

The perspective laid out here is rather discouraging, leaving no room for individual actors, planned action or public policy. Is there no room for deliberate action? The case study on the emergence of digital image technology and an image processing network in Sweden shows unequivocally that public policy and the activities of individual actors were of importance in the path of development. Public policy and strategic action mattered. In this last section we will first discuss the effect of public policy and strategic action in Swedish image processing. We will then end the discussion, with the help of Sir Francis Bacon, with a general discussion of the support system for contemporary technological change.

In the development of digital image processing public policy most certainly was effective. The outcome was not always what had been anticipated or even desired, but public policy mattered in that it pushed the path-dependent development in certain directions. The two major public policy institutes affecting the image processing network have been STU and the Swedish Space Program. The major part of the support for image processing by the latter was without question issued to or through the Space Corp., hence the centrality of their position. The Swedish Space Program was a concentrated effort to develop Swedish remote sensing and the support was primarily concentrated to one actor. The question is,

though, if this strategy produced a better outcome than alternative strategies would have done. This we will never know, for now it is sufficient to observe that public policy was effective.

STU directed their support for image processing differently. After some initial years of passive support, STU issued a programmatic support of the technology. STU and the Space Program complemented each other in that when the Space Program represented a concentrated support for application development STU offered its widespread support for the development of digital image technology. This indicates that public activities aimed at the support of new technology interact: the effects of one activity can be strengthened or set off by other activities. The fact that one public institution supports a specific development can legitimate development at other institutions. STU's special initiative towards the commercial development of image processing technology not only supported the recipients directly, but also indirectly through legitimating the projects at other institutions, such as the Swedish Industrial Development Fund. Public support not only has an effect, it is also self-reinforcing.

The formulation and direction of public policy programs towards the development of new technologies is not autonomous it is affected by contemporary research and development. The leading Swedish image processing researchers had a significant impact upon the direction set in STU's special program. The outcome of the special program is illustrative to the point that public policy is effective, but that the effects are not always the ones desired. The program was designed to promote the transfer of image processing from science to industry. No one had anticipated that it would be instrumental in the spin-off of university based research firms, impoverishing the scientific institutes. Neither was the outcome of the ventures selected for support completely successful. This leads to the conclusion that public policy is effective in directing the efforts to develop new technology, but not the outcome of this development. This leaves us rather ambivalent regarding public policy towards technological development. It is encouraging to note that policy measures are effective, but it is discouraging that the outcome not always can be anticipated or even desirable. Thus, a word of warning: directed public support of technological development ought to be issued with caution and with a certain degree of flexibility. That should, however, not be seen as a recommendation to abstain from experimenting with public policy. If public policy is to evolve it must be subject to variation.

Most public policy programs are designed to pick the winners in the technological battle: the support is directed towards the producers of the "best" technology. National and

international evaluations are used to identify research and development projects at the scientific or technological frontier. The Swedish Space Program, rather than selecting their winner, designated it. The STU programs for the development of digital image technology did not differ from the norm. Both the STU programs for development of digital image technology were designed to support projects at the cutting edge of the technology. The outcome of the special initiative display the difficulty in selecting future winners. Half of the projects in the first program turned out to be failures and the others were neither unquestionable successes. And in the second program new actors emerged as scientific leaders. Despite the self-reinforcing mechanisms embodied in the public support of technological development, unsupported actors could ascend as leading actors in the supported field.

In the special initiative STU tried new directions in that the aim was to support constellations of both producers and users of new technology. The producer - user constellations were, however, rarely spontaneous, they were constructed in order to pursue specific research projects. The outcome of the constellations was almost catastrophic; when the public support was withdrawn the projects collapsed. But on the other hand the transfer of technology effects were significant. The more spontaneous constellations were much more profitable. In general users are increasingly being supported as a part of policy programs. If we look at the direct effects of support of users this policy can be even more problematic to apply than straightforward support of producers of new technology. Picking winning users might prove as difficult as picking the winning innovators.

The public support of image processing technology has generally had a positive effect on the emergence and evolution of the Swedish image processing network. The question, however, is if a more positive outcome would have followed from a differently directed policy. I do not purport to have the answer to this question. But the critical issues in supporting the development of new technologies are how much money should be devoted, to whom it should be distributed and when. And maybe public policy is more effective when it comes to the generation of variety, than when it comes to selection.

What about the impact of individual actors? Implicit in the discussions above has been the tension between the development of the parts and the development of the whole. The outcome of the whole is dependent on the outcome of the parts, which in its turn determines the outcome of the whole. Thus the outcome of the development pursued by individual actors is dependent on the outcome of the development pursued by all actors. The strategy of an individual actor should then be geared both towards the establishing of

a strong position and the strengthening of the whole network. As we have seen in the case study, the most successful actors, the Space Corp., Hasselblad, Sectra, Innovativ Vision and others have all managed to combine the establishment of a strong position with the establishment of fruitful relationships to others. The issue of what is most effective in technological development, competition or co-operation, is in this respect very interesting. Where, in the emergence of image processing in Sweden, competition seems to have induced imitative behaviour, fostering similarities, resulting in the coalescence of the network of exchange relationships. Co-operation, on the other hand, seems to have induced innovation, fostering dissimilarities, resulting in the dissemination of the network.⁵ Once again the recommendation would be that both co-operation and competition are necessary in the development of new technologies.

The presence of network externalities implies that economic benefits are to be gained from network integration. From this it has been, argued that actors can exploit the network benefits by assuming the role of system-builder or coordinator. Here the classical economic problems of external economies indivisibility, uncertainty and appropriability become evident.⁶ How large are the potential benefits and who can appropriate the profits from integration? Can individual actors appropriate the total benefits from their coordination of the network? Will the prospects of appropriating at least some of the potential benefits be sufficient to motivate actors to engage in the integration of the network? The traditional answer to this type of question is that, in the presence of external economies, individual actors will invest less than is socially desirable in network integration. Thus the role of public policy should be to support network integration directly or indirectly by encouraging collective actions.

In international competition where most industrial nations cherish public institutions for the development of new technology, it is difficult to see how Sweden would be able to maintain and develop a strong position in high technology without resorting to public spending on research and development. To establish viable positions in emerging technologies, assuming this is desirable, which is not as self-evident as it might seem,⁷

⁵ This is well in line with Schumpeter's thoughts on the static effect of price competition.

⁶ The external economies of scientific research is discussed in Arrow, K. J., *Economic Welfare and the Allocation of Resources for Invention*. In: *Universities - National Bureau Committee for Economic Research, The Rate and Direction of Inventive Activity*, Princeton, N.J.: Princeton University Press, pp. 609 - 625, 1962. and Nelson, R. R., *The Simple Economics of Basic Scientific Research*, *Journal of Political Economy*, Vol. 65, pp. 297 - 306, June 1959. The "simple" economic facts inventive activities purported by Arrow and Nelson further underscore the role of public policy in generating variety.

⁷ Richard Nelson discusses the virtues of high-technologies in, Nelson, R. R., *High-Technology Policies - A Five Nation Comparison*, Washington: American Enterprise Institute for Public Policy Research,

we must most likely need to rely upon vital and potent public policy measures towards research and development, especially if the technologies of tomorrow will increasingly emerge from basic research, an activity in which a market economy will under-invest. But how should the gaps between technological systems and science and industry be bridged? We will conclude this review with a short discussion of how public policy might be organized.

How should a national system for the support of science, technology and industrial innovation be organized? To begin answering this question I would like to take you back more than 350 years, long before the industrial revolution but at the origin of modern scientific thought, to the dark⁸ streets of London and to the chambers of Sir Francis Bacon (1561 - 1626). Long before any apparent connection between science, technology and economic progress Bacon advocated the usefulness to society of the pursuit of science. Knowledge was power and for efficient production of knowledge he proposed an organization for the quest of knowledge, a dreamt-of research institute, a Solomon's House of Science. The aim of the foundation was "... the knowledge of Causes, and secret motions of things; and the enlarging of the bounds of Human Empire, to the effecting of all things possible."⁹ The house was to be furnished with all known kinds of instruments for the pursuit of knowledge and there was a distinctive place for men of science with various capacities. It allowed "for all grades of ability and varieties of skills in a complex division of scientific labor".¹⁰ Solomon's House of Science was to harbour; "Merchants of Light", who were to bring from foreign countries: books, abstracts and patterns of experiment; "Depredators" who were to collect from books all experiments; "Mystery-men" who were to collect earlier experiments in science and the mechanical arts; "Pioneers or Miners" who were to "try new experiments, such as themselves think good"; "Compilers," or lesser theorists, who were to examine the accumulated materials, to draw inferences from them; "Dowry-men" or "Benefactors" who were to seek to apply this knowledge; the "Lamps," who "after divers meetings and consults of" the whole number, were to undertake to "direct new experiments, of a higher light, more penetrating into nature than the former"; "Inoculators," the technicians who were to

1984. Where he raises the question: What special economic advantages do high-technology industries give?

⁸ Here I most definitely reveal one of my biases. To me history prior to gas or electric light is without light. To me dark history really means dark history.

⁹ Bacon, F., *New Atlantis*, In: Robertson, J. M., (Ed.) *The Philosophical Works of Francis Bacon*, Ellis & Spedding, London: George Routledge and Sons Ltd., 710 - 732, 1905. p. 727. A fourth characteristic of Solomon's House of Science was the ordinances and rites that were to be observed.

¹⁰ Merton, Singletons and Multiples in Science, 1973. p. 348.

"execute the experiments so directed and report them"; and finally, his "Interpreters of Nature," who "raise the former discoveries by experiments into greater observations, axioms and aphorisms."¹¹

Sir Francis Bacon's vision of a scientific community devoted to the gathering of useful knowledge was to be realized in the Royal Society of London, established 1660¹². The emergence and diffusion of modern scientific thought in most countries was accompanied by the instigation of academies of sciences, modelled after Solomon's House of Science. The work and philosophy of Sir Francis Bacon was not the only source of the organization and growth of modern science. He was, as he himself would probably have put it, only a child of his time and the time was right for the organization of the pursuit of modern science.

The thoughts underpinning the outline of Solomon's House of Science are as valid today as they were 350 years ago¹³ and if Sir Francis Bacon was alive today, experiencing the increasing reliance of industrial change upon basic research, he would probably, interested as he was in the usefulness of science, have extended Solomon's House to include technology and industry. He might have added a few capacities and put more emphasis upon the roles of users of scientific discoveries. The men would perhaps be actors, profit motivated companies, and institutions of science and the house might be a industrial network. But, most importantly, and even though the problem is of a different magnitude, he would incessantly have repeated his vision; the pursuit of scientific research, technological development and industrial innovation, calls for instruments of various kinds and for actors with various abilities and capacities and different skills. The degree of heterogeneity affects the likelihood to reach solutions to perceived problems and effective communication or collaboration can reduce the scale of difference of the produced outcome.¹⁴

¹¹ Bacon, *New Atlantis*, pp. 731 -732. Also quoted in, Merton, *Singletons and Multiples in Science*, 1973. p. 348.

¹² Frångsmyr, T., (ed.) *Science in Sweden: the Royal Swedish Academy of Sciences, 1739 - 1989*, Canton, MA.: Science History Publications, 1989. p. 1.

¹³ Actually, it seems that Francis Bacon thoughts are having a renaissance. *New Atlantis* was recently translated into Swedish and the 75th Nobel Symposium, was dedicated to the revisiting of Solomon's House of Science. See, Frångsmyr, T., (Ed.) *Solomon's House Revisited - The Organization and Institutionalization of Science*, Nobel Symposium 75, Canton, MA.: Science History Publications, 1990.

¹⁴ Merton, R. K., *Singletons and Multiples in Science*, 1973. p. 349.

If Sweden, besides its traditional industry, is to maintain and develop a vital and potent national system for the emergence and evolution of new technologies and industries, that is a Solomon's House of Science, Technology and Industrial Innovation, room must be made for scientific organizations and business firms with various abilities and capacities and with different skills, and they must be encouraged to communicate and collaborate. No country can thrive on concentrated efforts on frontier science, technology and industry. Behind the frontier there must exist a viable infrastructure of complementary actors with different capacities. Second rank science might be of greater importance than frontier science in transferring science to industry. Problems should be defined by the inhabitants of the house and they should also decide where to search for solutions. The role of public policy should be to establish and maintain the house: to support communication and collaboration within and between science and industry and to encourage collective action.

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Appendix A

PERSONAL INTERVIEWS

Ingvar Hall	Technical Director	Aftonbladet (Swedish Newspaper)	1987-01-28
Björn Sporsén	Typographer	Aftonbladet (Swedish Newspaper)	1987-01-28
Lennart Berg	Typographer	Aftonbladet (Swedish Newspaper)	1987-01-28
Ewert Bengtsson	R&D Manager	Imtec AB, Uppsala	1984-12-06 1988-04-22
Claes-Göran Borg	R&D Manager Manager	Swedish Space Corporation	1984-11-28 1987-11-10
Roger Cederberg	Vice President	Teragon Systems AB	1988-04-05
Lars Dahlström	President	Dikon Recognition	1987-11-24
Roland Lans	Marketing	Erisoft, Västerås	1984-10-25
Per-Erik Danielsson	Marketing Professor	C. E. Johansson AB Erisoft, Västerås University of Linköping	1987-11-18 1984-10-25 1984-09-17 1987-12-04
Gösta Erikson	Manager	Saab Automation AB	1987-11-16
Jan-Olof Eklund	Professor	Royal Institute of Technology	1984-12-19 1987-12-03
Robert Forchheimer	Professor	University of Linköping	1987-11-17
Jan-Olof Brüer	President	Sectra AB	1987-11-17
Gösta Granlund	Scientific Advisor Professor	Context Vision University of Linköping	1984-09-19
Claes Gralén	Professor	University of Linköping	1984-09-20
Johan Halling	Manager	ABB Robotics	1988-04-18
Ingemar Ingemarsson	Professor	University of Linköping	1984-12-12
Stig Johansson	R&D Manager	Sandvik Electronics	1987-03-11
Rolf Johansson	Professor	Royal Institute of Technology	1984-09-25 1987-11-12 1984-09-12
Per-Åke Johansson	Research Director	STFI	1987-09-23
Bo Kennedy	President	Softtech AB	1984-09-28
Björn Kruse	R&D Manager	Teragon Systems AB	1984-12-05
Jörgen Lindgren	President	Saab Automation AB	1984-09-17 1987-11-17
Lars-Erik Nordell	R&D Manager	Innovativ Vision AB	1984-09-17 1987-11-17
Anders Rudgård	R&D Manager	Innovativ Vision AB	1984-09-17
Torleiv Orhaug	Research Director	FOA	1985-01-10 1988-04-13
Sven Olofsson	President	Imtec AB, Uppsala	1984-09-26
Lars Olsson	R&D Manager	Saab Wood AB	1984-10-02
Lars Svensson	Manager	Axel Johnson Instrument AB	1987-01-26
Hans Skoogh	R&D Manager	ASEA Robotics	1984-09-27

Lennart Stålfors	R&D Manager	Hasselblad AB	1984-09-11
	President	Hasselblad Electronic Imaging AB	1987-11-23
Gunnar Wedell	President	Context Vision	1984-09-19
Per-Erik Werner	Professor	Arrhenius Laboratories	1987-09-11
Nils Åslund	Professor	Royal Institute of Technology	1984-12-10
Göran Åsemyr	President	Semyre Electronics AB	1987-11-25
			1984-09-11
			1987-11-11

Interview Guideline

Interviews have in general lasted for two hours, some have though been longer.

The following themes have been covered during the interviews;

History

The initiation of the development projects
Critical events in the course of action

Internal resources

Organization
Technical capabilities
Finance
Ownership

External resources

Suppliers
Buyers
Others
Content in the relationships

Appendix B

NETWORK ANALYSIS OF THE IMAGE PROCESSING NETWORK IN SWEDEN 1975

Input Files

Actors

ACELund	Computer Engineering Lund
AJinstr	Axel Johnson Instr
ApplPhys	Inst. Applied Physics Sthlm
ArrLab	Arrhenius Laboratoriet
ASEA	ASEA
Avesta	Avesta Steel
Bildkodn	Bildkodningsgruppen
Caminstr	Cambridge Instruments
CERN	CERN Laboratories
ChemGbg	Chemistry Gothenburg
DfR	Del. för Rymdforskning
Elmät	Inst. för Mätteknik
ESA	European Space Agency
FOA	FOA
FysikIV	Fysik IV
GeoSthlm	Inst. for Geography Sthlm
Gop	Gop-gruppen
KretsGbg	Inst. Kretskortsteknik Gbg
LME	Ericsson
LMEMdal	Ericsson Mölndal
MAS	Malmö General Hospital
MIT	MIT
Picap	Picap-gruppen
QZ	Stockholm Central Computer
Robotics	Robotics General
SaabGbg	Saab Gothenburg
SaabJkp	Saab Jönköping
SaabLkp	Saab Linköping
Sandvik	Sandviken Steel
Space	Swedish Space Corporation
Spectros	Spectroscopy General
SteelAss	Swedish Steel Association
STURSK	STURSK
Tecnikus	Tecnikus
Teletran	Teletransmission Sthlm
Televerk	Swedish Telecom
Tement	Tement
UAS	Uppsala General Hospital
UDAC	Uppsala Central Computer
Wadell	Wadell Innovator

Relationships

ACELund	Picap
AJinstr	Avesta
AJinstr	Sandvik
AJinstr	Steelass
AppIPhys	ASEA
Caminstr	AJinstr
CERN	FysikIV
ChemGbg	ArrLab
ChemGbg	FOA
ChemGbg	SaabLkp
DfR	Space
Elmät	ASEA
ESA	DfR
ESA	SaabGbg
ESA	Space
FOA	Elmät
FOA	GeoSthlm
FOA	LMEMdal
FOA	Picap
FysikIV	MAS
FysikIV	SaabJkp
FysikIV	UAS
KretsGbg	Gop
LME	LMEMdal
LME	Teletran
LME	Televerk
MIT	Gop
QZ	FOA
Robotics	ASEA
SaabJkp	CERN
SaabJkp	SaabGbg
SaabJkp	SaabLkp
SaabJkp	Tement
SaabLkp	FOA
SaabLkp	SaabGbg
Sandvik	Avesta
Spectros	FysikIV
SteelAss	Avesta
SteelAss	Sandvik
STURSK	FOA
STURSK	Space
Teletran	Bildkodn
Televerk	Teletran
Tement	Tecnikus
UAS	UDAC
Wadell	SaabJkp

Centrality Analysis**KATZ point centrality indices**

Point#	Name	KATZ
18	KretsGbg	0.139
22	MIT	0.139
39	UDAC	0.147
34	Tecnikus	0.150
1	ACELund	0.154
25	Robotics	0.157
3	AppIPhys	0.157
7	Bildkodn	0.160
8	Caminstr	0.162
4	ArtLab	0.176
21	MAS	0.200
31	Spectros	0.200
40	Wadell	0.225
17	Gop	0.253
16	GeoSthlm	0.254
24	QZ	0.254
36	Televerk	0.323
38	UAS	0.327
32	SteelAss	0.327
11	DfR	0.329
37	Tement	0.353
23	Picap	0.382
12	Elmät	0.411
5	ASEA	0.414
20	LMEMdal	0.416
33	STURSK	0.417
9	CERN	0.425
35	Teletran	0.439
2	AJinstr	0.456
19	LME	0.464
30	Space	0.470
29	Sandvik	0.473
6	Avesta	0.473
13	ESA	0.488
10	ChemGbg	0.588
26	SaabGbg	0.594
15	FysikIV	0.797
28	SaabLkp	0.832
27	SaabJkp	1.025
14	FOA	1.284

Statistics on KATZ point centrality indices:

Minimum	0.139
Maximum	1.284
Mean	0.386
Median	0.341
Variance	0.061
Spread	0.898

BAVELAS point centrality indices

Point#	Name	BAVELA S
18	KretsGbg	17.276
22	MIT	17.276
17	Gop	17.287
8	Caminstr	18.196
32	SteelAss	18.209
6	Avesta	18.235
29	Sandvik	18.235
2	AJinstr	18.235
7	Bildkodn	51.240
39	UDAC	52.608
3	ApplPhys	53.711
25	Robotics	53.711
36	Televerk	54.395
35	Teletran	54.511
34	Tecnikus	54.979
31	Spectros	55.817
21	MAS	55.817
38	UAS	56.061
1	ACELund	56.308
11	DfR	56.681
5	ASEA	57.315
19	LME	57.833
4	ArrLab	57.964
13	ESA	58.493
40	Wadell	58.493
37	Tement	58.761
30	Space	58.897
9	CERN	59.169
15	FysikIV	59.720
24	QZ	60.000
16	GeoSthlm	60.000
23	Picap	60.282
33	STURSK	60.855
12	Elmät	60.855
20	LMEMdal	61.146
26	SaabGbg	61.884
10	ChemGbg	62.184
27	SaabJkp	62.794
28	SaabLkp	64.050
14	FOA	64.534

Statistics on BAVELAS point centrality indices:

Minimum	17.276
Maximum	64.534
Mean	50.100
Median	56.998
Variance	268.363
Spread	14.434

Appendix C

NETWORK ANALYSIS OF THE IMAGE PROCESSING NETWORK IN SWEDEN 1983

Input Files

Actors

AJinstr	Axel Johnson Instr
ASEA	ASEA
ASEARob	ASEA Robotics
Avesta	Avesta Steel
Bildkodn	Bildkodningsgruppen
Caminstr	Cambridge Instruments
CGuard	CGuard
Context	Context Vision
DEC	Digital Equipment
DfR	Del. för Rymdforskning
Elmät	Inst. för Mätteknik
Eloptic	Eloptricon
Erisoft	Erisoft
ESA	European Space Agency
FOA	FOA
FysikIV	Fysik IV
Gop	Gop-gruppen
GrafLabE	Grafiska Laboratoriet Espo
Hasselbl	Hasselblad
ImAnLaUp	Image Analysis Laboratory Uppsala
Imtec	Imtec
InnoLkp	Innovativ Vision
Itab	Itab
Karo	Karolinska Institutet
LME	Ericsson
Liber	Liber
LMEMdal	Ericsson Mölndal
Nada	Numerisk Analys och Datalogi
Picap	Picap-gruppen
Protop	Protop
Rema	Rema
SaabGbg	Saab Gothenburg
SaabJkp	Saab Jönköping
SaabLkp	Saab Linköping
Sandvik	Sandviken Steel
Satbild	Satellitbild AB
Sectra	Sectra
Semyre	Semyre Electronics
SGU	SGU
SLS	SLS
SMHI	SMHI
Softtech	Softtech
Space	Swedish Space Corporation

SpotIm	Spot Image
STFI	STFI
STU	STU
SUAB	SUAB
Sydat	Sydat
Sysscan	Sysscan
Teletran	Teletransmission Sthlm
Televerk	Swedish Telecom
Tollo	Tollo-system
Trätekn	Träteknikcentrum
Typplan	OY Typplan
UAS	Uppsala General Hospital
Utopia	Utopia
Valid	Valid Corp.

Relationships

AJinstr	Avesta
AJinstr	Sandvik
ASEA	ASEARob
ASEARob	Erisoft
Bildkodn	Gop
Bildkodn	Picap
Bildkodn	Sectra
Caminstr	AJinstr
Context	SaabLkp
Context	Space
Context	Valid
DEC	Context
DEC	Imtec
DfR	Space
Elmät	FysikIV
Elmät	LMEMdal
Elmät	Sydat
Elmät	Trätekn
Erisoft	LME
Erisoft	Rema
Erisoft	Tollo
ESA	DfR
ESA	SaabGbg
ESA	Space
FOA	LMEMdal
FOA	LME
FOA	Nada
FOA	Picap
FysikIV	Hasselbl
FysikIV	Karo
FysikIV	SaabGbg
FysikIV	Space
Gop	Context
Hasselbl	SaabGbg
Hasselbl	Sectra
Hasselbl	Space
ImAnLaUp	UAS
Imtec	GrafLabE
Imtec	ImAnLaUp
Imtec	Liber
Imtec	Space
Imtec	SUAB

Imtec	Typplan
Imtec	Utopia
InnoLkp	Bildkodn
InnoLkp	Context
InnoLkp	ImAnLaUp
InnoLkp	Imtec
InnoLkp	Itab
InnoLkp	Sectra
LME	Bildkodn
LME	LMEMdal
LMEMdal	Softtech
LME	Teletran
LME	Televerk
Nada	FysikIV
Picap	FysikIV
Picap	Gop
Picap	Imtec
Picap	InnoLkp
Picap	Sandvik
Picap	Semyre
QZ	FOA
SaabJkp	Eloptic
SaabJkp	SaabGbg
SaabJkp	SaabLkp
SaabLkp	SaabGbg
Sandvik	Avesta
Sectra	LMEMdal
Sectra	LME
Semyre	Eloptic
Semyre	Protop
Space	CGuard
Space	Satbild
Space	SGU
Space	SLS
Space	SMHI
Space	Sysscan
SpotIm	Satbild
STU	Context
STU	FysikIV
STU	Gop
STU	ImAnLaUp
STU	Imtec
STU	Picap
STU	Space
STU	STFI
SUAB	Liber
Teletran	Bildkodn
Televerk	Bildkodn
Televerk	Teletran
Typplan	GrafLabE

Centrality Analysis

KATZ point centrality indices		
Point#	Name	KATZ
2	ASEA	0.084
44	SpotIm	0.089
6	Carminstr	0.090
30	Protop	0.094
31	Rema	0.098
52	Tollo	0.098
48	Sydat	0.100
53	Trätekn	0.100
55	UAS	0.109
42	Softtech	0.109
57	Valid	0.131
23	Itab	0.134
24	Karo	0.140
45	STFI	0.147
56	Utopia	0.160
7	CGuard	0.170
40	SLS	0.170
39	SGU	0.170
41	SMHI	0.170
49	Sysscan	0.170
3	ASEARob	0.175
4	Avesta	0.184
12	Eloptric	0.186
28	Nada	0.245
36	Satbild	0.248
54	Typplan	0.249
47	SUAB	0.249
25	Liber	0.249
18	GrafLabE	0.249
1	AJinstr	0.257
10	DfR	0.268
33	SaabJkp	0.290
9	DEC	0.291
38	Semyre	0.314
35	Sandvik	0.326
34	SaabL.kp	0.332
50	Teletran	0.352
51	Televerk	0.352
13	Erisoft	0.366
14	ESA	0.370
11	Elmät	0.406
15	FOA	0.474
20	ImAnLaUp	0.520
27	LMEMdal	0.525
19	Hasselbl	0.535
32	SaabGbg	0.535
17	Gop	0.559
37	Sectra	0.608
26	LME	0.751
5	Bildkodn	0.830
8	Context	0.831
22	InnoLkp	0.877

16	FysikIV	0.958
46	STU	1.054
29	Picap	1.117
21	Imtec	1.243
43	Space	1.383

Statistics on KATZ point centrality indices

Minimum	0.084
Maximum	1.383
Mean	0.374
Median	0.249
Variance	0.099
Spread	1.009

BAVELAS point centrality indices

Point#	Name	BAVELA S
2	ASEA	34.239
6	Caminstr	39.010
31	Rema	40.861
52	Tollo	40.861
3	ASEARob	41.162
44	SpotIm	44.784
30	Protop	47.846
4	Avesta	48.052
1	AJinstr	48.259
42	Softtech	48.678
48	Sydat	49.760
53	Trätekn	49.760
12	Eloptic	50.432
55	UAS	50.661
13	Erisoft	51.123
33	SaabJkp	51.833
57	Valid	53.827
50	Teletran	56.545
51	Televerk	56.545
49	Sysscan	56.832
39	SGU	56.832
40	SLS	56.832
41	SMHI	56.832
23	Itab	56.832
7	CGuard	56.832
56	Utopia	57.122
47	SUAB	57.415
36	Satbild	57.415
18	GrafLabE	57.415
54	Typplan	57.415
25	Liber	57.415
24	Karo	57.711
10	DfR	58.010
34	SaabLkp	58.313
45	STFI	58.313
14	ESA	59.238
9	DEC	60.194
35	Sandvik	62.200
38	Semyre	62.547
28	Nada	63.614

27	LMEMdal	63.977
32	SaabGbg	64.345
26	LME	65.093
11	Elmät	65.859
20	ImAnLaUp	67.446
15	FOA	69.111
5	Bildkodn	71.312
17	Gop	72.701
8	Context	73.176
37	Sectra	73.658
19	Hasselbl	74.640
43	Space	78.845
22	InnoLkp	78.845
21	Imtec	79.404
16	FysikIV	80.547
46	STU	81.723
29	Picap	85.466

Statistics on BAVELAS point centrality indices

Minimum	34.239
Maximum	85.466
Mean	59.223
Median	57.415
Variance	129.993
Spread	26.242

Ebloc - Analysis

CYCLE RESTRICTIONS

Maximum cycle length = 3

CYCLIC POINTS

Block 1	1	4	35								
Block 2	5	17	29	22	37	26	50	51	8	46	43
	10	14	15	27							

ADJACENT CYCLIC BLOCK ACTORS

35 and 29	in blocks	1	and	2
29 35		2		1

UNBLOCKED ACTORS

1. Bridging points

9	between	8	21
11		16	27
48		16	27
53		16	27
12		33	29
38		33	29
30		33	29
28		15	16

2. Peripheral points

2	attached to	26
3		"
13		"
31		"
52		"
6		1
7		43
23		22
24		16
36		43
44		"
39		43
40		43
41		43
42		27
45		46
49		43
55		20
56		21
57		8

3. Isolated Trees

None

4. Isolated Points

None

Appendix D

NETWORK ANALYSIS OF THE IMAGE PROCESSING NETWORK IN SWEDEN 1989

Input Files

Actors

AFP	AFP
AmoLux	AmoLux AB
AMS	AMS
APress	A-Pressen
ASEA	ASEA
ASEARob	ASEA Robotics
BildAB	Svenska Bildbehandlings AB
Bildkodn	Bildkodningsgruppen
ByggE	Bygg Elit
CEJ	CE Johansson
CGuard	CGuard
Chemco	Chemco
Context	Context Vision
DEC	Digital Equipment
DfR	Del. för Rymdforskning
Dikon	Dikon Recognition
DocEye	DocEye AB
Elmät	Inst. för Mätteknik
Elproj	Elprojektbyrån
ESA	European Space Agency
FOA	FOA
FysikIV	Fysik IV
Gop	Gop-gruppen
Hasselbl	Hasselblad
HasselE	Hasselblad Engineering
HasselI	Hasselblad Imaging
Helax	Helax
HVind	H-Vinduett
ImAnLaUp	Image Analysis Laboratory Uppsala
Imnet	Imnet
ImServ	Image Server AB
Imtec	Imtec
InnoLkp	Innovativ Vision
InnoMoe	InnoVision
Itab	Itab
IVP	Integrated Vision Products
Karo	Karolinska Institutet
KIWAY	KIWAY
Korsnäs	Korsnäs Marma
Krets	Kretskortsmontör
LabEye	LabEye AB
LME	Ericsson
LMEMdal	Ericsson Mölndal

Nada	Numerisk Analys och Datalogi
NOW	NOW
Picap	Picap-gruppen
Post	Postverket
Radians	Radians
Rema	Rema
Renholm	Renholmens Bruk
SaabGbg	Saab Gothenburg
SaabJkp	Saab Jönköping
SaabLkp	Saab Linköping
Sarastro	Sarastro
Satbild	Satellitbild AB
Sectra	Sectra
Semyre	Semyre Electronics
SGÜ	SGÜ
SLS	SLS
SMHI	SMHI
SNet	SNet
Softtech	Softtech
Space	Swedish Space Corporation
SpotIm	Spot Image
STFI	STFI
STU	STU
SUN	SUN Microsystems
SwedFund	Swed Industrial Dev Fund
Sydat	Sydat
SydatI	Sydat Innovation
Sysscan	Sysscan
Teletran	Teletransmission Sthlm
Televerk	Swedish Telecom
Teragon	Teragon
TFK	TFK
TillFys	Tillämpad Fysik LiTH
Tipst	Tipstjänst
TRT	French electronics firm
Trätekn	Träteknikcentrum
UAS	Uppsala General Hospital
UnivK	Universitetet i Köpenhamn
UnivP	University of Philadelphia

Relationships

AmoLux	Itab
ASEA	ASEARob
ASEA	CEJ
Bildkodn	Gop
Bildkodn	IVP
Bildkodn	Picap
Bildkodn	Sectra
Context	Imtec
Context	SaabLkp
Context	STFI
Context	TRT
DEC	Teragon
DfR	Space
Dikon	CEJ
Dikon	Elproj
DocEye	SNet
Elmät	Renholm

Elmät	SydatI
Elmät	Sydat
Elmät	TfK
Elmät	Trätekn
ESA	DfR
ESA	SaabGbg
ESA	Space
FOA	LMEMdal
FOA	LME
FOA	Nada
FysikIV	Sarastro
Gop	Context
Hasselbl	HasselE
Hasselbl	HasselI
HasselE	Context
HasselI	AFP
HasselI	APress
HasselI	ImServ
HasselI	Sectra
ImAnLaUp	UAS
Imtec	Helax
Imtec	ImAnLaUp
Imtec	Imnet
Imtec	NOW
Imtec	Teragon
InnoLkp	AmoLux
InnoLkp	DocEye
InnoLkp	HVind
InnoLkp	Krets
InnoLkp	LabEye
InnoLkp	SaabLkp
InnoLkp	Sectra
InnoLkp	Teragon
InnoMoe	Radians
InnoMoe	Semyre
Itab	Krets
IVP	AMS
LME	Bildkodn
LMEMdal	InnoMoe
LME	LMEMdal
LMEMdal	SMHI
LME	Teletran
LME	Televerk
Nada	FysikIV
Nada	Teletran
Nada	UnivK
Picap	BildAB
Picap	Gop
Picap	InnoLkp
Rema	Renholm
SaabJkp	CEJ
SaabJkp	Post
SaabJkp	SaabGbg
SaabJkp	SaabLkp
SaabJkp	Teragon
SaabLkp	SaabGbg
Sarastro	Karo
Sarastro	SaabGbg

Sarastro	UnivP
Satbild	SLS
Sectra	ImServ
Sectra	Space
SNet	Tipst
Softtech	InnoMoe
Space	CGuard
Space	KIWAY
Space	Satbild
Space	SGU
Space	SLS
Space	SMHI
Space	Sysscan
SpotIm	Satbild
STU	Bildkodn
STU	FysikIV
STU	Gop
STU	Nada
STU	Picap
SUN	Context
SwedFund	Context
SwedFund	Imtec
SwedFund	Teragon
Sydat	ByggE
Sydat	InnoMoe
Sydat	Korsnäs
Teletran	Bildkodn
Televerk	Bildkodn
Televerk	Teletran
Teragon	Chemco
Teragon	LMEMdal
Teragon	Space
TillFys	IVP
Trätekn	Renholm

Centrality Analysis

KATZ point centrality indices

Point#	Name	KATZ
76	Tipst	0.100
6	ASEARob	0.100
20	Elproj	0.100
78	UAS	0.104
49	Rema	0.110
75	TillFys	0.113
3	AMS	0.113
64	SpotIm	0.116
37	Karo	0.119
80	UnivP	0.119
9	ByggE	0.120
39	Korsnäs	0.120
74	TfK	0.127
69	SydatI	0.127
57	Semyre	0.128
48	Radians	0.128
62	Softtech	0.128
4	APress	0.129

1	AFP	0.129
79	UnivK	0.133
47	Post	0.137
7	BildAB	0.143
31	Imnet	0.155
28	Helax	0.155
45	NOW	0.155
65	STFI	0.162
67	SUN	0.162
12	TRT	0.162
41	LabEye	0.176
29	HVind	0.176
82	Chemco	0.177
15	DEC	0.177
70	Sysscan	0.190
38	KIWAY	0.190
58	SGU	0.190
11	CGuard	0.190
61	SNet	0.198
5	ASEA	0.203
17	Dikon	0.203
35	Itab	0.213
25	Hasselbl	0.234
77	Trätekn	0.237
30	ImAnLaUp	0.247
26	HasselE	0.265
18	DocEye	0.276
81	ImServ	0.277
2	AmoLux	0.277
40	Krets	0.277
59	SLS	0.306
16	DfR	0.309
50	Renholm	0.322
60	SMHI	0.330
10	CEJ	0.337
36	IVP	0.358
55	Satbild	0.392
23	FysikIV	0.394
22	FOA	0.413
21	ESA	0.425
54	Sarastro	0.428
68	Sydat	0.442
72	Televerk	0.443
13	SwedFund	0.493
51	SaabGbg	0.508
19	Elmät	0.521
34	InnoMoe	0.542
27	Hassell	0.545
71	Teletran	0.566
44	Nada	0.601
53	SaabLkp	0.601
24	Gop	0.620
52	SaabJkp	0.642
43	LMEMdal	0.674
42	LME	0.681
66	STU	0.701
46	Picap	0.721
56	Sectra	0.775

32	Imtec	0.855
14	Context	0.943
8	Bildkodn	1.072
33	InnoLkp	1.117
73	Teragon	1.118
63	Space	1.285

Statistics on KATZ point centrality indices

Minimum	0.100
Maximum	1.285
Mean	0.347
Median	0.236
Variance	0.075
Spread	0.938

BAVELAS point centrality indices

Point#	Name	BAVELAS
49	Rema	49.546
74	TfK	56.798
69	SydatI	56.798
77	Trätekn	57.015
50	Renholm	57.124
20	Elproj	59.043
6	A5EARob	59.043
76	Tipst	62.112
9	ByggE	65.518
39	Korsnäs	65.518
19	Elmät	66.987
78	UAS	68.839
3	AMS	69.157
75	TillFys	69.157
37	Karo	69.479
80	UnivP	69.479
5	ASEA	70.131
17	Dikon	70.131
1	AFP	70.964
4	APress	70.964
64	SpotIm	71.817
79	UnivK	72.515
35	Itab	74.134
61	SNet	74.504
57	Semyre	76.214
62	Softtech	76.214
48	Radians	76.214
25	Hasselbl	77.802
68	Sydat	79.457
7	BildAB	80.312
65	STFI	82.303
12	TRT	82.303
67	SUN	82.303
47	Post	83.921
45	NOW	83.921
28	Helax	83.921
31	Imnet	83.921
30	ImAnLaUp	84.395
36	IVP	84.875

26	HasselE	84.875
54	Sarastro	85.360
81	ImServ	85.605
10	CEJ	85.851
23	FysikIV	87.613
27	HasselI	87.613
58	SGU	88.130
70	Sysscan	88.130
11	CGuard	88.130
38	KIWAY	88.130
59	SLS	88.653
55	Satbild	88.917
16	DfR	89.988
44	Nada	89.988
29	HVind	91.364
41	LabEye	91.364
72	Televerk	91.644
2	AmoLux	91.926
40	Krets	91.926
18	DocEye	92.495
71	Teletran	93.655
21	ESA	95.756
34	InnoMoe	95.756
82	Chemco	97.000
15	DEC	97.000
22	FOA	97.634
66	STU	97.634
51	SaabGbg	99.587
60	SMHI	99.587
46	Picap	102.315
24	Gop	102.315
42	LME	102.315
14	Context	105.569
53	SaabLkp	105.943
13	SwedFund	106.320
8	Bildkodn	108.246
52	SaabJkp	108.246
32	Imtec	108.246
56	Sectra	109.036
63	Space	115.351
43	LMEMdal	116.703
33	InnoLkp	120.955
73	Teragon	131.035

Statistics on BAVELAS point centrality indices

Minimum	49.546
Maximum	131.035
Mean	85.229
Median	85.482
Variance	266.613
Spread	45.806

Ebloc - Analysis**CYCLE RESTRICTIONS**

Maximum cycle length = 3

CYCLIC BLOCKS

Block 1	8	24	46	66	42	71	72	22	43	23	44
Block 2	13	14	32	73							
Block 3	16	21	63	55	59						
Block 4	19	50	77								
Block 5	27	56	81								
Block 6	51	52	53								

ADJACENT CYCLIC BLOCK ACTORS

24 and	14	in blocks	1	and	2
43	73		1		2
8	56		1		5
73	63		2		3
14	53		2		6
73	52		2		6
63	56		3		5
21	51		3		6

UNBLOCKED ACTORS

1. Bridging points

2		between	46	53	56	73
33			46	53	56	73
35			46	53	56	73
18			46	53	56	73
29			46	53	56	73
40			46	53	56	73
41			46	53	56	73
61			46	53	56	73
76			46	53	56	73
9			19	43		
68			19	43		
34			19	43		
48			19	43		
57			19	43		
62			19	43		
25			27	14		
26			27	14		
37			23	51		
54			23	51		
80			23	51		
60			43	63		

2. Peripheral points

1	attached to	27
3		8
36		8
75		8
4		27
5		52
6		52
10		52
17		52
20		52
7		46
11		63
12		14
15		73
28		32
30		32
78		32
31		32
38		63
45		32
47		52
49		50
58		63
64		55
65		14
67		14
69		19
70		63
74		19
79		44
82		73

3. Isolated Trees

None

4. Isolated points

None

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