ENVISIONING INNOVATION

The communication of technological change through graphic representation

MATTHEW GUY OVERTON

Doctor of Philosophy

ASTON UNIVERSITY

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THESIS SUMMARY

Graphic depiction is an established method for academics to present concepts about theories of innovation. These expressions have been adopted by policy-makers, the media and businesses. However, there has been little research on the extent of their usage or effectiveness *ex*-academia. In addition, innovation theorists have ignored this area of study, despite the communication of information about innovation being acknowledged as a major determinant of success for corporate enterprise.

The thesis explores some major themes in the theories of innovation and compares how graphics are used to represent them. The thesis examines the contribution of visual sociology and graphic theory to an investigation of a sample of graphics. The methodological focus is a modified content analysis. The following expressions are explored: check lists, matrices, maps and mapping in the management of innovation; models, flow charts, organisational charts and networks in the innovation process; and curves and cycles in the representation of performance and progress.

The main conclusion is that academia is leading the way in usage as well as novelty. The graphic message is switching from prescription to description. The computerisation of graphics has created a major role for the information designer. It is recommended that use of the graphic representation of innovation should be increased in *all* domains, though it is conceded that its content and execution need to improve, too. Education of graphic 'producers', 'intermediaries' and 'consumers' will play a part in this, as will greater exploration of diversity, novelty and convention. Work has begun to tackle this and suggestions for future research are made.

Key Words:

theoretical concept; management of innovation; innovation process; innovation network; performance and progress.

"Should there be any mistake committed in this Work, or should mankind improve upon the idea, I hope it will be remembered, that this is the first, as it is new in its nature, it has a particular claim to the indulgence of the Public, both as an invention and as a book."

William Playfair (1759–1823), in the first edition of
The Commercial and Political Atlas, 1786.

"Even a stopped clock tells the right time twice a day."

Anonymous.

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Chapter One
INNOVATION: CONCEPTS AND COMMUNICATION

This chapter introduces the thesis. It explains the purpose of the research — an examination of the communication of ideas about innovation theory through graphic representation — and the rationale of why it merits attention. A review chronicles the contribution and limitations of past work, and evaluates how and where the thesis will add to the current state of knowledge. A summary is made of the key concepts that will be examined later in the thesis — those that underlie theories of technological innovation. Since these theories have been analysed visually for their conceptual content, the main approaches to examining graphic representation are then briefly reviewed before a fuller analysis in Chapter Two. The chapter concludes with an outline of the thesis's structure.

1.1 THE NEW 'GRAPHIC' MODELS OF INNOVATION THEORY

Professor Howard Newby said, as chair of the Economic and Social Research Council, that "Business Schools should be doing much more to help the transfer of knowledge between academic life and the business community" (quoted in the *Times Higher Education Supplement*, 1993a: 4). Newby argued that the traditional notion of *technology transfer* was far too limited; a case in instance was the representation of the relationship between scientific discovery and innovation — expressed through high-technology projects such as Maglev and Concorde — using a linear model of scientific progress. According to Newby, *knowledge transfer* was needed, which emphasised the creation of networks — "the complex web of relationships" (*Times Higher Education Supplement*, 1993b: 14) as Newby called them — of information linking higher-education institutions, industry and commerce, and the public sector.

These comments have particular relevance to this thesis. One theme examines how innovation is represented graphically by academics, policy-makers, the media and businesses so that differences may be better understood. Part of this specifically involves an assessment of the portrayal of models of the innovation process and compares linear depictions with the network example. Also, it is interesting to consider the 'graphic' language used by Newby — metaphorical allusion is covered in Chapter Two and all graphic depictions display this to a greater or lesser extent. Though Newby did not acknowledge it, knowledge transfer will be achieved only with increased and improved communication *within* the organisation; the nature of information and the optimisation of its communication is discussed throughout the thesis and recommendations are made in Chapter Seven. Finally, this thesis *does* try to cross the boundary between academic and business research through its comparative emphasis.

Background to the research

The investigation and discussion of the concepts behind (new) models of innovation theory have become increasingly more prominent and popular in recent years. The resultant emphasis that has been placed on communicating this has led to a reevaluation of the importance of graphic representation — a primary form of information exchange — and how this may be maximised. Preliminary readings revealed the vast number of possibilities for research in this area.

Companies recognise the importance of conveying an image to an audience, whether this is their customers, other companies, the media, City analysts or government (Thomas, 1990). It is conceded that a corporate identity *does* convey aspects of a company's innovative ability through various means. However, while some pictorial representations invariably express explicit propositions, there are others — such as logotypes, typography, packaging, illustrations and advertisements — that do not always do so. Consequently, this field of research was excluded for that fact.

Other literature inspected varied from the psychological and perceptual study of information presentation, e.g. Easterby and Zwaga (1984), to collections of praiseworthy examples, e.g. Herdeg (1971, 1974, 1976), that were visually literate but lacking in explanation as to their construction and intent. Research such as this was discounted, too; a psychological analysis — implicitness again — would have required a confined scope of examination while, alternatively, the aim was not to gather an 'art gallery' of impressive illustrations.

Also, it was recognised that academics want to disseminate their research findings, e.g. Garvey and Griffith (1968), Lin *et al.* (1970), Small and Griffith (1974) and Garvey (1979). Therefore, the choice of the communication channel to be studied has proved to be influential.

The rationale for the thesis

An inspection of innovation texts revealed that a variety of graphic techniques have been developed for the representation of technological change and achievement. These include product and technology life cycles, long waves and 'bunching', innovation S-curves and design trajectories, as well as a range of pictorial and typographical forms. They embody sets of ideas concerning innovation theory. Recent developments in innovation theory were identified that were characterised by their emphasis on novel graphic expressions, notably performance curves, representations of progress, innovation cycles, modelling processes, matrices, mapping and networks. Hence, the research focused on an evaluation of the manner in which these conceptualisations have been represented in graphic displays, taken from publicly available published material, to a defined audience — *ex*-producer.

The thesis makes an exploration of the origin and application of these theories, and an analysis of the assumptions and intentions expressed within them, in the academic literature of the management of innovation, the study of the innovation process and the measurement of technological change — performance and progress. Some of these characteristics have been taken up by the media and the corporate and public sectors; the thesis reviews and compares the range of graphic techniques and the significance and usage of these forms of representation. Practical examples were selected largely from a survey of policy, media and business organisations in the information and communication technologies (ICT) and bioscience sectors. These were chosen as they represent two rapidly growing, innovative industrial sectors. A few general examples have been considered as well. The aim of the thesis is to discuss the communication of information through graphics by which some concepts of technological change theory may be understood more easily. It has sought to analyse how graphics are used in this field, what they try to portray and how effectively they achieve this.

Past work

An academic precedent for this type of research in the innovation field has not been discovered. This does seem surprising, especially when what has been written about this subject is considered.

Garvey and Griffith (1963) counted 29 ways in which knowledge may be conveyed and declared that the scientific paper was the most important of these. Mullins *et al.* (1988) analysed the structural elements that comprise a standard scientific paper. They claimed that all parts of a paper — the title, author list, affiliation, abstract, text, tables, graphics, charts, photographs and references — represent possible data sources for investigation. While references and citations have been used extensively as science indicators, due to their quantifiable nature, Mullins *et al.* (1988: 99) argued that "graphs … virtually have been ignored". According to Eisenstein (1983), the main purpose of graphs and charts in scientific papers is to present data in a compact form, enabling comparison not communication.

While different groups of papers are not uniform in the varieties of illustrations employed, certain types of illustrations are prevalent in certain kinds of work. Almost every paper has either graphs, photographs, equations, drawings or other illustrative materials; Latour and Woolgar (1979), for example, considered the utilisation of graphical material as the inclusion of laboratory device inscriptions — these include graphic displays, laboratory notebooks, tables of data, brief reports and lengthier, more public articles and books — in papers. But they did not account for the types of inscriptions, the number used or why that number varies from paper to paper; the emphasis was on the translation between them. In this sense, the analysis of graphics so far completed has only scratched the surface.

Mullins *et al.* (1988: 95) concluded that the "formal properties of illustrations need to be emphasized and researched more fully". Yet, despite this, applied bibliometrics and the textual analysis of scientific papers have become more developed subdisciplines in comparison.* Mullins *et al.* proposed that an exhaustive examination of the structural and textual characteristics of scientific papers be carried out; from this, an appreciation of their historical development, prescriptive rules for their implementation, previous use as quantitative analysis tools and potential application as policy tools may be gained.

Something similar to this *has* been achieved, though in a completely unrelated area — environmental geography. Crothers (1981) reviewed a collection of graphics taken from a journal, *Field Studies*, and analysed them as aids to the understanding and communication of quantitative data. There was a strong historical emphasis. Suggestions, though not guidelines, on usage were made. The method of graphic presentation was examined and the presentational choices — report, paper or transparency — were discussed. However, policy issues were not considered.

Bowker's (1992) study *did* focus on the field of innovation, but looked at the presentation of patents as *texts*. Technical objects in patents, scientific literature and company archives were examined and discussed, as was the relationship between the different presentations of patents taken from those sources. Law (1986) concentrated on the heterogeneity of texts — their transportability, durability and structure mean that they are autonomous of their creators, like graphics — while work by Spharim and Seligman (1985), Schubert and Braun (1986), van Raan and Hartmann (1987), Cohen (1988) and Barbiroli (1990) has focused on graphic methods rather than an analysis of the graphics themselves.

The approach undertaken in this thesis is similar to that adopted by the Bureau of Social Science Research's *Graphs* project (Feinberg & Franklin, 1975), an annotated and illustrated bibliographic survey of the exemplary use of social graphics. This considered the principles and practices of the graphic representation and communication of social indicators and other quantitative social data. In addition, it was reoriented to make it applicable to traditional, technologically-simpler modes of representation and dissemination, and in adapting graphics to technological *innovations*. However, Feinberg and Franklin did not examine technological *innovation*; it was predominantly a qualitative study with no attempt made to address content or meaning, though Feinberg and Franklin claimed that many areas of science, technology and applied arts have some pertinence to the field of social graphics.

Previous research in the examination of graphics has focused on the *excellence* of the graphical technique or the sociological *discourse* generated. The thesis draws upon both approaches through an examination of the *visual arguments* and concepts

* For instance, Narin's (1976) research-performance measurements by co-citation analysis; Latour and Woolgar's (1979) reconstruction of laboratory life through texts; co-word analysis (Rip & Courtial, 1984; Callon *et al.*, 1986a); bibliometric mapping and co-citation cluster analysis (Small & Sweeney, 1985; Small *et al.*, 1985).

and this point is developed further below. By analysing the exemplary use of graphics in a particular context through a survey, the objective is to provide a coherent basis for the choice and interpretation of such graphic techniques for the purposes of academic research on technological change, as well as on the communication of innovation by policy, media and business organisations (including graphic design consultancies who are often briefed to facilitate this).

1.2 THE COMMUNICATION OF INFORMATION ON INNOVATION

Communication is defined as "essentially the *exchange of information*, be it words, ideas or emotions. Information, in turn, is the *carrier of meaning*. Communication is only possible between people who to some extent share a [common culture]" (Trompenaars, 1993: 67, emphasis in original). The communication of information about innovation is achieved chiefly through two printed means: text and graphics.

Text

According to Trompenaars (1993: 68), Western society has a predominantly verbal culture since people "communicate with paper, film and conversation", though Trompenaars contends that two of the best-selling computer program 'families' in the Western world — word-processing and graphics — have been developed to support written communication. Usually, reports are presented in this mode. Ordinary language and the more esoteric analytic vocabularies — or lexicon — of innovation theory and related subject areas from the social sciences constitute the terminology of material published in this field. In contrast, innovation practice often involves the analysis of graphically plotted trends, the processing of quantitative data and the summation of metaphorical ideas gathered by the researcher's senses. Vision is primary among these, as the frequent use of the term 'observe' attests. These witnessings and observations then are transformed into a written account; experience is translated into linguistic descriptions. The enormous symbolic power of language is the obvious justification for this practice.

This method of conducting enquiry is not being questioned; its widespread acceptance as a convention and the consequent neglect of visual modes of representation that accompanies it *are* being raised to highlight this fact. This has resulted in "language doing the work of eyes" (Tyler, 1986: 137); the visual is mediated verbally and images are (sometimes badly) translated into words. This thesis surveys how graphics have been used in innovation theory — a discipline primarily of words as any standard introductory text book shows — to demonstrate why language should be doing *less* of the work of eyes.

Fyfe and Law (1988b: 1–2, 2) have lamented that "the visual has been deleted from most sociologies ... to an extraordinary extent". Whereas it is difficult to read about the sociology of art without referring to representations of the very pictures that are being discussed, it seems relatively easy to argue about politics, scientific research or the publication of official statistics "without considering the specifically visual technologies that are built into and help to reproduce them".

Graphics

Graphics practice is a long-established method of communication.

> Three thousand years separate the appearance of the first alphabet from the invention of printing with movable type, and the sudden expansion of knowledge which followed it. ... [But] twenty thousand years or more separate the way of life of the Aurignacian hunters, who contributed the first pictures to the modern symposium of human communications, from the beginnings of settled community life and the beginnings of a priestly script. (Hogben, 1949: 123)

Platt (1975) similarly noted that much communication took place before the invention of moveable type: the hieroglyphics of ancient Egypt, the pictographs of China and America, the paintings of prehistoric times — all were attempts at visual forms of communication. (Appendix One details some other notable events in the development of graphics.) Funkhouser (1936) even dated a graph representing changeable values to the 10th century. Consequently, there have been calls for the use of graphics to receive greater prominence.

Traditionally, the importance of graphics as a means to display information has been under-utilised. This is surprising considering that the human eye-brain system is very advanced; people absorb graphically the equivalent of a billion bits of information per second — as much as the text in 150,000 magazine pages — as they look around them (Smarr quoted in Bylinsky, 1991). But a person's mental textual ability is limited because they can read only about 100 bits — or characters — per second. Since about half the brain is dedicated to visual processing, a graphic-based system is the most natural way for people to understand and manipulate data.* Ackerman presented another reason why images should be predominant:

> For us the world becomes most densely informative, most luscious, when we take it in through our eyes. It may even be that abstract thinking evolved from our eyes' elaborate struggle to make sense of what they saw. Seventy percent of the body's sense receptors cluster in the eyes, and it is mainly through seeing the world that we appraise it and understand it. (1991: 230)

Gombrich (1982: 143) maintained that the real value of the image, however, was "its capacity to convey information that cannot be coded in any other way". Far from serving to imitate nature, pictures have an unmatched capacity for arousal and perform an important function as a vehicle for expression. Curry and Clarke (1978: 47) asserted that "we are re-entering a period in which the image will be dominant over the written word". Over a decade later, The Henley Centre (1989) continued to believe so; it maintained that people in Western society were becoming 'alliterate', using their reading skills for distraction or information purposes and combining them with their highly developed visual abilities to help comprehend more abstract or 'difficult' concepts. Consequently, people are very receptive to messages commu-

* Experiments also revealed that linguistic memory is different from pictorial (Haber, 1970).

nicated through more complex hybrids of words and pictures. Visual imagery will continue to increase in importance as a very effective form of communication and graphs play a prominent role in this.

The advantages of graphs*

Bertin (1980) maintained that all disciplines use graphs to a greater or lesser extent; tables and graphs improve the comprehension of science topics over text alone (Powers, 1966). Although some people can absorb information from tables of numbers (Pearson, 1956), most people can only appreciate matters with full insight by looking at graphical representations. Tukey and Wilk (1970: 381) pointed to graphics as being one of the three main strategies of data analysis and maintained that "wisely used, graphical representation can be extremely effective in making large amounts of certain kinds of numerical information rapidly available to people".

According to Moore, data are presented most vividly in graphs:

> The purpose of a graph is to give a visual summary of data. A good graph frequently reveals facts about the data that would require careful study to detect in a table. (1979: 136)

Tukey and Wilk (1970: 381) maintained that graphic representation served "to display clearly and effectively a message carried by quantities whose calculation or observation is far from simple". In addition, Tukey and Wilk (1970: 375) declared that a graph "is not merely worth a thousand words, it is more likely to be scrutinized than words are to be read".

One advantage of graphics is their free-form approach. While a textual account has a logical flow, made necessary by its structure and for ease of reading, a person may start 'reading' a graphic from any level, whether it is from the title and proceeding to the detail or vice versa or from any where in between, and any 'place' in the diagram may be used as an 'entry point'. Graphics can set the stage for a discussion, convey a message or reinforce a central point. Data-based analytical graphs are essential tools of the sciences and, for the technically trained, often convey data in a concise and readily digestible format. The use of graphical displays has not always been so common. Only 15 or so years ago, a publication-quality graph required a graphic artist to transfer a data set onto the page of a report. The process consumed considerable time and expense. Now, most software programs that process quantitative data will produce graphs, allowing researchers to generate and refine graphical displays on the screens of their desktop computers.†

It is fortunate that the means for producing graphical displays has come at a time when their power and utility are becoming appreciated. The power of graphics comes from their ability to convey data directly to the reader, in a sense revealing it.

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* Appendix Two provides an introductory review of graphic theory and a more thorough analysis of the use of graphics.

† Appendix Three reviews the impact of computerisation and new technology on the production of graphics.

People use their spatial intelligence to retrieve the data from a graph; data become more credible and convincing when the audience has a direct interaction with them. The communication process becomes more direct and immediate through graphical displays; seeing — rather than being told — produces an understanding of the subject that approaches that of the originator of the graph. By using graphical displays, people are no longer passive observers; they become active seekers of information and are able to understand some of the complexity of the subject under study, perhaps reaching the limits of current knowledge.

The emphasis on communication

Crick (cited in Garvey, 1979: ix) maintained that "communication is the essence of science"; indeed, the collection and communication of information on technological innovation has recently received increased attention. Sectoral and national policy analysis of business performance and competitiveness has sought to measure and compare innovative activity more explicitly (Cabinet Office [Office of Public Service and Science/Office of Science and Technology], 1992; Kleinknecht & Bain, 1993). In addition, the publication of R&D expenditure in the *UK R&D Scoreboard* (Company Reporting Limited, annually) has enabled intrasectoral, intersectoral and international comparison and ranking at a corporate level. Kramer has stated the need to examine this area of scholarship as thus:

> An important task of modern research and technology policy can be seen in anticipating and analyzing technological change. The development of new technologies — products and production processes — should go together with increasing knowledge on those developments: on alternatives, on time horizons or the speed of developments, on economic chances and risks, and — last not least — on comparative national advantages for certain technologies. Unfortunately, early indicators of technological change are not well established yet. The present state of the art does not allow ready adoption by companies, research institutions, and research administrators. (1987: 3)

Technological innovation is recognised as a key factor in corporate economic performance and the competitiveness of national economies. The perception of technological innovation at corporate and sectoral levels plays a vital role in shaping investment and policy decisions. The communication of information about the innovation process is critical to these perceptions and consequent decisions. This concern is expressed in a context where the communication of business information by graphic representation has become increasingly significant. Although firms apply graphic forms of representation to their financial performance, it is much rarer for graphics to be used with other dimensions of corporate performance. As in many aspects of business and economic performance, graphic devices have become increasingly prevalent in the communication process.*

A survey of companies' innovativeness by the Department of Trade and Indus-

* This has been recognised by the formation of the Association of Business Communicators in July 1991, though its emphasis is on the presentation of video graphics and data within audio-visual media.

try (DTI) and the Confederation of British Industry (1992) analysed the performance of UK-based institutions in the manufacturing and service sector. It found that only one UK company in ten was good at innovating. It also reported that those companies that innovated successfully managed to achieve a larger market share, higher growth rates and bigger profits in comparison to their competitors.

The DTI's Innovation Advisory Board Action Team on Communications (IAB ATC) (1991) has disclosed that companies that are less successful in communicating rarely discussed innovation. The IAB ATC (1991: 2) argues that "good communication on innovation is an essential element of the dialogue between companies and investors" while also conceding that the expected benefits of innovation are "more difficult to convey than past results". The IAB ATC (1991: 15) encourages the management of business enterprises to be "as open and communicative as possible about the role of innovation in the company strategy".

The Institutional Shareholders' Committee (ISC) (1992) has called for less secrecy in companies' long-term R&D plans. It criticises those that go no further than the minimum disclosure levels that are required legally under *Statement of Standard Accounting Practice No. 13 (1977): Accounting for research and development.** The analyses outlined above could be undertaken more easily if companies adopted the ISC's recommendations; others include the acknowledgement of time horizons and returns on product development, the declaration of the proportion of current sales attributable to products introduced in the last three to five years, and an understanding of international disclosure policies.

The ISC (1992) advises companies to consider the comparison of their R&D expenditure with their competitors. This process, known as *scoring*, occurs regularly in the USA — most notable is the data published every year in *Business Week* magazine — and tables are printed in Germany, Japan and Scandinavia. The *UK R&D Scoreboard*, originally published in the *Independent* newspaper in 1991, has been taken up and promoted by the DTI's Innovation Unit. As a result, the IAB ATC (1991: 2) has focused on the need to improve "the climate for innovation, by improving communication on the subject". This would, the IAB ATC (1991: 2) believes, "help innovative companies win investor support and help investors identify successful innovative companies".†

Additionally, the ISC (1992: 1) has stated that "the onus is now with companies to provide ... information [about R&D expenditure] ... since any information on successful innovation in the past is indicative of the likely success of current and future [research] expenditure". However, this should be more than a statement of

* Also, it should be noted that companies tend to restrict themselves to quoting R&D expenditure, which is an input, rather than something like patent successes, awards and the like, which are outputs. Clearly, company reporting on innovation offers much scope for improvement.

† Mayer (1990) declares that improved communication is welcome. However, institutional investors have shown a lack of interest in it, having little faith in R&D disclosure, limited use for it when it is received or different ways of obtaining the same information.

solely past expenditure; Akio Morita (1992: 4) of Sony Corporation has said that "for an accountant, the central concern is statistics and figures — of PAST performance. So how can an accountant reach out and grab the future if he is always looking at LAST quarter's results" (emphasis in original). Indeed, this is supported by the ISC (1992: 1) who maintains that such facts should not be confined to the accounts and that "other channels" should also be used.

The continuing emphasis highlighted above has been codified in the publication of the 1993 White Paper on science and technology. One of its themes is that

> steps should be taken which ... will help harness that strength in science and engineering to the creation of wealth in the United Kingdom by bringing it into closer and more systematic contact with those responsible for industrial and commercial decisions. Such a systematic interchange between industry, scientists, engineers and science policy makers ... would improve mutual understanding and allow each group to make its decisions against a better-informed background. (White Paper, 1993: 4)

One policy aim is "to achieve a key cultural change: better communication, interaction and mutual understanding between the scientific community, industry and Government Departments" (White Paper, 1993: 5). Another objective is to develop government schemes for technology transfer "to re-emphasise the importance of the interchange of ideas, skills, know-how and knowledge between the science and engineering base and industry" (White Paper, 1993: 6). The White Paper declares that its fundamental theme is the need for a closer partnership and better diffusion of ideas between the science and engineering communities, industry, the financial sector and government.

The White Paper also states that efforts are being made by the Government to improve the effectiveness and efficiency with which firms innovate. The promotion of the awareness of the importance of innovation is focused particularly at "senior managers in the business community (including investors and financial institutions), public and private sector support organisations, and within the education system and media" (1993: 12). In addition, a campaign to improve the public understanding and the complementary roles of science, technology and engineering, and "their vital importance to the country's future", should be targeted at "the City, media, company chairman and chief executives at all levels and in all regions and the educational fraternity at school and university level" (Royal Academy of Engineering submission quoted in the White Paper, 1993: 66).

The announcement of the Technology Foresight programme can be seen as the commencement of the implementation of the initiatives outlined in the White Paper. The emphasis is on knowledge-intensive and high value-added products and processes in science, engineering and technology. However, the creation of a forward-looking, technologically aware management is recognised as a significant contribution to the UK's competitiveness.

1.3 KEY CONCEPTS IN INNOVATION THEORY

Innovation theory is made up of many disparate strands and it is beyond the scope of this thesis to have examined each one or to have fully covered all the different interpretations. Instead, the thesis focuses on aspects of innovation that are important practically, considering a number of key concepts taken from theories of *dynamic* technological and innovatory change. These have been selected from the field of innovation studies and have been chosen for their (greater than average) usage of graphic formats to explain aspects of the theories.

As the research deals with the representation of innovation generally, rather than individual theories specifically, attention was focused initially on collections of writings to gain a varied perspective of an assortment of models, approaches and techniques, e.g. Roy and Wield (1986), Tushman and Moore (1988), Freeman (1990) and Sigurdson (1990a). At the same time, introductory books were used to gain an outline of the whole subject, e.g. Hawthorne (1978) and DeVore (1980). As a result of this work, the selection of concepts was reduced to those covering the management of innovation, the innovation process, and performance and progress. This was linked to the usage of graphics to express and explain these theories. The most common formats used to represent these were matrices, maps, 'black box' models, flow charts, networks, organisational charts, curves and cycles.

The rationale for this choice is ratified by their importance being highlighted in several significant policy documents. The first source is the 1993 White Paper on science and technology, which pays particular attention to strategy and networks and makes a passing reference to performance and progress. The Council of the European Communities (1992) also refers to networks. The final source, focusing on performance and progress, is Soete and Arundel's (1993) memorandum on European technology policy.

The management of innovation

A large part of the White Paper on science and technology is concerned with establishing a more strategy-oriented approach to the organisation of and approach to research in the UK and its contribution to the nation's wealth. For instance, the Government's Chief Scientists are pledged to take "a strategic overview of the contribution of science and technology to policy development over both the long and short term" (White Paper, 1993: 44). In addition, Business Schools are encouraged to

> include regular modules dealing with the management of innovation and the understanding of science and technology for general managers. ... New modules on innovation, new product development, and the management of science and technology will be developed by the Economic and Social Research Council in conjunction with the Business Schools both for inclusion in Master of Business Administration (MBA) degrees and shorter training packages. (White Paper, 1993: 54, 57)

The innovation process

A recent and frequently used expression to model the innovation process is the network representation. The influence of communication through networks, both formal and informal, is acknowledged in the science and technology White Paper:

> The academic traditions of international co-operation and partnership mean that the results of basic scientific research are rapidly disseminated to an ever-growing international community; improvements in global communications have accelerated this process. ... The Government recognises the important contribution of the individual links between scientists and laboratories, often organised along subject lines. (1993: 47, 48)

Furthermore, institutions, such as the Royal Society, are praised for their important role in promoting "unfettered" international contact, and the Government believes that it should be "encouraging networking amongst the many [organisations and individuals]" (White Paper, 1993: 48, 67). The White Paper (1993: 17) concedes that the ways in which the results of research are developed into processes and marketable products are "complex and interactive"; it seeks to encourage and ease the "increased exchange and flow of people, knowledge and ideas" and, by harnessing the "knowledge and insights" of the Government, industry and the science base, it is believed that a "closer and more fruitful relationship" will result.

In addition, the Council of the European Communities (1992: 51, 52) refers to the benefit arising from "the establishment and development of trans-European networks" and the encouragement of "an environment favourable to co-operation between [business enterprises]". Also, it will be pursuing "the implementation of research, technological development and demonstration programmes, by promoting co-operation with and between [business enterprises], research centres and universities", leading to the "dissemination and optimization of the results" (Council of the European Communities, 1992: 55).

Performance and progress

The science and technology White Paper (1993: 43) also mentions the significance of measurement by "identifying areas of overlap or duplication", the development of "relevant output measures and performance indicators" and the evaluation of the "success of [commissioned] programmes". Greater evidence, however, for an examination of the notions of performance and progress comes from Soete and Arundel (1993). They believe that such change is valuable socially, as well as economically, since "it contributes to the improvement of social welfare and to industrial competitiveness by enhancing the quality of existing products and services, by creating new goods with superior attributes, or by reducing production costs" (Soete & Arundel, 1993: 11).

For these reasons, programmes that affect the direction and rate of technical change are a component of government policies to improve both economic competitiveness and the quality of life and, as such, are worthy of further investigation and research.

1.4 APPROACHES TO EXAMINING GRAPHICAL REPRESENTATION

The different approaches to examine graphical representation may be visualised as a continuum. On the one hand, they may be summarised as broadly involving elements of sociological theory and the analysis of the graphic's meaning or *discourse*. On the other hand, there are theories that have been developed by graphic specialists where the emphasis is on the technique or *excellence* of the representation. In the centre, there is an approach that draws upon elements from both paradigms and it is this approach that has been adopted in the thesis; the study focused on the *visual arguments* or concepts represented by the choice of certain types of depiction. The content of the graphics, their relationship with form and their 'exemplary' usage in a particular context have all been analysed.

Sociology and discourses

The sociological analysis of visual representation has begun to attract serious study, e.g. Callon *et al.* (1986a), Bijker *et al.* (1987a), Fyfe and Law (1988a), Lynch and Woolgar (1990a) and Bijker and Law (1992a). Although much of the sociology of science literature is involved with the use of visual representation within natural science, Latour (1990: 39, 38) argues that there is "no detectable difference between natural and social science, as far as the obsession for graphism is concerned"; whether one looks at nature or the economy, the scientist or economist only *sees* a visual construction — it is the *process* of "visual construction" that "begs explanation". Foucault (1974) favoured the adoption of a general framework with the notion that a graphic was a *discourse* that should be analysed in its own terms.

Technique and excellence

The general issue of the communication of complex information has also received increased attention. Graphic devices merit analysis both as forms of communication and expression, and recent work by Tufte (1983, 1990a) and Bertin (1981, 1983) has begun this process. Tufte and Bertin are the foremost proponents of the examination of graphics conveying information through excellence, integrity and sophistication.* Their approach is concerned with the *efficiency* and *effectiveness* of the choice of graphic forms adopted, drawing concepts from theories of the construction (Bertin) or *de*construction (Tufte) of graphics. Part of this research has involved synthesising Tufte's and Bertin's approaches to develop an analytical framework with which to assess and classify examples.

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* Tufte has been labelled "the dean of display makers" (Miles & Huberman, 1994: 100) while Bertin was called "a leading figure in the developing field of optimizing graphical representation" (Kolers, 1980: 500). Macdonald-Ross and Smith (1977: 24) were unusual dissenting voices by describing Bertin (1983) as over-complicated and claimed that accurate construction did not guarantee accurate perception.

Visual arguments *and concepts*

The approach undertaken by the thesis, after Neurath (1936), Macdonald-Ross (1977a) and Simon (1981), maintains that a graphic constitutes a *visual argument* and that conceptual theories and models may be represented by graphic devices. It recognises that innovation graphics may not be graphically 'excellent' and that an understanding of sociological theory may not be fully appreciated by the designer or the reader. Despite their 'failings', the sense of what the graphic is intended to show *is* understood, e.g. the notion of technological progress.

1.5 THE STRUCTURE AND OUTLINE OF THE THESIS

The thesis comprises four notional sections. This chapter (and section) has concentrated on introducing some concepts underlying theories of technological innovation. For the purposes here, the emphasis has not been on theoretical details, but on the presentation of some exploratory and initial ideas to provide a background to the subsequent chapters. An evaluation of the evidence to support the increased communication of information about the innovation process has been made. In particular, support for the inquiry into the concepts underlying the strategy and process behind innovation and the notion of technological progress and performance has been documented. These ideas are discussed, elaborated on and illustrated later in the thesis. The three main approaches to examining graphical representation are introduced as a precursor to a fuller exploration of their theoretical underpinning in Chapter Two.

The topic of Chapter Two — the second section — starts off where this current chapter ends: graphics as a mode of communication. A summary of the main theories behind the representational methods that may be used to examine graphics — metaphorical, graphical and mathematical — is presented. Following the choice of the representational method, there is a discussion of the differing approaches, and the theories within them, that may be undertaken when following a such a method. The contribution of visual sociology and pictorial representation is contrasted with the development of the graphic theories as a means to examine representation. In addition, the approach undertaken by this thesis is analysed in greater depth.

Chapter Three (and the third section) sees a discussion of the methodological issues that underlie this study. The research purpose is appraised, and the research strategy and sample of graphics are identified. This is followed by an appraisal of the research design and the technique used for data collection. Finally, the quantitative and qualitative methods of data analysis are compared; in addition, the theories behind the representational approaches that were discussed previously are synthesised to provide an analytical tool.

In Chapters Four to Six — the fourth and final section — the concepts that were introduced in Chapter One are explained, illustrated and discussed with the aid of a sample of primarily academic examples, though there are some that have been taken from printed policy, media and business sources. Chapter Four considers the representation of the management of innovation. In particular, strategic or holistic tools and techniques — check lists, matrices, maps and mapping — are examined.

The representation of the innovation process is the focus of Chapter Five and it is considered at three levels. At the macro-level, the modelling of the innovation process is contrasted between the linear, interactive and network depictions. At the meso-level, the genealogy of inventions and innovations and the source and generation of ideas is studied: flow charts are contrasted with networks. Finally, at the micro-level, the organisation itself is considered and the different expressions to represent it; on the one hand is the traditional organisation chart while on the other is the network model — in other words, prescribed versus emergent networks.

The subject of Chapter Six is the representation of technological performance and progress. This continues the examination of pairs of visually contrasting concepts, but the subjects — rather than being compared with alternative expressions as in the previous two chapters — are contrasted with alternative forms of *visualisation*. The linear and exponential curves are contrasted with the S-curve while life cycles are compared with long waves. In both cases, the emphasis is on single and multiple representations of the same expression. Despite this, these are the only techniques discussed in the thesis that can dynamically represent time without the need for multiple representations.

Finally, in Chapter Seven, a schema to visually depict theories of technological change is introduced and recommendations are made to improve communication for innovation and graphics. This has implications for the theory and practice of 'envisioning' innovation for policy-makers, the media and business organisations, along with the graphic design consultancies that (try to) visually implement their ideas and — of course — academics. In addition, the contribution of some of the concepts developed by this thesis, while work-in-progress, to recently completed and current research is appraised and possibilities for future research are presented.

Throughout the thesis, *italics* are used to emphasise certain words or phrases to indicate importance or stress. In addition, they are deployed to call attention to special concepts or terminology — like *scoring*, *discourse* and *excellence* in this chapter — and the meaning, definition or usage will be found in the surrounding text. When a term that may be abbreviated is used initially, its abbreviation follows it in parenthesis and will be applied in that form for the remainder of the thesis.

For a piece of research concerned with promoting the analysis of stored visual phenomena, it might be argued that more graphics should be included: the limited collection of figures *have* been carefully selected since textual analysis is intended to grow from close attention to the visual information encoded within them. The graphics are not included for illustrative purposes, but are intended to engage the reader in an analytical investigation of the visual — the analysis of graphics is promoted by suggesting how they can serve as an investigative topic.* It should be realised that it does take time to 'read' and understand some of the figures. The graphics are not representative of the sample, but do denote the 'types' of graphics that are used. In addition, space constraints preclude reproducing any more. Finally, the title of a graphic has been taken from the source wherever possible.

Though colour is recognised as a useful tool to encode information perceptually (Albers, 1963; Barabba & Finkner, 1978; Wainer & Francolini, 1980a; Bertin, 1981, 1983; Tufte, 1983, 1990a; Robertson, 1988), Macdonald-Ross and Smith maintained that

> the use of colour in diagrams ... is one of the oldest problems ... . Nothing ... is so difficult to master as the use of colour; nothing else shows so clearly the truth of all practical art — there are no universal prescriptions, just particular solutions. (1977: 10)

Appendix Three discusses the impact of new technology on the production of graphics; no doubt, colour printing and photocopying will continue to fall in cost, but it is still prohibitively expensive for academic usage. The thesis concurs with Wainer and Francolini (1980b) who recommended that, in general, colour should not be used; a monochromatic representation is cheaper and more effective. Consequently, colour is excluded as a subject for general research and in discussion of specific graphics, and monochrome representations have been used exclusively in the thesis.

The main part of the research was conducted from October 1990 to September 1993 at Aston Business School, Birmingham, while the author was supported by a SERC CASE studentship. The practical component involved working with an outside graphic design consultancy — particularly in the early stages of the research. This helped to focus attention and allowed insight to be gained into how designers visualised graphic solutions. However, it also diverted resources and caused other demands that could not have been anticipated.

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* This is in contrast to Zimmerman and Pollner's (1971) study of the role of visual phenomena as a common illustrative resource; the thesis is concerned with the analysis of the graphic representation of technological innovation through *concepts*, as distinct from the more standard illustrative inclusion of drawings or photographs of technology, demonstrated by steam engines, bridges or people sitting in front of computer screens.

Chapter Two
GRAPHICS AS A MODE OF COMMUNICATION: METHODS, APPROACHES AND THEORIES

According to Novitz (1977), people are able to repeat words exactly, but not to reproduce images.* The latter was acquired through advances in technology and, as a result, pictures were reproduced with comparative ease. It was due largely to the arrival of picture printing in the 15th century and the more recent development of half-tone printing and photography in the 19th century that pictures were reproduced in sufficient numbers to allow the development of more complex communicative uses.† Muybridge's sequence of *Horse in Motion* photographs indicated that graphic images could record time and space relationships and the notion of moving images became a possibility. Ivins (1953: 93) speculated that "the number of printed pictures produced between 1800 and 1901 was probably considerably greater than the total number of printed pictures that had been produced before 1801".

This chapter develops the submission that the graphic is a primary mode of communication and that it demands investigation. The aphorism 'a picture is worth a thousand words' is a common expression. Novitz (1977) declared that few people were puzzled by it or deemed it worthy of explanation: graphics *do* provide a remarkably effective means of communication and there *does* seem little to be puzzled about. The pictorial treatment of information is being applied more than ever: diagrams, maps, networks and matrices all help to clarify and interpret the information carried by the accompanying text and this is likely to increase (Booth-Cibborn & Baroni, 1980). However, Novitz's (1977: 151) contention is that there are "many problems ... surround[ing] pictures and their use in communication; for even though it is clear that pictures provide a very effective vehicle for communication, it is by no means clear why they are so suited to this task, and how they can be used to perform it". A theoretical examination of representation provides a basis.

In the following sections, reviews are presented of how the analysis of visual phenomena is structured by the theoretical framework adopted. These exhibit certain of the characteristics of what Wittgenstein (1968) termed *language-games*, in that the conceptual apparatus and vocabulary are used to shape the analysis. Each theo-

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* The existence of oral cultures, traditions and histories in many parts of the world supports this.

† Macdonald-Ross and Smith (1977) claimed that the growth of science and the Industrial Revolution would have been stunted without print. Ivins (1953) termed the invention of photography and the photographic process as the most important single development of the 19th century. Appendix Three chronicles the contemporary influence of technology on graphics production.

retical framework suggests an investigative stance and, to a certain extent, each is self-sufficient as a coherent and consistent analytical enterprise — a language game — that is locatable within an academic context or 'form of life'. Researchers see in their data mainly what tends to support their beliefs and, of course, tend to overlook that which does not support them (Mitroff, 1974b). This behaviour is not restricted to academia; people cannot and do not see the same things in the same phenomenon since individual make-up will determine the interpretation of a given perception (Hanson, 1958). Thus, academics holding different theoretical beliefs may interpret their perceptions of the 'same' phenomenon differently. While this affects both text and graphics, it is more pronounced for the latter: what a piece of text *says*, for instance, cannot be disputed, but its *meaning* can; with graphics, both entities can provoke questions, e.g. different individuals may see a blue-coloured graphic as being composed of mid blue, navy blue, dark blue or variations of these, in addition to any divergence in its meaning.

Since the analysis of visual phenomena is the focus of the thesis, the different representational methods that may be used — metaphorical, graphical or mathematical — are reviewed. Following the choice of a graphical method, a continuum of the different analytical approaches used to examine graphics is introduced. The contribution made by visual sociology and pictorial representation — the analysis of *discourses* — is appraised, as is the role of *excellence*, epitomised by technique theorists such as Tufte and Bertin. A critique of the unifying style taken by the thesis — that graphics convey *visual arguments* and concepts — concludes this chapter. Figure 2.1 represents graphically how these paradigms may be located within one another.

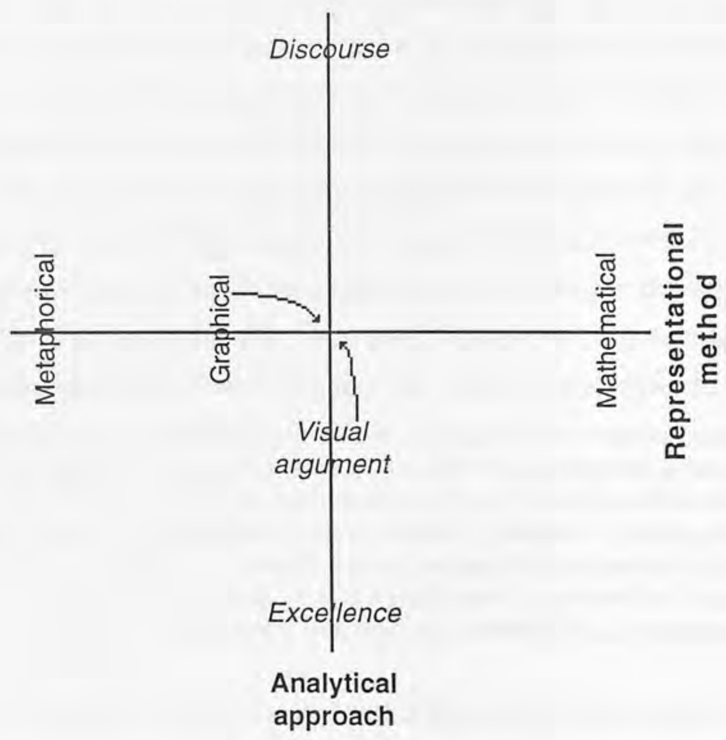

Figure 2.1
Matrix of representational methods and analytical approaches.

2.1 EVALUATING THE CHOICE OF REPRESENTATIONAL METHOD

There are three main methods that may be used in a conceptual examination of graphics: metaphorical, mathematical and graphical. One method is not necessarily better than the others since the method should be matched with the purpose of the research, thereby providing justification for that choice.

Metaphorical

The metaphorical tradition was pioneered by Pepper (1942), Kuhn (1962, 1970) and Hesse (1964). Metaphor is often regarded as a device to embellish discourse, but its significance is much greater than this "for the use of the metaphor implies *a way of thinking* and *a way of seeing* that pervade how we understand our world generally" (Morgan, 1986: 12, emphasis in original). Research in a wide variety of fields has demonstrated that metaphor exerts a formative influence on science, language, thinking and expression. Booth-Cibborn and Baroni (1980) maintained that it was characteristic of the human mind to think in metaphors; some objects are understood more readily with others. Rubin (quoted in Nussbaum & Neff, 1991: 41) claims that "metaphors are a way to draw a strong analogy to things people use in the real world". In computing, the metaphor — not the medium — is the message. The use of icons, popularised by Apple Computer's Macintosh personal computer, makes it far more accessible to the general population; the metaphor used on the screen — the Mac's use of a 'trash can' for deleting unwanted files — is a classic example.

Novitz (1977) discussed the philosophical aspects of the *visual* metaphor. Its use allows the reader to make both a visual and a conceptual link between the image and its intended portrayal; this leads to one idea opening the way to the transference of many. Visual metaphors can be applied to image *and* text: as appropriate, natural expressions they can improve the quality of graphics in printed media (Wainer, 1980) while Fyfe and Law (1988b) acknowledged their influence on the construction of sociological terminology. The latter point remains true for the study of innovation: matrices, flow charts, networks, S-curves, life cycles, clustering, trajectories — there are many that spring to mind. Small *et al.* were more explicit:

> When speaking about science we often use geographical or spatial metaphors such as 'field' of research or 'area' of specialization. The term 'interdisciplinary' suggests that there is space between disciplines and that boundaries between subjects exist in some sense. For whatever reason, we find it natural to think about science, and other abstract systems, in spatial terms. Perhaps this is rooted in the way information is stored in the brain, or it is a response to our need to 'visualize' a complex set of facts, the same need that leads scientists to build models of physical processes. (1985: 321)

DeVore (1980) highlighted that even the perception of technology was based on the extensive use of metaphor, e.g. the 'machine age' or the 'age of steel'. A metaphorical method, then, examines these types of analogies.

Mathematical

The use of graph theory started in 1736, according to Biggs *et al.* (1976). Tilling (1975: 193) claimed that the graphical presentation of experimental data provides "a rough and immediate check on the accuracy and suitability of the methods that are being used". There are occasions where *only* the analysis of experimental graphs will provide the information that is required, but usually the analysis of the results is carried out by computational methods. Therefore, the use of graphs is not so much a *necessary* part of scientific procedure as an extremely *useful* one. While it is a small conceptual step from the geometrical representation of a mathematical function to the mathematical interpretation of a simple experimental curve, the idealised relationship between physical quantities is expressed typically in algebraic or geometric form; the graph's usefulness as a *technique* is unrecognised. Concurring with Tilling (1975: 196), "to take advantage of the graphical mode of presentation ... [means] attempt[ing] to analyse the results given". Consequently, a mathematical approach is more of a presentational approach.

Graphical

Although graphics are employed for representational purposes in both the metaphorical and mathematical traditions, it is not the primary mode of communication for these methods. Indeed, there has often been polarisation between them. According to Koopmans (1957: 173), the "oldest mathematical tools in economics are the numerical example and the diagram". The diagram, in particular, is used as a visual aid to scientific discourse. Koopmans argued, however, that the

> eye is essentially the organ of perception rather than of reasoning. Nothing in the process of reading a diagram forces the full statement of assumptions and the stepwise advance through successive implications to conclusions that are characteristic of logical reasoning. (1957: 174)

More recently, economics has adopted formal mathematical concepts and theories that meet Koopmans's demands for a full statement of assumptions and display of reasoning; the use of formal mathematical proofs as a shorthand for logical reasoning is now a common form of visual presentation in economics research.

Similarly for innovation, the study of science and technology in the past has reflected the parallelism of model and method. Shrum and Mullins (1988: 108) cited Breiger (1976) and Collins (1974) as contrasting poles; they claimed Breiger's work was a "primarily methodological exercise" while Collins's was "imagery without the technique". The polarisation between and limitations of the metaphorical and mathematical methods — a metaphorical method may be too abstract while a mathematical one may be too precise — belie the reliance, in practice, on graphics as a mediator between them. This makes it ideal for adoption for this type of research.

Summary

The choice of a graphical method is logical for this thesis. A metaphorical or mathematical examination *is* possible, but would offer only qualitative or quantitative results respectively. The selection of a graphical method allows either interpretation with equanimity. However, there are a number of approaches that must be considered too and, just like the methods, they may be realised as a continuum.

2.2 A CONTINUUM OF ANALYTICAL APPROACHES

Stiles (1993: 101) believes that image is challenging the supremacy of the written word as researchers seek alternative means of analysis, "yet, despite fifteen-thousand years of art history, the use of image as a scientific instrument is still in its embryonic stages". In a wide variety of management texts, illustrations, charts and diagrams serve to summarise, clarify and enrich verbal arguments. Anyone with access to a personal computer can now produce technically sophisticated images; even if an individual's drawing abilities do not match those of a graphic designer that person is beginning to understand the visual process and is becoming image literate. Pictures have never been just a means of decoration; often they have been used to convey meaning (Gropper, 1963). It is endeavouring to understand this meaning that has created choices in the approach to undertake this.

Bachi (1978a) maintained that the theoretical background of graphical methods should be re-investigated from various viewpoints: mathematical, statistical, psychological, and so on. Representation has varying meanings in different disciplines, as Howard (1980) demonstrated. To philosophers, it means some sort of picture, a definition familiar to designers. The term is also used more broadly to signify any inscription that carries information — a picture, word, number, and so on. Psychologists have come to use the designation in another way, referring to how knowledge is expressed within the nervous system or the mind. So, among philosophers, representations are symbols that *refer to* knowledge or inscriptions that are members of some system used to *express* knowledge, but for psychologists they are often the mental embodiment *of* knowledge. Such distractions have curtailed the theoretical discussion of representation and there has been a lack of interdisciplinary interaction. This situation suggests that a clear understanding of the issues involved in and invoked by the term is needed.

Graphic-based theories may be used to analyse a sample of graphics, practically and conceptually.* It is possible to contrast the different representational approaches

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* Lowe (1993) makes the distinction between external aspects of representation — the application of established principles of graphic design in developing effective diagrams that apply at a general level across a wide range of subject domains — and internal (mental) aspects — those effecting a specific set of subject matter that influence what *sense* viewers make of a diagram. This thesis examines concepts using external aspects while Lowe's study compares the mental representation of weather maps by meteorologists and non-meteorologists.

and how they may influence this. Novitz (1977) maintained that a graphic may be used in many — often radically different — ways and chronicled the dilemma between convention and resemblance and between novelty and freedom of expression. Likewise, this duality is reflected in the choice of an approach. The review of the literature in the following sections is not intended to be comprehensive; rather it hints at the multiplicity of theories and interpretations that may be applied.

2.2.1 Pictorial representation: *discourses* and beyond

Within the social sciences, the implications of the omnipresence of visual imagery and the ordinary viewing of human beings was first identified by Simmel (1921: 358) with the claim that, of a human's five senses, "the eye has a uniquely sociological function". Simmel's fundamental point was about the enormous significance of the visual mode in social life. Becker (1979: 73) observed that "visual social science isn't something brand new … but it might as well be". Visual sociology, e.g. Becker (1981), is a rather more developed specialism than visual anthropology, e.g. Collier and Collier (1986); while the latter specialism *does* contribute to an understanding of this research, it is eclipsed by the former. Thus, it seems pertinent to review its influence and how it might effect the analysis of graphics. This is followed by brief reviews of the contribution of structuralism, semiology and philosophy.

Visual sociology and the sociological analysis of visual representation

Visual sociology has a history dating back to the 19th century as Stasz (1979) has documented. Among classical sociologists, Simmel's concern for visual depictions was unusual and it was not until the 1970s that a renaissance in this field could be detected, e.g. Becker (1974), Foucault (1974, 1979), Goffman (1976b), Bourdieu (1984) and Elias (1987).* The increasing interest in visual sociology has been more recent (Henny, 1986), particularly in the sociology of science and technology, e.g. Callon *et al.* (1986a), Bijker *et al.* (1987a), Fyfe and Law (1988a), Lynch and Woolgar (1990a) and Bijker and Law (1992a). The sociological analysis of visual representation now attracts serious attention, though Latour and Bastide (1986) maintained that the study of the image is less developed than the study of text and writing; over ten years later this still holds true.

Lynch and Woolgar (1990b: viii) welcome the increased attention devoted to visual forms of representation compared with the "privilege traditionally assigned to the verbal statement or 'proposition'." However, the tendency of transferring "correspondence theories from a propositional to a pictorial base" should be avoided; using diagrams or photographs "simply to describe the things they depict or the meanings they reflect" does them an injustice (Lynch & Woolgar, 1990b: viii). Instead, they argue for the need to pay "extraordinary attention to the distinctive

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* Beniger and Robyn (1978: 1) noted that, even in the late 1970s, "visual forms have passed virtually unnoticed by historians and sociologists of knowledge and science".

surfaces upon which representations are inscribed and the translations they undergo when transferred from one activity to another" or, in other words, "textual arrangements and discursive practices" (Lynch & Woolgar, 1990b: viii–ix).

Following Foucault, Lynch and Woolgar (1990c) contrast *resemblance*, the degree to which a depiction resembles the inherent characteristics of an original referent, with *similitude*, the significance of similarities between depictions that are disclosed through juxtaposition. Resemblance is 'crafted', a product of Gombrich's (1977) *illusionist* 'technique'; similitude, on the other hand, is an "inescapable resource" whose "chains and networks ... are laboriously built up" (Lynch & Woolgar, 1990c: 7). Representational devices used in science comprise graphs, diagrams, equations, models, photographs, instrumental inscriptions, written reports, computer programs, laboratory conversations and hybrid versions of these. According to Lynch and Woolgar (1990c: 7), the purpose of the analysis of representations is to "expose the conjuror's tricks" by which similitude is presented as resemblance. The task for sociologists is to address the "socially distributed competencies which establish the theoretic sense and import of any representational device", not to "learn to use representations in more rigorous, convincing, defensible ways" (Lynch & Woolgar, 1990c: 12). The method adopted to achieve this is the *particularistic case-study* that questions what the participants treat as representation in various contexts, not what representation means generally.

Fyfe and Law (1988b: 1) asserted that a depiction was not merely an illustration, it was a site where an active process of construction based on "principles of exclusion and inclusion" was expressed. This *material representation* marks where "a process of production gives way to a range of effects"; thus, there is a need to study "both the processes that lead to the creation of depictions, and the way in which they are subsequently used" (Fyfe & Law, 1988b: 1). They argued, after Simmel (1950) and Bell (1976), that even the modernisation of the world has a "distinctively visual aspect" and made a plea for "the visual to be taken seriously", even where the object of study is not explicitly visual in an obvious way (Fyfe & Law, 1988b: 3, 6).

There are two aspects of Fyfe and Law's (1988b) argument that are particularly relevant to this thesis. The first concerns what are termed *technologies of summarisation* where features of an object are quantified and then simplified using the "normal technologies of statistical manipulation"; this process often leads to "a visual display — a table, or a graph" (Fyfe & Law, 1988b: 4). The low utilisation of this type of depiction within sociology was explained, rather surprisingly, as arising from the "relatively uncontroversial" definition of objects in "most areas of scientific inquiry" outside sociology (Fyfe & Law, 1988b: 4). The second is the depiction of *individual* empirical elements — as opposed to *summary* data above — leading to the inference being drawn, after the consideration of data collected from the natural sciences, that "*seeing is believing*" (Fyfe & Law, 1988b: 4, emphasis in original). In sociology, however, belief arises from other sources; Fyfe and Law (1988b: 5) maintained that the "relative indifference to visual evidence" in sociology goes beyond its nature. Depictions in science were "constitutively conventional in character" (Fyfe & Law, 1988b: 5), leading to the development of visual languages in science, e.g. Rudwick (1976), Tufte (1983) and Fox and Lawrence (1988). That this had not happened for sociology Fyfe and Law (1988b: 5, 6) ascribed to "theoretical fragmentation" and "disputes about visualisation". Indeed, Turner (1984) has also accounted for the marginalisation of the visual in sociology and maintained that the analysis of perception and representation had resurfaced in psychology, biology, art history and anthropology.

Law and Whittaker (1988: 163, 161) have suggested that the role of technologies of representation was "constitutively political" in documents that were "*about* science" or that mapped the "dynamics of science" (emphasis in original). Through the analysis of a policy-oriented book, Law and Whittaker (1988: 162) "show the way in which a range of strategies underlie the rhetoric of representation [by] attending to the matched processes of suppression and creation that appear to have operated in the production of selected figures": different strategies generate different depictions of the world. The case is a useful example of how to study the "various techniques of visual representation and the way in which they become legitimated" (Law & Whittaker, 1988: 180); it was written from the standpoint of the sociology of translation and concerns the depiction of science by non-scientists. Their argument was that technologies of representation suppress what they purport to represent and create novel expressions to portray what has been subdued. Consequently, they maintained that the specificity of technologies of visual representation deserves analysis in its own right.

Three forms of visual representation are identified and analysed as "rhetorical technologies of simplification, discrimination and ... integration" (Law & Whittaker, 1988: 171, 169). One is the use of photographs to represent the 'purity' of the environment. The second is the use of *semi-naturalistic sketches* that, through scaling and stylisation, facilitate strong claims about specific causal relations. According to Law and Whittaker (1988: 181), they combine "a version of perspectival recognisability with quite deliberate conventional departures from that recognisability"; recognisability provides a general 'warrant' of representativeness. The departures from perspectival expectations make it possible to detect the typical relations linking the objects that have been so discriminated. The third is the use of graphs.

The function of graphs is to "re-present an unknown number of heterogeneous and intractable objects and measurements" (Law & Whittaker, 1988: 176). This form of visual depiction draws on the "technologies of quantification" that represent "an immensely powerful set of techniques for suppressing and merging objects into forms that are docile and easily manipulated" (Law & Whittaker, 1988: 181). Results from this process "are susceptible to visual depiction in terms of a limited number of conventions of which tables and graphs are the most obvious examples"; their 'warrant' is considered to arise from their 'democratic' character in which "many discriminable objects are able to find ... [a] voice" (Law & Whittaker, 1988: 181). Latour and Bastide (1986) maintained that readers could question the designer's claims embodied in a figure in two ways. Firstly, the reader could accept the claims, "but refuse to go to a level higher and refer to the sense of the legend" (Latour & Bastide, 1986: 57). Secondly, the reader could ignore the claims and "go to a lower level by referring directly to the experiment" (Latour & Bastide, 1986: 57). Both ways challenge the graphic's content.

Latour (1990: 21, 22) seeks an alternative to the *materialist* and *mentalist* models of the development of science in explanations that consider "writing and imaging craftsmanship", "the way in which groups of people argue with one another using paper, signs, prints and diagrams", and "inscriptions ... [and] the practice of inscribing" without adopting a *simplistic relativist* position. Latour (1990: 24) recognises that, with the pervasiveness of texts and images confining explanation to "the level of visual aspects only", there is the danger of merely producing a "series of weak clichés" or becoming diverted to many "fascinating problems of scholarship". Instead, the study should be combined with an analysis of the agonistic interaction between authors and how writing and imaging may affect the outcome of this process. To achieve this, inscriptions — called *immutable mobiles* — are needed that have "the properties of being *mobile* but also *immutable, presentable, readable* and *combinable* with one another" (Latour, 1990: 26, emphasis in original); the inventions of perspective in the Italian renaissance and the map in Dutch visual culture are seen as expressions of this. The introduction of the printing press is seen by Eisenstein (1979) as a critical development since it makes mobilisation *and* immutability possible simultaneously.

Though much of the sociology of science literature discusses the use of visual representation within natural science, Latour (1990: 39) believes that there is "no detectable difference between natural and social science, as far as the obsession for graphism is concerned": whether one looks at nature or the economy, the scientist or economist only *sees* a visual construction — an inscription or two-dimensional image. According to Latour (1990: 38), it is the *process* of "visual construction [that] ... begs explanation". Latour (1990: 46, 47, emphasis in original) maintains that the greatest advantage of the *two-dimensional inscription* is that it can "*merge with geometry* ... [:] everything ... can be converted into diagrams and numbers"; cascades occur of "ever more simplified" inscriptions that are more powerful through mobilisation. Latour (1990: 52) concludes that "all innovations in picture making ... will be selected for or against depending on how they simultaneously affect either inscription or mobilization".

The use of metaphorical imagery and perception

Ivins (1953) maintained that science and technology has some special communication needs to which print is well suited, believing that the invention of print was an essential precursor to the scientific revolution and that the growth of science was dependent on the exact replication of graphic images. Kuhn (1962, 1970) claimed that the communication of science in print followed a path: first was the announcement of new theories in journals or conference proceedings; this was followed by its appearance in texts and then in popular books using everyday language; finally, theories were incorporated in philosophical works and retrospective reflections.

Systematic studies of science content in the *mass* media confirm that the public presentation of science is rarely shaped by 'objective' scientific issues. Instead, images of science are shaped by — and sometimes intended to shape — particular cultural contexts. A relatively new area of research involves how the images of science and technology are conveyed by metaphor and other writing strategies. Considerable work has been completed in the USA and Canada on science and the media.* Nelkin (1987) examined how the image of science and technology was conveyed and represented by the printed media in the USA. Through a study of publications, including *Business Week*, *Science*, *Time*, *Newsweek*, the *Washington Post*, the *Wall Street Journal* and the *New York Times*, Nelkin showed that imagery often replaced content and substance, though this tended to be metaphorical rather than graphical, reinforcing the former's importance.

Davies *et al.* (1990) examine the growing dominance of visual over written communication.† However, there is a lack of practical detail about how people produce, interpret and reproduce pictures, arising from their assumption that these details are unproblematic. The notion that the rise of images will remove the barriers between disciplines with specialised languages is flawed since visual conventions have to be learnt just like language; not even iconic traffic signs are transparent, as Bertin (1983) has shown. Their survey of "the changing balance between the use of words and numbers, on the one hand, and of pictures and images on the other" *is* substantial though, presenting a choice between "one-dimensional information ... and two-dimensional ... images" (Davies *et al.*, 1990: 1, 4).

Davies *et al.* identify four broad historical periods. The first, until about 1000 BC, relied on pictures, pictograms and symbols for recorded communication. The second, from 1000 BC to 1500 AD, saw the dominance of words and numbers in recorded communication, with an important role for painting, but still reliant on individuals with writing skills. The development of printing at the end of the 15th

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* For instance, the Canadian Ministry of State for Science and Technology-sponsored survey (Dubas & Martel, 1975); Friedman *et al.* (1986); Nelkin (1987); Einsiedel (1992).

† For instance, molecular representation is based on the processes of selection and interpretation (Lynch, 1985; Amann & Knorr Cetina, 1990) and that they produce different effects suggests different objectives (Bastide, 1990; Myers, 1990). The discovery of the structure of DNA is an instance of visual thinking in biology.

century heralded an era in which words and numbers were the principal devices used in the new medium, though engravings also figured. The 100 years from 1850 saw the emergence of photography, with the new technology for pictorial representation becoming increasingly important and affecting the printed medium. But words and numbers were still dominant in the era of near universal literacy. From 1950, the emergence of video and computer technology has been accompanied by an "explosion of pictures" (Davies *et al.*, 1990: 35) and has seen a general shift towards the visual communication of information in contrast to the traditional reliance on text. Davies *et al.* (1990: 151) conclude that the development of the "powerful range of pictorial techniques" amounts to a "new era of communication" and the ability to learn the new methods will be critical to the pace of change.

Gombrich (1977) maintained that processes of seeing were subject to cultural and historical conventions: what readers see may depend on the institution of seeing involved. This supposition was derived from drawing a connection between the psychology of perception and the act of interpreting works of art. Hogben (1949: 183) pointed to the emergence of pictorial symbols as the "birth ... [of] an international ... [and] universal picture language" and means of communication, particularly in the natural sciences, and argued for a newly enhanced role in education and popularisation harking back to Comenius. Kuhn (1970) argued that consensual ways of seeing in science existed mainly through shared paradigms, consisting of rules and standards for correct scientific practice. Under this view, what scientists observe should be grounded in their commitments to particular research traditions or, according to Merleau-Ponty (1962: 78), "what you see depends on where you sit". Whatever role perceptual grammars may have in shaping what counts as evidence in different disciplinary traditions does not resolve the problems associated with the visual in day-to-day usage; just as scientific facts are the end product of processes of belief fixation, so visual data are the end product of socially organised procedures of evidence fixation.

(Post)structuralism, semiology and philosophy

Structuralists assume that content is a function of form and code and that meaning is a product of a system of relationships. Structuralism is a theoretical perspective *and* a methodological approach. Poststructuralism contains modifications of structuralist themes; poststructuralists urge reconsideration of written texts and their formulation, constitution and conventional interpretation. As the conventional canons of interpretation reflect dominant values (and writers), they obscure — to some extent — the virtues of writers, ideas, perspectives and values deemed marginal. In this sense, poststructuralism turns attention to the margins and reverses the usual adherence to dominant cultural values. A text, in poststructuralist terms, is not an object, but an occasion for the interplay of multiple codes and perspectives. This may be extended to a graphic, in conception, in application and in method.

A more general (and applicable) framework than visual sociology was provided by Foucault, who espoused a poststructuralist philosophy that also encompassed semiology. Foucault's (1974) focus was the analysis of *discourses*, defined as the group of *statements* that belong to a single system of formation. The statements that comprise a particular discursive formation were clearly identified as including graphic forms that were distinct from linguistic ones — "a graph, a growth curve, an age pyramid, a distribution cloud are all statements: any sentences that may accompany them are merely interpretation or commentary; they are in no way an equivalent" (Foucault, 1974: 82). Foucault described Linnaeus's classificatory table of botanical species, *Genera Plantaruma*, as a book of statements with only a small number of sentences; a genealogical tree was denoted similarly.

Semiotics provides a set of assumptions and concepts that permit systematic analysis of symbolic systems conveying image and effect. It assists in transforming data into information, and impression and effectiveness are achieved by this. Semiology is concerned with the existence of a general science of signs, of which linguistics forms only one part. It aims to take in any system of signs, whatever their substance and limits: images, gestures, musical sounds, objects and the complex associations of all of these that form the content of ritual, convention or public entertainment constitute, if not *language*, at least systems of signification. There is no doubt that the development of mass communications confers particular relevance today upon the vast field of signifying media. However, an in-depth study of this field is rendered difficult by variety of interpretations that maybe realised. This could be a study within itself and it is beyond the scope of this thesis to attempt it. However, the subject is broached to show its relevance and contribution: works like Lynch and Woolgar (1990a) *have* successfully combined studies of semiology, ethnomethodology and art theory from a sociological standpoint.

Concluding with the role of philosophy, Novitz (1977: xi) asserted that, "in what is nothing less than a visual age, philosophers have had … little to say about the visual image and its use in communication". According to Novitz, the modern use of graphics has more to do with the philosophy of language and epistemology than it has to do with traditional aesthetics.

Summary

Scientists *do* use the full range of literary devices and artistic conventions available to them (Edgerton, 1976; Alpers, 1983).* The review of the sociology of science literature shows that, while most empirical attention has been directed towards *practice* within the natural sciences, many concepts are potentially applicable to the representation of innovation within the business and policy communities. Indeed, Pinch and Bijker (1984, 1986) have argued that the analytical tools of the sociology of sci-

* Despite this, Vinck and Jeantet (1995: 124) are unusual in their use of a diagram to help visualise various theoretical viewpoints for *objects*, defined as "texts, drawings, software".

ence may be readily transferred to the study of technology. This notion follows the philosophical tradition of structuralism — the emphasis on relationships *between* elements rather than elements themselves — and the influence of positivism that, after Comte, methods of natural sciences are appropriate to social sciences.

Scientific discourse comprises ordinary language, diagrams, equations and special notations; this is what scientists use to describe their subject matter. Macdonald-Ross (1977a: 69) concluded that a study of how these linguistic and graphic systems combine would be "important and interesting", helping in the quest to understand the central issues of graphic communication. However, no such investigation has been identified as being attempted; Macdonald-Ross conceded that even partial examinations — focusing on particular subject matters or graphic formats — were quite rare. Social scientists tend to use their own descriptive terms when analysing visualisations (Callon, 1986). One way of preventing this is to adopt the language of the subject under investigation (Latour, 1987). Some knowledge of graphic theory is therefore useful, if not essential. It also provides the alternative approach in the continuum to examine graphics.

2.2.2 Graphic theory: analysing *excellence* through technique

Although graphics are widely used for analytical purposes in business research, it is important to recognise that they merit study as forms of communication and expression as well. Rather than being a qualitative analysis of the meanings or *discourses* generated, graphic theory focuses on the technique underlying graphics, applying a more quantitative analysis; Tufte (1983, 1990a) and Bertin (1981, 1983) are its principal proponents.* Great emphasis has been placed on the importance of graphic representation by companies; Tufte's works have been widely promoted to the business community.† The general issue of the communication of complex information has also received attention: Bertin has deduced a comprehensive, logical model from the principles of graphic theory to examine printed visual representation.

However, Tufte's and Bertin's methodologies were entirely different, addressing the graphic problem with different emphases that vary in their rigorousness. Bertin established a strict methodology, applying it to the subject matter to demonstrate why graphics were categorised thus. It is more of a scientific approach and the structure is such that it is possible to identify a definite schema of construction. Tufte's methodology — and terminology — is less precise or restrictive. Moore (1979: 131) maintained that there was "an art to presenting complex data clearly, an art best learned by example"; Tufte adopted this approach to derive a theory and descriptive

* Wainer and Thissen (1981: 233–234) maintained that much of Tufte's theory had its basis in the work of Bertin (1981, 1983) "who provides a thorough if idiosyncratic theory of graphic display".

† They are advertised in the general news section of daily and Sunday broadsheet newspapers (e.g. *The Observer*, 25 February 1996: 16), as well as in the business section (e.g. *The Observer*, Business Section, 14 January 1996: 7).

terminology from an examination of good *and* bad graphical practice. The emphasis is *de*construction; Tufte took the role of a social scientist and ascribed theory from practice. The following sections provide an examination of the work of Tufte and Bertin; according to Kolers (1980: 499), "theory surrounds us; we are immersed in it, and better to make it explicit than keep it tucked away in unspoken and sometimes unrecognized assumptions". In addition, as Lowe highlights,

> there are many diagrams that are a firmly entrenched part of a particular knowledge domain. As a consequence, those who wish to find out about that domain are obliged to develop competence in dealing with such diagrams. (1993: 4)

An introduction to graphic theory is presented in Appendix Two.

Tufte's *good principles*

For Tufte, visual representation was theory-driven, emphasising maximising principles, empirical measures of graphical performance and the sequential improvement of graphs through revision and editing. *Excellence* in graphics "consists of complex ideas communicated with clarity, precision and efficiency" (Tufte, 1983: 13). The four fundamental graphic designs provide the base on which to achieve this.

Tufte's fundamental graphic designs

Data maps convey large volumes of data in small spaces.* The data may be considered in many different ways at many different levels of analysis, ranging from general overall patterns to the detection of fine detail. However, the visual impression of the data is combined with the circumstance of geographical boundaries, shapes and areas; the reader wrongly equates the visual importance of each plotted area with its geographical area, rather than with its corresponding plotted variable.

The **time-series plot** is the most frequently used graphic construction. The natural ordering of the time-scale, represented on the horizontal axis, provides this design with a strength and efficiency of interpretation found in no other graphic design. Multiple time-series enforce comparisons within each series over time — as do all time-series plots — and between the plots, i.e. vertically. Time-series displays are most suitable for big data sets with real variability. Their problem is that the passage of time is not a good explanatory variable: descriptive chronology is not causal explanation. There are exceptions, especially when there is a clear mechanism that controls the vertical variable. Time-series plots can move more towards causal explanation by incorporating additional variables into the graphic design.

An effective device for enhancing this is to add spatial dimensions to the design of the graphic so that the data are moving over space — in two or three dimensions — as well as over time. Tufte's third fundamental graphic design was termed a **space-time narrative design**. Tufte did not allude to its drawbacks, but commented that it occasionally seemed "belligerently multivariate" (Tufte, 1983: 40), i.e. displayed the technique rather than the data.

---

* Data maps are termed *thematic maps* in cartography.

Relational graphics plot any variable quantity against any other variable quantity, measured for the same units of observation. Since it is relational and not tied to geographic or time co-ordinates, this design is especially relevant to all quantitative enquiry. Tufte (1983) claimed that about 40 per cent of graphics published in modern scientific literature had a relational form, with two or more variables — none of which were latitude, longitude or time. The relational graphic in its most simple form is the scatter plot and its variants; it links at least two variables and encourages the reader to assess the possible causal relationship between the plotted variables. It confronts causal theories that X causes Y with empirical evidence as to the actual relationship between X and Y. However, Tufte again failed to mention any significant factors that might count against it when considering it as the basis for a construction.

These designs can be reproduced in miniature to represent motion. *Small multiples* are a "series of graphics, showing the same combination of variables, indexed by changes in another variable" so that they resemble "the frames in a movie"; "the design remains constant through all the frames, so that attention is devoted entirely to shifts in the data" (Tufte, 1983: 170). In creating well-designed small multiples, Tufte (1983: 175) asserted that the frames must be "inevitably comparative", "deftly multivariate", "shrunken, high-density graphics", "efficient in interpretation" and "often narrative in content".

The principles of graphical excellence

According to Tufte, graphical displays should:

- show the data
- induce the viewer to think about the substance rather than about methodology, graphic design, the technology of graphic production, or something else
- avoid distorting what the data have to say
- present many numbers in a small space
- make large data sets coherent
- encourage the eye to compare different pieces of data
- reveal the data at several levels of detail, from a broad overview to the fine structure
- serve a reasonably clear purpose: description, exploration, tabulation, or decoration
- be closely integrated with the statistical and verbal descriptions of a data set (1983: 13).

Thus, graphical excellence is the well-designed presentation of interesting data; it is a matter of substance, statistics and design. Excellence in statistical graphics consists of complex ideas communicated with clarity, precision and efficiency. It gives the reader the greatest number of ideas in the shortest time with the least ink in the smallest space and is nearly always multivariate.

The principles of graphical integrity

A graphic does not deceive if the visual representation of the data is consistent with the numerical representation. There are problems though in defining whether visual representation is as physically measured or as visually perceived: different people see the same areas differently and perceptions change with experience — they are context-dependent (Macdonald-Ross, 1977b). However, graphical *integrity* is more likely to result if Tufte's principles are heeded.

> The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.
>
> Clear, detailed, and thorough labelling should be used to defeat graphical distortion and ambiguity. Write out explanations of the data on the graphic itself. Label important events in the data.
>
> Show data variation, not design variation.
>
> In time-series displays of money, deflated and standardized units of monetary measurement are nearly always better than nominal units.
>
> The number of information-carrying (variable) dimensions depicted should not exceed the number of dimensions in the data.
>
> Graphics must not quote data out of context. (1983: 77)

Violations of the first principle constitute one form of graphic misrepresentation, measured by what Tufte called the *lie factor*:

$$\text{Lie Factor} = \frac{\text{size of effect shown in graphic}}{\text{size of effect in data}}$$

If the lie factor is equal to one, the graphic is accurately representing the underlying numbers. Lie factors greater than 1.05 or less than 0.95 indicate substantial distortion, far beyond minor inaccuracies in plotting.

Tufte also suggested that a large share of a graphic's ink should present data, the ink changing as the data change, i.e. data should be packed into as small a display space as possible; this measure of *data density* can be used to assess whether a graphic is meaningful. Of course, human perception places limits on the size of marks used to plot the data and how close they can be and still be distinguished. Along with legibility come other limitations such as the quality of photocopier reproductions and the aesthetic appeal of the graph in the publication. An examination of the graphical displays with very high data densities contained in Tufte (1990a) reveals that most are either maps or use time as one of the planar dimensions. These forms are the least abstract and most used displays, indicating that there may be a relationship between the level of abstraction of a particular graphical form and the data density that can be employed. With more abstract, less common designs, it may be necessary to use less dense graphics.

Each part of a graphic generates visual expectations about its other parts and this determines what the eye sees. Deception results from the incorrect extrapolation of visual expectations generated at one place on the graphic to other places. A scale moving in regular intervals, for example, is expected to continue in a consistent fashion, without any non-uniform changes, to prevent design variation. The confounding of design variation with data variation over the surface of a graphic leads to ambiguity and deception, for the eye may mix up changes in the design with changes in the data. A false impression can also be created by design gimmicks or — as Tufte termed them — *chartjunk*. Another way to confuse data variation with design variation is to use areas to show one-dimensional data.

Bertin's *rules*

Bertin (1980: 586) developed a structure and language to analyse graphic displays, claiming that communication theory was not relevant to graphic perception and therefore "such tests as 'What do you see?' 'What do you prefer?' bear no relation to the objective of the graph". Bertin (1981: 1, 16) believed that the design of a graphic was not an art, in contrast to pictography, "it is a strict and simple system of signs, which anyone can learn to use. ... A graphic is not 'drawn' once and for all; it is 'constructed' and reconstructed until it reveals all the relationships constituted by the interplay of the data". Bertin (1980) maintained that there were no good or bad graphics; rather, some constructions answer the questions that are asked of it and others do not. Bertin did not believe that a graphic should be constructed *solely* for publication; its purpose is to analyse information and so only what was necessary and sufficient for this should be published.

Bertin (1983) defined information as the creation of a relationship between a set of variational concepts — called *components* — and an *invariant* — the central notion common to the relationship — from data that has been recorded. When the components are plotted on a graphic, they are represented by *variables*. The different identifiable parts of a component are called *elements*. Bertin isolated eight *visual variables* that determine how a mark (this may be a *point* — a position without area, a *line* — a linear position without area, or an *area*) may be represented in a graphic: they are the two planar dimensions (i.e. position according to the two dimensions of the axes) and the six *retinal variables* used to represent the third component, which may vary in size, value, texture, colour, orientation and shape. Figure 2.2 shows this.

Bertin's groups of imposition

Bertin called the utilisation of the planar dimensions the *imposition*. The nature of the relationship expressed in the graphic enables representation to be divided into what was termed *groups of imposition*. If a relationship in the graphic may be observed

- among all the elements of one component and all the elements of another component, the construction is a **diagram**.
- among all the elements of the same component, the construction is a **network**.
- among all the elements of the same component located in the graphic according to an observed geographic distribution, the network becomes a **map**.
- between a single element and the reader, it being exterior to the graphic image, then this is a problem involving symbolism that relies upon figurative analogies,

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Figure 2.2
Visual variables.
Adapted from Bertin, 1983: 43.

e.g. road signs, map codes and the like. This category has been excluded for the purposes of this research.

These divisions are represented in Figure 2.3.

Bertin's types of construction

For diagrams and networks, the free distribution of the dimensions of the graphic leads the reader to distinguish arrangements dispersed over the entire plane from those that structure it in some manner. Types of construction, termed *types of imposition* by Bertin, may be defined and characterised by schemas of construction.

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Figure 2.3

Schemas of construction: *groups* and *types of imposition*.
Source: Bertin, 1983: 52.

There are four principal constructions for diagrams with two components:

1. *Rectilinear* **construction** or **elevation:** For the construction, a straight line represents the total and it is divided into parts proportional to the quantities in each element. The second dimension of the graphic is not used. For the elevation, the areas are proportional to the quantities.
2. *Circular* **construction** or **elevation:** The construction is a circular version of the rectilinear construction. The elevation is obtained by curving the rectilinear elevation.
3. *Orthogonal* **construction:** Each axis of the graphic represents a component.
4. *Polar* **construction:** This is a circular version of the orthogonal construction.

Figure 2.4 represents the choices.

For diagrams with three components, Bertin defined the standard construction as the orthogonal with special cases requiring the usage of continuum, triangular or polar constructions. For diagrams with more than three components, graphic information-processing is necessary to simplify the data and thus the standard construc-

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Figure 2.4
Types of diagrammatic construction.
Source: Bertin, 1983: 195.

tion is the reorderable matrix, though an image file, an array of curves, a collection of ordered tables and a collection of maps may also be used.

For networks depicting one component, the situation is similar, with four principal types of construction:

1. **Irregular** or **regular** ***arrangement*:** The entire space is used to arrange the elements. For the irregular arrangement, neither of the planar dimensions are meaningful, but if either or both are used it becomes ordered and thus a regular arrangement.
2. *Rectilinear*: This orders the elements and depicts the relationships as curves.
3. *Circular*: By arranging the elements in a circle, relationships may be portrayed as

straight lines.

4. *Orthogonal diagram* — **parallel alignments** or **matrix:** The component is represented twice. Parallel alignments are useful for comparing (statistical) orders while the matrix can lead to the simplification of complex information by diagonalisation.
5. *Perspective drawing*: Whatever the arrangement of at least five points in a graphic, their correspondences will produce at least one meaningless intersection, though if three-dimensional space is used it is possible to avoid this.

Figure 2.5 reproduces the 20 types of network construction identified by Bertin.*

Image theory

The designer chooses one of the above constructions due to its *efficiency* — that it requires a shorter period of perception than another construction. The *rules of construction*, represented by standard schemas, define the most efficient construction for a given case. The *rules of legibility* govern the choice and utilisation of the (combination of) variables to increase differentiation. Three types of question can be asked of the information in a graphic, ranging from the very specific to the very general. To define the image (and answer the question), the reader will focus on that which meets their criteria. Since efficiency is inversely proportional to the number of graphics necessary for the perception of the data, it is this rule that governs the choice of preferred questions and leads to identifying the three purposes or functions of *graphic representation*:†

1. *Recording information*: Creating a storage mechanism that avoids the effort of memorisation. The graphic used for this purpose must be comprehensive and may be non-memorisable in its totality.
2. *Processing information*: Producing graphics that permit a simplification and its justification. The graphic should be memorisable (for comparisons) and comprehensive (for choices).
3. *Communicating information*: Creating a memorisable image that will register the information in the viewer's mind. The graphic used here must be perceived rapidly and be memorisable. It may be non-comprehensive, but the image should be a simple one.

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* Understanding is not helped with a change in Bertin's terminology from *irregular arrangement* (1983) to *pattern* (1981), from *regular arrangement* (1983) to *ordered pattern* (1981), and from *perspective drawing* (1983) to *stereogram* (1981). The diagrammatic impositions were also excluded in 1981. In addition, the ordering of these dates may seem confusing. Bertin's (1983) *Semiology of Graphics* was first published in French in 1967 as *Sémiologie graphique*; a second (revised) French edition appeared in 1973 and the English translation is of this edition. Bertin's (1981) *Graphics and Graphic Information-processing* was first published in French as *La graphique et le traitement graphique de l'information* in 1977. So, although their chronology indicates otherwise, *Semiology of Graphics* predates *Graphics and Graphic Information-processing*.

† Feinberg and Franklin (1975) similarly identified three different graphic techniques — display, analysis and communication — that are broadly synonymous with those of Bertin.

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Figure 2.5

Types of network construction.

Source: Bertin, 1983: 270.

Summary

Diagrams, maps and networks are abstract portrayals of the subject matter they represent. However, the mapping of the latter into a graphic is rarely straightforward and typically involves various types of transformation. Apart from the obvious transformation from three to two dimensions, there is a range of other transformations that have been developed such as those that allow non-spatial dimensions — time, semantic similarity, etc. — to be represented in a spatial manner. A comprehensive study of graphics as a means of presenting concepts needs to consider these conventions and what they demand of the reader. Since they are external representations, this aspect of graphics is readily accessible to systematic study given appropriate analytical frameworks by examining the graphics themselves without necessarily looking at the behaviour of graphic users.

Tufte's *good principles* of design are generalised statements of good practice, providing guideposts to improving design, but their strict utilisation in this thesis is more difficult. Several measures facilitate quantification of certain aspects of a graphic, but graphic theory is complicated and intertwined, as shown by Tufte and (particularly) Bertin. This makes any analysis based on the theories subjectively qualitative or restrictively quantitative. For instance, the issue of efficiency may be seen as an entirely quantitative one. Bertin's efficiency schema defined what is most efficient for a given case; these graphics are orthodox and non-comprehensive. Thus, by extension, any graphic that does not comply is inefficient! The problem is that, in defining efficiency, Tufte's theory is not precise enough while Bertin's is too precise. Using Bertin's rules and theory, it seems impossible to construct a user-friendly definition or, indeed, basic categorisation without extensive quantification. It seems prudent, therefore, to regard efficiency holistically in the spirit in which they intend by asking general, non-specific questions. For example, what is the graphic trying to show? Does it achieve this? Is it a good representation? Does it fulfil its purpose? Is there anything confusing about it? Are there any aspects that could be improved?

There are elements of both of their theories though that are applicable to the discursive nature of a conceptual examination. It is not necessary to understand fully the convoluted language, quantitative measures and standard schemas so long as the intent is understood and its purpose may be assessed. Likewise, knowledge of the variety of graphic forms is less necessary than an appreciation of what is trying to be conveyed.* The thesis will examine graphics for their conceptual content, though reference will also be made to design variation. No investigation will be made of misrepresentation by data quality or statistically validity.

* This approach has necessitated synthesising Tufte's and Bertin's theories to develop an analytical framework with which to assess and classify examples; this is discussed in Chapter Three.

2.2.3 Merging in the middle-ground*

Macdonald-Ross (1977a: 78, 49–50) defined a *graphic device* as "an artifact, intended to get across a particular idea to some particular readers" whose purpose was "to display conceptual information: numerical, logical, spatial, and temporal data" and that distinguished itself from "ordinary language" *and* "decorative illustration". It was "specially adapted for presenting scientific, technical, social, and commercial information" and could be grouped in a family — a graphic *format* — that used a particular *system of representation* applied to a specific subject *domain* (Macdonald-Ross, 1977a: 50). Macdonald-Ross believed that graphic formats varied in their degree of directiveness to the reader and whether their purpose was to aid performance of tasks or assist comprehension; the notion of *effective use* was considered to vary with these factors.

Research on graphics draws upon two main sources: "the experience of skilled graphic communicators and the formal laboratory experiments of applied psychologists" (Macdonald-Ross, 1977a: 49). (This is broadly synonymous with the concepts of *excellence* in technique and sociological *discourse* discussed above.) Macdonald-Ross (1977a: 52, emphasis in original) resolved the tension between the "tacit skills" and "systematic empirical testing" of these groups by combining methods to "*externalise* the ... tacit know-how of the ... expert ... so that it [could] be talked about, criticized, and improved" for mutual benefit. This situation has been replicated to an extent in practice where two extremes are mediated in a unifying style. For instance, Gooding (1989) was concerned with experiment as an influence on the imagery scientists use, firstly to construct experience and then to theorise that experience. Addis *et al.* (1993) maintain that most representations of conceptual modelling involve an essential pictorial or diagrammatic representation. Larkin and Simon (1987) asserted that mental images played a role in problem solving analogous to the part played by external diagrams. According to Cheng and Simon (forthcoming), diagrams have an important role in scientific creativity because their representational properties make them effective for problem solving *and* discovery.

This approach has been applied to technical illustration where the aim is not to provide an accurate representation of the device, but to "show to the best advantage whatever ... must be understood ... correct[ly] ... which otherwise might be misrepresented" if a more exact but less communicative format was used (Gibby, 1970: 1). Thomas (1978: 3) agreed with this emphasis, referring to a technical illustrator as a

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* Narin (1978: 35) faced a similar choice when establishing a conceptual framework for the emerging field of scientometrics; on the one hand were descriptive, quantitative 'counting' techniques and on the other were interpretive, qualitative techniques that attempted "to capture the social and philosophical milieus which surround scientific advances". For Narin, the most objective technique — the publication count — was the least relevant while the most relevant technique — the interview — was the least objective. By situating scientometric techniques between these two extremes, Narin felt that they should be capable of producing analyses that were both satisfactorily relevant and satisfactorily objective. That belief is echoed by this thesis.

communicator: "the main purpose of technical illustration is to show a representative three-dimensional picture of an object and, in doing, provide added communication which simplifies and clarifies the visual interpretation of the shape of the object". Fleck urged caution though about graphics being theory-driven:

> When I selected this illustration for the present work, I was tempted to add a 'correct' and 'faithful' one for comparison … . I found one particular photograph in a textbook on dissecting techniques. This too was tailored to theory with orientation lines and indicating arrows added to make it graphically suitable for use in teaching. I thus once again convinced myself that it is not possible to carry out such a comparison. It is only theories, not illustrations that can be compared. (1979: 33–35)

Thus, the context in which the graphic is used is fundamental. Neurath (1936) believed that signs were arranged to construct a *visual argument*. Macdonald-Ross (1977a: 65) maintained that "communication was for a purpose: … statistics were not just displayed, they were organized to get a message across" — a graphic represents a problem so as "to make the solution transparent" (Simon, 1981: 153) or fits "the task onto the strategies available for its solution" (Macdonald-Ross, 1977a: 59). The approach undertaken by the thesis adopts this, maintaining that a graphic constitutes a *visual argument* and that conceptual theories and models may be represented by graphic devices. Accordingly, understanding and representation are aided by visual imagery. It follows that a graphic may assist problem solving, along with its representational role.

This approach is ideal, then. It recognises that innovation graphics may not be graphically 'excellent' and that an understanding of sociological theory may not be fully appreciated by the designer or the reader. (To comprehend a set of phenomena is to learn what kinds of elements there are in the set, to develop a taxonomy; that this has not yet been taken concerning representation, Simon (1981: 154) maintained was due to "sketchy and incomplete knowledge of the different ways in which problems can be represented and much less knowledge of the significance of the differences".) Despite their 'failings', the sense of what the graphic is intended to show *is* understood, e.g. the notion of technological progress. This approach obviates the need for an extensive knowledge of graphics theory, semantics and semiology, (post)structuralism and visual sociology.

Chapter Three
RESEARCHING INNOVATION GRAPHICS: METHODOLOGY

Presented in this chapter will be a discussion of the method, procedure and instrumentation used to collect and analyse the data. In attempting to develop a coherent methodology for this study, the main obstacle was that this type of research remains something that is viewed with suspicion: that 'pictures' are being used as a short-cut, an alternative to data gathered through 'hard' research. Hence there is a paucity of specific research into studying, or even discussing, the graphic representation of concepts.* This has led to the consideration of some of the research methods used by the study of entrepreneurship, e.g. Paulin *et al.* (1982). This 'adoption' may seem incongruous at first consideration, due to the dissimilarity between the subject areas. However, the belief is that this thesis represents original research into an emergent field, like entrepreneurship, and therefore there are similarities in the problems faced and methods adopted, if not in the specifics of the themes.

The possibilities provided by the wide scope of the field to be studied, its multi-disciplinary nature, the approaches that may have been followed and the plurality of research methods led to a sense of being overwhelmed by choices. The lack of a solid background of literature to provide directions, together with the examination of a nebulous subject, produced — inevitably — a scenario highlighted by Jones:

> Most of my peers seemed to have clear conceptual frameworks for their work. In contrast, after almost 3 years I was still searching for a theory or a model around which I could convincingly present my empirical material. When asked to define my 'area', I would claim that the work was 'multi-disciplinary'... (1995: 120)

Like Jones, ideas were being drawn from a multiplicity of sources; as such, the field encompasses sociology, graphic theory, semiology, ethnography, anthropology and psychology, though particular attention was paid to graphic theory and visual sociology, as discussed in Chapter Two. At the same time, the words of Moser and Galton (1971: 4) were being heeded — "to insist that a sociologist must not collect facts until he has a hypothesis would merely encourage the use of arbitrary hypotheses, which can be as bad as indiscriminate fact-collecting" — though this was due more to expedience (as a result of time constraints) than explicit methodological reasoning.

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* For instance, Harper (1994) restricts discussion to research methods for *photographs* while Lowe (1993) focuses on methodologies to explore the mental representation of exploratory diagrams.

3.1 RESEARCH PURPOSE AND STRATEGY

The thesis' focus is the representation of innovation concepts taken from models and theories. According to Gilbert (1978: 9), "theoretical discourse is conducted in terms of 'concepts', which are defined in a language of theory, and which have no immediate or direct connection with the social world". Finne (1994a) reasons that models are simplified representations of the phenomena under study, extracting and focusing on the features of greatest importance or interest. Kerlinger (1964) maintained that theory was a set of interrelated concepts, definitions and propositions that presented a systematic view of phenomena by specifying relationships among variables with the purpose of explaining and predicting the phenomena. These concepts and models are explored by comparing pairs of graphical expressions. In doing so, the research examines the documentary use of graphics in the domains of academia, policy, media and business, and chronicles how the depiction of innovation and technology has changed over time, and how it compares between different sectors.*

The appraisal of the expression of innovation concepts was discussed in Chapter Two; it draws upon a tradition of sociological work that analyses visual representation in the context in which it is situated and its embodiment of concepts and social meanings, along with an examination of the efficiency of the choice of graphic forms adopted. The research resists the evolution towards increased quantification (Tukey & Wilk, 1970), and adopts a qualitative approach due to the complexities of the phenomena being studied (Rothschuh, 1971) and the belief that a quantitative analysis would not yield a deep enough insight into the subject area.

Duncan (1979) would class a study such as this as exploratory: it is theory-building research, inductive in nature. Due to a lack of previously developed knowledge, theory or method, it was difficult to construct specific hypotheses or to anticipate responses before data gathering. Indeed, a specific methodological approach was not adopted before data collection was started; the belief was that data should be collected and retained as near to their original form as possible. This would allow different analyses to be undertaken and a methodology to be matched according to the themes that emerged. This process of post-justification was defensible, at least to the researcher, on the grounds that while texts on research methodology were explicit about the approach to be taken when there was a clear understanding of the subject matter, they were conspicuous by their absence when it came to any discussion of the issues faced when research did not adopt the structure of problem/hypothesis/data collection/data analysis.

Despite the lack of adoption of a formalised research methodology, it was clear

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* The notion of technology that is adopted in this study is that expounded by MacKenzie and Wajcman (1985): technology may represent physical objects or artefacts, but it can also refer to activities or processes and portray what people know as well as what they do.

that data collection must commence. Since the data would be unstructured, they would be *content analysed* according to some sort of logical rules and procedures (Kerlinger, 1964). An exploratory research technique is more suitable for an emerging field such as this because it focuses on discovering *what* phenomena occur and *how* this is achieved when use of a more systematic research technique is not possible — researchers must determine *what* occurs before they test *why* it occurs. However, this only became apparent after the data were gathered and a decision had to be made about how they would be analysed.

As discussed above, difficulties were faced when attempting to chose an appropriate methodology. One of the problems is that part of this research reorganises theory; yet the texts consulted on research methods did not recognise this as research in itself. It was with some relief therefore that the work of Runkel and McGrath (1972) was discovered. They developed an eight-part research strategy classification to define the researcher's choice of settings, subjects, behaviours and measurements that could be used. According to their theory, one of their classifications, anecdotal or formal theory, uses "prior empirical knowledge in [its] construction [and] rearrange[s] existing information into new forms to make it more useful" (Runkel & McGrath, 1972: 85). Another of their classifications, theory building, is also appropriate. It is a non-empirical strategy since it does not result in any new information, but uses empirical data to hypothesise relationships, developing theory through contemplation and logical analysis.

This addressed the theoretical considerations of the research strategy — at least in retrospect. However, justification for a practical research instrument to collect the data was still outstanding. Runkel and McGrath (1972) provided this once again. They defined a sample survey as comprising a questionnaire or an *ex post facto* field study. Their definition of a sample survey is particularly appropriate since they maintained it was independent of setting — data collection does not take place where the phenomena in question naturally occur. In addition, sample surveys offer the advantage of random sampling to control unwanted or unobserved variation, and allow a qualitative analysis to be undertaken — the desire of the researcher.

Sample identification and selection

To undertake a sample survey, a sample of graphics is required. Identifying them requires that decisions are made over the choice of medium, source, industrial sector and companies within it. This was one aspect of the research in which criteria were specified in advance, as opposed to the post-justification that has largely occurred, since a clear understanding of what was to be achieved was present from the start.

Medium

Printed graphics were chosen as the data source for various reasons. Firstly, they are widely and easily available. Secondly, they are a common, long-established method to represent information. Thirdly, they are easily reproducible, compared with, say, graphics taken from television programmes. Fourthly, there is a heritage of this type of analysis; ethnography, anthropology and sociology have made extensive use of the photograph. Fifthly, graphics may be continually reviewed since they are not transitory and are an easy method with which to record information. Finally, print media continues to be the primary source of information about science and technology (Wade & Schramm, 1969; Lichty, 1982; Witt, 1983).

Source

Four groupings of 'producer' were used as sources for a survey of printed graphics:

1. **Academic:** This includes texts, edited collections and proceedings, and journal, conference and working papers.
2. **Policy:** This comprises documents and publications from 'official' sources: governments, trade bodies and European organisations.
3. **Media:** This grouping is the printed business media: daily and Sunday newspapers, trade magazines and business, science and technology periodicals. In particular, *Business Week*, the *Economist*, the *Financial Times*, *Fortune*, *New Scientist* and *Scientific American* were examined due to their wide coverage of business, science and technology topics and their usage of graphic formats.*
4. **Corporate:** This includes reports, reviews, R&D papers and market surveys.

Regarding the last grouping, since the mid-1980s, there has been a sharper focus on company literature's role as the focal point of corporate identity (Cobb, 1990). The annual report, generally regarded as the flagship of a company's literature, has changed dramatically in recent years (cf. Chambers, 1955). It is now often a detailed, well-illustrated explanation of a firm's activities, image and aspirations. In combining text, illustration and design in its reports and brochures, industry has adopted many magazine techniques. Indeed, for *Graphis Annual Reports 3*, Pedersen (1992: 25) selected reports "on the basis of their innovative and intelligent concepts". It was thought this would provide rich data for exploration.

One aim of the research was to compare practice *between* the groupings identified above, to explore the belief that academia was leading the way in terms of usage and novelty, and that this was transferring between the groupings in the order listed above. However, another aim was to compare practice *within* the groupings. The individual graphics were selected according to certain criteria discussed below and, for the academic, policy and media groupings, the sources were largely self-selecting. The corporate grouping presented a special case. Rather than examine corporate enterprise in its entirety, two industrial sectors and a representative sample of companies within them were selected so as to render the findings more conclusive.

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* A dissenting voice was that of Evered (quoted in Macdonald-Ross, 1987), who claimed that *New Scientist* was a magazine for other scientists, not for the general public. This might have been true during the 1980s, but recently *NS* has been reoriented for the remerging pop-science market.

Industrial sector

The ICT and bioscience industries were chosen because they are two rapidly growing, innovative sectors and were believed to use graphics to a greater extent than other sectors. Anderson and Ortinau (1988) cited examples of ICT-based products with poor penetration into consumer markets. It might be expected that the marketing of these products might use graphics to a greater extent to demonstrate the increase in performance over previous generations or alternative (competitive) products. Software technology is becoming increasingly important to economic performance, e.g. OECD (1985), Barras (1986) and Coopers & Lybrand (1987). Tylecote (1991) identifies microelectronics (late 1970s) and biotechnology (1973) as new technological patterns or *styles* linked with the fourth Kondratieff wave, while Orsenigo (1993) highlights pharmaceutical firms as being exceptions when examining companies that invest little in basic research.

Grupp (1990a) arbitrarily defined the technologies in Table 3.1 as making-up high-technology product groups. The product groups and the technologies they embody in turn are partial descriptions of the technologies that comprise the ICT and bioscience sectors. de Woot's (1990) EU FAST (Forecasting and Assessment in Science and Technology) Programme report defines pharmaceuticals, telecommunications and electronics as high-technology sectors, and information technology, optical electronics and biotechnology as *metatechnologies* — technologies of the future. Though the sectors were chosen before reference to the citations above was sought, the body of evidence presented here demonstrates in retrospect that ICT and bioscience are sectors worthy of comparative investigation, and that it might be expected that their usage of graphics to be at least comparable to other sectors.

Table 3.1

Examples of technologies embodied in high-technology product groups.
Adapted from Grupp, 1990a: 230.

Company selection

The FAME database was used to generate a sample of UK companies to examine corporate graphics practice. Following the choice of the bioscience and ICT sectors, a search was keyed in the trade description field on variations of the words 'biomedical', 'biotech*', 'medic*' and 'pharmac*', which identified 671 companies, and 'communicati*', 'information', 'technolog*' and 'telecom*', which identified 960 companies. Holding companies and near-duplicates were excluded, reducing the sample to 42 companies operating in the bioscience sector and 37 in the ICT sector. These were contacted by post in a letter addressed to the Technical Director, asking for help in a preliminary study and requesting any documents, reports, reviews or brochures that included graphics illustrating technological innovation within their company.

However, this was only partly successful in eliciting a response. While specific replies will be discussed later in this and subsequent chapters, a larger proportion of companies did not respond or responded in the negative. When follow-up telephone calls were made, many respondents complained of being 'bombarded' by requests due to the increasing amount of taught-postgraduate and research into these sectors. For instance, Steve Firth, systems development manager of Serono Diagnostics Limited, claimed that, due to the number of inquiries received, he would be willing to participate only if his company's costs were met.

Kleinknecht (1993) recommends literature-based research over a mailing survey method in a sample survey of innovation. Firstly, the data collection can be performed without contacting firms; hence there is no non-response problem. Secondly, the data set can be extended to the past, in which case comparisons over time become possible. While Kleinknecht's first assertion is true if analysis is confined to publicly-available annual reports, it will also reduce the variety of designs since these documents tend to employ unremarkable graphics. Also, a letter might not have been the best tool to gather data; using personal contacts, a company's inclusion in an award scheme or similar, or even the PR department might have proved to be more fruitful methods. The relative lack of response in this area curtailed any additional research into an longitudinal study of graphics generation, even with the assistance of the CASE sponsoring partner, a graphic design consultancy.

A similar study of the media grouping was attempted, but this was met with relative indifference. As subsequent employment has revealed, this is not due to a lack of interest in the field; indeed, informal discussion with art editors proved that they considered it to be a mutually beneficial study. However, magazine production schedules dictate that art editors have little time to spare. Research into these groupings lacked an element of interaction that academics, whether they be writing for journals or policy documents, were able to provide. The academic involvement might have been due to their professionalism in helping a fellow academic or that they found the subject matter interesting. These points should be borne in mind if future research into any of the points raised by this thesis is considered.

Graphics selection

Feinberg and Franklin (1975) surveyed the literature to compile the first bibliography of social graphics practice. However, their methodology was not as explicit as might be expected from an academic paper; *Graphs* was a government-backed project. In addition, their work did not have an analytical dimension: it was a chronicle of practice, though some effort was made to categorise the sources.

So, the criteria for selection were made explicit. The graphic must refer to science, technology or innovation. The graphic should be interesting and, if possible, display some novelty: a wide collection of different types was desired. However, as remarked above, corporate annual reports are generally poor in their implementation of novelty so some effort was made to extend the coverage for this grouping. As Feinberg and Franklin highlighted, most graphics are traditional in form; novel graphics were selected if they went beyond the ordinary in their subject matter, sophistication of display or message, despite their infrequent occurrence. Similarly, the bioscience and ICT sectors were preferred over others. Though this section is presented last, these criteria were decided before any aspects of the source were debated, and believing that evidence would be found to justify the decisions made.

Table 3.2 reviews the techniques that can be used to justify the selection of specific cases from a sample survey. Although the original list is longer from which this is extracted is longer, the techniques reproduced below were all used in this study. Maximum variation involves looking for outlier cases to see whether main patterns

Table 3.2

Typology of sampling strategies in qualitative inquiry.
Adapted from Patton, 1990; Kuzel, 1992.

still hold. The critical case is the instance that 'proves' or exemplifies the main findings. Searching deliberately for confirming and disconfirming, extreme or deviant, and typical cases serves to increase confidence in conclusions. Some of the strategies benefit inductive, theory-building analysis (e.g. intensity and opportunistic). Though this list was obtained following the choice of the sample, the element of post-justification was not so extreme as with other parts of the research. Such techniques were known; the problem was translating the thoughts into words and finding other research that had employed similar methods.

3.2 DATA COLLECTION

According to Bouchard (1976), there are three primary methods of data collection: observation (indirect, pre-recorded archival data or the actual phenomena in question), questionnaire and interview. Paulin *et al.* (1982) added a fourth — contemplation — that involves the subconscious or unspecified 'analysis' of internally stored data and its rearrangement into new patterns. While contemplation is the primary technique of non-empirical theorising research, the discovery of new relationships *through* contemplation is an important part of any research study.

Due to the problems discussed above, a larger part of the documentary research was devoted to an examination of academic sources. The intention was to collect data for this audience first to identify themes so that they might be more easily recognised in the other groupings. There is always the danger that this affects subsequent collection, but a holistic view should be sought if the types of sampling strategies identified above are being undertaken. Indeed, it could be argued that the process of collection/analysis, collection/analysis is fundamental to this type of research. A positivistic approach, where the researcher is 'outside' the research process, is a theoretical ideal; the reality is that researcher is likely to become 'tainted' by the data collection process, whatever their objectivity and detachment. For this research, this interaction does not represent a failing of the research or method; indeed, it could be argued that it was an integral part of arriving at certain conclusions and provided feedback that led the research in new directions.

Certain academic texts and papers were identified as including notable examples of certain graphic formats, evident by their subsequent widespread citation. These were classed as critical cases according to the criteria established in Table 3.2. In particular cases, the critical cases emerged; in others, knowledge of the subject area meant that they were explicit from the start. Other types of sampling strategies were employed, including random, to select a sample in the areas under investigation. The scope of the problem meant that serendipity played a part. This, in turn, led to the use of an opportunistic strategy when a key document led the investigation along an avenue that had previously not been explored.

The data collection itself was a laborious and expensive task. Field visits were made to a variety of libraries, and photocopies were made of any graphic that might be useful. The process was not straightforward; the context of the graphic had to be noted and understood, and references had to be sought: the originating publication, the source if it had been cited, the quantitative data if the graphic was based on it, and so on. In many cases, these were as important as the graphic and the research was as much as tracing a graphic back to its original source as searching for new graphic types. For instance, Figure 5.60, a depiction of the genealogy of a video tape recorder, was an early addition to the study. Its reference to the *TRACES* study (Illinois Institute of Technology Research Institute, 1968) was noted, but it was only when Figure 5.40 was collected, a similar portrayal, that the decision was made to examine the original *TRACES* document. By undertaking the research in this way, the critical cases were continually reaffirmed and made more valid.

During data collection, the graphics were grouped by arbitrary criteria — format, content, source, purpose — to make some sense of what had been gathered, and to aid in the pursuance of the sampling strategies. One of the problems with *ad hoc* analysis such as this is that it does not allow the subtleties of the data to be explored fully. In fact, as more data is gathered, more time and effort is spent trying to justify how a new graphic should be categorised: whether it was an extreme case, whether it required a new category (in which case should other graphics be reclassified?), or whether the whole series of criteria should be reassessed. Another disadvantage of graphics is that it is not easy to identify or summarise them, which necessitates physically working with them. Compare this situation with, say, the ease that data in a spreadsheet or database might be reformatted. However, the closeness to the subject matter did make analysing the data more straightforward.

3.3 DATA ANALYSIS

According to Bryman (1989), document examination is one of the main data collection techniques associated with qualitative research. However, the social sciences have not developed systematic evaluative techniques for documentary analysis, with the exception of content analysis — a quantitative technique (Berelson, 1952; Holsti, 1969). Content analysis subjects unstructured data to a formal and reproducible procedure, but graphics have not played a large role in this (Einsiedel, 1992), Paulin *et al.* (1982: 361) maintained that qualitative techniques can be used to "draw conclusions ... from data recorded in ... pictures", but has little else to say on the matter. This section explores problems faced in analysing the data. Firstly, the role that quantitative and qualitative methods play in data collection and analysis is discussed. It might be expected that this discussion should be separate the two processes and they should be covered in their respective sections. However, the practical interaction between collection and analysis — where the former affected the latter — meant that this process was viewed as a single event. This is distinct to the positivistic approach recommended by research methods texts. To outsiders, the research process might comprise a series of distinct events. To researchers, the stages are inextricably linked. The interaction between collection and analysis led to a synthesis of Tufte's and Bertin's approaches to develop an analytical framework with which to collect, assess and classify data This is discussed in the following section.

3.3.1 A discussion of quantitative and qualitative methods

Although qualitative methods were employed to collect the data, the graphics would be analysed according to their content. This section explores what might be seen as a dichotomy since the research methodology books advocate one method or the other, rarely both. Bryman (1988: 18) defined quantitative research as being "often conceptualized by its practitioners as having a logical structure in which theories determine the problems to which researchers address themselves in the form of hypotheses derived from general theories". As a review of the literature has shown, there is an absence of theories examining the conceptual reasoning behind representation so this thesis adopted an exploratory role rather than an explanatory one. Quantitative researchers are also preoccupied with establishing the causal relationship between concepts. However, the emphasis here has been on exploring concepts, not their cause and effect or explanation.

Participant observation is probably the method of data collection with which qualitative research is most closely associated. However, in this case, the data are not people but graphics. Indeed, Bryman (1988: 47) believed that "participant observers are rarely simply participant observers; they often ... examine documentary materials ...". Bryman (1988: 94) summarised qualitative research as being the "means to exploration of ... interpretations". Since qualitative research tends to be more open than quantitative, the delineation of a research focus may be deferred as long as is possible. Whyte (1984) saw ethnographic research as deriving much of its strength from its flexibility that allowed new leads to be followed up or additional data to be gathered in response to changes in ideas.

Since content is seen as so significant, it has been systematically and repeatedly searched for its underlying themes, images, stereotypes and biases. Social scientists have sought to devise and codify methodological procedures, the desire being to produce hard, objective data (Beardsworth, 1980). This is achieved through consistently applied rules. Beardsworth made the distinction between *textual* and *theme* analysis. Theme analysis does not rely on the use of specific words as basic content elements, but upon the coder to recognise certain themes or ideas in the subject under study and to allocate these to predetermined categories. It could be maintained that use of this approach would tend towards a more qualitative, semiotic analysis, away from the overtly quantitative, content analysis. According to Beardsworth, the use of content analysis techniques, particularly in exploratory roles, can be seen as an example of inductive social research where the researcher attempts to extract features from a set of cases, events or instances; generalisations thus produced are given the status of *laws* or, less deterministically, *tendency statements*. Besides the methodological problems associated with any quantitative technique, content analysis has been unable to capture the *context* within which a written text has meaning. Ethnomethodological approaches — the analysis of *discourses*, for example — attempt to understand context as taken-for-granted knowledge.

Strauss and Corbin (1990: 21) maintain there is a case for data not being analysed since the researcher's task is to gather the data and present them in such a manner that "the informants [are] speaking for themselves". With graphics, the situation is slightly different. The situation is easily reproduced: compare the inclusion of a graph with the reference to an interview. Secondly, the visual material means something different to each individual so the interpretation is personal. Other qualitative researchers are concerned with accurate description when conducting their analysis and presenting their findings. Since the investigator cannot possibly present all the data *en toto* to the reader, it is necessary to reduce these data. The principle here is to present an accurate description of what is being studied; reducing and ordering materials represents selection and interpretation. The difference between theory and description, according to Strauss and Corbin, revolves around two points. Firstly, theory uses concepts: similar data are grouped and given conceptual labels, placing interpretations on the data. Secondly, the concepts are related by means of statements of relationship. In description, data may be organised according to themes that may be conceptualisations of data, but more likely to be a précis or summaries of words taken from the data. There is little, if any, interpretation of data, nor is there any attempt to relate the themes to form a conceptual scheme.

The analysis of images raises complex methodological and theoretical issues. It is difficult, but not impossible, to transcribe images as well as words. Moreover, the theoretical basis for the analysis of images is complex. Curry and Clarke (1978: 1) claimed that, "traditionally, sociologists have limited themselves to the collection of verbal or written information and have for the most part overlooked visual data". Communication is moving from an emphasis on the verbal to an emphasis on the visual, yet little is known about the power and significance of visual information. The documentary approach has the longest history in sociology, but much of the work of this genre is essentially descriptive, rather than analytic. Photographic images, for instance, serve primarily as an illustrative function. It seems that the linkage of data with visual methods is largely related to conceptualisation.

One of the reasons that social scientists have been slow to develop sophisticated theoretical schemes for imagery is that their traditions are heavily biased towards verbal thought. Even disciplines that are more visually grounded, such as anthropology, have found it difficult to overcome the notion that words are superior to pictures. Arnheim (1969) argued that the anti-visual bias in Western intellectual life resulted from the reification of the distinction between perception and reason made by early Greek philosophers, who believed that these antagonists were equal and both performed crucial roles in the thinking process. Over the centuries, however, the equality has been lost; while linguistic skills have become associated with the ability to reason and think, visual skills have not been similarly associated.

Social scientists have not been trained to be aware of the qualities and capabilities of visual modes of communication and, as a consequence, they have been unable to generate conceptual schemes for analysing imagery. Images represent a non-linear, holistic form of communication while written or verbal statements represent a linear, sequential model of communication. The attempt to build conceptual schemes for imagery will not be a simple task; the language of imagery has not been adequately deciphered and the interpretation of the significance of images is often controversial. Images are often viewed as pictures of reality rather than the conveyers of meaning; Silverman (1993: 70) maintains that "images are … [a] neglected source of data" in ethnographic analysis, while Denzin and Lincoln (1994: 355) state that "it is clear that visual methods will soon have a place of increased importance and centrality in the qualitative research project".

The situation did change in sociology in the 1970s. The journal, *Studies in the Anthropology of Visual Communication*, published papers that presented photographs and other visual as primary source material rather than illustrations, e.g. Goffman (1976a) included 500 pictures of advertisements so that readers could evaluate the system of inferences in dealing with these materials. Other sociologists began to develop theoretical and empirical approaches that dealt more directly with the information contained in photographs and the social and cultural contexts and conventions used to create and produce imagery, e.g. Tuchman (1973), Thompson and Clarke (1974) and Thompson *et al.* (1974). While the focus of these studies differs with this, the common characteristic is the systematic examination of imagery from a theoretical perspective designed to accommodate the features of imagery. However, it was clear that representational approaches need to be synthesised to achieve this.

3.3.2 Synthesising representational approaches

The research methods adopted in this study were largely dictated by the nature of the problem. For the analysis of meaning, an ethnographic discourse approach was employed to examine which concepts of innovation theory are embodied in the graphics. To examine technique, the graphic theory of Tufte and Bertin was used to appraise how the graphics perform, their utilisation of the range of graphic formats and the extent to which they subscribe to principles of excellence and efficiency. Dey maintains a need for a structure to categorise the data once they are gathered:

> Without classifying the data, we have no way of knowing what it is that we are analysing. Nor can we make any meaningful comparisons … It would be wrong to say that before we can analyse data, we must classify it, for classifying the data is an integral part of the analysis: it lays the conceptual foundations upon which interpretation and explanation are based. (1993: 40)

By classifying the data, they lose their original shape, but may be more usefully analysed. However, Dey (1993: 45) also cautions about 'reinventing the wheel': if an existing classification scheme can be used then it should since "conjuring up concepts is challenging work, and there is little point in adding to the burden by refusing to sharpen existing tools". In addition, Dey (1993) supports the use of graphic forms of representation to construct classification schema, especially those depicting hierarchies. Miles and Huberman (1984) similarly maintained that it was an appropriate method for qualitative analysis since it simplified complexity.

With this in mind, an attempt was made to employ the work of Tufte and Bertin to establish a classification. Table 3.3 depicts one possible classification: the relationship between function and format. Bertin was explicit over a graphic's purpose, as explained in Chapter Two. Efficiency is a hybrid concept since it adopts many of the themes from both theorists. Using Tufte's terminology, the graphic would exhibit *excellence* and *integrity*; according to Bertin, the graphic would be *efficient* and use the appropriate *rules of construction*. In a sense, efficiency is analogous to the *visual arguments* approach undertaken by the thesis and discussed in Chapter Two; it seeks the middle-ground between two bodies of theory. In doing so, meaningful questions can be asked without recourse to graphic theory. In comparison, Tufte's theory alone has been used for the format side of the relationship. Although the concept of efficiency is not explicit compared with the other components, a term nevertheless needs to be used to aid identification of these types of questions — and for most people, it is likely to be the most important question and one that can be answered without consulting theory: is it a good graphic?; does it tell me what I want to know?

Although this classification only has one level, compared with Bertin's *types* and *groups*, the typology is easier to understand when compared with Bertin's, e.g. space-time narrative design against orthogonal diagram. This is apparent when Table 3.4 is considered. This alternative classification combines the different format structures to place more emphasis on the plurality of designs — an aspect which Table 3.3 does not make prominent. Tufte's are plotted in the cells while Bertin's are plotted on the axes. However, this schema only depicts Bertin's standard examples with a consistent number of variables — two for diagrams and one each for networks and maps, and it concentrates solely on design.

While these classifications are both relevant, they are not inclusive and so an attempt was made to establish a wide-ranging classification that went some way to combining the major themes discussed above. Figure 3.1 is a taxonomy of formats with 1, 2, 3 and more than 3 variables in a regular reverse tree representation with levels denoting the different classifications that may be made. Bertin's theory has been implemented for the first three levels of classification. On looking at a graphic, the researcher can decide what type it is, and how many variables it employs. Since some graphic formats sub-divide the method of construction, a sub-level has been employed. Tufte's theory has been used for the fourth and fifth levels of classification. The next classification is according to the type of variable (not) employed. From this, it is possible to classify a graphic according to Tufte's definition. However, Tufte's theory is lacking in certain areas, most notably for matrices and networks. These classifications, and the *function of representation*, solely employ Bertin's theory.

However, the taxonomy is not a statement of practice, rather of theory, since the function of representation indicates the likely manifestation if a particular path from the graphic through the levels of classification is followed. As Bertin (1983) pointed out, information with three components or less, constructed as a single image, can fulfil all three functions of graphic representation! The reality is often different, but the taxonomy at least allows a comparison between theory and practice, itself interesting and valid. However, it does mark a starting point in the classification of graphics and enables research to be conducted in this and future projects until it is modified.

Table 3.3

Comparison of function with format.
Adapted from Bertin, 1983; Tufte, 1983.

Table 3.4

Format: combining Bertin's *groups* and *types* with Tufte's *fundamental graphic designs*.
Adapted from Bertin, 1983; Tufte, 1983.

Figure 3.1

A taxonomy of graphic formats.
Adapted from Bertin, 1983; Tufte, 1983.

Summary

Due to the lack of research methods that address graphics, the research was largely conducted without an explicit strategy, though some prior choice was exercised in the selection of the sample. The approach that was adopted required post-justification when it came to writing this chapter, though evidence was found to justify the actions taken, which reinforced the particular approach. Due to the complexity of the criteria under investigation, it was not possible to follow the methodology outlined from the outset. While positivistic approaches are recommended in books on research method theory, this methodology can be defended in practice.

Chapter Four
REPRESENTATION OF THE MANAGEMENT OF INNOVATION

Finne (1994b: 252) maintains that technology became "elevated to a strategic concern in the corporate world of planning during the 1980s", as evidenced by the American literature. By the late 1970s, the two functional elements of strategy — marketing and finance — were failing to generate the required corporate results in US companies (Hayes & Abernathy, 1980). Technology had been recognised as an important ingredient in the success of many foreign firms and, as a result, technology development and manufacturing operations acquired strategic status during the early 1980s, technology becoming the third functional element of corporate strategy.

> Technology strategy ... is, in essence, that set of activities by which management chooses its technological activity, allocates the resources for its technological undertakings, and structures the overall context for the development and maintenance of the technological resources that support the long-term strategic direction of the firm. (Friar & Horwitch, 1986: 52)

However, Peter Benton maintained, as Director of the British Institute of Management, that "technologists are often ignorant of business strategy and managers innocent of scientific education, so the transfer of technology faces special difficulties in Britain" (quoted in Roy & Potter, 1990: 9); this has affected the UK's national competitiveness and the progress and performance of products and technologies. Roy and Potter (1990) contend that innovation is a corporate-wide task: in a recession, technological choice may be the factor that ensures the survival of a firm. Thus, companies have been recommended to take a strategic stance towards their technology activities, both by innovation theorists, e.g. Pavitt (1984), and management consultants, e.g. Porter (1980, 1985). Similarly, government-supported initiatives have promoted the diffusion of specific applications or stimulated firms to improve their technological basis, e.g. Rothwell and Dodgson (1992).

Rothwell (1977) identified the eight most important issues in the management of innovation; communication was specified as the essential factor and this was also supported by Rothwell's (1983) later work. As is shown elsewhere in the thesis, communication is aided or enhanced with graphics. In addition, Stiles (1993: 103) believes that "image ... can provide a valuable instrument in assisting" the formulation of strategy. This chapter introduces some concepts in the management of technology and focuses on changes in strategic thinking and the way this is represented visually. Two sets of expressions — maps versus mapping and check lists versus matrices — have been chosen to illustrate this and they both involve a change in emphasis from a prescriptive typology to a positioning method.

4.1 MAP VERSUS MAPPING

This section examines the shift from maps to mapping. Tilling (1975) maintained that any map could be considered as a graph while, according to Robinson (1982: 1), "numerous innovative ideas have advanced the evolution of abstract thinking ... including ... many concerned with geographical comprehension". Mapping similarly uses co-ordinates to plot data, but the structure on which this is based is not explicit. The main difference between them though is their capability: maps, whatever their implementation of retinal variables, tend to plot a single attribute while mapping typically presents multiple attributes, often of a quite different nature.

4.1.1 Maps

The use of maps to represent the management of innovation is, perhaps, as idiosyncratic as the use of historic paintings in publications like part-works or children's encyclopaedias, books on the history of technology like Bernal (1954), old magazines like *Illustrated London News*, *Scientific American* and *Life*, and current magazines like *National Geographic*. These attempt to place artefacts in an active context, bringing back to life ancient peoples and events, recreating lost moments in a modern journalistic style of art or primitive style that suggests the early culture. There are many illustrative tools to represent the innovation and technology of yesteryear: visual catalogues of the subjects; scale drawings and artists' impressions; cutaway or exploded-view photographs and airbrushed paintings; schematic diagrams and flow charts to help synthesise complex subjects; collages — all have been used. But one of the most common — and one of the most persistent themes in cartographic literature — concerns the role of the map as a communications device.

Robinson (1982: 3) maintained that the third of the three functions of maps was "as a vehicle for the figurative expression of abstract, hypothetical, or religious concepts". It is not so large a category as the other two, but it does include greater variety. This kind of map came into prominence at the third International Statistical Congress held in Vienna in 1857 (Funkhouser, 1937). Since geography is used as the framework for the graphic display, it is sometimes difficult to distinguish the functions of locating and identifying features from the figurative function of giving substance to abstract ideas and concepts. Metaphor has a role in the history of maps; geographical space was often metaphorically modified with the Holy Land being greatly enlarged and the lesser-known outer fringes substantially reduced.

By the latter part of the 17th century and the early part of the 18th, profound changes were beginning to occur in intellectual areas that affected map-making in a variety of ways. These primarily involved changes in the intellectual aspects of cartography, namely the mental modes, concepts and paradigms that motivated the cartographers, shifting the primary objective from the subjective and aesthetic to the scientific. In contrast to the general map, the thematic map concentrated on showing the geographical occurrence and variation of a single phenomenon or, at most, a few. Robinson (1967: 95) termed a thematic map as a "graphic geographical essay"; instead of its primary function being the display of the relative locations of a variety of different features, the thematic map focuses on the difference from place to place of one class of feature, that class being the subject or 'theme' of the map. The number of possible themes is virtually unlimited, ranging over the past and present physical, social and economic world, from geology to religion, from population to disease.

An important difference between general and thematic maps, and a characteristic of the latter, is the portrayal of variations within a class of features so that the pattern of structure of the distribution becomes more apparent.* This is considered essential because one of the major reasons for making it a thematic map is to discover the geographical structure of the subject, which is impossible without mapping it, to relate the 'geography' of the distribution to that of others. This can be achieved either by correlating the distribution with one's mental maps or other distributions or by physically comparing one map with another. From the mid-17th century to the mid-19th century, almost all maps were made to be reproduced, the period from 1800 to 1860 seeing the rapid development of thematic mapping.

From the mid-17th century, the development of a concern for science and for a universal system of measure in Europe was accompanied by a parallel growth of interest and competence in statistics and method, especially in physical science. It was focused on such topics as population, fertility, mortality and the comparative characteristics of nations. The development of statistical theory in social science and the mapping of statistical data took place later. The time lag between the development of the physical sciences and that of the social sciences is illustrated by thematic mapping. Numerous maps, on such subjects as magnetic phenomena, currents and geology, appeared from 1650. By contrast, very few maps of social subjects, such as population, religion or production, appeared before 1820; there were pre-map, graphic representations of statistics in the latter part of the 18th century by Crome and Playfair, but there were no thematic maps portraying statistical data.

Early thematic maps of social subjects portrayed 'moral statistics'; these dealt with population and crime distribution. Coincident with their introduction was another group of maps concerned with human illness, specifically problems of health. Maps of occupations, production and trade were among the last of the maps to appear during the developmental period of thematic cartography. This was probably due to a lack of statistical data; such information was not collected in a central place because of a lack of official interest. The concept of a national economy worth investigating from a geographical point of view had to wait until the Industrial

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* Petchenik (1979) supplied a thorough analysis of the fundamental distinction between the two classes of maps, while Robinson and Petchenik (1976) discussed more fully the concept of structure in thematic mapping.

Revolution had gathered momentum, the turmoil of the French Revolution and the Napoleonic wars had abated and the era of road, canal and railway building had progressed. Accordingly, there were few thematic maps of economic activity before the second quarter of the 19th century. The first flow map was printed in 1837, but it was not until the 1840s and 1850s that such maps were being produced regularly (Robinson, 1955, 1967). Thereafter, they also became common and, because they were developed later than the other categories, they could take advantage of the greater use of printed colour, a technique that had evolved by then.

The growing maturity of a field is reflected in its increasing tendency to specialise. Far more sophisticated maps of economic geography began to appear in the early 1850s, portraying fewer phenomena. The maps of the 1840s and early 1850s, depicting manufacturing regions, were considerably more sophisticated than the economic-geographic maps of former times that depended largely on a multitude of individual symbols. However carefully drawn, earlier presentations were little more than general reference maps, since there was little portrayal of the organisation of regional variations of economic activity. Cartographic portrayal of regionalisation and concentration on individual activities or commodities began in the late 1840s and, by the mid-1850s, data were specific enough that more specialised maps could be made. Thrower (1972) maintained that all the common techniques of thematic cartography in use today had been developed by 1865!

As the scientific and Industrial Revolution gathered pace, cartographers developed special-purpose maps whose purpose was to display particular sets of scientific or social data. One of these was the flow map. According to Robinson (1982), flow lines were first used in 1837 by Harness and, soon after, Belpaire and Minard employed them to depict the movement of goods and passengers on roads, railways, rivers and canals, drawing parallel lines the requisite distance apart and colouring the spaces between them to show the class or classes of data being portrayed. Largely due to Minard's series of *cartes figuratives*, the flow-line technique of representing quantitative data soon became well known among statisticians dealing with commerce, especially in France (Robinson, 1967).

Minard was more concerned with portraying the basic structure of the distribution rather than the maintenance of strict positional accuracy of the geographic base. Despite being an engineer, Minard appreciated the power of the metaphor. In Figure 4.1, Minard gave quantity as well as direction to the data measures located on a world map in a portrayal of the exports of French wine in 1864. According to Robinson (1982: 151), the logic was unassailable: "if a flow line of a given width is to portray ocean transport it would be as ridiculous to have it cross land, such as the margins of the Channel or the Straits of Gibraltar, as it would be to plot a railway across water to avoid overcrowding. The solution was simply to widen the Channel or the Strait". Minard always included the term *carte figurative et approximative* whenever it was appropriate, which was in over 90 per cent of 51 maps.

Figure 4.1

A redrawing of a portion of *Carte Figurative et Approximative des quantités de Vins Français exportés par mer en 1864.*

Source: Robinson, 1967: 103: "The original in the Bibliothèque de l'École Nationale des Ponts et Chaussées has a light gray tint on the land with the flow lines in red-brown. Only a few countries and continents are named."

Figures 4.2 and 4.3 present the use of maps to chart patterns of disease. Dr John Snow plotted the location of deaths from cholera in central London in September 1854. In Figure 4.2, deaths are shown by black rectangles and the water pumps by circles. Figure 4.3 presents an alternative visualisation: deaths are marked by dots and the area's 11 pumps are located by crosses. Examining the data scattered over the map, Snow observed that cholera occurred almost entirely among those who lived near (and presumably drank from) the Broad Street water pump. The handle of the suspect contaminated pump was removed and examined, ending the epidemic in which more than 500 people had died in ten days. In the figures, the pump is located at the centre of the maps, just to the right of the D in Broad Street.

Similarly, maps are used in the management of innovation to plot distributions so that they may be observed as patterns. This is achieved at a national or sectoral level, as well as at a company level. The expression tends to be used to analyse the data rather than describe them, as in Figures 4.2 and 4.3, though it can be conceded that description does play a part in Figure 4.1.

Aston University

Illustration removed for copyright restrictions

Figure 4.2

Detail of Snow's map of cholera cases and water pumps around Broad Street, London in 1854.
Source: Howe, 1971: 341.

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Illustration removed for copyright restrictions

Figure 4.3

Location of cholera deaths in central London for September 1854.
Source: Tufte, 1983: 24.

4.1.2 Mapping

The term *bibliometrics* and its definition are attributed to Pritchard (1969) and involves the application of mathematical and statistical methods to books and other media of communication to assess the volume, composition and structure of a subject speciality. Analyses of this type can be of considerable interest for the study of scientific and technological trends, scientific communication, R&D organisation and various aspects of science and technology policy. The term *scientometrics* is used to describe a variety of research approaches within the study of science with the general idea that quantifiable aspects of science can be applied to assess characteristics of science. However, scientometrics and bibliometrics are often used as interchangeable terms with the same meaning.

The mapping of science is one of the most frequent expressions of the bibliometric or scientometric technique. According to Small and Sweeney (1985: 391), maps can "indicate the state of science in a particular year, and by observing the changes from year to year, the overall progress of science". Garfield *et al.* (1978) maintained that the notion of mapping implied dealing with objects or entities that had a location in a space of some number of dimensions, in which the distance between the objects was meaningful and well defined. Mapping science is an attempt to arrive at a physical representation of fields and disciplines and, at a lower level, of individual papers and scientists in which the relative location of entities is depicted. Price was one of the earliest proponents of the mapping method and used a metaphorical approach to link the concept of a spatial model to a map of science. Price's (1980) vision was of a comprehensive and dynamic *war map* of science and the analogy evolved from the *jigsaw puzzle* model of science to the *onion skin* and, finally, the *torn fish net*.

Use of the Institute of Scientific Information's (ISI) Science Citation Index (SCI) has led to the development of the *Atlas of Science* (Garfield, 1981) and the mapping of scientific 'clusters' by co-citation analysis (Small & Griffith, 1974; Griffith *et al.*, 1974).* These examine and explore the relationships between groups of highly interactive documents, the graphical expressions of which are mapped as network diagrams showing how the clusters are linked. Garfield (1968) maintained that several citations clustered together represented a milestone event. An example is provided as Figure 4.4. As befits an emergent technique, this graphic attempts to portray a great deal of data in an unsophisticated way. One dimension is used to present time, but the scale is not uniform, though the key does provide the specific date. The links represent two types of data — citations and Asimov's historical connection — with two classes for each. The links crossing one another and the use of shape to denote them combine to give the impression of a complex but connected map. According to

* The SCI was followed by the Social Science Citation Index in 1973 and the Arts & Humanities Citation Index in 1978, showing how it is such an applicable technique.

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Figure 4.4

Network diagram for history of DNA based on Asimov's book, *The Genetic Code.*
Source: Garfield, 1968: 184–185, based on a composite of six network diagrams as reported in Garfield *et al.*, 1964.

Garfield (1968), the conception of knowledge in citation indexing is a large graph or multidimensional network; a graphical description of the literature considers each document as a node in this. Garfield referred to this type of representation as an historical map and, since each document is dated, a complete bibliography expressed as a network represents an approximation of the history of the subject covered.

Figure 4.5 presents a less complicated map, suggested by Doyle (1961). Borko's (1968) assertion was that a graphical index such as this did not have to imitate a textual list, where the emphasis was on *finding words* that start with the same letter of the alphabet; the purpose was to *associate topics*. This is readily achieved with connecting arrows and with the application of bold type and increased font size to denote important terms.

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Work has continued to improve the mapping of science, leading to multidimensional scaling (MDS) being used to form multidisciplinary maps of science (Garfield *et al.*, 1978) and an iterative 'clustering of clusters' method being developed (Small *et al.*, 1985). The application of MDS also provided the means to measure structural change in disciplinary maps from year to year more objectively. The production of multiple levels of clustering suggested a way to control the complexity of the maps by using the natural hierarchical structure of the clusters. Garfield (1981) applied the concept of nested maps to construct an overall map of biomedical areas, as well as several submaps corresponding to individual points on the overall map in which they were contained hierarchically. The concept of nesting maps gave the overall map a simplicity of structure by incorporating that complexity in several submaps that were magnified or detailed views of individual points on the main display.

A comprehensive map of science is certainly possible using the methodologies identified by the above authors; Small *et al.* (1985: 339) claimed that the social sciences could be included "in the same overall structure with the natural sciences and that significant links exist between these worlds of knowledge". Such a comprehensive system of mapping would have to rely on some kind of spatial retrieval system, analogous to that developed for geographical information (Herot, 1980). In such a system, the user first views the overall map, selects a node on it and then sees the map for this subregion, which represents a discipline. Nodes on this submap may also be viewed as maps of specialities. The user may progress down this tree of nested maps until the document level map is reached, for retrieval of specific papers. In addition, the user might have access to textual information at each stage, describing the disciplinary or speciality network currently displayed. For a specific map, efficient ways of 'walking through' the nodes of the map can be used, such as the shortest path or most concentrated branch. Clearly such a system is more than a bibliographic retrieval system; it is more like an encyclopaedia of science integrated with a bibliographic structure, as envisioned by Garfield (1968). While the Price metaphor of the war map of science may have appeared to be whimsical, with the 'generals' of science policy observing the progress of their specialities, the technical feasibility of such a system may now be realised. However, the real scenario is likely to be less centralised; the absence of a 'field marshal' at the top of the hierarchy means that the problem of delineating the 'armies' is a very real issue. In addition, problems over copyright and payment for 'information on demand' would be solved in a more localised environment.

In spite of the emphasis on distances and their depiction, maps can also be used to measure of association without assuming a metric space; the depictions need not be of the 'snapshot' kind and may even be like mental maps. Such a qualitative or non-metric approach was developed by Callon *et al.* (1986a) and based on co-word analysis, in which the maps were visualisations of network structures. Starting from an analysis of innovation and the role of texts in science, Callon *et al.* described a novel computer-based method for displaying dynamic change in science and technology and pinpointed the individuals, groups and countries that lay behind that change. Figure 4.6 presents eight word clusters as shaded areas, with the 'passageways' between them indicated by 'signposts' and the links indicated by arrows.

In addition, mapping methods have been adopted as a set of methodological tools for depicting and analysing managerial thought (Huff, 1990a) and assessing technological capabilities (de Wet, 1992). Huff (1990b) groups the purposes of mapping into five generic families, progressively requiring increasing interpretative input from the researcher:

1. Maps that assess attention, association and importance of concepts. These are word-based.
2. Maps that show dimensions of categories and cognitive taxonomies. These examine complex relationships, specific links, hierarchy or association (and the results can be mapped out along the general lines shown in Figures 4.7–4.10).

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3. Maps that show influence, casuality and system dynamics. These are action-based.
4. Maps that show the structure of argument and conclusion. These show logic behind conclusions and decisions to act.
5. Maps that specify schemas, frames and perceptual codes. These provide understanding between thought and action.

The US National Science Foundation's *Science Indicators* series presented patent statistics for *policy* analysis; Narin (1978) maintained that counts of papers, citations and the like were descriptive techniques of the measurement of science, echoed by Pavitt (1988: 512) with the claim that most bibliometric-based analyses were "purely descriptive". For Rip, mapping was

> becoming increasingly important for science policy in a strategic age ... [since] there is a lack of systematic, independent data characterizing current activity in science in a form that can be used by policy makers, and bibliometric 'models' or 'maps' of the literature output of particular science fields form a particularly promising possibility to overcome the lacuna. (1988: 253)

At the same time, Huff's (1990b) maps seem to be attempting to achieve a similar outcome and present a variety of expressions through which this may be achieved. Though essentially the same technique is being used, the scope is different; Huff

(1990a) and de Wet (1992) focus on the corporate dimension while the other academics previously mentioned have concentrated on the macro perspective and policy issues.

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4.1.3 Comparison

Although historical and other types of schematic maps are typically nonstatistical, they nevertheless exemplify many of the characteristics and require many of the same design and construction techniques as other maps, according to Schmid and Schmid (1979). In a wide ranging review, Woods (1993) chronicles a wide variety of methods of implementation in a number of disciplines. Despite this, the thematic map is not a popular expression with a contemporary usage.

Figures 4.11–4.16 depict thematic maps that are geographically recognisable, though with increasing abstraction. Figure 4.11 shows the sources for a piece of research: US companies, Japanese companies and European companies. Though alliances between them were being examined, this is not clear and the arrows seem to serve no purpose. Figure 4.12 is similar to Figure 4.3, depicting the locations of the

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establishments used in the research by dots. The propensity to agglomerate in Orange County is readily apparent, but no reason can be drawn why this is so, due to the absence of other data (cf. Figures 4.2 and 4.3). Figure 4.13 plots the members of networks using the geographical components of longitude and latitude. Rather than connecting the institutions physically by links, the visual variable of value is employed to encode membership. Bertin (1983: 51) noted that, "since a geographic network cannot be reordered arbitrarily, the image can only be simplified by eliminating certain correspondences [linkages]". In the original version of the graphic, membership was denoted by the use of colour; as a result of its monochromatic reproduction, it is not readily apparent which institutions belong to which network; geographical sensibility has won over the message of the graphic. The theme of Figures 4.14 and 4.15 is the growth of a technology. Geographical information is minimised and the labelling refers to the different electrical companies that make up the

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network. Figure 4.14 depicts the map at its original size. Figure 4.15 presents the data in reduced form. Their reduction enables the growth of the technology to be appreciated using Tufte's (1983) principle of *small multiples*. Figure 4.16 shows the world market for Boeing and Airbus aircraft and portrays two types of data. Most notable, due to the dominant use of textured hatching, is the Airbus market share for each continent, which also allows the geographical outline to be visible (cf. shading using value). Simultaneously, proportional circles are employed to represent the size of each market.

Figure 4.17 depicts investment flows, though in a more abstract form. This abstraction could be reduced if the plotting of Japan and the European Community was transposed to make their positioning more geographical. The width of the link denotes the amount of money being transferred and the arrow denotes the direction of flow in an unambiguous manner.

Examining the representation of mapping, Figure 4.18 illustrates the relation of word analysis to the structure of a cluster for nuclear physics with co-citation strengths. The grouping is so loose knit that it can be represented without nodes or links overlapping or crossing one another. Small and Griffith (1974: 39) maintained that this diagram was "relatively simple to draw. All the linkages appear as straight lines, and their strengths can be indicated". Small and Griffith asserted that the mapping of specialities to show their structures and relationships to one another is of prime importance for the understanding of science and its structure. By using a consistent data source and graphing relationships in a uniform manner, one speciality can be compared to one another, as can periods of science with consecutive annual data. However, without careful consideration, the document that provided the 'spark' is not readily evident. Figure 4.19 reproduces Frumau's (1992) *connection diagram*; the arrows point *from* the citing *to* the cited area. The technology areas were arranged in their positions to avoid (almost) the crossing of the links and to keep the links as short as possible. Thus, no mathematical interpretation should be drawn

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World penetration by the A300/A310.
Source: de Woot, 1990: 111, reproducing part of Airbus Industrie's literature.

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Investment interchange among Japan, the USA and the European Community (cumulative total at end of fiscal 1982; unit $1 million).
Source: de Woot, 1990: 86.

from the distance between two areas. The use of thicker lines for the links, compared to those denoting the nodes, serves to draw attention to the connections *between* the technology areas rather than the technology areas themselves. Figure 4.20 illustrates patenting activity within and between a variety of electronics- and mechanical-related fields in Japan. Quantitative information is encoded in the nodes using two different font sizes and bold type while in Figure 4.21, a related graphic, the surface area of a node is proportional to the number of patents in the particular technologi-

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Figure 4.18

Graph of 'nuclear physics' cluster at Level 3.

Source: Small & Griffith, 1974: 29: "Dotted lines indicate points of connection of 'nuclear physics' to 'particle physics' [the other speciality examined] at Levels lower than 3."

cal field it represents. In both graphics, a combination of size (width) and value (shading) is employed to denote a link, simultaneously encoding the quantity of patents that relate to the two fields, though Figure 4.21 does offer more options for encoding information than Figure 4.20. In Figure 4.20, computer control field provides the 'bridge' between the different groupings, with electrical machinery — EM on the diagram — providing a similar role for Figure 4.21.

In Figure 4.22, grouping is more explicit; the co-word clusters are denoted using

Figure 4.19

Citation pattern between technology areas.
Source: Frumau, 1992: 116: "Arrow points from citing 1984–86 patents to cited 1981–83 patents only if actual number of cites is twice the expected number and is more than 10 percent of total cites given by area (both excluding self-citation)."

Figure 4.20

Co-word map for (opto)mechatronics (research map), database INSPEC (1987).
Source: Engelsman & van Raan, 1994: 22.

Figure 4.21

Co-classification (co-IPC) map for Japanese national patents, database WPI/L (1987/88).
Source: Engelsman & van Raan, 1994: 12. The codes represent technology fields, e.g. EM for Electrical Machinery, ME for Biomedical Engineering (genetics), etc.

a bold line and they are numbered for identification with the text. The links and nodes are significant; size and texture are used to represent the links while size and shape play a similar role for the nodes. However, the node itself is represented in a constant fashion; information is depicted using a variable symbol *within* it. In addition, two quantitative measures are reproduced with each co-citation cluster so that, along with communication, the diagram also functions as a recording device. In Figure 4.23, like Figure 4.19, the citation pattern between the technology areas is made independent of size, highlighting the similarity of R&D effort. The cross-area connection pattern is visible, like the exchange in laser-optics-printer technology between Sharp, Canon and Hewlett-Packard. The map shows that there is no strong structural overlap among the six areas. The areas themselves are grouped using polygons of different values though, in contrast to Figure 4.22, a company may be a member of more than one.

Figures 4.24 and 4.25 represent more abstract concepts of inclusion, more akin to Figure 4.9. Figure 4.24 shows that innovations and patents are partially related to technology though areas within the field are not indicated. To demonstrate some

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Figure 4.22

Similarity of co-citation cluster word-profiles to co-word cluster word-profiles, for the field of chemoreception research.

Source: Braam *et al.*, 1989: 326–327.

Figure 4.23

Citation pattern between 30 companies.

Source: Frumau, 1992: 119: "Arrow points from citing 1984–86 patents to cited 1981–83 patents only if actual number of cites is twice the expected number and is more than 5 percent of total cites given by the company (both excluding self-citation). Clusters have been drawn according to nr. 1 position in Revealed Publication Advantage (and nr. 2 position if less than 20 points difference) for 1981–83 period." The darkest shaded area is that of consumer.

major differences between the approaches made in their area of research, Grupp and Hohmeyer (1988) divided papers into three categories; Figure 4.25 illustrates this. The differences were discussed over four pages, but the location of their theory relative to others is made somewhat quicker using the Venn diagram — theirs is marked X. It would have been more useful to allocate the letters by date of appearance though; without reference to the key, it is not possible to ascertain that papers A, E, R and S were published in 1982 or that paper F was the first published. While labelling a paper A does not denote its date, it can be assumed that sequential letters D–F do at least indicate that they were published at around the same date and that X was the most recent, as in this case.

In a case-study examination of representation, Law and Whittaker (1988) explicitly stated the conventions that were devised to draw research maps, one of which is reproduced as Figure 4.26. Firstly, depictions should be easy to read and thus the crisscrossing of linking lines should be minimised. Secondly, the reader should be able to compare the diagrams over time, placing limitations on the movement of clusters. Thirdly, the diagrams should 'tell a story' so, due to historical reasons, emissions were placed on the left, modifications in the middle and their effect on the right. Finally, the size of the node and link were significant — indicating magnitude — and, along with labelling, a numeral was linked to each box using a key. Thus, as well as depicting the state of research into acidification of the environment, Figure

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Figure 4.24

Technology couplings.

Source: Dror, 1989: 243.

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Figure 4.25

Diagrammatic classification of technological models similar to the technometric model.

Source: Grupp & Hohmeyer, 1988: 618: "For details of classification see text. Letter allocated alphabetically as from the first author." The letter X represents Grupp & Hohmeyer's paper.

4.26 illustrates the production of the pollutants and their effect on the environment and the positioning of the nodes *is* significant.

Figures 4.27 depicts the findings of a co-word analysis of dietary fibre research. Callon *et al.* (1986b: 117) described this representation as "multi-polar" since it is headed by four groups of problematisations — *alimentation, colon, régime enrichi* and *traitement* — though this is not evident from the graphic because they are not located on the same horizontal level; however, the authors also conceded that these key words mean little in isolation — it is only when they are aggregated with other key words that they can be "interpreted". Callon *et al.* emphasised that inclusion maps do not represent research problems, only their *simplification*. Figure 4.27 depicts that fusion is starting to occur between the research fields — *alimentation, voie biliaire* and *tumeur* — and Figure 4.28 reveals that it has taken place, though through an alterna-

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Figure 4.26

Depiction of research on acidification of the environment, 1983–1984.
Source: Law & Whittaker, 1988: 170.

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Figure 4.27

Inclusion map for dietary fibre research, 1973–6.
Source: Callon *et al.*, 1986b: 118.

tive route. Visual variables are not employed to encode information.

Figure 4.29 depicts a more regular taxonomy, like Figure 4.10, with a central point of origin. Taxonomic analysis is another method to classify the component elements of a system; a taxonomy orders elements according to a theme, its hierarchy and their relationship. Figure 4.29 shows an association that would be somewhat verbose to describe in words, especially considering that from the category level only the subsystems relating to power are represented. Figure 4.30 shows a more

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Figure 4.29

Example of use of a taxonomy in analysis of transportation technology system. Phase 1 only shown.

Source: DeVore, 1980: 247.

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Figure 4.30

Major component elements of the electronics industry in the US and W Europe, 1974.
Source: Sciberras, 1977: 45.

quantitative breakdown. The information is encoded in the diagram in two ways: the value of each level is recorded in monetary terms with pie charts or splits being used to represent how the elements that make it up are subdivided.

Figure 4.31 is another taxonomic representation though, in this case, a three-dimensional block shows the infrastructure for the study of technology. This form of diagram presents a compact map of the dimensions, but suffers from 'pigeonholing' the subject matter and, by presenting the taxonomy in three dimensions, certain aspects are not as apparent as they might be with a two-dimensional representation. Figure 4.32 provides a visual projection of the future of technology and society in two dimensions. Diagrammatic representations of the future are common in that they portray likely outcomes; the danger is that they provide a simplified summary

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Figure 4.31
The study of technology — infrastructure.
Source: DeVore, 1980: 341.

and may not encourage the viewer to think beyond the representation. While this is not the fault of the graphic (rather the perceiver), it should be remembered. Figure 4.32 tries to counter this by not connecting the likely future events and by presenting them in an arbitrary manner. Figure 4.33 chronicles technological fusion in Japan from 1970 to 1982, clustered around ordinary machinery, electrical machinery and industrial chemicals, using blocks to represent the fields. According to Kodama (1990), the triple connection among food, drugs and medicine and industrial chemicals in 1974 can be interpreted as the emergence of biotechnology. The technological fusion between ordinary and electrical machinery in 1971 is the beginnings of mechatronics, though this is only realised in 1975 with the existence of a quadruple connection between them, precision instruments and communication and electronics (equipment). The emergence of new ceramics in 1982 is represented by technological fusion between ceramics and ordinary machinery and between ceramics and electrical machinery. By presenting the field in a constant fashion and in the same position, the fusion is highlighted. In addition, by presenting fields that are not connected, the fusion becomes all the more apparent though it should be noted that some of the crisscrossing is avoidable. Since change is only represented over time (since space is not used meaningfully), this graphic cannot properly be regarded as a *space-time narrative design*.

Imai (1989) maintained that a ubiquitous feature of the modern Japanese industrial scene was its network-type organisations. Figure 4.34 represents a multifaceted

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Figure 4.32
Who will make the links?
Source: Hawthorne, 1978: 185.

network among manufacturers, wholesalers and retailers in the household goods industry. However, rather than depicting this by connecting one node to another using a link as in most network diagrams, Imai grouped the relationships and represented them as a map; the nodes, however, employ a combination of shape, orientation and size. Membership of multiple networks can easily be appreciated, as can the role of the Planet network, on which several subnetworks are based.

Figure 4.35 maps out themes according to explicit dimensions using a graph's positive and negative values; the themes are not located quantitatively though. Figure 4.36 shows past, present and future info-mobility using only the positive dimensions of a graph. It is purely relational, designed to chronicle relative change; this is achieved very simply by using movement away from the origin and the measures depicted are notional. Figure 4.37 is similar, using areas of different sizes; the scale is exponential so the data range that each area covers is large and, in addition, there is some overlap. Figure 4.38 used two axes against which 30 companies are depicted. One axis makes the distinction between the consumer and information companies while the other distinguishes between consumer and measurement companies; they reveal that there is not a strong degree of overlap among the six different business

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Figure 4.33

Technical fusion in Japan in 1970, 1974, 1975, 1982.
Source: Kodama, 1990: 50–51.

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Figure 4.35

Strategic diagram: positioning of themes with relation to one another.
Source: Courtial & Sigogneau, 1995: 41.

areas depicted. The diagram employs a matrix with four different themes — two per axis — as the underlying device on which the information is arranged; in comparison, Figures 4.35–4.37 depict only two themes, one per axis. Value is used to indicate inclusion in Figure 4.38 and the edges are delineated.

Figure 4.39 takes this concept one stage further: it depicts the structural *trans-*

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Figure 4.36

Future info-mobility.

Source: Svidén, 1985: 39: "Improved information services and functions can substitute [for] some travel, but also generate more new demands for travel; improved mobility makes it possible to combine the advantages of city life and the ecological qualities of dispersed living, and both with the contact networks available today in cities only. The future high info-mobility 'trans-urbia' can be an alternative to most living and working patterns today."

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Figure 4.37

Transmission rate and duration features of telecommunications.

Source: Arnold & Guy, 1989: 163.

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Figure 4.38

Characterisation of company portfolios.

Source: Frumau, 1992: 117: "Factor scores of business areas (measured as a percentage of deliveries 1986). Clusters have been drawn according to nr. 1 in Revealed Delivery Advantage 1986."

Knowledge-Intensive

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Unskilled-Labour-Intensive

Figure 4.39

The evolution of industrial structure.

Source: Rothwell, 1985: 206.

formation of Japanese industry. Rothwell (1985) explained that the Japanese Economic Planning Agency used it to demonstrate Japan's economic development, illustrating Japan's movement towards higher value-added, more knowledge-intensive sectors. West Germany is compared with Japan, using two axes that both carry two variables each like Figure 4.38. However, by using broken and solid lines, this graphic can also depict change over time; since only four data sets are depicted, the shift is readily appreciated. The only drawback to this graphic is that the scale is not constant. This may have been deliberate, but it would have been a simple error to rectify. Figure 4.40 arrays 14 product groups according to a polar imposition. Rather than plotting the different data sets on one diagram, each country is depicted individually so that changes may be observed using Tufte's (1983) *small multiples* principle. The product groups are fixed in position so that *relative* change may be observed against the norm, represented by a regular shape — the circle. In addition, imports and exports are delineated so that it is also possible to analyse differences in surpluses and deficits. Figure 4.41 is a less visually pleasing presentation of change. In this case, the axes depict indicators — patents, research expenditure, and so on — though this fact is only gained from the text due to the use of letters to denote this.

Odd man out

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Figure 4.40

Trade specialization: Japan, US and West Germany.
Source: Rothwell & Zegveld, 1985: 9.

Figure 4.41

Indicators of technological potential in the 1960s and 1970s.

Source: Rothwell & Zegveld, 1985: 13. The dashed line indicates technological potential in the latter half of the 1960s, the solid line the latter half of the 1970s. The indicators are represented by code letters: A. total added value in manufacturing; B. number of patents registered; C. number of patents registered overseas; D. number of researchers; E. research expenditure; F. exports of technology; G. trade in technology; H. exports of technology-intensive products.

However, a scale enables actual comparisons to be made (cf. Figure 4.40) that has the added effect that the area covered is significant — it *physically* relates to magnitude — though there is no indication of the reasoning behind the dashed horizontal line that stretches across each diagram.

Figure 4.42 presents 19 major technology groups and their inbred patent share. With careful consideration, it can be seen that all the inbred shares increased during the period from 1975 to 1984. The long-dash short-dash line indicates the mediums; the area above the dashed line indicates relative growth while the area below indicates decline. In addition, the diagram shows that, according to their position on the horizontal axis, pharmaceuticals and information are young technologies while electrical systems, materials and mechanical technologies are the most mature. Finally, the area of each technology group is proportionate to the number of all patents in that technology.

Figure 4.43 is based on Osgood *et al.*'s (1957) *semantic differential scale*, which consists of a number of bipolar adjectives; the cluster of factors it represents — *evaluation* (e.g. good–bad), *potency* (e.g. strong–weak) and *activity* (e.g. active–passive) — account "for nearly 50 per cent of the total 'meaning' of a concept, irrespective of the concept involved, the adjective used, or the respondents questioned" (Williams, 1981: 104–105). While no map has been discovered exhibiting this expression, the

Figure 4.42
Technology inbred shares.
Source: Dror, 1989: 247.

profile from which it is derived *has*. Figure 4.44, for instance, reports on the impact of research projects. As Williams highlighted, profiles are highly comparative; their drawback is that different semantic meanings may be attached to an adjective — for instance, the research possibilities of Figure 4.44 may have no impact to one person and strong impact to another — since the scale is subjective with the inevitable consequence that the profile is descriptive, not analytical. Figure 4.45 is a comparative representation, deftly illustrating the Federal Republic of Germany's shortfall in beam divergence orthogonal and mode structures when compared the USA and Japan. The figure has been enhanced with shading though it should be noted that the variation in the shape used to achieve this is not necessary. In addition, rather than the three alternatives used in Figure 4.44, the results are depicted against only two measures making it more difficult to assess values around the median.

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Figure 4.43

The three-dimensional matrix for mapping a concept in 'semantic space'.
Source: Williams, 1981: 105.

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Figure 4.44

The national economic utility of ELE's general projects.
Source: Ormala, 1985: 132.

In summary, mapping can be seen to be more flexible and less specific than a map. The lack of any real usage of the map format — by any 'producer' grouping — *is* puzzling. In fact, the examples included here required painstaking sourcing to demonstrate a variety of facets. While a map may not be prescriptive — it tends to

Figure 4.45

Technometric profile of semiconductor lasers for optical communication by selected countries in 1986.

Source: Grupp, 1990b: 62

describe data — its very format tends to provide limitations which perhaps accounts for the paucity of exhibits. Also, its historical origins may endow it with a certain amount of 'emotion baggage'.

As has been stated, mapping can use co-ordinates to plot data, but the structure on which this is based is not explicit. Using the map as an analogy, it is like plotting roads on a map without reference to any features except, say, towns and that the map cannot be used to infer distance between the towns, by road or space. But a mapping method is definitely a positioning method and, since the level of abstraction can be varied, it makes it suitable for a variety of 'producers' to exhibit a variety of phenomena.

Perhaps the greatest difference between maps and mapping though is the way they handle movement or dynamics. Maps, by their very nature, do not change over time.* Instead it is the *data* that changes relative to the identifiable format; this is achieved through the use of *retinal* variables or small multiples. Mapping on the other hand is not restricted by geographical comprehensibility and can encode movement using *visual* variables. This allows changes in the data to be reflected in the format *or* the data, providing the designer with more options.

* The exception is, of course, maps depicting physical geography, but it is unlikely they would be used to represent any aspect of innovation.

4.2 CHECK LIST VERSUS MATRIX

This section explores the move from the use of check lists towards matrices. For the former expression, it is necessary to be explicit from the outset as to its meaning and inclusion. 'Check list' is used as an inclusive term, referring to the use of a list of bullet points to achieve a strategic goal, the breakdown of theory into easily identifiable stages or the employment of typologies. Strictly speaking, a check list is not a graphic expression; according to Bertin (1983), it is classed as a figurative analogy based on symbolism. Despite this, the technique has been extensively used in the management of innovation and, thus, is worthy of inclusion due to this. What is interesting is the way it was — and still is — used as if it is a graphic technique, even though it is clearly not. A matrix is similarly regarded as not being a graphic, though it has been inserted in Table 3.5 for completeness and comparison; according to Bertin's terminology, it could be considered as an arrangement and located within the diagrammatic or network groups. Bertin maintained that the purpose of a matrix was to process data graphically for inclusion in diagrams or to present a diagrammatic interpretation of a network.

4.2.1 Check lists

The use of check lists is a somewhat old-fashioned concept, finding favour with the theorists of the 1960s and 1970s to package neatly the results of some large-scale studies. For instance, Booz, Allen and Hamilton (1968) identified six stages in its empirically based model that explored the marketplace. Myers and Marquis (1969) used a five-stage model to outline the results of a study of 567 case histories of incremental innovations. The *Wealth from Knowledge* study (Langrish *et al.*, 1972) identified two basic models of innovation, discovery-push and need-pull. The Science Policy Research Unit's *Project Sappho* study (University of Sussex, 1972) highlighted five attributes of the successful management of innovation:

1. Successful innovators have a much better understanding of users' needs.
2. Successful innovators pay much more attention to marketing.
3. Successful innovators perform their development work more efficiently than unsuccessful ones, but not necessarily more quickly.
4. The responsible individuals in successful attempts are usually more senior and have greater authority than their counterparts who fail.
5. Successful innovators make more effective use of outside technology and scientific advice.

The technique has also been applied to more smaller-scale studies. For instance, Miles and Snow (1978) characterised organisations according to their strategic orientation: *defender*, *prospector*, *analyser* and *reactor*. Their typology was described by Weisenfeld-Schenk (1994) as a theoretical framework that could be used to analyse and classify strategies of a firm. Cooper (1979) found 18 factors to distinguish successful industrial products from unsuccessful ones. Freeman (1982) analysed innovation policy, making a six-fold classification of innovation strategies that ranged from *offensive* strategies designed for technical and market leadership, though *defensive, imitative, dependent* and *opportunistic* strategies, to *traditional* strategies of producing unchanging products for unchanging markets. In addition, Maidique and Zirger (1985) proposed ten factors for success in the electronics industry. Anderson and Ortinau (1988) presented the key factors in the successful introduction of an innovation, subdivided into their different types — *continuous, dynamically continuous* and *discontinuous* — and listed them as a series of points.

But, by far, the most successful published study of the attributes of innovative and commercially successful companies was that of Peters and Waterman (1982).

Figure 4.46

Organizing for action and innovation.

Source: Morgan, 1986: 61, based on Peters & Waterman, 1982: 89–327.

They gave the check list approach a high profile:

> The eight attributes that emerged to characterize most nearly the distinction of the excellent, innovative companies go as follows:
>
> 1. *A bias for action*, for getting on with it. ... (1982: 13)

This is typical and there are many such examples and exhortations throughout. However, the effect was more far-reaching than this: the expression was given legitimacy. Peters and Waterman wrote a popular textbook that appealed to people who were engaged in business as well as those who were studying it — entrepreneurs looking for something to transform their business at the railway station bookstand and students seeking simplification and codification. The use of check lists is akin to a 'get-rich-quick' chain-letter: simply follow the instructions and success will result. Morgan even cited the summarised principles as an exhibit (Figure 4.46).

Check lists have also been used by policy-makers. They feature as a dominant force of expression by the IAB ATC (1991) and a double-sided card, with a check list for managers and investors, can be detached from its back-cover. Woot (1990) introduces four types of research worker in a list and these are restated in a matrix immediately following it (Figure 4.47). Matrices though are the dominant form of expression in the management of innovation.

- The 'expert' who regards himself as an active agent of strategy and looks to a career in research. This category is the most useful to corporate competitiveness.
- The 'scientist' who also looks to a career in research but has no interest in strategy. This category is, of course, less useful to corporate competitiveness.
- The 'manager' who is interested in strategy and aims to leave research as soon as he can to go in for management. The enterprise soon loses him from its research staff.
- The 'careerist' who has no interest in the strategy and no longer does research but is gambling on an ambiguous situation in which his outside chances are enhanced by belonging to the enterprise and his internal chances are enhanced by his outside contacts

Figure 4.47

Typology of R&D people.

Extract from de Woot, 1990: 156.

4.2.2 Matrices

The matrix diagram uses a familiar device to map ideas in one dimension against ideas of another dimension: one set of ideas is listed along the vertical axis of the matrix, the other along the horizontal axis. The matrix provides a structure for systematically evaluating the relationships between the ideas in the two dimensions. Each cell of the matrix represents a question that can be asked of the relationship of the idea represented by the cell's column and the idea represented by the cell's row. Davies *et al.* recount an anecdote:

> A now well-known figure once said, when he was Planning Officer of a large technological company, "Never show the Board a graph. If it is simple enough to be understood by the accountants it will insult the engineers, and if it is interesting to the engineers it will puzzle the accountants. Keep it down to a comparison between twelve or so numbers, perhaps in a 3 x 4 table". (1990: 124)

This perhaps explains the wide-spread usage of matrices: they are easy to create, appreciate and use, and offend no one due to their lack of requiring any specialist knowledge. Matrices, featuring text rather than numbers in the cells, are recognised as a focused way of displaying data (Miles & Huberman, 1984, 1994; Eisenhardt, 1989a, 1989b). The organised and compressed assembly of information permits conclusion-drawing or action-taking. For numbers, matrices can be used to compare information across cases; as well as identifying regularities and variations, matrices can draw attention to singularities in the data. There are two ways in which matrices may be used regarding the positioning within them: generally and specifically.

The Boston Consulting Group's (BCG) matrix

This is the most common expression of this generalist approach, though others do exist. The BCG matrix selects one concept, relative market share, as the key indicator of competitive strength and the other, growth, as indicating the potential and attractiveness of the market, presenting the different outcomes in a standard 2x2 matrix (Figure 4.48). The BCG matrix is ostensibly a tool of simplification; Morrison and Wensley (1991: 105) maintain that it is a popular technique for both practitioner and academic domains since it provides a "powerful means of simplifying and 'boxing

Figure 4.48

BCG matrix.

Source: West, 1992: 153: "Cash cows: products generating cash which have high relative market shares and are established in slowly growing markets. Dogs: products unlikely to be generating substantial positive cash flows due to the fact that they are in slowly growing markets with low relative market shares. Stars: products generally with negative cash flows but with high relative market shares in rapidly growing markets. Question marks: products also with generally negative cash flows but with low relative market shares in growing markets."

up' complex issues ... [by] 'box[ing] in' strategic discussions to a limited set of options and prescriptions", drawing together and packaging various strands of thought so that they may be effectively communicated. For innovation specifically, the BCG matrix can provide estimates as to the likely future cash flow, necessary to evaluate the choice of which of the possible innovation routes could be followed.

There has been criticism though. Slatter (1980) believed that the concepts represented by the BCG matrix were too simple and therein lay both their appeal for managers and their main weakness; it purported to provide rational answers in an area that had long been regarded as more of an art than a science. Morrison and Wensley maintain that it was often regarded as a comprehensive theory rather than the specific tool as was developed. In addition, the BCG matrix is not an innovation tool *per se*; it could be considered that it is *against* innovation since the contention that dog products should be discontinued due to their poor prospects eschews low-cost incremental innovation to improve profitability or market share. Despite this, a proliferation of variants followed in the 1970s; according to Wind and Mahajan (1981) four matrices were in common use and five others were in circulation.

Other matrices

General Electric (GE) produced what is probably the best known alternative to the BCG matrix. The GE matrix involves a nine-cell model that uses composite parameters of industry attractiveness and business strength. Each of the parameters is constructed from factors selected and weighted by management (Figure 4.49). The matrix concentrates on ROCE in contrast to the BCG model, which focuses on cash flow; the top-left cell indicates a strong position in an attractive market and business units or products located there should be invested in due to high returns, while the bottom-right cell indicates the opposite and divestment is recommended due to poor yield. Much of the relevance of the GE portfolio depends on how the various components are rated and weighted; this shortcoming does not affect the BCG matrix, which relies on absolute measures. West (1992) asserts that this will result in a technically based company placing more importance on technical advantages in its assessment of its capabilities, rendering comparison more difficult.

Figure 4.49

The GE matrix.

Source: West, 1992: 155: "Components of the GE portfolio: market attractiveness — market size, market growth, number of market subdivisions, competitive intensity, profitability, inflation trends, technical requirements, social components, legal issues — and business position — business size, market share, price position, product quality, technical superiority, market knowledge, profitability."

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Figure 4.50
Technology position/market growth matrix.
Source: West, 1992: 161: "1. Technological leader: first to market. 2. Technological acquirer: first to market. 3. Research follower, strong developer: first to market. 4. Technological follower: strong marketing thrust. 5. Technological follower: weak marketing thrust. 6. Minimal technology: acquire leadership position early. 7. Minimal technology: acquire follower position early. 8. Minimal technology: acquire follower position late."

Another matrix relevant to technology management is the technology position/market growth matrix. In it, companies are categorised whether they are technological leaders, followers or developers, or by the fact that they do not compete with technology. Their position within the matrix suggests a number of alternative strategies (Figure 4.50). The identification by this matrix of developmental speed and non-technological concentration as a means of penetrating particular markets is different to other approaches that concentrate on technology as a key component; the resultant effect is that it is closer to the realities of the market place.

Matrices are widely used in business textbooks. The reader is informed 'at a glance' of what may take several paragraphs to explain. The concepts have intuitive appeal and the taxonomic urge of people fits with their need to differentiate between competing options (Day, 1977). In addition, fashion, according to Wilson and Atkin (1976: 118), has played its part: "businessmen being no less susceptible than the public at large to taking on fashionable theories".

4.2.3 Comparison

Though the use of check lists may be somewhat old-fashioned and unfashionable, it shows no sign of declining. Indeed, it could be argued that the use of categorisations, taxonomies and other such neat, identifiable divisions is the application of check lists in principle but not name. For instance, Langrish et al. (1972) identified two basic models of innovation, *discovery-push* and *need-pull*. These two main types

Figure 4.51
Basic models of innovation.
Adapted from Langrish *et al.*, 1972.

were further divided as shown in Figure 4.51. Despite their research, Langrish *et al.* admitted that it was not easy to 'fit' innovations into any one of these models in a clear and unambiguous way. Similarly, a further classification of innovations was developed by Myers and Marquis (1969). Two broad groups were identified: the *offensive* and *defensive*. The former, as its name suggests, aims to protect market share and corporate growth, while the latter refers to a product/market strategy positively planned to secure new business. Again, in real life conditions, a blend of these approaches is highly likely.

Figure 4.52 is taken from Apple's annual report. The suggestion is that its growth in market share has led to record sales and increased profits, allowing R&D investment to continue and alliances to be developed, and promising a bright future. Of course, subsequent events have proved that such prescriptive pronouncements do not always come true. However, as a device for convincing current or potential investors, it is a good example of the 'bullet-point' approach.

Similarly, the role of the matrix in Figure 4.53 is to display results. Rather than employing one retinal variable simply, say texture, it uses two — value and shape, and not altogether successfully — to achieve this. The matrix is used in promotional material by the company with the winning model; one suspects that this is due to the fact it won rather than any appreciation for the design of the graphic. Due to the distinction between solid and transparent colours — the black and white respectively — it is evident which model is the winner and which is the loser. What is not so apparent is the intermediate placings.

Figure 4.54 summarises the characteristics of the product cycle. It uses size to rank factors according to the role they play. However, the effect is offset by some superfluous number ranking within each box; since there are only three classes, this does smack of overkill or lack of trust in the reader. Despite this, the positioning of the product cycle phases in order means that it is possible to draw some kind of

- MARKET SHARE GROWTH: *Macintosh unit shipments increased 20 percent over last year, outpacing the industry.* In fiscal 1992, Apple sold more than 2.5 million Macintosh computers.*
- RECORD NET SALES: *$7.1 billion.*
- INCREASED PROFITABILITY: *Net income of $530.4 million, compared with $309.8 million in 1991.*
- ONGOING INVESTMENT IN R&D: *8.5 percent of net sales.*
- KEY ALLIANCES: *Apple's alliance with IBM resulted in the introduction of new connectivity products. Apple forged partnerships with Sharp and Toshiba to work on future products.*
- EXCITING NEW BUSINESSES: *Apple unveiled Newton—a revolutionary technology that will be the basis for new, intelligent products.*

**Based on unit shipments for the first half of calendar year 1992 (InfoCorp, 1992).*

Figure 4.52

Key achievements in 1992.

Source: Apple Computer, 1992d: 1.

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Figure 4.53

***PC Week*'s Labs analyst's scoreboard.**

Source: AST Computers, 1991b: 3.

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Figure 4.54

The relative importance of various factors in different phases of the product cycle.

Source: Freeman, 1982: 182: "The purpose of the blocks is simply to rank the importance of the different factors, at different stages of the product cycle. The relative areas of the rectangles are not intended to imply anything more precise than this. [a] Considered to be of equal performance."

curve around the boxes to aid understanding of the interplay between the production factors. There is no indication given though for the role of the symbol in the bottom left-hand corner of the graphic.

Figure 4.55 also uses a matrix structure, though the data is displayed where the dimensions intersect rather than being located in the cells. In this case, the addition of numbers does aid perception of the use of size to denote rank (cf. Figure 4.54). Dominant categories can be readily identified; the number 'fills in' the details. Note also the thoughtful inclusion of the total adjacent to the countries which enables comparison by proportion to be undertaken more easily.

Figure 4.56 presents results by what might be termed the *Which?* method, after the famous consumer-rights publication: the same shape is used, with multiplicity denoting significance and texture for the two classes of data. Monochrome reproduction of the *Financial Times'* famous salmon-pink paper has rendered the distinction less legible than in the original; however, it remains a quick-and-easy way to present salient facts and rapid comparison is enabled.

Moving onto matrices, Figure 4.57 uses the simple 2x2 matrix to present different product strategy options. In doing so, it creates the impression that there could be no other course of action than those identified — there is a solution in each quadrant for all possible outcomes. Figure 4.58, on the other hand, arrays the characteris-

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Figure 4.56
Optoelectronic technology.
Source: Dixon, 1988: 19.

tics of four types of emerging industries. The emphasis may not be strategic, but again an industry is identified for each cell, giving the notion that the theory is all-encompassing.

Figure 4.59 is used to illustrate a section on the role of innovation in the company and attempts to draw a distinction between the leader and the follower. The IAB ATC (1991) contends that being a follower does not imply that a company is less successful. Conversely, it maintains that being a leader in innovation does not always guarantee commercial success. One of the problems in identifying companies and products as such, as Peters and Waterman (1982) found to their cost, is that history is not a good predictor of the future. Figure 4.60 might not look like a matrix on first glance due to its orientation and lack of uniformity. The use of oblique and acute angles ensures that the text is readable in all the sectors. Once again the matrix is being used to conduct 'gap' analysis, for Lederle's 'Deteclo', something to which it is well suited, though an entry — unsurprisingly — cannot be found for the 'dog' category of expensive and less potent.

Figure 4.61 uses the matrix to display a variety of data in a concise manner. It might be expected that such data would be presented in a table. However, the

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Figure 4.57

Product strategy options.

Source: Hawthorne, 1978: 115.

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Figure 4.58

Four generic types of emerging industries.

Source: Calori, 1990: 23.

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Figure 4.59

Winners and losers.

Source: IAB ATC, 1991: 8, taken from an Arthur D. Little Limited booklet.

matrix format enables the reader to view the results as well as the subsequent groupings into which they have been placed. The addition of the sample size in the top right-hand corner of each cell allows the reader to assess the results against the sample size. Figure 4.62 is not a different matter in concept though its execution is more confusing. The positioning of actors according to some criteria makes sense,

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Figure 4.61

Research scheme and sample characteristics.

Source: Kim *et al.*, 1989: 33: "NE: *Number of Employees.* AGE: *Age of the Firm.* TC: *Technological Capability* is a composite measure derived from the linear summation of standardized factor scores of TMR, HIMR, and RDR, which are the outputs of a principal component analysis. TMR: *Technical Manpower Ratio* refers to the ratio of employees with degree in science/engineering to NE. HIMR: *High Level Technical Manpower Ratio* refers to the ratio of employees with postgraduate degree in science/engineering to NE. RDR: *R & D Investment Ratio* to total net sales."

but the criteria have not been made explicit. While identification of the cells is straightforward, identification of the axes is not. In particular, the restatement of the four categories — global, local, internal and external — causes problems.

Initially Figure 4.63 does not look like a matrix due to its divergence from the familiar 2x2 structure. In fact, it portrays the continuum of the technology which is created by the synergy between biology and chemistry. Understanding would have been made better with more sensitive labelling: the top arrow, from biology to chemistry, looks as if it is linking the headings of 'Base technology'.

Even though identification of the cells is arbitrary, the examples up to now have used them as discrete entities. Figure 4.64 marks another way matrices may be used. The cells are similarly delineated, but the categories are spread *across* them rather

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Figure 4.62
Positioning of relevant actors.
Source: Bruhèze, 1992: 145.

Biotechnology meets new chemical technology

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Figure 4.63
Synergy between two major technologies.
Source: de Woot, 1990: 151.

than being constrained *within* them. Figure 4.65 adopts this concept, but the data are car models — not nations — so they do not span boundaries. The text explains the differences between them over seven pages, but the matrix achieves this using considerably less. According to Abernathy and Clark (1985), the categories of innovation identified are linked to patterns of industry development, innovation and, ultimately, managerial environments, though this is not evident from the figure. In this case, its role is recording information, though some attempt is made to communicate it with the use of descriptive labelling.

Figure 4.64

National differences in strategic themes.

Source: Carr, 1990: 74.

Figure 4.65

Transilience map and selected automotive innovations.

Source: Abernathy & Clark, 1985: 8.

Figure 4.66 describes graphically Apple Computer's end-users. In 1981, Apple's products appealed to the education and office markets. It was envisaged that the Mac would appeal primarily to the office segment with some penetration in the other fields. In reality, the Mac surpassed its predecessor, the Lisa, and the final matrix shows that a replacement for the Apple IIe would have to complement the Mac and Lisa. The graphic also shows the rapidly expanding market, though this is a notional concept.

After a number of graphics that try to show something novel or *be* novel, Figure 4.67 shows the reality of corporate graphics. It states no more than the CSO (Complex Systems Organisation) of Unisys works with large organisations, within multi-vendor environments and on projects of long duration with major financial com-

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Figure 4.66

Product positioning and target segments for Apple products.

Source: Burgelman & Maidique, 1988: 314.

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Figure 4.67

CSO positioning diagram.

Source: Unisys, 1990: 217.

mitment. However, no other information is included in the diagram — due to commercial sensitivity or some other reason — so the net result is a diagram that does not inform the reader any more than words, which is a damning criticism for a graphic.

According to Figure 4.68, SUN and DEC are the price/performance leaders in the mid-range computer market, while IBM's AS/400 range offers the worst price/

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Figure 4.68

Price/performance in the mid-range.

Source: Schofield, 1993: 17.

performance ratio. It can also be seen that client/server systems are more expensive than they were five years ago, while performance varies from stagnation to significant. There is no origin on the axes; they cross at the average values to provide the four quadrants. The diagram demonstrates that investment in a more expensive, powerful processor is a better decision than saving money and buying a less powerful processor. It also shows that the media often try to add analysis to a graphic — the concept of movement — rather than depicting something that is static.

The addition of arrows linking the data points could have made Figure 4.65 look like Figure 4.69. The graphic proves that it is possible to shows movement and motion. The figure plots nine data points over a wide distribution and the chronology of their occurrence can be observed, not only from the correction orientation of the arrows but the alphabetical ordering of the events. Figure 4.70 presents how Japan's technology has evolved over time. The concept is notional — compared to the precision of Figure 4.69 — yet it numbers the cells to indicate how the technology advances and uses shading to signify the position just passed, current and expected in the near future.

Figure 4.71 marks another change in the depiction of the matrix. This graphic breaks out of the constraints of two dimensions to display a limited amount of information three dimensionally. Rothwell and Zegveld (1985) have decided that the

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Low

Figure 4.69
The trajectory of TSR.2.
Source: Law & Callon, 1992: 50.

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Figure 4.70
Turning on: evolution of Japanese technology.
Source: *The Economist*, 1989: 4.

Figure 4.71
Classification of innovations.
Source: Rothwell & Zegveld, 1985: 197.

product under question is a new product with new technology in a present or new market. However, due to the box's orientation, it is located at the back, so the effect of texture is reduced somewhat. Placing it at the front of the box — the existing position of a new product with present technology in a present or new market — would maximise the effect since all three dimensions would be affected by texture.

Figures 4.72–4.74 may be viewed as a triptych, with Figure 4.72 as the centrepiece. Figures 4.73 and 4.74 represent alternative visualisations of Figure 4.72 though with an added dimension: operating risk. Figure 4.72 represents the classical product-market approach, based on the strategy options derived from the well-known 'square' of new to existing product-market relationships. Hawthorne (1978) maintained that these relationships were naïve since, as a company moves into the high-risk technology market, the need is not only for technological resources but also for capital to sustain the enterprise and termed this 'operating risk' — encompassing non-technology, non-market factors. Thus, large firms tend to dominate the low-risk market while conglomerates, consortia and governments tend to dominate high-risk technology sectors (Figure 4.73). The implication for small companies is illustrated in Figure 4.74, showing the strategic positions such firms tend to occupy and the barrier to growth that many companies face.

In summary, though most matrices are two-dimensional entities, a check list is restricted to one dimensional by its nature. Though the check list is not a widely used expression — like a map, it is considered to be old-fashioned — it has been adopted more readily by the policy and media sectors, and by populist academics: it may be a prescriptive typology, but it does communicate a strategic course of action simply and clearly, and its 'bullet point'-style means that it is symbolic.

A matrix can also achieve this clarity — Figure 4.47, for instance. However, a matrix is more likely to use position to communicate significance rather than repurposing information from one dimension to two. As position has become more

Figure 4.72

Dominant resource pattern: board's responsibility (two dimensions).

Source: Hawthorne, 1978: 117.

Figure 4.73

Dominant resource pattern: board's responsibility (three dimensions).

Source: Hawthorne, 1978: 118.

Figure 4.74

Dominant resource pattern for smaller firms.

Source: Hawthorne, 1978: 124.

important so matrices have moved away from stating absolutes and the concepts they convey have become more notional. The differing degrees of complexity it can portray also makes it suitable for use by all types of 'producer'.

4.3 SUMMARY

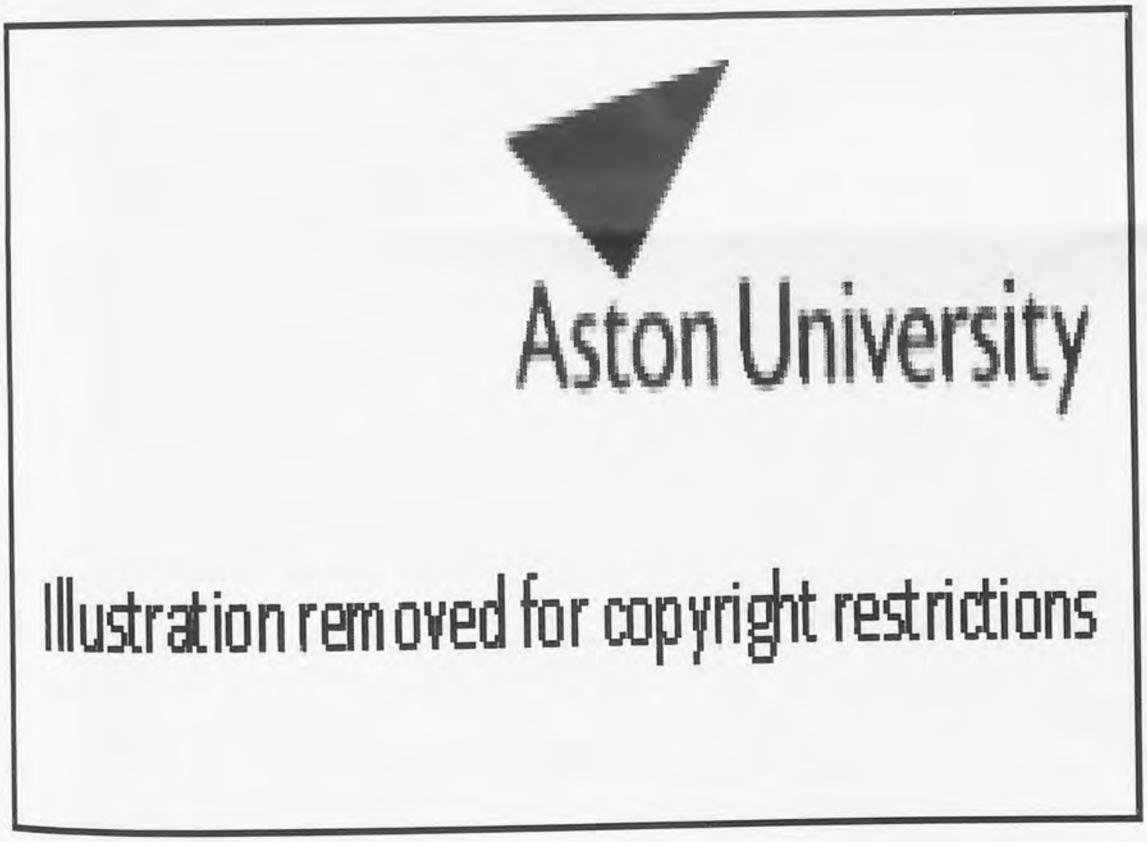
Corporate enterprise does not seem to represent strategy graphically. For instance, Apple Computer (1992a: 4) describes one of its documents (1991b) as a "road map of strategic thinking", but there is little here that is graphically similar to a map. Similarly, James A. Unruh, CEO of Unisys Corporation, states:

> We are seeing measurable benefits from our focus on line of business solutions … . Product reliability, installation times, and overall customer satisfaction all improved in 1989. Today we offer the strongest and broadest product line in our history, and we are building the type of open, integrated solutions needed by our customers to compete in the 1990s.
>
> We owe this progress to our people. In 1989, Unisys employees were busy serving our customers and introducing and delivering new products … that are the key to our future success. (Unisys, 1990: 13)

These pronouncements could be enhanced with a graphic, even something as simple as Figure 4.52. The examples reproduced in this chapter tend to be derived from academic sources; Table 4.1 presents the full breakdown.

Table 4.1

Typology of expressions cross-referenced with figure numbers and source for Chapter Four.



* The source for this graphic is unclear; no explicit mention is made of its source or purpose.

Probert and Gregory maintain that there is

> a rich assortment of analytical tools and representational techniques to assist the practising manager … . Many of these derive from industrial experience and have been developed through use, others are the suggestions from academic research. (1995: 434)

From Table 4.1, it is evident that academic sources are predominant. This is not to say that Probert and Gregory are wrong, rather that more academics tend to represent strategy graphically compared to other 'producers'. This may be partly due to companies' managements not wanting their strategy to be expressed explicitly, either for commercial sensibility or for fear that something 'cast in stone' might be used to criticise them in the future, or that the teaching of strategy means that it is illustrated more. Despite this, both mapping and matrices are commonly-used tools in the management of technology; in particular, two- and three-dimensional matrices, tree structures and profile charting are identified as playing an important role.

Traditionally, strategy mapping has emphasised spatial relatedness, explaining why metaphors abound (O'Keefe & Nadel, 1978).* The concept of *network* has been employed to examine many configurations in science and technology since the early 1960s. Wolek and Griffith (1974) argued that much of this research has been encouraged by the search for ways to stimulate science and technology, and as such has received extensive support from policy-makers.

In recent years, both policy-makers and research managers have become increasingly interested in the use of indicators of scientific output. The early use of bibliometric methods in the study of science and technology were frustrated by a lack of historical data, hindering analyses *and* development. Since then progress has been rapid, aided by the simultaneous development of methodological knowledge on the use of bibliometric techniques, e.g. King (1987), and Rip (1988) maintained that maps of scientific fields were becoming decision support tools in the strategic implementation of science policy. Warren (1993) even suggests that the simulation of a dynamic representation of strategy and policy will increase the understanding of business dynamics, and recommends the creation of a visual map of the system under study.

However, the support for matrices is more uneven. Kiechell (1981: 148) claimed that "companies may be disturbed to learn that many of the matrix's original champions now view it as outmoded, if not dangerously wrong", while Warren (1993) asserts that management views the prescriptions arising out of research into strategic management with scepticism since they prove to be unenduring or simply wrong. Even though the matrix uses position, its widespread use is seen as prescriptive. It seems that the matrix is used more because everyone else uses it and recognises it, and less because it provides something that words do not.

* Likewise, Monge and Eisenberg (1987) maintained that network theory was a theory of spatial relations. However, networks will be discussed in the next chapter.

From an examination of the graphics contained in this chapter, in addition to drawing upon sources that have not been reproduced, it is possible to identify certain formats that are more popular — for whatever reason — than others.

The **geographic map** uses geographic comprehensibility upon which it plots data, e.g. Figures 4.11–4.13. Its main purpose is to record data. The **abstract map** is not geographically comprehensible, but presents the data in such a way that it is easy to visualise the underlying structure, e.g. Figure 4.17 (which might be even less of an abstract map if the positions of Japan and the European Community were swapped). It tends to represent flows of data.

Network map(ping) has been termed as such since it bridges both maps *and* mapping. Position is not necessarily geographically comprehensible — as in Figure 4.26 — but it *is* significant since it tells a story, e.g. Figures 4.14 and 4.15. Alternatively, elements might be grouped to designate likeness, as can be seen in Figures 4.22–4.25. Whatever the emphasis, network map(ping) tends to depict relationships.

MDS mapping on the other hand is definitely an expression that has been developed from the mapping tendency. The use of MDS means that the strength of the link, the proximity or size of the nodes or their position is significant, e.g. Figures 4.20 and 4.21. Since this expression is based on quantitative measures, it can be used for accurate measurement. In **tree mapping** — as shown in Figures 4.27–4.33 — everything exists in relation to other elements, there is a hierarchy and a central theme. New elements that are identified may be classified and added to the taxonomy, reinforcing the concept of heritage. Despite an expression not alluding to the visual metaphor of a tree, it still might exhibit certain key features of the term; for instance, Figure 4.31 uses a matrix to depict a taxonomy of technology while Figures 4.32 and 4.33 use time as a central theme. **Cell mapping** employs more than one dimension to plot the data, as shown by Figures 4.34–4.43. This may be explicit (Figure 4.37), notional (Figures 4.35 and 4.36) or implicit (Figure 4.34). Compared with Figures 4.31 or 4.33, it is a more discrete expression.

A **check list** presents a information as a simple plan of action, e.g. Figure 4.46. If this prescription is followed, success is likely to result.

All matrices plot the relationship of the data against at least two axes, though there are different ways in which this may be achieved. The **results matrix** is the simplest form of the matrix chart and is used to represent results — quantitative *or* qualitative. This is achieved through straight statements (Figure 4.47 and 4.61), shading (Figure 4.53), size (Figures 4.54 and 4.55) or quantity (Figure 4.56). It is inclusive and taxonomic. Following on from this, the **position matrix** is less explicit, and displays results more descriptively and more discretely, e.g. Figures 4.65 and 4.66. The **motion matrix** takes this one stage further by incorporating movement, either of one product over several periods in time (Figures 4.69 and 4.70) or several products over one period in time (Figure 4.68). By doing so, it emphasises more strongly than the position matrix what has occurred and therefore what is likely to happen in the

Table 4.2

Typology of the interaction between graphic expressions, innovation concepts and their practical usage for the management of innovation.

EXPRESSION	CONCEPT	MESSAGE	EMPHASIS
Geographic map	Geographic comprehensibility	Recording data	Archaic
Abstract map	Position is *not* significant	Flow	Archaic and academic
Network map(ping)	Change	Relationship	Academic
MDS mapping	Position *is* significant	Accuracy	Academic
Tree mapping	Heritage	Taxonomic	Academic
Cell mapping	Inclusion	Discrete	Policy
Check list	Prescription	Simplicity	Academic, media and policy
Results matrix	Inclusion	Taxonomic	Corporate
Position matrix	Description	Possible futures	Media
Motion matrix	Description	Possible futures	Academic and policy

future. Table 4.2 presents a typology that summarises some of these ideas.

It could be argued that the representation of the management of innovation still has some way to progress before it approaches the sophistication of, say, chemistry. The periodic table, for instance, as it is normally depicted, is a matrix, a taxonomy, records five features for each element, where position according to the horizontal and vertical axes is significant — both for the surrounding elements and the chemical 'family' in which it is located, and, with the addition of elements as they were discovered, provides some record of the history of scientific development in the field of atomic chemistry.

Chapter Five
REPRESENTATION OF THE INNOVATION PROCESS

This chapter looks at three prominent themes. The first concerns the macro modelling of the innovation process, and the shift from linear and interactive representations to the all-encompassing characterisation of the network as a metaphor. The second examines how the meso process of the genealogy of ideas and contacts behind invention and innovation has moved from the almost universal portrayal as a sequential process of events in the form of a downward-running flow chart to a network representation where the informal sources of ideas and communication have been promoted as being more important. Finally, the organisational structure behind the innovation process is examined; organisation charts are a common and well-established expression of the structure of a company yet this idealised prescribed network differs from what occurs in everyday working practice and there exists an emergent network that shows relationships more truthfully.

MacLean *et al.* (1995: 9) maintain that "networks are becoming more and more widely used ... reflecting[ing] a growing awareness of the interactivity of many economic phenomena, including the creation and adoption of innovation". The network diagram is recognised as a focused way of displaying data (Strauss, 1987; Werner & Schoepfle, 1987a, 1987b; Gladwin, 1989); the organised and compressed assembly of information permits conclusions to be drawn or action to be taken. Larkin and Simon (1987) asserted that object-based representations preserve the complexity of the relationships in the domain under investigation, providing a means to generate solutions that could not be achieved using traditional text-based representations. (This may explain why 'black-box' modelling methods and the recent move towards network representations have become a popular and usable way to explore, understand and explain the innovation process.) However, Shrum and Mullins (1988: 108) argued that "for most practitioners ... networks are neither a neutral methodological tool nor an amorphous bundle of images, but a set of theoretical and methodological commitments". It is for precisely this reason that the lack of attention to the use of graphic representation has been so surprising though, as MacLean *et al.* (1995: 9) concede, this may be due to the fact that "networks are far from being a tool which can be used in a standardized form".

Likewise, this is true of their graphic depiction. Courtial (1986), for instance, regards a network as being what a graphic theorist would term as either a flow chart or logical (or family) tree (Figure 5.1), while Scott (1991) depicts a more familiar example of a regularly arranged network (Figure 5.2), which is visually pleasing but fails to convey the strength of certain relationships in the most obvious manner.

Figure 5.1

Elementary patterns of key-word networks.

Source: Courtial, 1986: 204.

Figure 5.2

Scottish companies: a circle diagram.

Source: Scott, 1991: 150.

5.1 LINEAR AND INTERACTIVE VERSUS NETWORK

This section reviews several conceptual models of technical change. It begins with the simple linear stage model, passes through the interactive model and concludes with the more complex but more realistic 'systems' model, which is based on the network metaphor. Technical change occurs within the firm and at an aggregate level within a country's economy; while research has tended to examine change at a corporate level, invariably the results are translated upwards to provide some kind of macro model — hence the discussion in this section.

5.1.1 Linear and interactive models

Linear models

Technological innovation is generally considered to be a dynamic, iterative process rather than a one-off event. This is illustrated in Figure 5.3, which suggests that a successful new design involves only a temporary balance of price and non-price characteristics and continued success requires frequent adjustments to this balance.

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Figure 5.3
Innovation as an iterative design process.
Source: Rothwell & Gardiner, 1983: 164.

However, some over-simplified early models of innovation emphasised the causal role of scientific and technological advances, and were generally linear. The 'technology-push' model of innovation (Figure 5.4a) promotes the idea that discoveries in basic science lead eventually to industrial technological developments that result in a flow of new products and processes to the market place. From the early to mid-1960s onwards, largely as the result of a growing number of empirical studies and descriptions of actual innovations, the role of 'felt need' in innovation began to be highlighted, which led increasingly to the adoption of the linear 'need-pull'

Figure 5.4

Two extreme models of the innovation process — the 'traditional' views.
Source: Rothwell, 1983: 4.

model of innovation (Figure 5.4b); researchers believed that innovations arose as the result of a perceived, and often clearly articulated, market need.

The work that stressed most strongly the role of technology in innovation and economic change was probably that of Schumpeter (1910, 1943). In 1910, Schumpeter emphasised the importance of exogenous science and invention that, via entrepreneurship, led to the growth of new industrial branches and new areas of demand. The Mark I model is presented as Figure 5.5. In 1943, Schumpeter emphasised the role of endogenous science and technology in the R&D laboratories of major companies — strongly coupled to exogenous science and technology — that again led to new patterns of production and new market structures. The Mark II model is reproduced as Figure 5.6.

Figure 5.5

Schematic representation of Schumpeter's model of entrepreneurial innovation (I).
Adapted from Walsh *et al.*, 1979: 1.13.

Figure 5.6

Schematic representation of Schumpeter's model of large-firm-managed innovation (II).
Adapted from Walsh *et al.*, 1979: 1.13.

It was the work of Schmookler (1966) that pointed most strongly to the importance of demand factors in innovation. Mainly based on a detailed study of the evolution over time of patents and investment in four US capital goods industries, Schmookler's research led to the conclusion that market growth and market poten-

Figure 5.7

Schematic representation of Schmookler's model of demand-led invention.

Adapted from Walsh *et al.*, 1979: 1.9.

tial were the main determinants of inventive activity (Figure 5.7).

To reconcile the fact that two economists using detailed time-series data had reached opposite conclusions, the Science Policy Research Unit at the University of Sussex sought to establish some answers to this dilemma. It concluded that there was support for a weak version of Schmookler's theory, but little to justify a strong version. In general, Walsh *et al.* (1979) saw their overall findings as being more consistent with Schumpeter's theories than with those of Schmookler. However, they did concede that the entrepreneurs studied under Schumpeter Mark I had anticipated rather than followed demand. They also felt that companies studied under Schumpeter Mark II had institutionalised the process of creative exogenous research to create captive industrial R&D laboratories.

In the past 15 or so years, both the technology-push and need-pull linear models of innovation have increasingly been regarded as extreme and untypical examples of a more general process of coupling between science, technology and the marketplace: technological innovation is generally too complex a process to be described by a simple chain of casuality in one direction or the other (e.g. Mowery & Rosenberg, 1978). This has been attributed to varying reasons. Firstly, more R&D has not necessarily resulted in more innovation. Secondly, over-emphasis on market needs can result in a regime of technological incrementalism and lack of radical innovation (Hayes & Abernathy, 1980). Finally, the relative importance of technology-push and need-pull might vary during different phases of the industry cycle.*

The interactive model

These concerns led to a more accurate representation of industrial innovation being developed, called the 'interactive' model. Innovation is regarded as a logically sequential process, though it may not necessarily be continuous. The process may be subdivided into a series of functionally separate, but interacting and interdependent, stages. The overall pattern of the innovation process can be thought of as a complex net of communication paths, both intra- and extra-organisational, linking together

* The major arguments underlying this area have less to do with specific cases concerning products and processes and more to do with philosophical viewpoints concerning the evolutionary dynamics of new generic technologies or industrial branches.

the various in-house functions and joining the firm to the broader scientific and technological community and to the marketplace. In other words, the process of innovation represents the confluence of technological capabilities and market needs within the framework of the innovating firm. This concept is shown as Figure 5.8.

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Figure 5.8
Interactive model of the innovation process.
Source: Rothwell, 1983: 4.

Despite the increasing acceptance of the interactive model of innovation, it nevertheless remains clear that many governments and industrial companies continue to adhere, at least implicitly, to the technology-push model. This is reflected in the emphasis in most countries on funding R&D — often to the neglect of other areas, such as demand — in the belief that more R&D does indeed result in more innovation. While it might be accepted that there is a close connection between development and innovation, the extent to which the results of basic research, in the form of scientific advance, contribute to technological innovations in industry might be questioned. Is basic scientific understanding a prerequisite to technological progress? If so, is the gap between scientific advance and industrial technological application decreasing? These questions, which are important from a public policy point of view, were raised in the recent science and technology White Paper (1993) and continue to generate debate.

5.1.2 The network model

The network or systems approach to technical change developed in the 1980s, partly in response to studies on the organisation of innovation in successful firms, e.g. Rickards (1985). There has been much criticism of linear and interactive models. According to DeVore (1980), the *TRACES* study (Illinois Institute of Technology Research Institute, 1968, 1969) demonstrated that a relationship between technology and science *did* exist, but not in a direct linear form. Similarly, Finne (1994a: 51) maintains that the representation of technological innovation as a linear process — from basic research via applied research to development and application — is an "outdated descriptive model" while A.S. Shrub, Director for Exploitation of

Research and Technological Development, Technology Transfer and Innovation for the Commission of the European Communities, writing in the Foreword to Soete and Arundel (1993: 6), urged "policy makers, industrialists and economists" to "abandon the linear view of technical change and try to understand industrial innovation as a system". Frey (1989) was more abrupt, advising managers to "junk [their] linear R&D" model and to adopt integrated development techniques to shorten product development times and develop a competitive lead over other firms.*

Walsh *et al.* (1979) concluded that the relationship between science, technology and the marketplace was rarely unequivocally unidirectional, nor was it a simple one, and within particular branches of industry causality could switch from being mainly in one direction to being mainly in the other. The linkages between science, technology and the marketplace are complex, interactive and multidirectional, the dominant force varying over time and between one branch of industry and the next. The modelling of the innovation process in the form of a network seems a logical and anticipated next step in the development of such theories.

Nishioka (1992: 74) believes that "a diagram that needs to visualize the interrelations of data and the flow of changing data requires a somewhat more free-form approach". Being a "formula that has been schematized graphically", it is a "visual expression that evolves in many directions at once ... [using] space for this purpose". This may vary in magnitude: at one level, "it may be a simple schematic to indicate a basic concept and its logical structure" — a network does not necessarily need to be complex or, indeed, to show complexity.

A systems approach to technical change is more realistic than alternative conceptual schemes. By dividing the innovation process into several sequential and independent stages, attention is focused on each stage in isolation from the others. A systems model emphasises the interactive links between different stages and the composition of these linkages. This approach also assumes that technical change must be understood as a whole instead of a sequence of isolated processes, and recognises the cumulative creation of knowledge through learning.

Soete and Arundel (1993) highlight five main characteristics of a systems model of technical change. The first is that multidirectional links occur at the same point in time between the stages of technical change. This requires a well-developed communications infrastructure to facilitate networking and the circulation of information and knowledge among the various actors and activities involved in innovation. Secondly, cumulative processes over time can lead to self-reinforcing feedback loops and lock-in effects. Thirdly, technical change is dependent on the capacity of both individual actors (such as scientists and engineers) and institutional actors (such as private firms and public research organizations) to accumulate knowledge, know-

* It is interesting to note that linear models are likewise criticised in other fields of study. Rogers and Kincaid (1981: 31) maintained that linear models "almost completely dominated communication research in the past" and proposed a convergence model to take their place.

how and skills through learning from codified sources of information, from direct experience, or from other individuals. The fourth characteristic is that the details of the development path and diffusion process for each innovation are unique. Finally, technical change is an interdependent and systemic process.

According to Josty (1990), innovation is a social process in some ways analogous to natural selection. Rather than seeing a series of stages, Josty uses 12 elements and shows how they interact. A partial model containing eight of the elements is reproduced as Figure 5.9: 'Relevant Environment' is shown as affecting the other elements. However, Josty believes that chance plays an important role as well as linking the environment to the elements that it will most influence. The refined model, featuring all 12 elements, is shown as Figure 5.10. The interconnection and absence

Figure 5.9
Partial model of the innovation process.
Source: Josty, 1990: 40.

Figure 5.10
Model of the innovation process.
Source: Josty, 1990: 40.

of starting point truly make this a network diagram of the innovation process.

While a systems model of the innovation process may not be so widespread as linear or interactive depictions, it still does have something to offer. However, its restricted usage might be explained by a lack of graphics modelling the concept: Rothwell (1992) reviews several firm-level systems models that were developed between the late 1970s and the late 1980s, but they are all without illustration.*

5.1.3 Comparison

Reflecting the academic literature, the simplest and most widely-depicted expression of the innovation process is the basic linear model. This model has been metaphorically compared to a pipeline because it suggests that an increase in the flow of upstream or supply-side inputs into the pipeline will directly increase the number of marketable products and processes flowing out of the downstream end.

Figure 5.11 represents technical change as a series of sequential steps, from the perspective of both the firm and the aggregate economy. According to Soete and Arundel (1993), the basic difference between the two versions is that the aggregate model is extended into basic research on the supply-side and into diffusion and imitation on the demand-side. However, this depiction is slightly skewed in that it appears that both models start together and the aggregate model continues for longer. The firm-specific representation should have been centred to reflect the viewpoint expressed in the text.

Figure 5.11

Linear models.

Source: Soete & Arundel, 1993: 31.

Despite a model of innovation being developed as long ago as 1910, Pinch and Bijker (1987) maintain that only recently have theorists started to examine the 'black box' of content. This failure, they contended, has resulted in the widespread use of simple linear models to describe the process (Figure 5.12). The number of develop-

* Rothwell also develops the "integrated model" — innovation is a parallel process involving simultaneous development paths — into a "systems integration and networking model" — a normative model of fully integrated parallel development that idealises how innovation should be organised in the future.

Figure 5.12

A six-stage model of the innovation process.
Source: Pinch & Bijker, 1987: 23.

mental steps is these types of models seems to be, as recognised by Pinch and Bijker (1987: 22), "rather arbitrary". What is more interesting, however, is the employment of an ISO 5807 (1985) computer flow-charting symbol; this appears to 'drive' the flow across the page.

Figure 5.13 shows that the relationship between basic research, applied research, technology and production is complicated, and that they are connected in numerous and complex ways. The dotted lines between the four streams of information indicate paths of information between them. Path 'a' represents the traditional process,

Figure 5.13

Communication among basic research, applied research, technology, and production.
Source: Garvey, 1979: 33: "Path 'a' represents a flow of information from basic research to applied research which uses it in relation to an applied problem and then passes information to technology. Technology develops the information into a potentially manufacturable product, and this in turn becomes the basis upon which production proceeds. Path 'b' indicates a more direct connection between basic research and technology and Path 'c', a direct transition of information from technology to production, without any apparent drawing upon basic or applied scientific information. Path 'd' shows the direct transfer of basic scientific knowledge to production. Path 'e' depicts an interactive path arising out of a need in society for which there is neither a technology nor sufficient scientific knowledge to create a solution. Basic science is stimulated to develop the basic information, applied research builds it, and technology develops from it, which in turn leads to production. Path 'f' shows information flowing from applied research to basic research, whereupon the course of the latter activity is change. Path 'g' occurs when some advance is made in technology which leads basic research to seek to 'understand' or exploit its potential. Paths 'h' and 'i' describe situations where either teams of scientists and engineers collaborate on a problem which spans two or three streams or a single scientist changes roles and moves back and forth as the need arises to advance the work."

while path 'e' depicts an interactive scenario; the text accompanying the figure explains the alternative paths not mentioned. Time on the vertical axis is explicit, rather than being the notional concept that is normally expressed in linear expressions on the horizontal — like a time-series; the steepness of the line indicates speed of change between each stage. This idea was also used in Figure 5.14. It reports on a survey that examined how external perceptions of the JRC (Joint Research Centre of the Commission of the European Communities) can differ. By focusing upstream, the diagram can represent the inputs in more detail, with the position of the line indicating emphasis. The concept of magnitude — up signifying more — is so deeply ingrained that no vertical scale is necessary.

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Figure 5.14
Schematic profiles of research in various organisations.
Source: Bain & Rinaldini, 1989: 182.

Rothwell and Gardiner (1988: 373) asserted that, when innovation and marketing literature referred to a 'new product', it was not new in all of its aspects. It was likely to be a redesign of an existing product "containing only limited additional technical novelty". This redesign process might be of considerable benefit to both the producer and the user of the emerging product: the original users' suggestions would be incorporated into the redesign — for mutual benefit — while improvements to the production process or economies of scale might result in lower costs. Figure 5.15 reflects this, though adopts a flow-chart approach down the page despite being a linear model. The arrows issuing forth from each stage indicate fecundity.

Figure 5.16 expands upon Figure 5.15. To Rothwell and Gardiner (1988: 378), a robust design was one that had "sufficient inherent design flexibility or 'technological slack' to enable it to evolve into a significant 'design family' of variants". By

Figure 5.15

States of technical change.

Source: Rothwell & Gardiner, 1988: 374.

doing so, it could satisfy the changing needs of 'sets' of users. The manufacturer would benefits with shared experience and economies of scale, while the users had the advantage of a proven design and maximum choice. There is much text in the diagram but this adds to the graphic due to its design. The text is in a small point size and is inconspicuous compared to the drawing which attracts the eye and encourages the viewer to read the accompanying text. The graphic is almost illustrative in its use of strands of rope intertwining to form the robust designs, and their subsequent separation into design families.

Figure 5.17 represents Roy's (1986c) interpretation of Figure 5.16. The graphic's use of the image of a cloud to represent creativity is a clever touch, but the rest of the diagram fails to be so original. Two of the 'strands' of composite design are left hanging, while the 'frayed' design families fail to give the impression that they are separate entities derived from consolidated designs. In addition, the identification of the stages is inaccurate; the scope for robust designs is too wide, while the other

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Figure 5.16

Composite and consolidated designs are convergent design processes, while stretched designs are a divergent process.

Source: Gardiner, 1986b: 144: "Composition, consolidation and stretching phases do not all have to be done by the same individual or group or even within the same organization. In the innovation literature there are lots of second-to-the-market firms who are good at the consolidation phase and/or particularly the stretching phase. Big aviation and automobile firms normally proceed through all three phases, but if competitors come up with something new which allows the whole process to be shortened, most firms will take it up and incorporate it into their own designs."

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Figure 5.17

The stages through which dominant, 'robust' designs evolve.

Source: Roy, 1986c: 252, adapted from Gardiner & Rothwell, 1985.

labels overlap somewhat.

Moving onto less linear models, Figure 5.18 is a redrawing of Figure 5.7. After close study, it is apparent that there are more differences that simply those of shape. Firstly, the arrows indicating Route 4 are correctly oriented. Secondly, a description is added — 'Demand met with new or changed technology' — even though it does seem to float unattached and it is not clear to the casual reader to which route it applies. There is nothing significant in the change in the dimensions of some of the shapes — it is clear that the visual similarity of the blocks continues to denote inclu-

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Figure 5.18

Schematic representation of Schmookler's model of demand-led invention.

Source: Freeman *et al.*, 1982: 37.

sion — since it is not a change in emphasis: a change in size does not denote a change in importance.

Figure 5.19 reproduces the model that was shown to interviewees as part of the *Interactions* study. Battelle (1973 maintained that its inclusion had no significance — it did not mean that this modelling of the innovation process was advocated above others — since the purpose was to locate the subjects. While it may have no significance for policy, it does signify that it was accepted that this representation would be understood or recognised by a cross-section of scientists, engineers and business people. In actual fact. the figure is a fairly standardised linear depiction.

Forrest (1991: 440) maintains that while sequential-linear models of the innovation process might not be "as relevant today they do have historical value". Utterback (1971b) viewed innovation as a three-stage process — 'generation of an idea', 'problem solving or development', and 'implementation and diffusion' — and depicted it this way (Figure 5.20). Saran (1984) termed this an *activity stage* model since the focus was on the activities involved at each stage. Time characteristically moves across the page from left to right, though no explanation can be provided for the inverted ends of the current 'environments'. According to Forrest (1991: 445), the Schmidt-Tiedemann model has "practical applications and can be readily used in the management planning process". Figure 5.21 is certainly the most complicated depiction of those examined so far, attempting to combine the research, technical and commercial functions of a company throughout the innovation process. The overall impression on first glance is one of complexity; however, careful study reveals that

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Figure 5.19

The process of technological innovation.

Source: Battelle, 1973: B-2, adapted from Myers & Marquis, 1969.

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Figure 5.20

Utterback's stage model.

Source: Forrest, 1991: 440, taken from Utterback, 1971b: 78.

the model is well constructed and makes good use of typography.

Figure 5.22 also provides more interactivity, despite Grupp (1990b: 59) describing it as "simple" and "very crude". Rather than the phases being positioning across the page from left to right, notionally against time, as is typical, they are positioned down the page and time is not represented. To the unwary observer, the dominance of heavy arrows moving from left to right would give the impression that these conveyed the sequence of events. However, Grupp's focus is on the inputs and outputs

Figure 5.21

Schmidt-Tiedemann's concomitance model.

Source: Forrest, 1991: 446, taken from Schmidt-Tiedemann, 1982: 20.

Figure 5.22

A simple input-output model for research, development and innovation stages and corresponding S&T indicators (stand alone or combined).

Source: Grupp, 1990b: 59.

of the model, together with the corresponding indicators, hence the emphasis given to their depiction. The employment of size for the arrows also denotes relative importance; since there is no key, it must be assumed that this is notional.

Twiss (1980) drew on several studies on successful and unsuccessful innovations, and concluded that certain factors were important for success and these would vary in each case. Figure 5.23 recognises the effects of both the internal and external environments, yet still manages to represent the innovation process as a linear

Figure 5.23

Twiss's activity stage model.

Source: Forrest, 1991: 442, taken from Twiss, 1980: 19.

sequence. It is interesting to note that the marketing department is not depicted in having a role in the product that emerges in the external environment and, in the light of later discussions in this chapter, that creativity is shown as being generated from within the company.

Oakley (1984: 15) maintains that "there are always dangers in attempting to present a 'typical' model of any human activity", but concedes that it is necessary "in order to have some common ground between reader and writer" and advises that some constraints should be stated. Despite adherence to the latter, Oakley notes that Figure 5.24 is "unsatisfactory" since it models theoretical perfection rather than practical reality. Indeed, it is the most basic representation encountered in this section. Figure 5.25 presents a spiral conceptualisation that emphasises that the process is an evolving activity. In addition, market response — missing from Figure 5.24 — is incorporated. The spiral represents the benefits brought about by the learning curve and new technology: as each cycle is completed, more knowledge is gained, while convergence is helped by computer-aided design (CAD) which helps to combine different stages of the process, e.g. evolution and transfer.

The circular metaphor is continued in Figure 5.26. According to Rothwell and Gardiner (1985: 167), the relationship depicted has been "pictured variously" and that this is "one of the better attempts". The diagram promotes a recurring Rothwell/Gardiner idea of the innovation process failing to cease at market launch but rather continuing in a process of evolutionary development. Influences are depicted with a textured arrow and the development phases within circles.

The innovation chain (Figure 5.27) is another model that was proposed to

An elementary linear model of the product design process.

Source: Oakley, 1984: 16.

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Figure 5.25

A spiral model of the product design process.
Source: Oakley, 1984: 16.

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Figure 5.26

Model of the evolution of a successful invention.
Source: Rothwell & Gardiner, 1985: 168.

explain the innovation process. From it, Pannenborg (1986) asserted, the notions of *technology-push* and *market-pull* had been derived. Despite this, Pannenborg (1986: 176) maintained that "innovation [was] not a linear phenomenon", though the addition of feedback loops made it "a proper description of reality". While the depiction makes it evident that there is interaction between pure and applied science, some of the other relationships are not so explicit. For instance, do the arrows indicate there is contact between market research, purchaser and user? Also, the positioning of feedback loops over the notional divisions of the process — ' 'nonprofit' science', 'industry' and 'market' — confuse the representation.

Figure 5.27
Innovation chain with some of the feedback loops.
Source: Pannenborg, 1986: 176.

Figure 5.28 uses a flow-chart approach to depict the innovation process and the flows are much more evident in this representation. Buijs (1979: 27) maintained that a strategy of some kind was necessary before the process could begin and the idea "must be found within the product/market strategy". This is not reflected in the diagram; indeed, the 'strategic planning' box is the only concession to any type of strategic involvement. However, while there may only be one feedback loop, the diagram does represent choice at two stages in the process.

In an introductory article on innovation, Roy (1986a) examined the different textual definitions of innovation. When it came to its graphical representation though, Figure 5.29 was the sole entry. According to Roy (1986a: 2–3), "it includes all the various activities — research, design, development, market research and testing, manufacturing engineering, etc. — involved in converting a new idea, invention or discovery into a novel product or industrial process in commercial or social use". The process is depicted as involving three stages. The 'design/development activity' is boxed with a broken line, indicating that flows can pass in and out. While the diagram does not use the circular metaphor, it does employ 'white space' to create overall a square impression of the process, significantly different from the linear depictions that were subsequently discussed.

Brown and Karagozoglu (1989) described their theory as being a systems model (Figure 5.30). The basic nature of the representation shows that this depiction is, at

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Figure 5.28

The process of product innovation.

Source: Buijs, 1979: 27.

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Figure 5.29

The process of technological innovation.

Source: Roy, 1986a: 3.

heart, a linear model with interactive feedback loops. A more sophisticated representation might have hidden this, but the flow from left to right is evident. This paper was identified by an on-line literature search in title and abstract; it is clear that the

Figure 5.30

A systems model of technological innovation.

Source: Brown & Karagozoglu, 1989: 12.

figure does not accurately represent the 'systems' model that might be expected.

The activities of West German research institutions can be seen in Figure 5.31. The steps of the technology transfer from research to application are indicated along the vertical axis; the distinction between public and private status is shown along the horizontal. The figures represent the annual expenditure on research and development in billions of dollars and they are proportionate to the area of the rectangles. While universities, the Max-Planck-Society and, to a degree, the public research centres are primarily involved in fundamental research and long-term application-oriented research, the Fraunhofer Society, research associations and, in particular, industry are concentrating on short-term application-oriented R&D; this is indicated by the position of the rectangles in the graphic. While not fully quantitative, this graphic manages to be multivariate, informing about the nature of the innovation process, notional divisions, the legal status, and expenditure. That is such a good representation is reflected by Figure 5.32 since it must be concluded that it is based on Figure 5.31 in some way. Indeed, the notional divisions are grouped while the areas of performance are subdivided, at the same time as engendering comparison between Germany and the UK.

Malpas (1991: 10) describes the process of harnessing technology for profitable growth in "topographical terms". Innovation may arise anyway along a 'route' from science to business, with technology in the middle. Money 'fuels' the vehicles that travel the route. The route is 'illuminated' by knowledge and experience, and it is technologists responsibility to build 'bridges' over the 'valleys' between science and technology, and between technology and business. The description may be prosaic, but Figure 5.33 accurately reflects the metaphorical language Malpas was using to

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Figure 5.31

The R&D structure in West Germany, 1987.

Source: Krupp, 1990: 198.

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Figure 5.32

Research expenditures in 1987.

Source: Leadbeater, 1991: 10.

Figure 5.33
The topology of technology.
Source: Malpas, 1991: 11.

deliver the lecture. It is almost an illustrative depiction but it does not suffer because of this. The same can be said of Figure 5.64, which is derived from a business magazine and appears in a policy report. While not a depiction of the innovation process, the figure does portray similar types of relationships in the manner that a 'systems' model might. The diagram features a certain degree of complexity and different types of activity flows. If some of the illustrative features were ignored, the relationships would be highlighted more.

Similarly, Figure 5.35 is not a 'systems' model of the innovation process in the strictest definition of the term. Sigurdson (1990c) depicts the structure of R&D in the

Figure 5.34
The telecom network.
Source: de Woot, 1990: 26, taken from *The Economist*, 23 November 1985.

Figure 5.35
R&D system — networking.
Source: Sigurdson, 1990c: 174.

global economy as a system. According to Sigurdson, this comprised universities and research institutes, and corporate laboratories. To this has been added research consortia, and depicted as an intermediate layer — 'ultrastructures'. Flows in and out of the network boundary are shown with arrows, but simple links are used to represent the relationships between the actors. It is not the easiest of diagrams to comprehend, but it is one of the more realistic depictions of the (manifestation of) the innovation process.

The strength of the linear models lie in tradition division of the innovation process into several discrete and identifiable stages. This, in turn, reflects the traditional division of the innovation process within firms into separate departments such as R&D, production and marketing. It seems as if theory of the innovation process is between paradigms; though the linear model has been widely discredited by academics and policy-makers alike, there seems no alternative to it unless companies change the basis upon which they are organised. While networks are a flexible expression, the systems model has not generated anything like the amount of research — or consensual support — as the interactive and, more particularly, linear models have. The linear representation and the theory it embodies remains the implicit model on which public policy makers and industrial strategists rely.

5.2 FLOW CHART VERSUS NETWORK

Since the 1960s, a number of research projects have attempted to determine the nature and source of the stimuli leading to the initiation of successful innovation, e.g. Myers and Marquis (1969). Coincidentally or consequently since then, there has also been a strong interest in the mechanisms of idea and information transfer. The primary focus in the 1960s was on the charting of the communication patterns of scientists and engineers, and the identification of the principal mechanisms by which these actors received ideas and information, e.g. Shilling and Bernard (1964), Allen (1969). To help conceptualise this, a number of normative and descriptive models were proposed that portrayed the process in sequential stages. The 1970s saw the concern switch to the mechanisms employed to transfer ideas and information in the development of specific innovations (Langrish *et al.*, 1972; Gibbons & Johnston, 1974). Allen (1977), in particular, identified scientific and technical journals, and in-house publications as mechanisms for the transference of ideas and information across the organisational boundary.

In a review of the literature, Freeman (1991: 500) noted that empirical studies of innovation since the 1950s have demonstrated "the importance of both formal and informal networks, even if the expression *network* was less frequently used", and that "multiple sources of information and pluralistic patterns of collaboration were the rule rather than the exception".* This dichotomy is reflected in the graphic representation of the expressions that are used to depict these concepts. A flow chart plots a path, tracing the lineage of an invention from inception to culmination; typically this is a linear sequence of events over time. A network shows relationships. It embraces the concept that innovation should not be viewed as resulting from a single idea, but from a *bundle* or *ensemble* of ideas, information, technology, codified knowledge and know-how that may or may not be embodied within the product process. Typically a network graphic portrays a set of relationships in space — a one-off event, recognising their dynamism — though it may also achieve this over time with additional representations.

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* The distinction between networks representing communications patterns of ideas and information, and networks representing informal intercompany relations is not absolute. For ease of discussion, where there is significant exchanges between companies — in the form of collaborations, alliances and the like — that might be alternatively represented by a flow chart, the expression will be included in Section 5.2 and examined as an idea network; where the emphasis is on exchanges within companies that might be alternatively represented as an organisational chart, the expression will be included in Section 5.3 and examined as an emergent network.

5.2.1 Genealogy of inventions by flow chart

Flow charting was defined by Oakland (1989) as the systematic planning or examination of any process. Harrington (1991) discusses the use of four types of flow charting tools to provide an overall model of a process:

1. block diagrams to provide a simple overview;
2. American National Standards Institute (ANSI) standard flow charts that detail the activity and flow interrelationships;
3. functional flow charts depicting process flows between functions or areas; and,
4. geographic flow charts showing the flow between locations.

Flow charting is a well-established tool used in traditional systems analysis, work study and as a tool in quality improvement programmes. Schmid and Schmid (1979) specifically termed charts applied to these types of uses as 'control' charts — typically schedule or production tools used in planning or co-ordinating certain administrative, procurement, production and distribution processes.

The shape of a tree is a symbol that has been portrayed everywhere throughout the history. According to Booth-Cibborn and Baroni (1980), its timeless appeal was due to its many meaningful values, but it was important above all for the intrinsic sense of immortality it evokes, through the development of a circular path that brings it back to the seed that regenerates it. Likewise, genealogy has been the symbolic expression of the authority of each dynasty. These metaphors are also used in the portrayal of innovation.

The chronicling of inventions combines several diverse factors. While block diagrams are often used, it is the time element of innovative flow charts that differentiates them from the linear 'black-box' models of the innovation process. Similarly, while the use of symbols is not the rule, neither is it the exception. Innovative flow charts frequently show flows between functions or areas and geographical locations, yet they also depict input from actors and or the influence of artefacts. The concept of the 'tree of invention' or genealogy is a consistently strong visual metaphor; since flow charts are rarely used to predict the future, the idea of heritage seems to be have become reinforced to demonstrate what was achieved in the past.

As was discussed in Section 5.1, one of the two commonly held views concerning the innovation process perceives innovation as a rational, orderly linear procedure that can be organised and managed. It follows that this should be the case at a corporate or individual level. Schon (1967) believed that creativity was a matter of applying conscious intelligence to the solution of identified problems. As might be expected, Figure 5.36 graphically represents this in a manner that is entirely sympathetic to the tenets of the theory. Buijs (1979) outlined idea generation and selection for the product innovation process (Figure 5.37). The feedback mechanisms evident in Schon's depiction are missing, but the element of choice has been introduced, along with flow charting symbols denoting the different procedures.

Figure 5.36

Diagram of linear perception of creative process and product design system.
Source: DeVore, 1980: 67, adapted from Schon, 1967.

Though the flow chart is often thought of as a descriptive charting technique, its utility is often not fully appreciated or applied. Cooper (1983) drew standardised flow charts of 58 new product processes and then used to diagrams to analyse the similarities and differences between them. Figure 5.38 shows an example of this. Rather than conceiving the process as a series of sequential 'black-box' stages — similar to the modelling of the innovation process in the Section 5.1 — Cooper's flow

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Figure 5.37

Idea generation and selection in the product innovation process.
Source: Buijs, 1979: 29.

charts graphically displayed that, typically, a number of activities occurred simultaneously and that one stage did not need to end before the next started, as depicted by Figure 5.39.

However, the flow-charting expression that most characterises the depiction of the genealogy of inventions is typified by that used in two large-scale government-backed research studies: *TRACES* (Illinois Institute of Technology Research Institute, 1968, 1969) and *Interactions* (Battelle, 1973). To take one example, the tracing of the development of the video cassette recorder (VCR) was covered by *TRACES* and *Interactions*. Its development has subsequently been examined by, among others, DeVore (1980) and Rosenbloom and Cusumano (1987). As Figure 5.40 shows, the origins of the VCR's invention extend back to basic work in magnetic materials, con-

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Figure 5.38

Flow diagrams of the market-oriented process (left) and design-dominated process (right).
Source: Cooper, 1983: 8.

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Figure 5.39

Flow diagram of the 'average' new product process.
Source: Cooper, 1983: 5.

trol systems and mechanical design due to a need created by television and the convergence of R&D. As well as the reverse tree map with a time dimension employed here, linear time scales were also used by these studies. It should be noted that Fig-

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Figure 5.40

The research origins of the video tape-recorder.

Source: Irvine & Martin, 1984: 19, taken from Illinois Institute of Technology Research Institute, 1968: 56.

ure 5.40 has had its dimensions massively reduced; the original source from which it is derived is actually printed on an A2-sized piece of paper that folds out from the main body of the report.

5.2.2 Sources of ideas by network

In recent years, innovation studies have shown a new focus on the relationship between organisations and between individuals; the network concept is the most prominent expression of this orientation. According to Kruskal and Seery (1980: 22), "the use of diagrams to describe networks is a classical application of graphical presentation. Such diagrams are widespread, perhaps because networks are ubiquitous and a well-drawn diagram seems to provide the best way of describing a complex network".

Cataldo's (1966) perceptual laws provide the graphic designer with a reliable psychological basis for the spatial organisation of graphic information. The fourth law — similarity — requires that visual units that resemble each other in shape, size, colour and direction will be seen together as a homogeneous grouping. This law is based on the tendency of the eye to organise visual stimuli into an ordered pattern, a tendency that is closely allied with the fifth law, the law of proximity. This proposes that in visual perception what is closest together tends to unite. Images of objects that are close to one another form groups and are seen against an empty space.

The use of graphic representations to illustrate actor networks dates back to the sociogram of Moreno (1934), while the utilisation of graphics to depict networks of actors or artefacts has been widespread since the late 1960s (Marquis & Allen, 1966; Frost & Whitley, 1971; Levine, 1972; Allen, 1977; Hughes, 1983; Auster, 1990). Despite this, network graphics have tended not to employ a set of recognised conventions. Indeed, Kruskal and Seery argued that:

> Diagrams of the same network can differ in many ways: location of the nodes, the paths followed by the edges, the size and shape of the symbol at each node, the thickness and character (solid, broken, dotted, etc.) of the lines indicating the edges, the content and placement of the labels, and so forth. (1980: 22–23)

In addition, Bertin (1983: 271) noted that "the elements [actors] ... can be represented by points and the representations by lines, or conversely. In certain cases, the lines alone can represent both elements and relationships". Following a review of the network literature, Steward *et al.* (1993) noted the existence of a wide variety of approaches and styles in the arrangement of nodes and the depiction of these nodes and their relationships. Kruskal and Seery (1980: 22) also observed that network graphics are often the product of a process of extensive trial-and-error, arguing that "designing a *good* diagram requires both skill and tedious effort".

An example of the use of network depict to chronicle the exchange of ideas is provided by Pinch and Bijker's (1987) chronicling of the development of the bicycle. They maintained that Figure 5.41 is a quasi-linear view of the development of the bicycle, obtained by retrospective distortion, and contended that the so-called 'safety ordinaries' — Xtraordinary, Facile and Club Safety — were "amusing aberrations that need not be taken seriously" (Pinch & Bijker, 1987: 28). Of course, it was only possible to state this with the benefit of history; in the view of the producers of that time, these variants were quite different from one another and were serious rivals.

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Figure 5.41

The traditional quasi-linear view of the developmental process of the Penny Farthing bicycle.
Source: Pinch & Bijker, 1987: 31: "Solid lines indicate successful development, and dashed lines indicate failed development."

Figure 5.42 presents a multidirectional model to explore why some variants 'die' whereas others 'survive'. The shaded area represents the selection part of the developmental process where the problems are presented to the manufacturers; their effectiveness in finding a solution affects the bicycles future success. Figure 5.43 presents a network diagram of the problems, solutions and artefacts. It is interesting to note certain 'conflicts': technical (speed and safety), solution (indirect front- and rear-wheel drive) and moral (women's attire). From this, it is clear why Lawson's Bicyclette gained a market succeeded, and why the Xtraordinary became marginalised and failed.

Contemporary research into networks is concentrated at the organisational level, focusing on the analysis of networks of innovating organisations within and between industries, regions and states, e.g. Hakansson (1989), Hagedoorn and Schakenraad (1992); DeBresson and Amesse (1991) and Freeman (1991) have

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Figure 5.42

A multidirectional view of the development process of the Penny Farthing bicycle.
Source: Pinch & Bijker, 1987: 29: "The shaded area is filled in and magnified in [Figure 5.43]. The hexagons symbolize artifacts."

reviewed the literature. For the purposes of discussion, graphics depicting these types of relationships will be examined in the following section; where there is a tendency to portray exchanges within the organisation, or where the balance is tilted towards the company, the depictions are classed as emergent networks and are included in Section 5.3, though it is recognised that the distinction between them is not absolute and it may not be strictly correct according to network theory.

5.2.3 Comparison

A systematic exploration of a review of the network literature by Steward *et al.* (1993) reveals the existence of a wide variety of approaches and styles used to illustrate the relationships between a group of actors or artefacts. A network graphic "allows for easier and quicker assimilation of the data" and is "also able to provide information concerning the nature of the relationship … and the direction of flow … without too much visual distraction or additional cognition by the viewer". (Steward *et al.*, 1993: 7) However, before networks became such a ubiquitous technique and visual expression, ideas — and the products in which they embodied — were characteristically graphed by flow chart.

The first instance is provided by Figure 5.44, which presents two design trajec-

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Figure 5.43

Some relevant social groups, problems, and solutions in the developmental process of the Penny Farthing bicycle.

Source: Pinch & Bijker, 1987: 37: "Because of lack of space, not all artifacts, relevant social groups, problems, and solutions are shown."

tories as a temporal series. Given the time lines, decade by decade comparisons can be made. The diagram links with the accompanying table to provide a tabular summary of the comparisons of the major changes in the design trajectories. This is an ingenious way of providing extra information without overloading the graphic.

Normally, design trajectories promote lineage; Figure 5.45 demonstrates that, in this particular case, that heritage is a disadvantage. By depicting the development process of the PowerPC 601 chip as being only three years, compared with the 22 year history of the predecessors of the Pentium processor, the implication that the PowerPC is based on newer technology and everything that it represents. This is reinforced with the statement of the bit technology employed; Intel have been developing 32-bit processors for eight years, while the PowerPC consortium moved from

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Figure 5.44

Two design trajectories.

Source: Gardiner, 1986a: 127–128.

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Figure 5.45

Time line showing the evolution of the Intel 80x86 from the 4004 calculator chip in 1971 to Pentium, compared with the evolution of PowerPC from the IBM POWER architecture in 1990 to the Power PC 601 chip in 1993.

Source: Apple Computer, 1994b: 4.

32- to 64-bit after just three years — the implication being what has been achieved in the past is possible in the future.

Figure 5.46 depicts the processes that are experienced during the discovery and development of a drug against time. The figure is positioned across the centre spread of the source document, eight pages after it is discussed in the text. The likely reason for this is that the Office of Health Economics — an organisation working on behalf of the pharmaceutical industry — wanted to emphasise the length of time it could take before a drug could come to market; Wells (1983) claimed that regulation had increased this from a period of approximately three years in the early 1960s to

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Figure 5.46

Stages in the discovery and development of a typical drug.
Source: Wells, 1983: 26–27.

over ten years at the time of writing. The temporal element is stressed by depicting the events in a linear fashion, while the centre spread enables the events to be located across two complete pages without the limitations of binding or stitching, or turned on its side and confined to one A5-sized page with the resultant loss of impact.

The development of the key conceptual innovations, their development and the resultant demonstration are shown in Figure 5.47. The first operating laser, a device using ruby as the active medium, was demonstrated in 1960. This contrasts with the development of the neural-atom laser, whose key concept derives from the 1930s, the impact of which is not fully graphed due to the foreshortened depiction of time. This visual affect of this is that the free-electron laser appears to have had a significantly longer development period when, in fact, it was marginally longer than that of the neural-atom laser. In addition to development, the lasers are grouped, the free-electron type being in its own, yet to be labelled, category.

Figure 5.48 emphasises the diffusion of technology. In this case though artefacts are not being dispersed through alliances and collaboration; rather it is the movement of key R&D personnel in American semi-conductor industry and the know-how they take with them — the contribution of Texas Instruments is particularly noticeable. This figure is one of three that Freeman (1982) included; Shockley Transistor (marginalised in Figure 5.48), Hughes Aircraft, Sperry Semiconductor, General Electric, RCA and Radio Receptor are other companies whose spin-offs are charted. Complexity probably precluded their simultaneous charting; in addition, problems are caused by the width of these types of representation and in the way that time is depicted as flowing down from the origin.

Time is not featured in Figure 5.49 despite being an illustrative depiction of the lineage of the Harrier. (Some dates are reported but in a small font size so that significance cannot be drawn from them. Similarly, the two branches do not track time comparably, while the 1983 Sea Harrier Mk51 for the Indian Navy is depicted in the same position as a design introduced four years previously.) However, unless the

Figure 5.47

The development of major laser types.

Source: Granberg, 1990: 79.

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Figure 5.48

Spin-offs from Bell Telephone Laboratories and Westinghouse Electric.

Source: Freeman, 1982: 97.

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Figure 5.49

The Harrier family.

Source: Roy & Potter, 1990: 28.

Figure 5.50

Rolls-Royce RB211 engine family.

Source: Rothwell & Gardiner, 1990b: 287.

reader is knowledgeable about fighter design, the illustrations are visual decoration. Figure 5.50 presents a better representation, showing how Rolls-Royce derived a family of products from the RB211 aero engine. Time is even more notional than the previous figure, once again arrayed from left to right, but the diagram is interesting because it plots thrust on the vertical axis so that the reasoning behind the strategy is made evident.

Figure 5.51 shows a much reduced detail taken from an A2-sized full-colour advertisement in *The Financial Times*. The metaphorical aspect of the tree representing lineage and growth has been exploited to the full by depicting Airbus Industrie's aircraft as branches on the tree. It is interesting to note that while most academic, or even policy, representations of lineage use the tree metaphor, they use it in a reverse manner, in the same way as genealogists; Airbus's advertising agency obviously felt that it was more positive to show the products as being derived from a strong base and growing upwards.

Figure 5.52 is a practical example of the evolution of a design. According to Roy (1986c), the development of the bicycle closely matches Gardiner and Rothwell's (1985) original model (reproduced as Figure 5.16). However, unless this figure is viewed against Gardiner and Rothwell's model, the visual similarity is less than striking and close attention has to paid to the identification of the stages down the right-hand side of the diagram. The main areas for divergence are that there only seems to be one 'strand' of composite design and that the design families on the left of the diagram do not appear to have been derived from a stretched design. However, illustrating the bicycles' designs does allow for design changes to be observed; these are more obvious than those in Figure 5.49.

Figure 5.53 shows the genealogy of products from the Boeing Company. Again,

Figure 5.51

The family tree.

Source: detail from Airbus Industrie advertisement, *The Financial Times*, 2 September 1982: XIV: "Every Airbus aircraft has been designed to meet the needs of airlines throughout the world, and in particular to satisfy the demanding economic criteria of our customers. We have designed in a high degree of commonality between most of the family, which is a major factor in reducing airline costs. Our aircraft set industry standards. For example, the whole family is capable of handling LD3 compatible containers, something none of our competitors can claim. The combination of many such attributes on aircraft that have the lowest seat mile costs in their categories, highlights our success and is why our family tree continues to grow fruitfully."

there is another attempt to depict divergence into composite designs, then consolidated designs and finally stretched designs — the concepts leading to design families. In particular, it was used to demonstrate a robust design, starting with the 707's prototype — the 367-80 or 'Dash 80' — in 1954, that led to the development of the

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Figure 5.52

Evolution of the bicycle through divergent, convergent and divergent phases between 1860 and 1980.

Source: Roy, 1986c: 253.

KC-135 jet tanker for military purposes and the 707-120 in 1957. Several stretched designs were based on the latter, including the 220, 320 and 420 models and the Boeing 720 was a derived design. In the 1960s, more variants of the original Dash 80 robust design brief followed, including the 727 series and 737 series. In 1969, the Boeing 747 was produced, based on the 707 design concept. The addition of another variable (maximum altitude, speed, payload, among others) would have transformed this time-series plot into a speed-time narrative design. As it stands, it is not clear why the aircraft are arranged in this manner, apart from visual similarity.

Figure 5.54 shows the genealogy of companies in Silicon Valley, California to highlight the role of SMEs. According to Rothwell and Zegveld (1982), the beginnings of the semiconductor industry can be traced to the invention of the transistor effect in Bell Telephone Laboratories in 1947. In 1952, Shockley — the research team leader — left and subsequently formed a company backed by the Clevite Corporation. Again, key personnel from this company subsequently departed and established Fairchild Semiconductor. During the next few years, there was considerable spin-off from Fairchild as can be seen from the figure. There is some attempt to depict divergence and convergence but this is hampered once again by the volume of data — labelling always seems to cause problems by overemphasising its importance compared to the lines. The depiction of the timescale has been sacrificed to graphical and typographical constraints; the error is not vast but the less wary reader could be caught off guard.

Figure 5.55 illustrates the range and growth of telecommunications services that are appearing. Rather than using lines to link discoveries, the inventions are cumulatively plotted to promote the impression of expansion. The right-hand side of the diagram lists different communication technologies and it is possible to trace the lineage back to explore how they are derived. Figure 5.56 was not referred to in the source text (Lorenz, 1986), a summary of an article by a Booz, Allen & Hamilton consultant that had been first reported on five years previously in *The Financial Times*. The key concept was the 'cascading pattern', the description given to Japan's gradual penetration of US consumer electronics that began with carefully selected small segments (e.g. transistor radios) and resulted in market dominance. The figure illustrates the point very effectively and uses the flow chart metaphor for developments to work down the page as they are introduced and across the page for time. The figure is similar to Figure 5.55, but in this case the plots overlap each other to reinforce the desired impression of 'crowding out'.

Figure 5.57 attempts to locate the development of key IT innovations in time. Typically, lists like this tend to relate a rather static picture since they do not capture the trajectories of the technologies in time. In this case, the convergence between communication technology and computer technology seems artificial with no 'trigger' apparent in the diagram to cause the change. Surely, this is one of the most important features to represent!

Hawthorne deployed Figure 5.58 to demonstrate that the development of numerically controlled machine-toll technology could be traced back through the technological routes of feedback control, Jacquard's command technology, Babbage's computer and the precision machine-tool technology of die-sinking and bor-

Figure 5.53 (over)
Boeing family tree.
Source: Gardiner, 1986b: 154–155.

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Figure 5.54

Silicon Valley geneology.

Source: Rothwell & Zegveld, 1982: 30–31.

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Figure 5.56

Japan's expansion strategy: by a 'cascading' penetration of related market segments.
Source: Lorenz, 1986: 153.

ing. However, there is no consistency over the portrayal of the time-scale and the overall impression is a series of disparate events in time coming together to produce an innovation. Figure 5.59 was used by Hawthorne to postulate about the development of the 'home-movie videocamera', which had not been invented at the time of writing. Hawthorne claimed it would owe its existence to four main streams of technological development: semi-conductors for the circuitry, electronic television cameras, tape information storage, and battery power storage. Hawthorne found it difficult to forecast which events would have a predominating influence and so gave

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Figure 5.57

Some key events in the convergence of information technology.

Source: Arnold & Guy, 1989: 152.

each route equal importance: simply, it is a number of pertinent events represented by blocks. However, the 'errors' are more 'forgivable' in this case.

Figure 5.60 displays the genealogy of the invention of the video-tape recorder — an alternative representation of Figure 5.40. It side-steps the problem of text and labelling with a special key and extensive notes either side of the diagram. However, the use of a photograph of an early video-tape recorder is unclear; is it decorative or does it serve a purpose? In addition, the original source for this figure is displayed over three larger-than-standard pages, which necessitates a flow-chart approach. However, when this figure is compared with Figure 5.40, it gives the impression of being less dynamic: the source of inventions seems narrower, partly due to the width-oriented approach undertaken by *TRACES*, the information is not contained within one page and the text either side of the events detracts from their importance.

Monk (1989) maintained that network representations of the diffusion of IT offered flexibility, simplicity and coherence. Figure 5.61 shows a network model of technology interrelations in which IT forms one node. The selection of technologies and their pattern of relations shown in the model are arbitrary; their purpose is merely to illustrate Rosenberg's (1982) proposition that different technologies are necessarily interrelated. The use of a network model allows the hypothesis that sets of technologies may be linked by different patterns of relations. The model shown in Figure 5.61 describes one such pattern; rather than using lines with arrowheads at each end, a single-headed arrow is used so that density is equivalent to more interaction between the technologies.

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Figure 5.58

Four-line development of numerical control.

Source: Hawthorne, 1978: 4.

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Figure 5.59

Technological routes to a home-movie videocamera.

Source: Hawthorne, 1978: 14.

Figure 5.60 (over)

The geneology of an invention — video tape recorder.

Source: DeVore, 1980: 70–72, adapted from Illinois Institute of Technology Research Institute, 1968: 56.

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Figure 5.61
Network model of technology interrelations.
Source: Monk, 1989: 155.

Figure 5.62 uses some unusual shapes to add to a representation of triad rivalry and technology competition for international R&D. The reasoning in the choice of the shape is not alluded to in the text and the purpose cannot be drawn from the diagram either, apart from suggesting the NICs are derived in some way from the LDCs. Differences in shading are used to denote differences within the same block, e.g. Western Europe and Eastern Europe/USSR. All the links are two-way lines, though a curve is used with different arrowheads to link the EC with the USSR. Also, it is unclear whether the 'emerging "alliances" ' are a different type of link, or a line that has failed to have arrowheads added. It is fair to say that this is not a particularly successful or elucidating graphic.

Figure 5.63 maps the relationships between a small group of companies. It provides information concerning the nature of the relationship (such as joint venture or direct investment) and the direction of flow through the relationship without too much visual distraction or additional cognition by the reader. While the structure on which it is based is not explicit, it appears as if the actors are arranged in a regular manner around a circle. The circle concept is to the forefront of Figure 5.64. The different types of alliances are separated into different pieces of 'pie'. The lines play no purpose other than to draw the attention back towards IBM in the centre.

Alliances are also depicted in Figure 5.65. However, the subtitle to the diagram is "When worlds collide"; though industry alliances are being mapped, it is evident that a company is either an ally or enemy of IBM or AT&T; McDonnell Douglas US is the only enterprise that has indirect contact. Figure 5.66 shows the situation for the telecommunications industry. This is much more than the 'two-horse race' of the

Figure 5.62

Triad rivalry and technology competition.

Source: Sigurdson, 1990c: 189. LDC stands for less developed country, NIE for newly industrialising economies.

previous figure; indeed, sole alliances are a feature that characterise the smaller actors. Why only certain of the actors should feature as significant nodes is unclear; it must be related to the type or significance of the links since it is not due to their number. No such delineation affects the nodes in the representation of the alliances in the semi-conductor industry — Figure 5.67. However, three different types of link are used to encode data; in fact, this might be four, since it is not clear whether 'Joint Activities (equity based)' and 'Cross-Licensing. Second Sourcing' are the same feature — they use the same kind of link.

Figure 5.68 shows how MDS may be applied to depict changes over time. These are multivariate graphics: as well as the two dimensions, the strength of the link is indicated with four divisions, the actors are represented with one of four differently shaped nodes (denoting their origin) and, when two graphics are placed side-by-side using Tufte's (1983) principle of *small multiples*, changes in the morphology become evident. For Figure 5.68, the increased level of contact is the most significant

Figure 5.63

Interorganizational linkages created between top US electronics companies and top Japanese electronics companies.

Figure 5.64

IBM's alliances.

Source: de Woot, 1990: 187.

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Figure 5.65
Alliances in the telecommunications industry.
Source: de Woot, 1990: 185.

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Figure 5.66
Alliances in telecommunication.
Source: de Woot, 1990: 187.

Figure 5.67
Alliances in the semi-conductor industry.
Source: de Woot, 1990: 186.

change between the two depictions. However, while contact may have increased, it is only of the type of one alliance; there are a few contacts of the order of two alliances, even less for three alliances and only one for four or more. Tracing movement of individual actors is more difficult; a general shift is apparent, particularly towards the top right-hand corner and towards the upper centre-left. The links are far stronger visually in Figure 5.69. It is interesting to note that the key showing the links is repeated with each diagram, yet the key for the actors is not; this is because the depiction of the nodes remains consistent, while the number of divisions, and what they represent, of the links changes between networks.

The image processing network depicted in Figure 5.70 shows that 'Image' and 'Vision' are both important actors, as the use of bold text attests. Rather than depicting a number of actors, Lundgren used two different shapes to reflect singularity and aggregation. While the direction of the relationships is evident, it is less easy to detect strength. Since the network is longer than it is wide and the 'Supplier of Electronic Components' dominates the top of the diagram, the impression is more of a flow chart than a network. Figure 5.71 illustrates the flow of product innovations between different sectors in the UK. The role of the different types of lines is not immediately apparent — the key may be missing or it may signify different (and unspecified) types of flow. Certainly arrowheads are missing from some of the flows, e.g. paper and printing. Once again, this is a network resembling a flow chart; in this case, it is the effect of the downward motion, from the use of dominant arrows in the centre to smaller ones that cascade down the side.

Figure 5.68

The structure of strategic partnering in microelectronics, 1980–1984 (bottom), 1980–1989 (top).
Source: Hagedoorn & Schakenraad, 1992: 179–180.

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Figure 5.69

The structure of strategic partnering in telecommunications, 1980–1989.

Source: Hagedoorn & Schakenraad, 1992: 182.

Figure 5.70

The image processing network in 1988.

Source: Lundgren, 1992: 156.

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Figure 5.71

Innovation flows between manufacturing product groups in the UK.

Source: Rothwell, 1986b: 55.

5.3 CHART VERSUS NETWORK

Organisational charts and job descriptions generally reflect the formal or *prescribed* network in a given organisation. Such prescriptions are often guided by the missions and strategies of the organisation (Chandler, 1962), even though their explicitness may vary greatly between one organisation and another. In contrast, informal or *emergent* networks refer to the informal relations that emerge over and above prescribed patterns of interaction (Tichy *et al.*, 1979; Tichy, 1981). Both prescribed and emergent networks may transcend the organisational boundary.

5.3.1 Organisational charts

The typical organisation chart is not used to portray or interpret statistical data. Nevertheless, it is possible to present a large number of facts and relationships simply, clearly and accurately with a well-designed chart without resorting to extensive, and sometimes involved, verbal description. Characteristically, the chart is used to present structural forms, and logical and functional relationships, portraying essential components of an organisation in relation to other components. More specifically, it shows: the relation of one official or department or function to another; the titles and sometimes names of officials, and the names of departments and their functions; and sources, lines, the flow and type of authority.

For Bertin (1981: 131), "when there is only one way to go from one element (node) to another, the network is a 'tree' ". This is broadly synonymous with the domain of the organisational chart: charts tend to draw out single relationships. According to Bertin, and depicted in Figure 5.72, it is preferable to simplify relationships like **1** and **3** and represent them as **2** and **4** respectively, whether using shapes (**2**) or lines (**4**). Indeed, if authority is being depicted, it is better to use a representation like **6** than **5**; it follows that **8** is stronger than **7** since "the plane is naturally ordered from top to bottom by gravity" (Bertin, 1981: 131). Bertin stressed that charts like these must take natural order into consideration, as well as making the vertical axis correspond to a meaningful order and the horizontal axis to an equality.

However, in some cases, simplification and order are not sufficient enough. The relationships shown by **9**, **10** and **11** are not similar, but it is easier to understand and remember three groups (**11**) or two groups (**10**) than six elements (**9**). The complexity of **14** becomes only readable when points are replaced by lines (**15**). Genealogical trees ordered by generation may adopt the sector construction (**16**), but the triangle (**17**) is preferable (A is clearly anterior to B). Very numerous populations lead to the square (**18**). Though there are no standardised rules or practices that have been prescribed for the design and construction of organisation charts, the majority of charts exhibit some degree of visual similarity.

Hawthorne (1978) maintained that the R&D function in companies could be

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Figure 5.72

Simplification and transformation of a network.

Source: Bertin, 1981: 130.

classified in one of four main patterns. These comprised:

1. *Subject discipline,* in which personnel were grouped by their specialisation (Figure 5.73a).
2. *Stage phase,* in which the structure was divided according to the types of tasks undertaken during the project (Figure 5.73b).
3. *Product type,* in which an individual was concerned with only one range of product (Figure 5.73c).
4. *Project type,* where groups worked on only one project (Figure 5.74d).

Although these patterns have been described in terms of the organisation of R&D,

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Figure 5.73

Types of R & D organization. (*a*) Subject discipline; (*b*) stage-phase organization; (*c*) product-type organization; (*d*) project-type organization.
Source: Hawthorne, 1978: 105.

they can be readily identified in all other activities of a firm. Figure 5.74 illustrates how a typical manufacturing firm, and the production department within it, might be structured.

Researchers have found that there is no idealised general structure for organisations; in some cases flat, decentralised structures performed well (Figure 5.75 left), while in others tall, hierarchical structures were more effective (Figure 5.75 right). According to the classic work of Burns and Stalker (1961) and several recent studies (e.g. Pilditch, 1987), successful innovation tends to be associated with a participative management style and a non-hierarchical, horizontal company structure, emphasising consultation and a free flow of information rather than direction from above. Trompenaars (1993) has examined the effect of culture on hierarchical relationships: Turkey tends to have the most hierarchical companies, while the USA has the most decentralised organisations (Figure 5.76).

Traditional methods of organisation that involve passing the emergent product from the marketing department to design to development to manufacture (and often

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Figure 5.74

Organization chart illustrating the principles of classical management theory and bureaucratic organization.

Source: Morgan, 1986: 28: "Chart A illustrates an organization divided on the principle of functional specialization. Each functional department has its own hierarchical mode of organization. Chart B illustrates details relating to the production department. Note the chain of command which runs from top to bottom of the organization. From any place at the bottom of the hierarchy there is only one route to the top, a reflection of the principle that each subordinate should have no more than one superior. An example is indicated by the highlighted line. Note the different 'spans of control'. The chief executive in Chart A has a span of control equal to seven. The foreman of the forging section in the production department (Charts A and B) has a span of control of twelve. The production manager has a span of three. Note how the advisory or 'staff' departments (e.g. finance, personnel, legal, R & D) have no direct authority over 'line' departments such as the production department."

back again) are no longer deemed fast enough or suited to innovative product development. Instead, multidisciplinary team-work, or other methods of collaboration between marketing, design, manufacturing and other staff, is vital, to provide the different skills required for innovative product development and to be fast enough to keep up with the competition. The matrix structure is one such solution where, for instance, a project manager would influence functional specialists without having direct line-control responsibility (Figure 5.77).

However, Trompenaars (1993: 17) believes that "it is quite possible that organisations can be the same in such objective dimensions as physical plant, layout or product, yet totally different in the meanings which the surrounding human cultures

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Figure 5.75

Structures of organizations.

Source: Williams, 1981: 181.

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Figure 5.76

Company triangles.

Source: Trompenaars, 1993: 144.

read into them". Trompenaars showed an employee the company *organigram* and asked them to indicate how many layers they were above and below them. The employee indicated more levels than there were on the chart and, when asked how this was possible, responded with the explanation that " 'This person next to me [...] is above me, because he is older' " (Trompenaars, 1993: 17).

Figure 5.77

Matrix organization.

Source: Morgan, 1986: 58, taken from Kolodny, 1981: 20.

5.3.2 Emergent networks

Morgan (1986) has examined a number of organisational metaphors, including the organisation as *machine, organism* and *brain.* In viewing the organisation as an organism, for example, the emphasis was placed on understanding the relations between organisations and their environments, while the brain metaphor drew attention to the importance of information processing, intelligence and learning. By using metaphors to understand the complex and paradoxical character of organisational life, Morgan (1986: 13) argued that "we are able to manage and design organisations in ways that we may not have thought possible".

The *network* as a metaphor is also a powerful way of viewing organisations, "bring[ing] to the surface the webs of relationships ... where constellations, wheels, and systems of relationships are examined" (Auster, 1990: 65). Trompenaars (1993: 19, emphasis in original) maintains that "all organisational instruments and techniques are based on *paradigms*". However, these sets of assumptions often differ in theory and in practice; "the organisation and its structures are ... more than objective reality; they comprise fulfilments or frustrations of the mental models held by real people" — so if the theory is the organisation chart, then the practice is the emergent network. Tichy (1981: 227) argued that "metaphorically, a prescribed organisational network provides pegs from which emergent networks hang".

Tichy (1981: 225) maintained that "social networks play important roles in business organizations" since "unplanned structures ... emerge because organizations are so complex that plans can never anticipate all contingencies". The importance of social or informal networks to innovative organisations is also highlighted by Kreiner and Schultz who argue:

> In recent years, the traditional boundary activities bridging the company to its environment has been supplemented with a host of collaborative ventures. ... Most noticeable, probably, is ... when it takes the form of strategic alliances and other formalised collaborative structures. Increasingly, we are becoming aware that much of such collaboration is also pursued along unpaved paths in the undergrowth of less formalised, personalised networks. (1993: 189)

Research has shown that some communication patterns are more effective than others. Figure 5.78 depicts a number of different types of communication network. For simple problems, centralised communication is more efficient — the wheel, for instance. For complex problems, decentralised networks are better; both the circle and the all-channel networks are decentralised, although there is less interconnectedness between group members in the case of the circle. The 'Y' and chain networks represent intermediate systems. Koenig and Thiétart (1990) have examined different types of relationships that exist in high-technology industry. In Figure 5.79a, a firm is engaged in a one-shot contract. When there is a recurring relationship, as in Figure 5.79b, the bonds are more permanent. In Figure 5.79c, the parties are learning to work with another, exchange information and share risk. If these partners are incorporated into the firm, a situation similar to Figure 5.79d is likely to result as each member plays a specific role. Figure 5.80 shows that it is possible for an organisation to be represented as a system, much like relationships.

Figure 5.78

Communication networks.

Source: Williams, 1981: 185.

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Figure 5.79

From market to hierarchy.

Source: Koenig & Thiétart, 1990: 163.

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Figure 5.80

How an organization can be seen as a set of independent subsystems.

Source: Morgan, 1986: 49.

5.3.3 Comparison

It is normal practice to describe the structure of an organisation in terms of an organisation chart; this shows the division of work. These charts tend not only to be historical in character, but often serve as a factor in blocking structural change. An emergent network, however, tends to describe an organisation's structure in terms of information flows, and the relationships on which those exchanges are based.

The emphasis in Figure 5.81 is on the personnel rather than the links between them; the use of drop shadow emphasises their role. Since more vertical space is needed than is available, two officers have been placed on another plane; the effect is one of demotion. The functions in Figure 5.82 are less important, but the upward flow from the 'LOB Business Unit' to the account team to the customer is seen to be more significant than the links between the links into (and from?) the 'LOB Business

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Figure 5.81
Indirect division.
Source: Unisys, 1990: 57.

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A network of skills and resources.
Source: Unisys, 1990: 8.

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Figure 5.83

From typewriters to office automation: Olivetti's strategic partnerships, 1985.
Source: de Woot, 1990: 212: "[a] European Strategic Programme in Information Technologies."

Unit'. Also, this depiction reverses the characteristic flow; metaphorically, at least, the customer *is* king.

After a quick glance, a casual viewer might be puzzled at the inclusion of Figure 5.83 in this section. While it does display the alliances discussed in Section 5.2, the fact that a company is at the centre of the diagram and that the relationships are positioned according to their nature (from left to right across the bottom of the figure) means that it is included here, even though it seems to fall between being an organisational chart and an emergent network. Not only are the links are given meaning with their position, but the relationship to technology is also stated.

Figure 5.84 is a schematic portrayal of the ties between Centocor and other organisations. Like the previous figure, position is significant: close study reveals that relationships representing *sources* of funding, information or technology are located on the left, while agreements through which Centocor *provides* funds, information or technology to other organisations are listed on the right. Relations that entail reciprocal or *mutual exchanges* are depicted by double-headed arrows and situated on the figure's vertical axis.

Sigurdson (1990c) identifies four kinds of foreign R&D units in a multinational company (Figure 5.85). A Technology Transfer Unit (TTU) facilitates the transfer of the parent company's technology to the subsidiary, and provides local technical services. An Indigenous Technology Unit develops new products for the local market and draws on local technology. A Global Technology Unit (GTU) develops new products and processes for world markets. A Corporate Technology Unit generates basic technology for use by the corporate parent. While position from top to bottom of the diagram is significant, the horizontal plane is not used, save the depiction of a

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Figure 5.84
Centocor network.
Source: Freeman & Barley: 1990: 149.

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Figure 5.85
Location pattern for R&D in a multinational company.
Source: Sigurdson, 1990c: 184.

joint-research strategic alliance.

Even though Allen is famous for network depictions, Figure 5.86 presents a representation that looks more like an organisation chart than a network due to the downward-flowing links. There are no links in Figure 5.87 and there is no controlling individual, in the centre or otherwise. Rather than showing personnel, the circle depicts the applications of groups of individuals and, to assign no importance to the left to right positioning, uses a circle to represent inclusion. This concept was used by Allen (1977) in Figure 5.88. The chief engineer is revealed to be at the hub of this communications network, and groups of actors are denoted according to the section from where they are derived. A ring around the chief engineer probably indicates a section head. By depicting relationships in this manner, Allen managed to present a

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Technical discussion network in Laboratory B, showing the effect of status on communication.
Source: Allen, 1977: 231.

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Figure 5.87
Document imaging systems market opportunities.
Source: Unisys, 1990: 86.

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Figure 5.88

Communication network in a typical department of Laboratory E, showing the influence of formal and informal organization.
Source: Allen, 1977: 208.

quasi-organisational chart/emergent network; the hierarchical relationships are just evident as the sideways ones, whether they are based on social or formal contact.

Figure 5.89 displays the role of the gatekeeper, an individual who controls or influences the flow of information within an organisation. The gatekeeper network of four actors is depicted with a broken line, the metaphor enhancing the selectivity of information passing through this 'sieve'. The role of gatekeeper is represented typographically in Figure 5.90 with a superscript letter 'G', though not with the underlining as noted in the text accompanying the title. Rather than depicting separate actors, groups or 'strong components' are seen as synonymous entities and either receive or generate one flow, which reduces the complexity of relationships depicted. In Figure 5.91 the gatekeeper can be recognised by underlining. This diagram represents the most standardised form of network depiction: one shape for a node, a line with a single arrowhead for a link and no significance in positioning.

Figure 5.89

The functioning of the gatekeeper network.

Source: Allen, 1970: 201: "New information is brought into the organization by 1. It can be transmitted to 2, 3, & 4 via the gatekeeper network. It reaches its eventual users (squares) through their contacts with gatekeepers.

Figure 5.90

Departmental communication network after reduction into strong components.

Source: Allen, 1977: 156: "Strong components are shown in brackets, and gatekeepers are shown by underlining with 'G' superscript."

Figure 5.91

Graph of regular technical discussion contacts.

Source: detail of Frost & Whitley, 1971: 73: "Arrows, e.g. (02 → 48), indicate 02 obtained information from 48. Members of strong components with at least three people (02, 34, 41, 08, 10, 38, 93) are underlined."

5.4 SUMMARY

This chapter concurs with DeBresson and Amesse's (1991: 363) assertion that "the network approach has something original, useful, and durable to bring to innovation studies". Indeed, they contend that "the concept of network may provide a bridge between disciplines" during a period in which — according to Clark (1987) — knowledge about technology is fragmented, and enable social science researchers to "overcome this artificial division between the economic unit and its environment". DeBresson and Amesse remark that the attraction of the network approach may reside in its compatibility with a variety of disciplinary approaches; Table 5.1 provides a summary of the varying purposes to which the network depiction — and the other methods of expression — may be applied and the different sources from which they are derived.

Bijker *et al.* (1987b: 9) maintained that "system builders are no respecters of knowledge categories or professional boundaries". They noted that Edison's inventive thoughts composed a "seamless web", mixing thoughts that would today be classed as economic, technical and scientific; Figure 5.43 reflected this in some way. Similarly, the chapter has demonstrated that the network expression is a flexible and powerful technique, as seen in the shift from formalised processes — representing the macro innovation process, the meso genealogy of inventions and the micro charting of organisations — to informalised communication, whether it be 'systems', the sources of ideas or relationships.

Despite the applicability of the network expression, little research has focused on the graphic representation of network data. Despite parallel fields of work developing around the concept of a network — the modelling of the innovation process; the development of technological systems (e.g. Hughes, 1983); actor-network theory, after Callon (1980); sociometry and sociograms, after Moreno (1934, 1953); large-scale computer-based behavioural analysis (e.g. Rogers & Kincaid, 1981) — there is little sign of common, or even individual, consensus in how data should be best depicted. Harary (1977) presented a graph theoretic approach, combined with matrix theory and set theory; Kruskal and Seery (1980: 22), recognising that to design a *good* diagram "requires both skill and tedious effort", devised a method based on MDS, though it was computer-based and made no attempt to standardise schema; Wood (1991) developed a rule-based approach for management students, though the emphasis was on operational research.

Preliminary work has been undertaken to review and synthesise existing approaches and styles in depicting networks (Steward *et al.*, 1993, 1994a), as well as to provide a palette of options for encoding both quantitative and qualitative data concerning nodes, links and transaction content (Conway & Overton, 1994; Steward *et al.*, 1994b). This area provides the scope for further interesting, original and useful study, not least in the suggestion of graphic conventions typical of the pictorial rep-

Table 5.1

Typology of expressions cross-referenced with figure numbers and source for Chapter Five.

EXPRESSION	ACADEMIC	POLICY	MEDIA	BUSINESS		
				Bioscience	ICT	Other
Linear & interactive model	3 4 5 6 7 8 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31	4 5 6 7 8 11 19 33	32			
Network model	9 10 35	34	34			
Genealogy by flow chart	36 37 38 39 40 41 44 45 47 50 52 53 54 56 58 59 60	40 46 49 55 57 60	55 56 62	46	45	50 51 56
Ideas by network	42 43 55 61 62 63 68 69 70 71	64 65 66 67	65			64 66 67
Organisational chart	73 74 75 76 77 84 85	83			81 82	83
Emergent network	78 79 80 86 88 89 90 91				87	

resentations of cartographers (Figures 5.92 and 5.93) and chemists (Figures 5.94–5.96), since unlike, for example, geneticists, chemists, architects and cartographers, network designers do not employ a set of recognised conventions in their pictorial representations. Instead, network designs are often arrived at through trial-and-error, while "designing a good [network] diagram requires both skill and tedious effort" (Kruskal & Seery, 1980: 22). Illinois Institute of Technology Research Institute (1968) used the retinal variable of shape to differentiate between the different types of activity occurring at each stage or junction on the flow charts depicting the development of the innovations. Battelle (1973) took this one stage further using colour to reinforce differences in shape, and employing value to contrast between significant and decisive events.

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Figure 5.92

Abstract maps.

Source: Robinson, 1988: 139: "The detail of the Tokyo subway system shows the stations and routes for the central city area. Public-transport maps often abandon cartographic formalities and construct their relationships on a geometric grid. This technique allows the sequence of points on the route and the points of the intersection to be correct, but not their actual distances apart or their relationships to other stations on other lines."

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Figure 5.93

Inter-terminal links by London Underground.

Source: British Railways Board, 1993: 13.

The power of a network graphic can transcend its comparable expressions when it is constructed efficiently. Like the sociogram of Moreno (1953), this network diagram aims to be more than a method of presentation: it is also a method of exploration where position is significant, if not absolute. Figures 5.97 and 5.98 are graphic representations of the same innovation action-set. In Figure 5.97 the data are randomly located with no coding of node or link. Figure 5.98 uses a variety of retinal

Figure 5.94

Chemists' languages and ideograms.

Source: Davies *et al.*, 1990: 76, 75: "Few chemists use, or even know about, Wiswesser notation. ... With existing methods and disciplines, the requirements are two-fold. On the one hand, there is a need for computer retrieval by linearizing the description of molecules unambiguously. On the other hand, chemists require pictorial representation that summarizes chemical properties. The Wiswesser formulae say nothing immediate about properties, and must be translated into two-dimensions (or three) before such messages emerge. This accounts for some of the lack of interest in Wiswesser."

Figure 5.95

Different ways of writing the propane molecule.

Source: Allinger *et al.*, 1976: 253: "Because the corners of a tetrahedron are equivalent, the different ways of writing the compound shown above correspond to different spatial orientations of the *same* molecule. There is only one propane molecule, and the different ways of writing the structure that are shown all correspond to the same molecule."

variables — shape and size for the node, and size, texture and value for the link — to encode additional qualitative data. Shape has been used in the past to denote the organisation type of the node; however, 'families' of shapes (e.g. four-sided polygons, stars, etc.) and 'increments' in that family (for instance, from five-pointed stars up to eight-pointed stars) may be employed to assign similarity or some other asso-

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Figure 5.96

Models of the ethane molecule.

Source: Allinger *et al.*, 1976: 253, 249: “Because it is difficult to visualize three-dimensional structures such as tetrahedra, chemists have developed sets of models from which molecular structures can be built and studied. The two kinds of models in most general use are the *ball-and-stick models* and the *space-filling models*. … We … use pictures such as these to illustrate three-dimensional structures on two-dimensional pages.”

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Figure 5.97

Conventional sociogram of the Xenos innovation action set.

Source: Steward *et al.*, 1995: 148.

Figure 5.98

Depiction of node and link attributes in the Xenos innovation action set.
Source: Steward *et al.*, 1995: 148.

ciated characteristic. In addition, the use of rounded corners may be an additional subtle way of conveying extra information whose meaning may not be readily apparent — a case might be the deployment of a standard rectangle or a rectangle with rounded corners to denote some fact. Some of these ideas are represented in Figure 5.99. In addition, while position is not significant within the depicted organisation, position is significant in the environment that affects it.

From an examination of the graphics contained in this chapter, in addition to drawing upon sources that have not been reproduced, it is possible to draw certain conclusions about the employment of certain types of expression.

Unsurprisingly, the strongest concept in a **linear model** is that of linearity. The message is one of simplicity and the emphasis is on the academic and policy domains. The **interactive model** is visually similar to the linear model though it does employ feedback to enhance the communicative aspects of the expression. Likewise, it has received strong support from academics and policy-makers, though its usage is not as numerous as the linear model. The **network model** is more rare, being a more recent expression. It depicts the innovation process as a complex system and, while discussed in policy circles, fails to be represented there and it remains tied to the academic field. The lack of utilisation of these types of models by the media and business is not surprising; macro modelling is neither newsworthy or likely to be depicted in a company report respectively.

A **flow chart** is used to plot the heritage of inventions and innovation. It emphasises the importance of what has gone before, in some ways compensating for the fact that it is not a forecasting expression. However, it is one of the most popular expression, certainly in this chapter, and is used by all four domains. An **idea net-**

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Figure 5.99

Network for Iceland Foods plc's portable and depot CFC reclaim units.

Source: work-in-progress under Contract EV5V-CT94-0381.

work represents relationships. There is a fair degree of cross-over with the **emergent network** expression, graphically at least, since they both portray similar types of relationships; only scale at which they operate differs. Where alliances, collaborations and the like — between companies or countries or on some large scale — are being drawn out, the expression is an idea network — ideas, represented by contacts, are being shared. This expression is used in academia and policy making.

An **organisation chart** represents structure. The message it portrays is that the organisation is bounded. It is used by academia, despite criticism of it, but more particularly in the corporate domain. When intercompany friendships are being mapped out, an **emergent network** is the expression that is used. Since these friendships are flow across the organisational boundary and between functional specialism, it gives the impression that the organisation is boundless. Currently, this expression receives support from academia. Table 5.2 presents a typology that summarises some of these ideas.

Table 5.2

Typology of the interaction between graphic expressions, innovation concepts and their practical usage for the innovation process.

EXPRESSION	CONCEPT	MESSAGE	EMPHASIS
Linear model	Linearity	Simplicity	Academic and policy
Interactive model	Feedback	Communication	Academic and policy
Network model	Innovation is a system	Complexity	Academic
Flow chart	Heritage	Importance of what hasgone before	All
Idea network	Relationships	Importance of contacts	Academic and policy
Organisation chart	Structure	Bounded organisation	Academic and corporate
Emergent network	Friendships	Boundless organisation	Academic

Chapter Six
REPRESENTATION OF TECHNOLOGICAL PERFORMANCE AND PROGRESS

Virtually all historians agree that science and technology has made a major contribution to standards of living. Sometimes this contribution was direct, as in the discovery of new drugs, such as penicillin, or in the invention of the telephone, radio and television. In other cases, it was indirect, through numerous new types of machine, improvements to industrial processes and the introduction of new materials, such as aluminium, steel alloys, polyethylene and PVC. The notion of performance and progress has long been of interest; Playfair (1786: ii) commented that "Should this Work [*The Commercial and Political Atlas*] meet with the favour of the Public, it will be continued, as an index, pointing out the state of our commercial health".

The influence of technology permeates everyone's lives, yet trends and trajectories are unclear (Bernal, 1939). Progress is easy to measure by parameters — physical or scientific — but it is less easy to map social and political aspects, or to forecast future possibilities. The concept of technological progress has been studied by academics, the media, business organisations and governments alike; Pavitt (1988) highlighted the recognition among industrialists, policy-makers and social scientists of the importance of technology and technical change in the competitiveness and growth of firms and countries, maintaining that technology had to be measured and understood like any other factors of production.

Performance and progress are often represented by graphs featuring curves. Curves are a simple expression — the most obvious manifestation of this is the linear curve, though the exponential curve is scarcely more complex. The S-curve, on the other hand, depicts a situation that only an exponential curve bending towards the vertical axis hints at — that progress eventually declines. Cycles are the other, more complex, expression through which technological change is modelled. Bijker and Law (1992c: 17) maintain that the concept that technologies have natural trajectories is "deeply built into the way we talk" and that an individual technology "moves through a natural life cycle". The product and technology life cycles have certain visual similarities, but the time period over which they operate is the real factor that unifies them. In contrast, the long wave is an expression that depicts change over a longer time scale. While both linear, exponential and S-curves can be used to represent the same subject, life cycles and the long wave are not comparable expressions; the issue that binds them together is the shape they draw out.

6.1 SINGLE CURVE VERSUS MULTIPLE CURVE

As Bowker (1988) has shown, people perceive the same curve differently. In addition, there are different ways of representing 'the curve', resulting in different visualisations, and hence perceptions, of progress. The traditional view is that progress plotted on a graph reveals itself as an upward-moving linear or exponential curve. However, the S-curve adds a note of caution and indicates progress will reduce and eventually stop.

6.1.1 The linear and exponential curve

The idea that progress may be represented as a constant, upward-moving linear or exponential curve is embedded in the concept of the biological metaphor; Darwin's (1882) hypothesis was a theory of evolution by natural selection while Malthus (1798) postulated doom for civilisation due to food shortages caused by unrelenting population growth. The early studies of technology were conducted by historians, anthropologists, political economists, physiocrats, demographers and sociologists. The quantitative analysis of change *per se* was not undertaken, but progress was documented by examining its effect on society and technology was represented through (exploded or cross-sectional) drawings and photographs of steam locomotives, engines, bridges and the like, particularly to children. For example, Wallis (1930) analysed the history of civilisation based on the creation of techniques and technical systems, and the perception of magnitude. By representing a one-hour time period as the total duration human beings have been on Earth, Wallis revealed that five minutes ago Neolithic culture began, two minutes ago iron was smelted, five seconds ago the Industrial Revolution commenced and less than one second ago cars were invented. Without actually illustrating the process or directly expressing it, Wallis demonstrated the speed of technological progress on a massively exponential scale through analogy.

Hart (1957a) chronicled the acceleration of social change in a review that encompassed the views of the first social scientists and studies of speed and war. Quotations from as long ago as 1877 were cited demonstrating the exponential nature of societal progress. Yet Hart (1931, cited by Hart 1957a: 28) *did* concede that such progress was not always the rule: "man's power to control his physical environment has been increasing with accelerating speed, with only temporary and local set-backs and stagnations". While some studies focused on the past, others tried to predict the future. For instance, Hart (1957b) also attempted to forecast the trend of world speed records, utilising a curve in the process, but the conservative estimate was wrong even before the book went to press. This left Hart (1957b: 458–459) to conclude that "the confirmation of the accelerating trend is obvious".

Speed has long been a much portrayed concept. Marey's train schedule for Paris to Lyon in the 1880s graphically represents performance (Figure 6.1). Arrivals and departures from a station are located along the horizontal with the time spent at stations indicated by the length of the horizontal line. The stations are separated in proportion to their distance apart. The slope of the line between them represents the speed of the train: the more towards the vertical, the faster the train. The crossing of the lines indicates the time and place when trains going in opposite directions pass each other. It was updated by Tufte (1983) to show the time-savings that the TGV — the bold line — has created (Figure 6.2).

Figure 6.1
Marey's graphical train schedule.
Source: Tufte, 1983: 31.

The comparison of speed trends in transportation by Samaras in Figure 6.3 demonstrates the magnitude of the invention of the internal combustion engine. From 1750, speed increases linearly, but exponential growth starts around 1900, compressed by the logarithmic vertical scale. The graph makes use of the impression of many small curves to gain an overall understanding through their combined summation as the 'envelope'. Hart's (1957a) alternative representation (Figure 6.4) shows the massive impact that the airplane has had; the effect of the automobile (and internal combustion engine) has been eclipsed. However, it should be remembered that speed records rather than Samaras's generalised speeds have been plotted and the vertical axis is constant in its portrayal of miles per hour. The design flaw — the graph is narrower than it is taller — contributes to the notion of the exponentiality of progress.

Hart (1957b) also reported Ogburn's experiences with predicting passenger miles flown. Ogburn's graph showed data from 1930 to 1948 and Figure 6.5 has had subsequent data-points inserted by Hart. Ogburn's prediction for 1953 was made in 1945 and published in 1946. The figure has a fitted exponential trend line, but the

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Figure 6.2

Marey's graphical train schedule overlaid with the path of the TGV.

Source: Tufte, 1983: 31.

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Figure 6.3

Speed trend curve.

Source: DeVore, 1980: 11, taken from Samaras, 1962.

actual data for the years 1949 to 1953 show an increasing downward departure from the exponential trend, despite the logarithmic scale (whose linear trend would be a declining exponential trend on a constant scale). Hart's examples tended to plot the progress of technology through outputs. This may have been due to historical or fashion reasons, but showing an increase in world speed records represents the improvements in the technologies behind those records — aerodynamics, propul-

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Figure 6.4

The accelerating rise in world speed records, 1750–1956.
Source: Hart, 1957a: 32.

sion, motion — just as an increase in life expectancy demonstrates increased knowledge of medicine, physiology, biology, pharmacy, and so on.

The charting of a linear or exponential relationship seems to be prevalent in any study of the history of technology. As Foster (1986: 102) maintained, the implicit assumption is that "the more effort put in, the more progress that results". Figure 6.6 represents how three industrial revolutions (machine, 1750–1860; scientific, 1880–1920; and computer, 1945–1990) have affected the world in terms of employment. Quantity is represented against time in a standard time-series plot; of the nine graphs illustrated, three depict linear change while the other six show exponential growth. All feature constant scales on the horizontal and vertical axes to maintain a similarity of representation between the diagrams. Marsh (1981) utilised the graphical practice of what Tufte (1983) termed *small multiples*; it is the identicality of the graphs that renders them comparable. The range of the scales may vary between the graphs in each set, but the purpose does not. The reader looks at the similarity and

Figure 6.5

Passenger miles flown by domestic airlines.

Source: Hart, 1957b: 460: "The trend was fitted in 1949 on the basis of the O's and X's. Ogburn's prediction of 1945 was based on the O's only. The +'s represent data which become available after the trend was fitted."

difference, and seeks answers for both.

Price's (1956) study measuring the number of papers published in selective scientific fields revealed that, for such collections of data, nearly all the curves of growth show the same trends, the growth was exponential and that the constant of the exponential was such as to effect a doubling in size in an interval of the order of 10–15 years. Price (1956: 240–241) concluded that the growth of most organisms tended to be directly related to their size — "the bigger they get, the faster they grow" — and pointed to the increase in a colony of bacteria as evidence. The assumption that scientific growth is linear was rejected. The study of the growth of science frequently uses such metaphors, plotting these as exponential relationships. Indeed, scientific literature like this can be seen as paralleling technological progress in a similar sort of way, e.g. Dedijer (1962), Gilbert (1978), Price (1971), Moravcsik

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Figure 6.6

How the world's three industrial revolutions over the past 200 years have left their mark on civilisation.

Source: Marsh, 1981: 419.

(1973) and Studer (1977). The biological metaphor has been prevalent in recent literature too. In Freeman and Jahota (1978), four factors — food, energy, non-renewable resources and technology — were examined in the light of current economic and social theory for the future of the world. Cole (1978) summarised the neo-Malthusian outlook and claimed there was little difference in content between Malthus's *Essay* and Meadows *et al.*'s (1972) *The Limits to Growth*, despite being two centuries apart.

6.1.2 The S-curve

The belief that technological progress may be adequately represented by a linear relationship could be considered to be somewhat naïve. A technology may be slow to prosper initially — the problems of learning — and over time the influence of other factors will lead to a slowing down of growth — the concept of diminishing returns. The rationale affects innovation as it affects so many other things.

The exponential curve takes some account of this. It may bend either towards the horizontal axis (and by extension away from the vertical axis) or away from the horizontal axis (and towards the vertical axis). However, the movement occurs in the centre of the curve, not at the extremities. One curve suggests early learning succeeded by near linear (and perfect) growth. The other starts up with an increase at little cost that falls away to diminishing returns. The S-curve combines these two exponential opposites to plot a more linear curve over time while taking account more fully of diminishing returns. It is called an S-curve because "when the results are plotted what usually appears is a sinuous line shaped like an S, but pulled to the right at the top and pulled to the left at the bottom" (Foster, 1986: 31).

Although much of the early work was concentrated on the exponential progress of science — as detailed in the previous section, Price (1956) refined the theory, accepting that, with a curve reaching the value of unity, saturation will be reached. Thus, the exponential curve is represented as modifying into an S-curve (Figure 6.7). Saturation was explained by what now is termed as 'information overload' and the problems of specialisation.

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Figure 6.7

Diagrammatic representation of the effect of saturation on growth.
Source: Price, 1956: 242.

Rose (1967) proposed that the S-curve should be used as a technique to level off spending on research and development to reduce the exponential growth of science as presented by Price. Rose claimed that Price's concepts had been over-used and stretched beyond the point of credibility, and that scientific growth was more complex than suggested by simple graphical extrapolation of global trend curves. Rather, Rose argued, Price's exponential curve was the sum of a larger number of subject curves and that the definition of science had been continuously enlarged. Rose presented two alternative S-curve plots to illustrate the point, one of which is reproduced as Figure 6.8. This very stylised representation contrasts with the other, termed a " 'Levelling off' — linear plot", that barely exhibits traces of the S-curve.

Foster (1986) assessed the S-curve practically. The S-curve is useful because it can trace the development path of new products and processes, with each successive point on the curve representing an improvement in performance. Foster pointed to empirical observations coupled with the underlying theory of why it was happening as evidence that these curves described reality and would continue to do so in the future. If the limit for an S-curve can be predicted, then it could yield valuable

Figure 6.8
"Saturation curve" — linear plot.
Source: Rose, 1967: 35.

insights. Foster stated that such a basis could be established by defining important performance parameters. This would enable the forecasting of the extent to which current products could be improved and how much effort it would require to reach the next level of performance. If the S-curves of a company's competitors were also sketched, then some insight could be gained about them. Equally, the technique could give insights about how products would fare in future, what new products to try to develop and how much effort would be required to develop them.

The primary purpose of using S-curves is to establish the relationship between effort expended and results achieved. However, according to Foster (1986: 100), it would be a mistake to plot results against the amount of time involved — "it is not the passage of time that leads to progress, but the application of effort". If results were plotted against time, extrapolated conclusions about the future could not be drawn because assumptions about the rate of effort involved would be included in the chart. If this rate were to change, it would increase or decrease the time it would take for performance to improve. The difficulty is predicting the rate at which competitors will spend money to develop the technology, not predicting how the technology will evolve; it might appear that a technology still has potential but what is actually sustaining its advance is rapidly increasing amounts of investment.

Foster (1986: 102) maintained that S-curves "almost always come in pairs". The gap between a pair of S-curves represents a discontinuity — a point when one technology replaces another — and is shown vividly in Figure 6.9. The two interlinked exponential curves take account of learning and diminishing returns.

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Figure 6.9
S-curves almost always appear in pairs.
Source: Foster, 1986: 102.

6.1.3 Comparison

Despite the widespread use of curves to represent performance and progress, textual description and comparison still play a major role, especially for corporate users:

> Pentium requires far more transistors devoted to core logic in order to implement its CISC architecture. The considerably higher core-logic transistor count increases the cost of Pentium, imposes barriers to easily achieving higher clock speeds and contributes to higher heat output. (Source: "X86 sequels increase power but complicate choices", (US) *PC Week*, 28 June 1993: 104.) (Apple, 1994b: 5)

Examples like this are very common, especially in advertising; a comparative graphic would be more effective. However, depictions employing curves *are* the most popular expression in the representation of innovation.

Figure 6.10 uses three dimensions to represent data (the third dimension is barely visible in this monochromatic reproduction), but the effect is mollified by the lack of diagonal perspective. The graphic uses a hairline rule to illustrate the vertical scale with slight breaks in it, allowing the richer background colour to permeate through, to denote the horizontal. Progress is upward and linear, with that of the new CMOS chip being more rapid and reflecting its later introduction. Colour is also used in Figure 6.11. It attempts to show that the use of Data Tables improved the amount of work a benchmark CICS system could process by more than 95 per cent, as suggested in the accompanying text. However, the three dimensions and the lack of a vertical axis make it virtually impossible to verify this; indeed, it is not even clear what is being plotted vertically, only that it is linear.

Figure 6.12 shows an arithmetic line chart with annotations plotting the development of telecommunications. Since the notion of progress (time on the horizontal axis) and performance (capacity on the vertical axis) is so strong, it has been included in this section as an example of a linear curve, albeit using a logarithmic scale. It would not have looked out of place in Section 5.2.3.

Figure 6.10

Microprocessor performance direction (millions of instructions per second).
Source: Brown, 1991: 30.

Figure 6.11

The Data Tables feature radically improves CICS performance for certain types of work on large computer systems.
Source: IBM Hursley Park, 1991a: 29. Note: Z notation is a new way of specifying code; PLAS is a high-level systems programming language; CICS stands for Customer Information Control Systems.

Figure 6.13 is a double time-series. The main variable is date, running from left to right on the vertical axis. However, since speed is being measured, time — in seconds — is shown on the horizontal axis, but as technological progress is reflected by less time, it is represented inversely (otherwise, the plot would not depict the characteristic bottom left to top right flow) and logarithmically.

Figure 6.14 is another projection, with more linearity than the previous figure, though four different plots are depicted. In the early 1960s, Gordon Moore first noticed a trend that still holds: the amount of information storable on a given amount of silicon has roughly doubled every year since the technology was invented. The figure shows that advances in processor speeds exceed all other. Figure 6.15 features a similar portrayal. With a logarithmic scale on the vertical axis —

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Figure 6.12

The sequence of inventions in telecommunications.
Source: Schmid & Schmid, 1979: 46.

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Figure 6.13

Speed of operation of electric kettles.
Source: Oakley, 1984: 35

the number of transistors that can be etched onto a typical silicon chip — it shows that capacity doubles (or miniaturisation increases) more or less every *18* months, as Moore predicted — according to Flynn (1997). Somehow this looks more truthful than the previous depiction, probably due to the fact that individual data points are plotted. Figure 6.16 shows that the time lag between a record speed and that speed becoming commercially available for transport. The data points suggest a scatter graph, while the inclusion of boundaries helps to provide comparison.

Figure 6.14
The hypothetical effects of dissimilar doubling rates over a decade.
Source: *Edge*, 1996: 59.

Figure 6.15
Moore's law.
Source: Flynn, 1997: 68.

Figure 6.16
History of aviation in terms of speed.
Source: Lockwood, 1969: 12.

Figure 6.17 returns to the depiction of Moore's law. What makes this representation interesting is the simultaneous plotting of a linear and exponential curve. Though the left- and right-hand axis both depict the same variable the scale used differs. It is not totally clear, but it most likely that the linear relationship uses the left-hand scale.

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Figure 6.17
Gordon Moore's law for X86 family.
Source: Jolly & Humbert, 1995: 138.

Figure 6.18 is a good illustration of an exponential curve. The legend accompanying it states:

> Unlike demand for users, computing funding is finite. So IS [Information Systems department] strives to provide more computing resources without a corresponding increase in costs. As the diagram shows, computing resources now are 70 times cheaper in real terms than 15 years ago. (IBM Hursley Park, 1991b: 21)

Graphically, there is not much in favour for this diagram. It uses three dimensions to represent one-dimensional data, thus overstating the change (Tufte, 1983); the diagonal depiction of the horizontal renders comparison to the curve difficult; the vertical scale, "work units (EMUs) per pound", is likewise difficult to correlate, and a definition of the unit of measurement is not provided in the accompanying text or glossary. However, the notion that progress in computing is continuing to increase, rather than slow down, is reassuring to users, and graphically demonstrated.

Likewise, Figure 6.19 is not visually arresting, but it is notable for its attempt to show product growth and development on a historic basis (against sales). A similar representation is provided by Figure 6.20 which quantifies events more particularly than the previous figure. Both curves in Figure 6.21 show exponentiality. However, exports are rising more quickly than imports, and comprise a greater portion, a net benefit to the balance of trade — the message that the Office of Health Economics was keen to deliver.

Figure 6.22 is derived from the publicity literature of a pharmaceutical company. Three-dimensional charts are used to disguise a lack of data and it is missing a scale too. It attempts to show that C started higher than A and B, and while all of them progress upwards, C is advancing more steeply than its rivals. However, it is not

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Figure 6.18

More computing resources without a corresponding increase in costs.

Source: IBM Hursley Park, 1991b: 21.

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Figure 6.19

3M historic growth.

Source: Kennedy, 1988: 9.

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Figure 6.20

Cumulative major drug discoveries 1875–1965.

Source: Cooper, 1966: 7.

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Figure 6.21

Pharmaceuticals: exports and imports 1950–1978.

Source: Teeling-Smith, 1980: 30.

possible to verify this. The same cannot be said for Figure 6.23, which demonstrates the superiority of one product over the other in a simple, clear, concise manner.

Figure 6.24 does not plot a relationship per se, but the notion of linear growth is provided by the 'steps' approach of the decades, with the increasing number of

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Figure 6.22

Simple made complex.

Source: Robinson, 1988: 11.

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Figure 6.23

The Pilot HX reduces the risk of straight-line aquaplaning at speed by 20%.

Source: detail from Pilot MICHELIN advertisement, *The Guardian Weekend*, 18 September 1993: 24–25.

notable events, and exponential with the curved line with the diamond shape at the end. Likewise, Figure 6.25 makes uses of the exponential curve — several of them, in fact. However, it attempts to plot too much on one diagram — number and type of users, time, business structure and computing model — so that it is difficult to evaluate which is the most important message or are the concepts linked.

Figure 6.26 is less troublesome. It chronicles the development of the PowerPC microprocessor family. It shows that the 601 will be replaced by the 604, with higher performance. Before that happens, the 603 will be introduced for the portable personal computer market. The 620 offers double the performance of the 604. Figure 6.27 was used to explain mapping in Chapter Four. It depicts the Swedish living patterns and examines the trend of more dispersed living, showing the trade-off between dispersed living and city dwelling.

The policy-oriented depiction of bioscience in Figure 6.28 illustrates Price's 'growth of science' in reverse. Projection indicates that, rather than saturation, extinction is the result; the Office of Health Economics blamed this on the require-

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Figure 6.24

Technological innovation — the key to sustained achievement.

Source: detail from Fujitsu, 1989: 3–4.

Figure 6.25

Evolution of computing, business and connectivity models.

Source: IDC, 1996: 22.

Figure 6.26

PowerPC microprocessor family.

Source: Motorola, n.d.: 1.

ments of the international regulatory bodies. The objective was to prevent governmental intervention in the industry through demonstrations like this that the future was not so positive as was thought. It is not clear why the projection should be extended from 1976 when data for 1977, below the projection, has been plotted. Figure 6.29 shows that the costs for colour printing are dropping quickly: "we believe that an important breakthrough in color publishing is just around the corner"

Figure 6.27

Future info-mobility.

Source: Svidén, 1985: 39: "Improved information services and functions can substitute [for] some travel, but also generate more new demands for travel; improved mobility makes it possible to combine the advantages of city life and the ecological qualities of dispersed living, and both with the contact networks available today in cities only. The future high info-mobility 'trans-urbia' can be an alternative to most living and working patterns today."

Figure 6.28

Percentage of Hoechst world-wide R+D budget devoted to innovation: 1972–1977; with arithmetic projection to 1988.

Source: Teeling-Smith, 1980: 30.

Figure 6.29

Projected costs for color laser printers.

Source: Apple Computer, 1991a: 3.

(Apple Computer, 1991a: 3). Since the graph was included in a marketing document, it was evident that the motive was to persuade people to buy the next generation of printers as they became more affordable. Figure 6.30 is similar to Figure 6.29 in depicting how prices have fallen. Rather than showing this with specific years, data has been aggregated. Why the different markets need large (dashed for prototypes) arrows to denote their influence is unclear. The differences between the markets would not be so obvious were it not for the logarithmic scale on the vertical axis. Figure 6.31 is taken from a policy document and shows that not only is model life

Figure 6.30

Unit cost and market penetration.

Source: Sciberras, 1977: 64.

Figure 6.31

Decline in model life in the consumer electronics industry.
Source: IAB ATC, 1991: 4.

declining but converging too.

The cubes of Figure 6.32 demonstrate exponentially in reverse and using three dimensions. Instead of showing how a technology has advanced, this graphic depicts how price has fallen. Unfortunately, three dimensions are used — not one — accentuating the $1,000,000 in 1960. (Also, no mention is made whether the money units have been deflated.) The selection of years is questionable: a 30-year interval

Figure 6.32

Comparative cost of memory technology 1960–2000 (1 megabyte of memory).
Source: Brown, 1991: 27.

and a ten-year interval. Even if there is a lack of data 1960–1990, a bar chart would enable readers to make up their own minds; this is what Playfair intended by invent-

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Figure 6.33

Nearly 25% smaller than other desktop computers, our Bravo systems don't take up a lot of space on your desk.

Source: AST Computers, 1991a: 8.

While Figure 6.34 may be very striking, it is less easy to make comparison on volume. Considering the concepts are notional, it could be argued that the figure did not need to quantify the relationship. Similarly, the growth of science (Figure 6.35), like a fan, is a dramatic and original solution, especially since knowledge does not just growth in one direction. The notional concept saves this representation from disgrace since it is not based on statistics. Figure 6.36 is based on the same visual metaphor, though time is depicted explicitly along the vertical axis.

Figure 6.37 plots the relationship between time and the power/volume ratio of the internal combustion engine. It draws the classic S-curve shape. Since the ratio is being depicted, it is not necessary to employ a logarithmic scale of the vertical axis. Figure 6.38 is more interesting because it relates data points with what they represent, while Figure 6.39 depicts the penetration and diffusion of electronic goods using two different time bases superimposed so that direct comparison is possible.

Figure 6.40 plots the cumulative number of patents issued in the US in the areas of semiconductor internal structure technology and semiconductor preparation technology between 1963 and 1974. As an industry and its technology mature, the focus moves from being based largely on productive innovation to being based largely on process innovation. The figure confirms that the balance of inventive activity did indeed move from product (internal structure technology) to process (semiconductor preparation technology).

Rogers (1986) maintained that there were four main elements in the diffusion of

Figure 6.34

The information problem that the typical modern scientist faces compared with that his counterpart faced 30 years ago.

Source: Garvey, 1979: 106: "The schema on the left represents the literature reservoir, relevant to an individual scientist's speciality in 1947. The typical 1947 scientist was just barely able to keep up with the literature of direct relevance to his work. He could not, however, keep up with the rest of the literature in his discipline even with that which had some possible relevance to his work. The situation in 1977 shows the amount of literature available in each speciality has increased well beyond the typical scientists' ability to assimilate and process it."

Figure 6.35

The structure of scientific consensus, or the tree of consensus (configuration of divergence), the atomization process (increasing divergence).

Source: Trouvé, 1992: 104.

innovations. Figure 6.41 outlines graphically the basis of this model, showing the effects of earlier or later adoption. While diffusion is depicted as having a normal curve, this alternative scenario portrays the process as a series of S-curves. Figure 6.42 also uses the S-curve. Teeling Smith (1983: 8) argued that "in order to under-

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Figure 6.36

Expansion of telecommunications service from 1847 to the year 2000.
Source: de Woot, 1990: 197.

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Figure 6.37

The motor car: power/volume ratio.
Source: Deforge, 1990: 428.

stand the potential for future progress in pharmaceutical innovation, it is necessary first to understand the background". Early scientific studies are represented on the bottom of the S-curve — learning. The 'first therapeutic revolution' occurred between the 1940s and 1960s, represented by the wave of innovations — the products of learning. Figure 6.43 represents the optimistic scenario — the decline is merely discontinuity:

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Figure 6.38

Electronics miniaturization 1940–75.

Source: Freeman *et al.*, 1982: 112.

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Figure 6.39

Saturation rate (percentage of households in Japan possessing colour television in the 1970s and tape recorders, and estimate for video tape recorders in the late 1980s).

Source Freeman *et al.*, 1982: 106.

> Just as Pasteur's basic understanding led on eventually to the first therapeutic revolution, it seems likely that fundamental scientific discoveries in the 1950s will pave the way for a new upsurge of pharmaceutical innovation in the 1980s and beyond. ... This new wave of innovation will justify the epithet of 'The Second Pharmacological Revolution'. (Teeling Smith, 1983: 8)

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Figure 6.40

No. of patents issued in the US in semiconductor structure technology and semiconductor preparation technology.

Source: Rothwell & Zegveld, 1982: 33.

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Figure 6.41

Diffusion is the process by which (1) an *innovation* (2) is *communicated* through certain *channels* (3) over *time* (4) among members of a *social system*.

Source: Rogers, 1986: 186.

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Figure 6.42

The first therapeutic revolution.

Source: Teeling Smith, 1983: 9.

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Figure 6.43

The second pharmacological revolution.

Source: Teeling Smith, 1983: 11.

The notional concept — without a scale — of the previous figure is continued. In addition, a lack of governmental intervention or regulatory interference is assumed. Figure 6.44 also uses a pair of S-curves to demonstrate that, while the performance improvement of successive CISC processors is levelling off, RISC performance is continuing to grow. Figure 6.45 shows the importance of understanding the S-curve. According to Foster (1986), DuPont did not know how far nylon had progressed along its S-curve so increased R&D expenditure resulted in little success. Polyester on the other hand was still in its infancy so Celanese benefited more with less investment.

Figure 6.46 is a simple line plot but there is too much information carried by the graphic. As well as plotting the data, the author has labelled the data points and, with seven plots and an element of projection, the effect is too much. In addition, the compression of time on the horizontal axis has destroyed the S-curve of 'General computers'. The S-curve concept is evident in Figure 6.47, yet the use of a 3D-perspective makes it difficult to examine the shapes drawn out.

Figure 6.44

CISC vs. RISC performance evolution.

Source: Apple Computer, 1994b: 3.

Figure 6.45

From cotton to rayon to nylon to polyester.

Source: Foster, 1986: 124: "DuPont, not understanding where nylon was on its S-curve, got little for its last $75 million of R&D, while Celanese progressed much faster with less money because polyester was just starting its curve."

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Figure 6.46

Percentage of Japanese enterprises using automation technology in the coordination sphere.
Source: Kaplinsky, 1985: 55: "Note: The figures in this chart represent the proportion of firms among 100 enterprises surveyed installing respective types of equipment in the years indicated."

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Figure 6.47

A physical profile of anxiety — steepness of curve indicates the speed of change taking place.
Source: Nishioka, 1992: 26, reproducing part of a Pentagram-designed Roche Products Limited promotional brochure from 1971 for a new tranquilliser. The monochromatic reproduction of the coloured original makes reading the labelling difficult. The horizontal axis plots arousal, from low through moderate and high to extreme. The vertical axis plots the six physiological measures; from front to back these are electro-myogram (forearm extensions), spontaneous fluctuations in skin conductance, forearm blood flow, heart rate, skin conductance level and finger pulse volume.

Figure 6.48 traces the development of an invention. Though the depiction is, in reality, a flow chart, the fact that it cumulatively plots resources means that it draws out the characteristic S-shaped curve. Figure 6.49 shows that, when the cumulative distribution of an S-curve is plotted according to frequency, it depicts a bell-shaped normal distribution, the same as the diffusion of innovations discussed in the next section. The curve in Figure 6.50 is a quasi-S-curve/product life cycle/normal dis-

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Figure 6.48

Naval systems program development.

Source: Schroeder *et al.*, 1989: 119.

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Figure 6.49

S-shaped diffusion curve.

Source: Bayer & Melone, 1989: 163.

tribution used to illustrate an article about the similarities between natural population dynamics and the sale of computers. It is an entirely notional concept, but the article accompanying it actually focused on S-curves, which may not be immediately apparent from a first glance at the figure.

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Figure 6.50

Life's ups and downs.
Source: Modis, 1995: 7.

6.2 SINGLE CYCLE VERSUS MULTIPLE CYCLE

A more contemporary view of progress accepts that it is subject to more cyclical variations and, though there may be overall upward movement, it is tempered by short-term downswings. This is believed to be true at the micro- and macro-level. Cycles are characterised by their cyclical variation: upward movement is countered over time by a downswing that may or may not be as severe as its predecessor. The representation of a cycle is a continuum that may just show one movement of the process (upward and then downward motion) to a scenario that represents swings over a 200-year period.* Thus, single-cycles over a reduced time period have been termed life cycles while more macro fluctuations will be discussed as long waves. However, the distinction between them is not absolute.

6.2.1 Life cycles

The product life cycle

The product life cycle (after Levitt, 1965) pictures the evolution of the sales and profit in an industry over an extended period of time. Several distinct periods have been traditionally identified. Reducing these to their most basic state, they comprise introduction, growth, maturity and decline. (Subsequent theories proposed in the marketing literature have not altered the model in any significant way for innovation theorists.)

The product life cycle starts with the launch of a new product. Sales increase only slowly. Once the potential customers have been convinced, demand increases sharply and the market grows rapidly. This ultimately results in market saturation. Sales will reach their maximum during the maturity stage. When the product loses customer appeal, this marks the beginning of the market decline stage, during which sales will decrease and finally fall to zero. The model is depicted by Figure 6.51. Technological maturity may occur in early stages of the life cycle while technological

Figure 6.51

The product life cycle.
Source: Moenaert *et al.*, 1990: 41, adapted from Levitt, 1965.

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* Perez and Soete (1988) maintained that the S-shaped diffusion pattern was similar to the emergence and long-term rise and fall of industries; an attempt at linking the two theories was made in Freeman *et al.* (1982).

turbulence may occur in the maturity stage.

The process is not dissimilar to the diffusion of innovations. The spread of ideas and practices among diverse cultures has been studied by anthropologists for many years. Tarde (1903) was the first to draw attention to the fact that the process of diffusion takes the shape of a normal curve: a few people adopt the innovation at first, then the majority follow suit and, finally, the rest join in. Rogers (1962) conceptualised five ideal categories of adopters, based on observation of reality; these are reproduced in Figure 6.52. Rogers declared that the divisions were to institute comparison since no pronounced divisions actually occurred.

Figure 6.52

Five stages of the diffusion of innovations.

Source: Chisnall, 1985: 214, based on Rogers, 1962.

The technology life cycle

The technological life cycle pictures the frequency of product and process innovations in a productive unit. The unit of analysis, the productive unit, is a product line and its associated production process. The Abernathy and Utterback (1978) model highlights the interaction between product, process and technology during the lifetime of a productive unit (Figure 6.53).

During the initial 'fluid' stage, product innovations will tend to be predominant as market needs are ill-defined and only vaguely stated. During the transition stage, the frequency of process innovations sharply increases. This occurs as the result of the emergence of a dominant design in the marketplace. A dominant design is the generally-accepted embodiment of all the relevant characteristics required by the users at an acceptable price. With performance criteria standardised in the industry, price becomes the new critical factor for success and the emphasis will logically shift from product to process innovations. Once process innovations are distinctly predominant over product innovations, the productive unit has reached the specific stage. The productive unit will subsequently move to the mature stage, during which innovative activity declines to a very low level.

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Figure 6.53

The technological life cycle.

Source: Arnold & Guy, 1989: 140, taken from Abernathy & Utterback, 1975: "The changing character of innovation, and its changing role in corporate advance. Seeking to understand the variables that determine successful strategies for innovation, the authors focus on three stages in the evolution of a successful enterprise: its period of flexibility, in which the enterprise seeks to capitalize on its advantages where they offer greatest advantages; its intermediate years, in which major products are used more widely; and its full maturity, when prosperity is assured by leadership in several principal products and technologies."

6.2.2 Long waves

The study of price and output swings of extended duration has a long tradition, having initially drawn the interest of writers around the turn of the century.* Langdon (1986: vii) claimed that the intellectual traditions of long waves "may be characterized by the work of Joseph Schumpeter and Herbert Simon". However, it was Kondratieff (1935) who first postulated that economic life was not simple and linear but rather complex and cyclical, comprising wave-like movements of about 50 years, and it was only Mensch's (1979) work in the mid-1970s that regenerated interest in this field. The discontinuous nature of Mensch's S-curves in Figure 6.54 contrasts graphically with the wave models postulated by Kondratieff and Schumpeter, much more than the theories seemed to; this perhaps accounts for the depiction of long wave theories in a visual manner.

Figure 6.54

The metamorphosis model of industrial evolution.

Source: Mensch, 1979: 73: "The wave model distinguishes phases: prosperity (P), recession (R), depression (D) and recovery (R)."

Langdon (1984: 5), in the introduction to a collection of conference papers, highlighted the "current [July 1982] economic depression following the post-war boom" as giving rise to a revival of interest in economic fluctuations and "the explanations for these phenomena such as the 'long wave' theory". Langdon also ascribed importance to the special issue of *Futures* (Freeman, 1981) as providing an important background to the debate. The late 1970s and early 1980s had seen renewed enthusiasm

* Even in the 19th century, this was an issue that attracted attention. Playfair (1821) plotted prices and wages over a 250-year period to show variations. This was preceded by the charting of "remarkable events" related to commerce and of idealised prosperity cycles for places in modern times, as well as for "ancient seats of wealth and commerce" (Playfair, 1805: Frontispiece). This outstanding piece of scholarship plotted the commercial history of trading countries over a period of more than 3,000 years, enabling comparison and understanding. The events were not innovations, but incidents that Playfair considered had changed — for better or for worse — trade. There was no suggestion of linking them with the rise and fall of prosperity cycles.

in the field, marked by book publications, journal articles and conferences on the subject — respectively, involving Freeman, for instance: Freeman *et al.* (1982), Freeman (1984) and Freeman (1986a).

Freeman (1986b) maintained that theories of the factors behind the long wave included: long-term trends in capital accumulation and profitability; monetary factors; industrial relations; long swings in the supply and price level for primary commodities; and, the relationship between new technologies and the economic and social system. To Freeman, the long wave theory was more than a short-term business cycle theory or product cycle theory — these ignored the long-term characteristics of many technological trajectories and diffusion processes; it provided the trigger for product innovations to 'swarm' and for 'new technology systems' to be established. Perez (1983: 461) identified 'technological styles', "a sort of paradigm for the most efficient organisation of production", that appear during booms and diffuse over the subsequent wave. By doing so, Perez attempted to broaden the scope of long wave theory and link it to process and product innovation, synthesising the Marxist and Schumpeterian traditions as a result. Figure 6.55 graphically represents some of Perez's ideas; it is interesting to note that only one wave is depicted.

Figure 6.55
The Perez model.
Source: Tylecote, 1991: 20.

The importance of long waves is seen in their ability to predict future economic conditions. For instance, Marchetti (1985) used ecological equations and graphs to model and forecast changes in world energy consumption. This was achieved by matching the innovation waves detected by Mensch with energy statistics, primarily from the USA. A new energy source was seen as a new technology and, as energy consumption is related to economic activity, so from this Marchetti was able to derive a date when the current global recession would end. The real motivating factor behind long waves is more idealised than this though: if downswings — recessions and depressions — are properly understood, then it might be possible to take action to avoid one or, more plausibly, how to reduce its duration by encouraging an earlier, stronger, longer upswing.

6.2.3 Comparison

Oakley (1984: 23) terms Figure 6.56 as a "generalised life-cycle". It fails to feature the characteristic skew of growth and the tail-off of decline. Instead it portrays a normal distribution. Figure 6.57 shows that the product life cycle does not necessarily have to follow a traditional depiction. Figure 6.58 illustrates a range of product life cycles,

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Figure 6.56

Typical form of product life-cycle curve.

Source: Oakley. 1984: 23.

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Figure 6.57

Variations to the simple life-cycle pattern.

Source: Rothwell & Zegveld: 1985: 18.

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Figure 6.58

Product life curves.

Source: West, 1992: 96.

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Figure 6.59

Automobile sector: segments and co-existence.

Source: Clark & DeBresson, 1990: 243.

each with increasing attractiveness — from A to C — to the company. Figure 6.59 plots the differing methods of car production and how they affect the product life cycle, while Roy (1984) attempted to link the product life cycle with the concept of robust designs, graphically representing the curve and illustrating it with bicycle models (Figure 6.60).

Despite the application of innovations to points on the curve — the plotting is skewed in the growth phase with only one example plotted in the decline — Figure 6.61 looks like an idealised depiction of the product life cycle; the model is too narrow for its height. The product life cycle of Figure 6.62 is a practical depiction of Figure 6.51. It is not extraordinary; it adds the stage "phase-out". The diagram does help establish the notion of progress in that field and where products fall within it. The fact that this is conjecture is demonstrated by the lack of any form of scale on either axis. However, with innovations plotted evenly along the curve, it still depicts a shape similar to that in Figure 6.61. Figure 6.63 depicts the "pessimistic view … that this Golden Age of Innovation is over, and that the adverse factors illustrated … will cause the innovative pharmaceutical industry to go into a decline" (Teeling

Figure 6.60

Divergent, convergent and divergent pattern of bicycle design evolution corresponding to the phases in the innovation life cycle.
Source: Roy, 1984: 93.

Figure 6.61

Integrated circuit product life cycle.
Source: Sciberras, 1977: 60.

Smith, 1983: 8); intervention and regulation will cause an innovative pharmaceutical industry to go into decline. Figure 6.64 shows the life cycle of an economy at one period in time.

Figure 6.65 practically represents the concept of substitution from Figure 6.59(a). Figure 6.66 depicts market share histories of product introductions. The shape of the

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Figure 6.62
Discrete device product life cycle.
Source: Sciberras, 1977: 55.

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Figure 6.63
Pharmaceutical progress under threat.
Source: Teeling Smith, 1983: 10.

line for the incomplete data for 1958–1960 is not known, but it must have originated from close to that for 1961–1963. Thus, a series of immature curves may be visualised giving the overall impression of products being in early maturity 7–9 years after their introduction. The plotting of dates according to their introduction would have produced a diagram more like Figure 6.43 or 6.59(a).

Figure 6.67 plots industrial output and employment in the EEC-9 between 1950 and 1980, with 1960 being indexed as 100. It can be seen that between 1950 and about 1963–64, as industrial output increased, so did industrial employment. Between 1963–64 and 1971–72, while industrial output continued to increase significantly, industrial employment (with some marked fluctuations) remained, on average, at about the 1963 level. Between 1972 and 1980, while industrial output

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Figure 6.64

Trends of various US industries.

Source: Dewey & Dakin, 1947: 49: "Diagrammatic representation of a growth curve on which there have been located with only approximate accuracy, various American industries, according to their present rate of growth. *Ratio scale. When* an industry is young and growing fast, it appears here at the left, where the curve is rising rapidly. As it gets older and more mature, it is located near the top of the curve, or even beyond."

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Figure 6.65

Intel's 486: no sign of weakness...

Source: Brandt, 1993: 32.

increased by about 30 points, industrial employment fell by approximately 8 points. Thus, according to Rothwell and Zegveld (1982: 118), the mid to late 1960s was "a period effectively of 'jobless growth', while the 1970s has been a period of 'deployment' ". This graphic is a rare example of the use in innovation of a Phillips curve plot. Tufte (1983) defines such forms as *relational graphs* since they demonstrate a relationship among the variables that is not based on time or space.

Figure 6.68 shows how different nations have contributed to the flow of innovations. If it is viewed on its side, it depicts the characteristic of the product life cycle, the maturity stage being in the mid-19th century. Figure 6.69 exhibits more of the look of an S-curve. Since this is derived from a company, it is not surprising that it focuses solely on products pre-launch. Figure 6.70 is one of a few examples found

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Figure 6.66

Market share histories of the product introductions of given years.

Source: Teeling-Smith, 1980: 25.

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Figure 6.67

Industrial output and employment in the EEC-9, 1950 to 1980. (1962 = 100; 1950–60 estimated).

Source: Freeman *et al.*, 1982: 154.

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Figure 6.68

The pattern of invention.

Source: *The Sunday Times*, 1970: n.p.

of a company illustrating their product portfolio in such a way. This graphic is an ingenious piece of design: the pipeline and growth sections of the curve appear on the front cover of Pfizer's annual report, while the mature and ageing sections are folded inside. Again, the concept is notional. This is to be expected; commercial prudence means that no company is going to allude to monetary values or sales quantities (or even proportions). This depiction emphasises pipeline and growth — the new — since most investors, analysts, etc., would know about the older products.

Moving onto the representation of the technology life cycle, Figure 5.71 represents the original version of the model. That it has proved to be a less popular depic-

Figure 6.69

Phase diagram showing the progressive development of pharmaceutical products.
Source: Nishioka, 1992: 31, reproducing part of Centocor, Inc.'s 1990 annual report.

tion than Figure 6.53 might be explained by the apparent complexity of the 'stimulation regions'. Similarly, Figure 6.72 is complicated with the addition of notional stages, akin to those found in the product life cycle, while Figure 6.73 distorts the relationship horizontal relationship.

The portrayal of Kondratieff's long waves in Figure 6.74 is schematic. However, it manages to inform the reader on many levels with the inclusion of additional information. Figure 6.75 is less successful, being an almost cartoon-like depiction, complete with pointing hand and explosions labelling the years. While this might be suitable for the media, it detracts from wide-ranging implications of the theory and does it an injustice. Figure 6.76 represents Juglar cycles that last typically for 7–11 years within the overall long waves. The former are shown with an unbroken line, while the stages of the latter are separated by a hashed line running across the Juglar cycles.

After representing change with exponential and S-curves, Price focused on long waves (Figure 6.77). However, the reasoning why the diagram portrays such rigidity in representation is unclear — it is not alluded to in the text. The curve is visible behind the angular line, but this representation of recent citation data is not reflected in the extension to the historical study; even the dotted portion of the line in an alternative depiction — Figure 6.78 — does not display the severity that is shown here. Like the other theories and their graphic representations shown above, long waves too can be used as a tool to assess the past and predict the future. Price (n.d.) has represented technological progress with linear curves (plotted on an exponential scale), exponential curves, S-curves and has subsequently moved to cycles. This progress has been chronological, perhaps reflecting the changing theoretical 'fashions'. To assess scientific trends, Price applied smoothing procedures to the time-

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Figure 6.70

Timeline chart showing the many drugs and drug candidates in Pfizer's current portfolio and R&D pipeline.

Source: detail of Pfizer, 1991: fold-out front cover.

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Figure 6.71

Innovation and stage of development.

Source: Utterback & Abernathy, 1975: 645.

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Figure 6.72

The technological life-cycle.

Source: Moenaert *et al.*, 1990: 42, adapted from Utterback & Abernathy, 1975.

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Figure 6.73

Radical-incremental patterns of innovations for products and for processes over the life course of the sector: case of automobiles.

Source: Clark & DeBresson, 1990: 225, modified from Abernathy & Utterback, 1975.

Figure 6.74

A simple schematic of the Kondratiev waves.

Source: Arnold & Guy, 1989: 137: "This diagram shows simply fluctuations over time and does not attempt to indicate the relative magnitudes of the economic upswings and downswings for the different Kondratievs. In practice, of course, the base line will rise from left to right as the average level of world economic activity has risen considerably during the period covered."

Figure 6.75

50 to 60-year-long cycles in economic activity identified by Kondratieff and linked to innovation waves by Schumpeter and Mensch.

Source: Hall, 1986: 266.

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Figure 6.76
World economic growth — a long wave pattern? Juglar growth rates in industrial production.
Source: Tylecote, 1991: 13.

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Figure 6.77
Acceleration of scientific progress.
Source: Price, n.d.: 169.

series to obtain a typically cyclical representation, shown as Figure 6.78. The diagram depicts an uncharacteristically long period of time, even for long waves.

There are also explanatory models depicting long waves. The representation of long waves in Figure 6.79, for instance, play a minor part compared with the chronicling of patterns of competition, the diffusion of innovation and the internationalisation of the capital cycle. By combining different theories in this, the message is that even long waves are part of a macro system and that all of these features are interrelated in some way. While Tylecote (1991) has not attempted anything as so holistic, Figure 6.80 attempts to summarise all the varying theories about the long wave within one diagram. Finally, Figure 6.81 moves away from the cyclical interpretation to depict long waves as a turning wheel: 'what goes around, comes around'. This approach engenders comparison within each phase.

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Figure 6.78

Ups and down in the pulse of science and technology.
Source: Price, n.d.: 165.

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Figure 6.79

Long waves, patterns of competition, diffusion of technical change and internationalization of capital.
Source: Corona, 1986: 201.

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Figure 6.80

A résumé of the theory.

Source: Tylecote, 1991: 36.

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Figure 6.81

A long-wave 'clock'.

Source: Cleary & Hobbs, 1984: 181.

6.3 SUMMARY

Back in 1914, Brinton asserted that there were relatively few businesses that made a practice of plotting curves to show operating records in a convenient form for the use of executives. Over 80 years later, the same is still sadly true. Though the representation of performance and progress using (particularly exponential) curves is the most multitudinous expression examined by this thesis, the word is still dominant. The concept of technology-related cycles is relevant at the level of individual products (product life cycle), at the level of industrial branches (technology life cycle) and at the level of the national (and world) economy (long wave).The examples in this chapter are drawn from a wider selection of sources than the previous two chapters; representations from the media are particularly more numerous. Table 6.1 cross-references figure numbers with their sources and the expressions they embody.

As has been shown, the different graphic forms are used to represent diverse theoretical concepts. Except for the technological life cycle, the linking elements between the graphics can be seen: an exponential curve shows a linear relationship when drawn on logarithmic paper; an S-curve is constructed from two exponential curves; the almost normalised distribution of the product life cycle can be represented as an S-curve when quantity is plotted cumulatively; a long wave can be depicted by a macro series of S-curves or of life cycles.

The significance of the difference between the expressions is due to the fact that they are used to demonstrate distinct aspects of each theory. While all theories concern technological performance and progress, it is the variance within this that dictates their usage. For instance, the Office of Health Economics used the life cycle to display the threat of intervention (Figure 6.63) with discontinuous S-curves to indicate the future without governmental restriction (Figure 6.43). For the purposes of forecasting, however, a simple linear relationship was shown (Figure 6.28); the criticisms that Rose made of Price's theory are equally relevant here. That there might be a fall-off is expected, but would this be as severe as a reduction from 42 per cent in 1972 to 28 per cent in 1977, a fall of one-third in five years?

From an examination of the graphics contained in this chapter, along with those that have not been reproduced but have drawn upon, it is possible to draw certain conclusions about the employment of certain types of expression.

The **linear curve** is a common expression. The concept underlying it is one of progress and it is typically employed to promote the message of continuity in all domains. The **exponential curve** is the most popular expression. Progress is also the concept behind this format, and this can be portrayed in two ways; the curve starts by showing modest success and this increases until it becomes nearly vertical, or the curve starts with an impressive beginning before success declines to be nearly horizontal. Like the linear curve, it is used by academia, policy-makers, the media and

Table 6.1
Typology of expressions cross-referenced with figure numbers and source for Chapter Six.

EXPRESSION	ACADEMIC	POLICY	MEDIA	BUSINESS		
				Bioscience	ICT	Other
Linear & exponential curve	1[*] 2 3 4 5 12 13 16 17 19 20 22 27 30 34 35	1 12 20 21 28 30 31 36	3 6 10 14 15 16 32	22	11 18 24 25 26 29 33	1 19 23
S-curve	7 8 9 37 38 39 40 41 45 46 47 48 49	42 43	50	47	44	
Product life cycle	51 52 56 57 58 59 61 62 64 67 69	60 63 66 68	61 62 65	69 70		
Technology life cycle	53 71 72 73	53				
Long wave	54 55 74 75 76 77 78 79 80 81	74				

business people. The **S-curve** takes account of learning and, more particularly for innovation, diminishing returns. It indicates that there has been or will be a shift in the innovation portfolio. Since this is not a positive message, the expression tend to be used by the academic and policy domains.

The **product life cycle** presents the volume of sales over time. Its underlying message is that sales eventually stagnate. Once again, since this is not a positive message that corporate enterprises want to communicate, it tends to be restricted to use by academics and policy-makers. However, even when companies tend to deploy this expression, they skew the representation with more new products than maturing ones, to present a rosy picture. The **technology life cycle** shows the number of nature of innovations over a series of stages; it indicates that there is a minimal level for the number of innovations. It tends to be an academic expression, since it is closely linked to the innovation process. The concept behind the **long wave** is one of the periodicy of growth and stagnation. The message is that the economic and

* The source for this graphic is unclear; no explicit mention is made of its source or purpose.

innovative activity is subject to long-term fluctuations. While this is of interest to policy-makers, the media and businesses, it tends to remain an academic preoccupation. The typology in Table 6.2 provides a thematic summary of the principal graphic forms that have been shown and discussed in this chapter.

Table 6.2

Typology of the interaction between graphic expressions, innovation concepts and their practical usage for performance and progress.

EXPRESSION	CONCEPT	MESSAGE	EMPHASIS
Linear curve	Progress	Continuity	All
Exponential curve	Progress	Increasing success or impressive beginning	All
S-curve	Diminishing returns	Shift in the innovation portfolio	Academic and policy
Product life cycle	Sales volume over time	Stagnation of sales	Academic and policy
Technology life cycle	Minimal level of number of innovations	Number and nature of innovations over stages	Academic
Long wave	Periodicity of growth and stagnation	Economic and innovative fluctuations	Academic

Chapter Seven
CONCLUSIONS

This chapter presents an overview of the main findings of the thesis through a synthesis of the ideas taken from each of the three preceding chapters. Building upon this, it makes recommendations for academics, policy-makers and individuals in the media and businesses alike; these have implications for both innovation research and graphics practice. Finally, the contribution of the central concepts of this thesis to current research — both completed and in progress — is reviewed, and a number of issues are proposed to be tested in future research related to this field.

The principal purpose of this thesis was to examine the practical aspects of innovation concepts' communication through graphic representation. Some leading academic theories of the management of innovation, the innovation process, and performance and progress were examined for their use of graphics. These examples were compared with a sample of figures derived from other academic sources and the policy, media and corporate spheres.

The thesis illustrates that the practical use of graphic devices reflects some element of choice in the selection of alternative models of theories in academic literature about technological innovation. It implies that there are different conceptions of innovation theory. This implication extends so that the choice of graphic form becomes important, not only for academics but also for policy makers, people who work in the media and in business, and the general public alike, due to the image's origin. The importance is related to the explicitness of the representation.

It is commonly accepted that aspects of innovation should be communicated more effectively. However, it is not only a matter of graphical excellence; it should be a recognition that graphic representation is under-utilised to depict such a dynamic subject. As the graphic message is switching from prescription to description, there should be greater emphasis placed on graphics — in the quantity that are produced and in the diversity of the dimensions that they represent.

Academia has led and still leads the way in graphic usage as well as novelty: academics do not always lag behind business people as cynics might claim. In spite of this, the graphic representation of innovation should be increased in *all* domains, though it is conceded that its content and execution needs to improve too. Education of graphic 'producers', 'intermediaries' and 'consumers' will play a part in this, as will greater exploration of diversity, novelty and convention, while the computerisation of graphics has created a major role for the information designer.

7.1 MAJOR FINDINGS

As a consequence of the research completed and reported on in the thesis, there are three findings that are particularly worthy of further discussion.

Prescription versus description

Throughout the thesis, pairs of graphic expressions have been contrasted. For Chapters Four and Five, this reflected the change that has occurred in the way that theory has been used to explain and explore different concepts of innovation (Finne, 1994a). As theory has gradually moved from being prescriptive to descriptive — from a plan or blueprint for action to an instrument to aid explanation and understanding — so too have graphics reflected this change. It is not clear though whether the change in representation preceded or followed the change in theoretical approach.

The situation for the representation of the performance and progress of innovation — Chapter Six — is slightly different, however, since there is no 'old' and 'new' way to depict technological change. While there may be little difference between an exponential curve and an S-curve, the same cannot be said of a life cycle and a long wave: the difference in scale means that they are not comparable expressions, despite their similar composition. The representation of performance and progress tends to bounded within its own domain and there are few attempts to change this status quo; whatever novelty there is tends to be a variation on a theme.

Throughout the graphical examples studied, there has been a strong emphasis on heritage. It can be seen that some types of expressions are more common than others, especially when they are stripped back to their fundamental graphic proposition. There are clear cases where, when a theory is subsequently enhanced by an academic, its graphic expression is enhanced likewise, but it is rare for the representation to be radically altered. There is evidence that graphic practitioners *ex*-academia tend to be influenced by practice from within.

A standard schema for depicting innovation concepts is presented, the adoption of which it is hoped will improve or increase understanding for innovation theorists and graphic practitioners alike. It is reproduced as Table 7.1. The major themes are grouped according to the dominant expression; the message column refers to the predominant statement expressed by the graphic while concept summarises the main theoretical proposition to which the graphic makes a metaphorical link. However, it must be stressed that the typology should be considered a first draft. The sample size was not large enough to quantify these result; instead they should be considered a statement of current understanding that can be developed.

Since maps have geographical origins, the message is comprehensive; though the concept is authoritative, it is old. The use of a map was not a popular format with usage divided into recording and communicating. For check lists, the message is simple and this is allied to a prescriptive belief of success in the concept behind it.

Table 7.1
Standard schema for depicting innovation concepts.

EXPRESSION	MESSAGE	CONCEPT
Map	Comprehensibility	Archaic authority
Check list	Simplicity	Prescriptive success
Matrix	Taxonomy	Descriptive possibilities
Flow chart	'Tree of innovation'	Heritage
Organisation chart	Authority	Structure
Network (including 'systems', mapping and emergent)	A dynamic and ever changing environment	Relationships, contacts and alliances
Curve	Faith in future progress	Growth...
Cycle	Fluctuations occur	and stagnation

Again, usage has diminished though it should be noted that policy documents retain this approach, along with matrices. Matrices allow different ideas to be classified so this is the dominant message, and the ability to explore these possibilities is the theory behind the graphic. The image of matrices seems welded to business schools in the 1980s, and the expression is typically used to demonstrate choice rather than to provide a basis for action.

The 'process' schema is interesting because the rival pair in each case is the network expression; all that alters is the scope. In each, the message is that the network graphic represents a dynamic environment; this is distinct to the flow chart which tends to restrict dynamism to the one dimension — down or across the page. With networks, the concept emphasised is relationships, contacts and alliance; with flow charts, the accent is on heritage — what has gone before. The message that an organisation chart sends is one of authority, and there is a strong concept of structure that underlies it. The network expression has been frequently employed in the 1990s.

Curves are the most frequent expression in innovation literature and the predominant message is one of progress, linking to theories of growth, whether they be linear or exponential. The usage is strongly metaphorical: that technology and innovation result in progress — it is one of the abiding images of innovation. This idealised portrayal is strongly favoured by companies. With cycles, the message of progress is tempered with an illustration that fluctuations occur, and the concept moves from growth to stagnation. Unsurprisingly, companies are less willing to recognise this, though those that do rarely put figures to it.

Innovation's innovation in graphics

Throughout history, many scientists have been artistic and creative individuals with visual imaginations (Root-Bernstein, 1985). According to Macdonald-Ross and Smith, scientists and technologists have been inventive in their use of graphics:

> These diagrams are not just 'illustrations' but essential tools of thought and communication. ... [However,] working scientists have almost never conducted experiments on their own diagrams: they seem mostly to use diagrams without being aware of what it is they are doing. The diagrams evolve by trial and error and consensus without any formal design (1977: 30)

The multiplicity in formats and the amount of work involved makes it difficult for any definitive statement to be made about the source of innovation graphics; indeed, the skill and knowledge that these types of graphics embody is largely tacit, not articulated. However, these graphics *do* seem to be strongly rule-bound; the manner of construction and interpretation is not arbitrary but codified as Table 7.1 identifies. Lockwood contrasted the construction dilemma:

> The diagram produced by the ... geographer or sociologist can convey a great deal of information in an interesting way but may lack the graphic distinction which a designer would give. And, conversely, the diagram produced by the designer may have all the current graphic clichés but fail in the aim of getting over information clearly and accurately. (1969: 6)

As Macdonald-Ross and Smith contended, scientific graphics are not just illustrations; they are as much a part of the subject matter as technical terms, formulae and methods that are used to explain the objects of investigation. Tufte maintained that graphics aid social scientists since they communicate information

> through the simultaneous presentation of words, numbers and/or pictures. The marvel of truly effective statistical representation, however, lies more in the substance of the message than in the method and design. (1986: 75)

According to Macdonald-Ross (1977b: 369), "the presentation of exact numbers is ... of secondary importance; ... the reader is meant to grasp the meaning or significance of the data in some particular context ... [and] will be expected to make comparisons and appreciate *patterns*". Since academic graphics have a restricted audience, compared with those of a newspaper or a company report, the readers seem willing to overlook 'failings' in design in return for a strong conceptual message. This is not to give the impression that academic graphics are always praiseworthy; many are inefficient, clichéd and seem to be used as decoration, but on the whole they do communicate something worthy. This proposition was made in Chapters One and Two, and was confirmed by sample of graphics studied.

Corporate failure in representation

In Chapter Three, the reasons for examining corporate graphics practice were justified, and annual reports were put forward as a source for investigation. However, as Cobb (1990: 28) identifies, most ascribe to " 'the legal minimum' category, where 'the objective is not to inform shareholders and investors but to get shot of an annoying interruption as cheaply as possible' ". The lacklustre implementation of graphics, and the lack of novelty when companies did so, coupled with a poor level of response, meant the analysis does not depict corporate graphics practice adequately.

Hwoever, if the evidence gathered is considered to be representative, then the thesis shows that, if the primary corporate focus is an image of innovation, then most businesses fail. Even when innovation is depicted, it typically comprises a list of awards, some statistics on how much money is being invested in R&D, or a series of pictures of new products — artefacts; innovation graphics tend not to receive a second thought. Hickinbottom highlighted a common problem:

> Often one gets the feeling that a picture has been used because it was readily available, rather than to make a specific point. … Few manufacturing plants are so impressive that they merit portrayal in a brochure. (1986: 172, 173)

Business media do not exhibit 'best practice' either; in a 'how-to' feature on effective presentations, the reader is advised that "graphs are an effective means of communicating a set of boring figures, but keep them simple and direct" (Stephens, 1995: 200). — Tufte, whose work was examined in Chapter Two, would disagree on both of these points. Designing a good graph takes time and money; it is easier to commission a photographer to take a stock picture than it is to explain to a designer the basis of the conceptual message behind a diagram.

However, some corporate enterprises do recognise that the representation of innovation is lacking. In response to the survey letter enquiring about the corporate representation of innovation, Paul Harvey, director of Manufacturing Operations at Lilly Industries Limited, wrote, "I have scoured some of our Corporate publications, such as Annual Reports, etc., and have not really come up with anything very helpful. … The type of illustrations that you seek are clearly thin on the ground!". W.D. Butt, research adviser to the Central Research Division of Pfizer Limited, replied, "I am afraid that we do not produce many reports of this nature and do not tend to use graphic illustrations of the type of interest to you". Yet the Pfizer (1991) annual report that was enclosed provided a depiction that could be used (Figure 6.70).

Other companies did not grasp what was being asked of them. Steve Firth, systems development manager of Serono Diagnostics Limited, was confused: "We do not understand the question. … We are scientists first and businessmen second[;] we have never been 'professional businessmen' and so do not understand the (often tortuous) language used in such circles. … Though we produce graphics showing the technical performance of our products, we do not produce retrospective studies of our productivity. Productivity is judged on hard and fast financial indicators, not on graphics. … If we fail we analyse why and where we failed but we don't produce a graph of our failure". P.J. Walker, manager of engineering processes of ICL's Product Operations, answered, "we have not required our Development and Manufacturing Divisions to collect in any systematic way the metrics, statistics and report which would have recorded this data". This has been considered, but he concluded that "our rate of technological innovation — if measured only by ICL's continuing success in the marketplace — is satisfactory!".

The thesis reveals that the representation of innovation by ICT and bioscience companies is not well established. Part of this is due to secrecy, as highlighted by Orsenigo (1993): Andrew Crisp, product planning and marketing manager of Fujitsu Europe Limited, maintained that "much of the information you have requested is not available to use in the UK. Some is considered Company Confidential, while other parts exist only in Kanji". A brochure was provided that detailed "the major milestones of technological development from 1935 to 1988 which may be of some use to you" (Figure 6.24). However, Elliot (1989: 36) maintained that a technology-based company's history and achievements was, in reality, a review of "its success in innovatively applying technology to meet the needs of customers". The usage of graphics by companies in the ICT and bioscience industrial sectors is not significantly different to companies operating in other sectors; the belief that companies operating in high-technology sectors would implement graphics more than companies in sectors with less technology — as expressed in Chapter Three — was wrong.

The emergence of the information designer

The PC has had an important influence on information design since it gave people "freedom from the cost constraints of hiring professional expertise" (Wright, 1991: 238). The consequence is that the quantity of graphics has increased while the quality has decreased. The **information designer** has been identified by this research as a key figure who is responsible for integrating information analysis with graphic representation. This individual needs to understands both graphic and innovation theory to create and produce graphics, and to interpret them in a particular context.

The role is one that has long been identified. Neurath (1936) used the term *transformer* to express the role of intermediary between the source and the reader. Macdonald-Ross and Smith (1977: 18) believed that, if this role was taken seriously, "it would utterly change the production-line system whereby [graphics] are produced in large organisations". Neurath (1936) relied on the transformer being educated and of integrity; Macdonald-Ross (1977a), on the other hand, saw a new role for a skilled intermediary to link practitioner and researcher, i.e. to convey the systematic knowledge from graphic research to the producer of graphics for practical purposes.

Information design has already attracted interest from the large or specialist graphic design consultancies (Bidlake, 1989). This seems to miss the point, however, in that the information designer should be as integral to an organisation as an accountant, marketer or managing director. Considering the average attention span for an annual report is reported as being between 4–6 minutes (Bidlake, 1990; Cami, 1992), it seems obvious to improve the information and entertainment content so that it becomes an object of desire — an information designer can help to achieve this. Such an individual also has a role to play in academia where they would be a resource that would be drawn upon by many people, from adviser to executor. The role of the information designer needs to be more fully explored. This was one of the intentions of this research, before the non-response problem discussed in Chapter Three became an issue.

7.2 RECOMMENDATIONS

The recommendations are applicable to academics, policy-makers and individuals in the media and businesses alike, and affect innovation research and graphics practice.

Implications for innovation research

The emphasis on graphics cannot be over-emphasised: O'Connor (1991: 20) maintains that "readers often look at tables and figures to see whether the rest of a paper is worth reading".* O'Connor even urges that the preparation of figures should be considered *before* the text is drafted. A perusal of the innovation literature, particularly in journals, shows that there does not seem to be a 'house style' or even suggested usage. In addition, few journals redraw figures submitted by authors, as noted by O'Connor (1991).

Increasing communication while improving efficiency

Tisdell (quoted in Laetsch, 1987) cited three reasons for the communication of science and technology. The first is political: universities and similar organisations are dependent on funding and thus lobby for support. The second is to gain public backing for research that might not be socially acceptable, e.g. nuclear energy. Finally, companies need to raise their awareness to customers or suppliers. The 1993 White Paper was cited in Chapter One following its suggestions for research into the management of innovation, the innovation process and performance and progress. It stated that its central thesis was that the United Kingdom "could and should improve ... [its] performance by making the science and engineering base even more aware of and responsive to the needs of industry and other research users" (p16). The most obvious way for all of this to be achieved is through the increasing use of graphic depictions. Graphics are a powerful and persuasive tool, a point that has been many times throughout this thesis. However, this is not to promote the proliferation of graphics as the expense of efficiency.

In addition, at a time when innovation studies, like so many areas of social science research, is expanding at an exponential rate, graphics can be used as an illustrative resource: people can 'taste' the paper by examining the graphics before deciding whether it merits further study. This has three implications. Firstly, since a person can 'read' a graphic more quickly than even a paragraph of text, it means documents with graphics are more likely to be examined — even cursorily — than those without. Secondly, since concepts play an important role in how someone defines their world, the inclusion of a graphic format that is familiar to that person means

* Table construction deserves consideration. Macdonald-Ross and Smith (1977: 27) claimed that "the design and setting of tables is an arcane art which few have understood well". O'Connor's (1991) focus is on tables constructed from scientific data; those formed from text or matrices are not covered. It is also worth consulting Ehrenberg's (1977) advice.

that it is likely to be categorised according to the concept label that it was identified with when it was last encountered. Thirdly, it follows then that if a person wanted to represent a unique concept they should represent it in a likewise novel way to increase consideration and prevent categorisation.

Diversifying research methods

Images have the ability to communicate ideas rapidly and universally, with or without verbal interaction, to record and summarise ideas, and to influence perceptions and behaviour. Yet the use of image in research has been limited. One explanation for this is the subjectivity of interpretation. Another is the technical difficulties in managing and printing text and graphics. The complexities of managing this for this thesis should not be underestimated; it is likely to be more difficult when graphics need to be depicted in a variety of research papers, presentations and so on. However, the fundamental reason is resistance to the use of a medium that is not only non-numerical, but also non-verbal.

In the social sciences, image has always been the poor relative of verbal expression.* Examples do, however, exist of its use as a research medium, e.g. Downs and Stea, 1977; Checkland, 1981; Kotler, 1984, 1986; Maddox *et al.*, 1987; Mintzberg, 1988; Majaro, 1991. Morgan (1993) has continued the use of visual metaphors to explore organisational problems. Metaphors occur in strategic management: 'milking' 'cash cows' and investing in 'stars'; Miles and Snow's (1978) 'defenders' and 'prospectors'.

However, certain graphics are flexible instruments. A network graphic, for instance, can be used for analytical and descriptive purposes, and to display anything from the transaction content of several individuals to the modelling of a 'system' of innovation or the mapping of a subject speciality. While it is unlikely that the exploration of image in this thesis will significantly alter someone's outlook on research methods, it is hoped that less orthodox alternatives will be considered.

It is worth commenting on two prominent figures that illustrate key approaches adopted by the thesis. Figure 2.1 addressed the representational methods and analytical approaches that it is possible to take with a study of graphics. The representational methods range from metaphorical to mathematical, with graphical methods mediating between the two. The vertical axis plotted the different approaches that might be taken, from discourse in one extreme to excellence in the other. The mediating approach — that graphics could be analysed according to visual arguments they depict — was located in the centre.

Figure 2.1 proved to be an accurate representation of the paradigms, and of practice. While some representational practice tended to the extremes — metaphorical or mathematical — the reasoning was explicit when it occurred. For instance, Figures 6.17 and 6.46 plot results while Figure 6.50, despite not being completely metaphori-

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* Tilling (1975: 194) was intrigued by the lack of graphs "in the scientific literature of the early 19th century. ... A number of isolated examples were found. The existence of these examples shows that the use of graphs in printed literature was by no means technically impossible".

cal, is as close to exhibiting it as any graphic considered for this study. However, the majority of graphics were clustered in the centre. On reflection, the reasoning seems obvious: few graphics plot purely mathematical data, while few depict metaphorical ideas. This results in a cluster of more-or-less similar graphs in the centre.

Likewise, an examination of graphics practice reveals that the analytical approach is similarly distributed. The lack of excellent graphics occurring is largely related to the lack of formal skill of practitioners, as highlighted by Macdonald-Ross and Smith (1977) above. This is true even when graphic designers are involved in the commissioning of figures, since the emphasis is on the entertainment or visual distration rather than informing. Similarly, the discourse approach is not favoured due to the sociological theorising that is required. Despite some sociological texts discussing this approach, they were noticeably absent in their employment of graphics of any kind. It is clear, due to the predominance of graphics that adhere to the visual argument approach, that many illustrations are purely that — graphics that demonstrate or reinforce a point made in the accompanying text.

Figure 3.1 proved to be less useful. While the theory behind the taxonomy is robust, its application to real-world examples is wanting. The problem is that the structure is too rigid, and since it attempts to quantify practice, requires a sample survey of upward of 1,000 graphics so that the each format is represented by more than a handful of examples. Despite this, it marks a helpful first attempt since, as has been remarked, innovation theorists being unskilled graphic communicators do not construct graphics according to standard schemas. This makes it difficult to *de*construct them according to similar rules — and, though long-winded, Figure 3.1 proved this. In most cases, the aim behind most figures is to communicate or process data. However, the most common impositions collected by the sample were those that recorded data. More research needs to be undertaken to explore how people construct graphics, and more work is required in this and other areas to ensure that graphic research methods are understood more fully.

Implications for graphics practice

Tufte (1983) maintains that the reason why the use of abstract, non-representation pictures to show numbers is a recent invention is related to the diversity of skills required: visual-artistic, empirical-statistical and mathematical.

Educating the 'producers', *the* 'intermediaries' *and the* 'consumers'

It is not possible to define in quantifiable terms the concept of quality as applied to graphics. Nevertheless, a consensus has been developed over the years among specialists to categorise graphics as 'good' or 'bad' and 'acceptable' or 'unacceptable' — the concept of efficiency discussed in Chapters Two and Three. Funkhouser (1937), Macdonald-Ross (1977b) and Wainer (1980) all maintained that the major errors in newspaper graphics have been made repeatedly for many years, even before the production of graphics by the individual.

Orna and Stevens (1991) believe that it is unfortunate that technological developments in graphics production have not been matched by a rising level of public appreciation of design or the development of design skills. Perkins (1980) levelled the blame at elementary school teaching: the emphasis is on learning to read text, not reading pictures. Consequently, most people achieve a routine competence in picture perception without formal instruction, yet considerable time was spent on the outset of this thesis exploring the construction and design of graphics so that Chapter Two could be written and the graphics could be examined with some authority. Tufte (1970b) claims that while students of political and social science gain useful knowledge of how to use statistical techniques to summarise and confirm, they lack the skills to discover the unexpected and inform their audience with their data.

Tufte (1974: 1) concluded that some studies "use statistics as a drunk uses a street lamp, for support rather than illumination". Graphical techniques are among the most powerful procedures for achieving the latter, but people need to be educated so that graphics may flourish; it is pointless to establish new ways of visualising data when mastery has not been gained of the basics — failure at an elementary level impedes progress. 'Consumers' must understand what they are being shown; 'intermediaries' must give more space and a higher status to graphics — in short, graphics are integral and should be treated like text; and 'producers' must rise to the challenge of providing graphics that are efficient, interesting and informative, that provoke but never decorate.

Encouraging novelty, experimentation and convention

It does seem that designers seize upon opportunities that can be visualised easily: in preparing the annual report for WPP Group plc, the basis for David Freeman of design consultancy Sampson Tyrell Limited was thus:

> We decided to ask every company [there are 48 in the Group] to submit three numerical facts about themselves. In consultation with each, we then selected one of these based on its visual potential, using the criteria of business effectiveness, wit, or skill-based facts. (quoted in Pedersen, 1992: 194)

This is echoed by personal experience. Yet Nelson (1986) demonstrated that annual reports need not be boring in design or content. Norman (1988) reasoned that graphic designers could not perceive a situation of misunderstanding or misinterpretation; they operate almost entirely on knowledge in their head while users rely almost entirely on knowledge from the world.

While the quest for novel representations should be promoted, Crothers's (1981: 510) words should be remembered: "enthusiasm for developing some special new type of display should be tempered by the realisation that a number of readers/ viewers will fail to comprehend it and will actually be distracted by the presentation and so fail to understand the message that the author wished to communicate". However, while an unfamiliar display may initially fare badly in comparison with a better-known, but in some case inferior, display, after the former is used for a while, its superiority will manifest itself (Biderman, 1978; Wainer & Reiser, 1978).

Convention should play a role too. There is a tension between establishing and adhering to a restricted set of conventional standards of graphic representation, on the one hand, and the desire to approach each problem anew to bring the full range of a person's ingenuity to bear on that problem's unique demands. Indeed, it was necessary to search for a justification for this quest for novelty and serendipity, as discussed in Chapter Three, since the unusual arrests the eye more than the normal. However, there is a need to restrain the innovative and creative impulse, even where it is clear that a new departure is an improvement over standard practice since some graphic forms have survived to become standard practice. At the same time, there is a need, and room, for innovative creation in graphics. While stopping short of conventions, it would be advantageous for the development of graphics to come to some agreement on units of measurement, symbolic representation, and rules and instructions pertaining to representation. Wainer and Francolini adopted Bertin's (1983) terminology, hoping it would contribute to the establishment of a standardised graphic vocabulary: it

> follows from [this] contention that if we do not have a vocabulary to discuss graphic concepts, those concepts will not be discussed in an unambiguous manner. Bertin's words are relatively well defined and uniquely related to graphical concepts. (1980a: 83)

As the use of graphics becomes more widespread, specialised diagrammatic conventions and symbols have been introduced to help clarify the subject matter (Modley, 1970; Beeby & Taylor, 1973; Wainer, 1974; McGill *et al.*, 1978; Jacob, 1980; Gilbert & Mulkay, 1984). Improvements in the design of diagrams and the establishment of conventions come not only from the work of design practitioners themselves, but also from subject matter specialists (Conway & Overton, 1994).

7.3 FURTHER STUDY

Since this research has been exploratory, the major findings could be made into hypotheses and investigated further. However, certain themes have more potential.

Research completed and work-in-progress

While this thesis was being researched, the author co-wrote a number of collaborative papers that examined specific aspects of the representation of networks using graphics (Steward *et al.*, 1993, 1994a, 1994b, 1995; Conway & Overton, 1994). Francis (1994: 10) stresses the "intense interest" in the study of networks, but concedes that "too little attention has been paid to the problem of how to map and to represent [them]". Indeed, Rogers and Kincaid (1981) promoted the utilisation of strict mathematical criteria in their computerised analyses to eliminate the problem of using a visual method to represent graphics: that different researchers produced different network graphics from the *same* data.

As a result of the work of Conway (1994) and the papers identified above, research has been undertaken to — among other things — explore the analytical and descriptive purposes to which networks may be applied, the development of graphic conventions to represent different aspects of networks, comparison over time, comparison within and between organisations, and the use of computer software to map networks (Conway & Steward, 1995, 1996; Steward & Conway, 1995, 1996).

Despite the work undertaken so far — and current research projects that are ongoing — that have examined aspects of the graphic representation of networks, it is clear that there is still much potential for research in this field.

Possibilities for future research

A taxonomy of innovation graphics

It is obvious that graphics represent a rich vein of future research. Macdonald-Ross and Smith maintained that a detailed understanding of graphics should be developed; to achieve this

> we need historical studies, conceptual analysis, taxonomic proposals and evidence of usage: in short, we need the kind of natural history which has preceded the growth of all the science. If there ever is to be a science of instruction it cannot leap into existence fully grown. Useful and interesting empirical tests are dependent on this ground-clearing scholarship. (1977: 30)

With the interest in graphic networks and the renaissance in graphics in general, it seems prescient to establish a research project of some kind to explore and chronicle graphical usage in innovation studies, just like Feinberg and Franklin (1975) have achieved for social graphics.

Network graphics

As depicted in Figure 7.1, Bertin (1981: 136) maintained that a flow chart (**1**) may have its "meaningless features" eliminated (**2**) and the others reordered to show its "longest line" (**3**). The representations numbered **4–9** are equivalent: quincunx (**4**), two-group (**5** and **8**), three-group (**7**) and linear (**6** and **9**). Bertin asserted that (**8**) was preferable to the others since it permits further simplifications, resulting in (**10**). Bertin (1981: 136, emphasis in original) declared that "*order and disorder* are very strong visual perceptions".

Likewise, care must be taken in presenting data in network graphics. Networks are not static structures and a number of researchers have highlighted the importance of studying networks over time (Aldrich, 1979; Auster, 1990; Stork, 1991; Hagedoorn & Schakenraad, 1992). However, there is no established practice for depicting change graphically: should the nodes remain static and the links encode change, or how should they be located if the nodes move? It is evident that a diagram characterises a network more than just words, yet, as McGrath *et al.* (1995a: 1) concede, "to date little research has demonstrated what influences the reader's understanding of the structure of social networks depicted in the sociogram". In Figure 7.2, five different constructions are used to depict the same relationships.

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Figure 7.1
The objective of 'flow-charts' and 'organigrams'.
Source: Bertin, 1981: 136.

McGrath *et al.* (1995b) have established that space and proximity are strong influences in how a network graphic is viewed. However, they did not explore positioning in the wider sense: is inclusion in the left of a diagram more significant than the right? The same is true for vertical positioning. When graphing data, there are (more-or-less) established conventions: that time is located on the horizontal and runs from left to right; that progress starts at the origin of the graph and works its way upwards across the diagram. There is no established practice for network graphics, only the beginnings of a convention for the depiction of nodes and links. As McGrath *et al.* highlight

> a large body of work exists on computer programs to draw graphs according to certain "aesthetics" .... However, almost all of this work considers aesthetics that attempt to improve graph readability from a very general point of view without considering specific applications and uses general aesthetics such as the regular spacing of nodes and minimization of edge crossings. (1995b: 2)

Since networks can be used for description and analysis, it seems prudent to explore these factors while the speciality is still in its infancy.

Cultural differences

Beniger and Westney (1981) compared graphics taken from two newspapers based in New York and Tokyo. They found that there were great differences in their number, type and usage and concluded that this was due to social, organisational and cultural contrasts. Tufte (1983, 1990a) has paid particular attention to the Japanese

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Figure 7.2

The five different spatial arrangements of the same labelled graph.

Source: McGrath *et al.*, 1995b: 23.

use of graphics, while Trompenaars (1993) devotes much attention to the world's general cultural differences. There seems to be some scope — and need — for graphic representation to be explored *culturally* in much greater depth. Trompenaars (1993: 68) wrote, as has already been quoted, that "Western society has a predominantly verbal culture". However, oriental societies tend to place more emphasis on graphics, which is reflected in an increased usage of this format and in *kanji* as a method of written communication. A cross-cultural comparison could examine graphics practice between two countries to test whether a verbal culture does experience less usage, less novelty and poorer graphical excellence.

The Internet

The impact of the personal computer has not been confined to the creation of printed materials; non-linear texts (hypertexts), multimedia, on-line information sources and the Internet — particularly the World-Wide Web — all offer different ways of interacting with graphics. While the Internet has been dominated by academia in the past, business and commerce have moved on-line and now eclipse academic usage. While the Internet is seen to have much potential as a leisure and marketing tool — from producers to users — it is also being used significantly for the communication of R&D issues, either officially or unofficially (Cronin, 1994). This is especially true for high-technology companies and sectors, none more so that the ICT industry who see Internet as a technology as well as a communication device. Graphics play an important role on the Internet and within all non-linear information sources: iconically, metaphorically, descriptively, etc. — their role and usage in this emerging field could be explored further.

Summary

The outcome of the research conducted may be less than the sum of its parts. However, the process of the research may be more useful to researchers that decide to follow some of the issues raised. In retrospect, it is the post-justification of the methodology that caused the research to develop as has been outlined. Indeed, the thesis calls into question the whole positivistic attitude towards research, at least when graphics are being considered. Their very nature and the lack of research into graphic methods means that it is less easy to take an objective view and remain 'outside' the research process.

Despite this, there still remains the belief that the research has been and will be useful — at least in the papers generated by the examination of network graphics, which continues to present the most obvious opportunity for further research. Even if the research is lacking in some ways, it offers the opportunity for future researchers to learn by the mistakes that were made and the decisions that were taken. The thesis started with two quotations that alluded to flawed success — perhaps this was prophetic. So, it is perhaps apt that it ends with one: in the (probable) words of Confucius, "in the kingdom of the blind, even the one-eyed man is king".

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APPENDICES

Appendix One
MILESTONES IN THE DEVELOPMENT OF GRAPHICS

Hellemans and Bunch (1988) have chronicled important events in the history of science and technology. Among the most notable happenings included in their chronology that are relevant to this thesis are:

1. Pictograms with 2000 signs were used in Erech, Sumeria, 4000–3501 BC.
2. Sargon of Akkad produced maps in Mesopotamia for land taxation purposes, 2400–2301 BC.
3. A map of the city of Lagash in Mesopotamia was carved in stone, 2300–2201 BC — it is the oldest surviving map of a city.
4. The Sumerian calendar was developed, 2200–2100 BC — it had a 360-day and 12-month yearly cycle that ran simultaneously with a 354-day lunar year.
5. Decimal numerals were in use in China, 1350–1251 BC.
6. The Egyptian calendar is known to have accurately matched the seasons with dates in 139 AD.
7. A map of western China was printed in China in 1155 AD — this is the oldest known printed map.

Appendix Two
AN INTRODUCTION TO GRAPHIC THEORY*

This appendix provides an introduction to graphic theory so that some issues discussed in the main body of the thesis may be better understood. Though this review may mention in passing the works of Tufte and Bertin, they are not examined explicitly due to their coverage as part of Chapter Two. Any reference to them is made, therefore, so that this synopsis can be located sufficiently for comparison.

A2.1 A brief history of graphics: from Playfair to the present†

Quantitative graphics have been central to the development of science and statistical graphics date from the earliest attempts to analyse data. Many graphic devices used today in business communication originated in the late 18th century as a result of the work of Playfair:

> As to the propriety and justness of representing sums of money, and time, by parts of space, tho' very readily agreed to by most men, yet a few seem to apprehend that there may possibly be some deception in it, of which they are not aware. … As the purpose of the following Charts is to convey information in a distinct and easy manner, like History, the chief merit that they can have is *truth* and *accuracy*. (1786: iii, i, emphasis in original)

Even then, it was appreciated that there would be doubts in the efficacy of using such a technique. Playfair remarked that the graphical approach was an accurate method for conveying information in *principle*, though errors may result in *practise*, again, a problem still faced today. The addition of tables containing the data — Playfair's solution — allowed any errors to be detected by the reader.

Playfair illustrated the economic and social data of the British Isles with bar graphs and pie charts to produce more manageable information. Thus, one of the modern roles of graphic representation and the focus of this thesis was realised: "the giving form and shape, to what otherwise would only have been an abstract idea, has … been attended with much advantage; it has often rendered easy and accurate a conception that was in itself imperfect, and acquired with difficulty" (Playfair, 1786: 3). By 1805, Playfair had understood that, as knowledge increased, it became more desirable to *abbreviate* and *facilitate* the modes of conveying information from one person to another and from one individual to the many, particularly regarding the burgeoning trade figures. Playfair's flair was the amalgamation of science and

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* For comprehensive bibliographies of the subject, see Feinberg and Franklin (1975) and Macdonald-Ross and Smith (1977).

† There are some excellent reviews of the historical development of graphics. For comprehensive coverage, see Funkhouser (1937) with its annotated bibliography or Beniger and Robyn (1978) with its comprehensive references grouped by themes and linked to a chronology of important dates. Funkhouser and Walker (1935) focused solely on Playfair, devoting attention to the background, influences and life of the progenitor of statistical graphics along with a critique of some notable graphics, while Izenman (1980) discussed graphic development in the 1960s and 1970s.

mathematics to plot social indicators over time:

> It is not only of importance that this species of information should be handed down, but also that it should go down in such a form and manner as that any person might even, though a native of another country, understand the nature of the business delineated. (1801a: v)

Playfair (1805: i) was the self-proclaimed "inventor of lineal arithmetic" and Schmid (1983) called Playfair the originator of modern graphic techniques. Both Selby (1979) and Tufte (1983) credited Playfair as being the first person to use a time-series plot with economic data and the bar chart as a way of expressing social and economic statistics (Playfair, 1786), and of inventing pie charts to represent divisions and proportional circles the size of different countries by similar forms (Playfair, 1801b).* Playfair's main contribution though was the use of space to represent something that is not spatial. The making of maps antedates Playfair considerably and the notion of using the plane of the paper to represent the plane of the Earth is natural and certainly represents no great intellectual insight. But Playfair, on the other hand, used space to represent variables like the value of imported goods. Using space as a representation of empirical but non-spatial data does not appear to have been achieved before and, even though the visual metaphor of a rising and falling line to show rising and falling imports seems natural, it was quite a breakthrough. Other visual metaphors were similarly established by Playfair: bigger means more (Bertin's *size*) and darker means more (Bertin's *value*).

According to Schmid (1983), graphics can perform two major functions: presentation and analysis. While it must be recognised that many basic developments — the principle of co-ordinates and the invention of analytic geometry, for instance — existed before 1786, Playfair can be considered to have established graphic presentation. Schmid and Schmid (1979) maintained that Playfair not only created a new and ingenious technique for analysing and portraying statistical data, but delineated the graphs in such expert fashion as to compare favourably with the highest standards of modern graphic presentation. Traditionally, presentation has always played a dominant role and this has continued to the present day: over 200 years of distinguished graphical history bears witness to this fact beginning with the publication of the first edition of Playfair's *Commercial and Political Atlas* in 1786. This was followed by innumerable contributions through the decades and the predominant emphasis on presentation in graphics is very apparent. To cite only a few instances that document this, Brinton's (1914) landmark contribution on graphic methods, Funkhouser's (1937) notable history of graphics and FitzPatrick's (1962) historical study of their growth in the USA are devoted almost exclusively to the presentation function. Even in the preface to a revision, Subcommittee Y15.2M of the Committee on Preferred

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* Of all the graphic forms, the bar graph is the only one which Playfair conceded use (and invention) by someone else. Even then, bar charts had only been used in a simple form in chronologies to show monarchical reigns and life-spans; Playfair originated the application of bar charts to economic data when faced with missing year-on-year records that prevented construction of a time-series and was initially sceptical about this innovation.

Practice for the Presentation of Graphs, Charts and Other Technical Illustrations stated that

> this standard is not concerned with the analysis of time series; therefore, it is not directly concerned with the analytical time-series charts. Some of the principles and many of the procedures listed apply to analytical charts as well as to presentation charts, but the emphasis throughout this standard is on charts for presentation. (1979: ix)

Additional evidence of the dominant importance of the presentation and communication aspects of graphics was revealed in surveys by Fienburg (1979) and Barabba (1980). According to Feinberg and Franklin (1975), while graphs and charts for the representation of information have been used since the late 18th century, it was not until the early part of the 20th century that the methodological and statistical tools were available to begin to evaluate the several modes of graphic representation that were then in vogue.

As Bachi (1978a) highlighted, existing graphical methods were formed largely during the enthusiasm for graphics in the 19th century: new graphic formats were invented to meet specific practical needs that could not be satisfied by existing means. This was followed by a period of evolution: a piecemeal, erratic progression by the experts of the day. In the 1930s, interest in graphical methods started to wane among academic statisticians, according to Beniger and Robyn (1978), as attention turned to more mathematical concerns. Only since the 1970s has an attempt been made to enlarge the field of existing methods, largely due to developments in computer technology: Wainer and Thissen (1981) have reviewed the new display techniques and tools. Izenman (1980) maintained that many recent developments and innovations in graphics originated with the statistical research groups at Bell Telephone Laboratories and its work, which started appearing in the 1960s, still continues to have a very important effect on the general usage of graphics today. During the 1970s, a theory or philosophy of graphics was beginning to be realised and developed. According to Schmid (1983), as graphics presentation evolved, it was fed by a number of interdisciplinary streams. Besides statistics, there have been important elements derived from technical drawing, graphic arts, cartography, psychology, psychophysics, computer science, and communication theory and practice.

A2.2 Classifications

Funkhouser (1937: 271) has stated that "the problems met in trying to classify and standardize graphic forms have been wrestled with for almost a hundred years". Schmid and Schmid (1979) maintained that graphic design literature provides many such classifications: some of these are clear, logical and useful whereas others are confused and contradictory. Though graphs may be used for embellishment (Wright *et al.*, 1990), serving primarily to attract readers to the text or relieve the monotony of too many words, the emphasis in this thesis is on the design and construction of graphics to transmit facts, ideas and concepts. They are used in: academic papers and books; policy documents; magazines, newspapers and similar types of reproduction; and corporate publications. Their embodiment may be summarised as being derived broadly from the persuasion and enlightenment components of the matrices reproduced as Figures A2.1 and A2.2.

Figure A2.1

Various methods of communication.

Adapted from Owen, 1985: 102.

Figure A2.2

A summary analysis of what diagrams accomplish.

Adapted from Owen, 1985: 102.

Doblin (1980) contended that diagrams comprise graphs and charts and drew a distinction between them. The former were defined as "diagrams of numerical interactions such as bell curves, bar graphs, nomographs, instrumentations, and so on" (Doblin, 1980: 92). The latter include matrices, trees, Venn diagrams, flow charts and the like. According to Murgio's (1969) classification, pictorial charts are, it seems, the most useful forms of graphics, but the least well defined (Figure A2.3) while Karsten (1923) divided graphics according to their primary content (Figure A2.4). Nishioka (1992: 6) maintains that a diagram is a "general term for that which uses graphic design as an expository tool to convey something which would be difficult to explain with text alone". Nishioka classified diagrams according to six divisions:

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Figure A2.3

Murgio's breakdown of the types of relationships that are diagrammed, matched to their most appropriate diagramming technique.

Adapted from Owen, 1985: 103, based on Murgio, 1969.

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Figure A2.4

Karsten's general headings for types of diagrams.

Adapted from Owen, 1985: 104, based on Karsten, 1923.

1. **Statistical Tables & Graphs** visualise data for the purpose of statistical comparison.
2. **Charts & Scores** visualise the relationships among and the flow of elements.
3. **Maps** visualise space and regions.
4. **Architectural Plans & Drawings**: a range of illustrations for architectural design, city planning, etc.
5. **Instructional Diagrams for Products**: a range of illustrations that introduce products.
6. **Scientific Illustrations**: a range of illustrations that explain phenomena and knowledge.

Feinberg and Franklin (1975) elaborated Lockwood's (1969) classification system to index their bibliography. Lockwood divided graphics into statistical diagrams, explanatory diagrams, and explanatory and statistical maps.* Statistical diagrams comprise 'traditional' graphs and diagrams, though pictorial elements are also included. Explanatory diagrams range from stages in a manufacturing process or the structure of an organisation to events related to each other in time. The main distinction between statistical diagrams and explanatory and statistical maps is that the map provides a basic framework on which information can be shown.

While classifying graphics is useful, Doblin (1980) believed it was more important to see how information flows and to structure how messages work. For Doblin, the most valuable tool for graphic designers was their understanding of a message's effectiveness. Doblin maintained that although much had been written about *iconographic messages* — representations by pictures or diagrams — most was ambiguous and little was understood, resulting in iconographic languages being poorly understood and taught. A greater understanding of the principles is more useful.

A2.3 Basic principles†

To achieve optimal communicative efficiency, well-designed graphics are indispensable. However, designers must rely primarily on principles and practices based on tradition, convention, intuition and personal experience. Statisticians, cartographers and psychologists have recognised this fact and believe that the solution lies in experimental research. In 1930, Mudgett commented that

> very few of the graphic methods in use today have been tested widely by experiment. Their validity is founded largely on logical considerations; and while the importance of this foundation is not to be denied, no less is it to be denied that these conclusions deserve to be subjected to careful testing wherever experimental methods may be applied and where the results may be set forth in quantitative terms. (p67)

Nearly 50 years later, Kruskal was still reiterating the lack of quantification:

* These are synonymous with Bertin's (1983) *groups of representation*: diagrams, networks, maps.

† For this section, Lockwood (1969), Macdonald-Ross (1977b), Purves (1987), Robinson (1988), Bounford (1991) and Holmes (1993) were primarily drawn upon, along with any works cited.

> In choosing, constructing, comparing, and criticizing graphical methods we have little to go on but intuition, rule of thumb, and a kind of master-to-apprentice passing along of information. You need only look at a good text on statistical graphics. Much of its advice will be excellent, no doubt, but it will also be dogmatic or arbitrary, in the sense that there is neither general theory nor systematic body of experiment as a guide. What we have instead are accumulated experiences, social conventions, and prescriptions. (1975: 27–36)

Wainer and Francolini (1980a: 80) maintained that the experimental evidence for effective graphical displays was "diverse, because of the lack of a coordinating theoretical structure and an allied unified graphical vocabulary". Indeed, in 1963, Feliciano *et al.* could cite only three studies. Wainer (1982) used good graphics as a point of departure for developing 12 rules of *bad* data display, justifying that this was more broadly practised than *good* data display! Macdonald-Ross and Smith (1977: 17, emphasis in original) concluded that "perhaps no *general* theory of visual instruction will ever be possible, because communication is a practical human art and not an abstract science". Despite this, it is important to establish some of the terms that are used and to present a summary of the principles of graphic theory. This starts with a discussion of the visual variables — the components that represent the data in the diagram, network or map — and is followed by a review of the formats or constructions through which this is achieved.

Visual variables

There are many perceptual codings in common use: spatial coding in maps, colour coding of main electric cables and so on. Some of them are very ingenious, such as the perceptual property of 'insideness' used in Venn diagrams to code the relation of inclusion, giving a less confusing notation than natural language. Given the limited vocabulary of perceptual dimensions and the limited amount of resolution available on each dimension, the first principle of a diagrammatic notation is, according to Fitter and Green (1979), that information encoded perceptually rather than symbolically should be *relevant*. Notations should restrict the user to forms that are comprehensible; they should redundantly recode important parts of the information; they should reveal the underlying processes that they represent, preferably in a responsive interactive system that permits manipulation of the diagrams; and, finally, they should be readily revisable. Like all good principles, it is difficult to measure up to all of them at once and, to a large degree, designers of a new notation have to use their intuition in seeking a compromise; as Tufte (1990b: 27) contends, "showing complexity is hard work".

The lines drawn on grids are called curves, even when they are straight! A curve may be represented by an equation and this is used to describe its characteristic shape, e.g. straight-line graph, normal (bell-shaped) curve, exponential curve and cumulative frequency (ogive or S-) curve. The scale used on the axes affects the interpretation of the curve; a compressed scale on the horizontal (or expanded vertical) gives the impression of dramatic change while an expanded scale on the horizontal (or compressed vertical) indicates sluggish change.

Formats or constructions

Crothers (1981) argued that there is no single ideal method of plotting graphs: the designer must select the technique most suitable for the required purpose and for the data that are available, though Fyfe and Law (1988b: 1) maintained that the "character of production and the effects upon an audience are historically contingent". According to Macdonald-Ross and Smith (1977), there is no rule for deciding when to use a graphic device though there may be good solutions — or satisfying solutions — for particular cases.

Practising communicators have always felt that some formats must be more effective than others or that the choice makes some kind of difference. However, no one format is universally superior: each has its domain of application that must be understood and respected. To choose a suitable format is not enough; the designer must be able to execute that format competently and the skill needed to produce good graphics is considerable. The categorisation of the following formats and constructions is based largely on Lockwood (1969).

Diagram

This is a term used in a generic sense to include all the various kinds of graphs and charts for the display and comparison of numerical data. It is not considered to include maps.

A **(line) graph** is a curve drawn on a co-ordinate grid to show the relationship between two variables. The grid is based on two rectilinear bisecting straight curves: the dependent variable should be placed on the vertical axis — the y-axis or ordinate [o] — and the independent variable (such as time, whose values are not affected by changes in other variables) on the horizontal axis — the x-axis or abscissa [a]. The point of intersection of the two axes is known as the origin [0] and the position of any other point in the plane can be denoted by a pair of co-ordinates. For most purposes, only that part of the grid is used where both variables are positive, resulting in the L-shaped graph. If the axes of a co-ordinate grid bear arithmetic scales, the grid is Cartesian. A **divided** or **compound line graph** shows the value of both the total and its parts by a series of curves on the same frame. A line graph shows changes in quantities, plotting exactly the increases or decreases; a **logarithmic graph** shows the *rate* as well as the amount.

The term **bar** or **column chart** or **graph** has a broader usage than histogram, though the graphic form — bars of constant width and variable length — is similar. A bar chart may show more than one dependent variable and may be **horizontal, vertical, segmented** or **divided, clustered** or **comparative, floating, deviation** or **stacked**. The bar chart is similar to the line graph, but stresses comparisons of absolute values rather than degree of change. White (1980) presented 74 variations on the basic theme! A **histogram** is visually similar to the bar chart; data are grouped and quantity is shown by length of columns. However, histograms must only cover one set of data, present the class intervals equally and display a numerical scale on both axes. Any curve can be turned into a histogram by grouping data. A **frequency polygon** is a histogram in the guise of a graph. The data are grouped and the mid-points are plotted and joined. This prevents superimposing histograms.

Circle charts or **graphs** use the size of circles to represent quantity. **Pie charts** are circle graphs subdivided into segments; they are used to demonstrate the relative proportions of the whole, represented by the area of the circle. **Exploded pie charts** show the slices pulled out or removed for emphasis.

The **scatter graph**, like the logarithmic graph, is a specialist tool. Since each value is separate and the plotted data are not joined by a line, the graph consists of a 'scatter' of dots and from this the basic message is read.

A **nomogram** is a computation chart representing formulae or empirical data. They allow values to be obtained directly instead of working from equations. Each nomogram is defined by a clear set of operational tasks that the user may perform. An **abac** is a nomogram drawn on a co-ordinate grid. An **alignment chart** consists of a system of nomograms in which variables are represented as a series of scales. Generally, all nomograms other than abacs are alignment charts.

Map

Maps are the most familiar diagrams there are, according to Nishioka (1992). They are two-dimensional representations, **geographic maps** showing areas of the world and **cartograms** displaying quantitative data. The latter are seldom general-purpose, usually being single-purpose or 'thematic'. A **thematic** or **distribution map** shows the distribution of various kinds of quantitative or qualitative data:

- **Chloropleth (maps)** use retinal variables — for example, texture — to show areas of the same data.
- **Dot** or **point symbol maps** use dots, circles or other symbols for absolute values or frequencies
- **Isoline maps** or **Isopleths**, familiar from weather charts, use lines to join points of equal quantity or value to show the boundaries of variables such as height or rainfall.
- **Flow(-line) maps** use arrows of different length, width and direction to show the flow and amount of a variable.

A **ray map** shows lines radiating from a central point to various other points. These lines can show explanatory spheres of influence. The statistical version of this type is the flow-line map. A map does not have to display an absolutely fixed framework; a familiar example is the London Underground map where the main representational element is the sequence of stations along each route. This expression of abstraction and modification is a **distorted map**.

Network and other explanatory diagrams

This category gathers together a wide variety of expressions. It includes **networks** as defined by Bertin (1983), as well as diagrams that explain, from stages in a manufacturing process or the structure of an organisation to events related to each other in time. These expressions do not usually make quantitative statements, though some may be adapted to do so. The main design problem is reducing information to the essential without distortion. This may be achieved in many ways from a representation approach to a near abstract one. Various factors will influence the choice, such as the audience, limitations of size, amount of information to be conveyed and the sources of references obtainable for the diagram.

Algorithms take readers on a path through processes or systems by showing where decisions have to be made to arrive at an endpoint or a correct answer. A **flow chart** or **logical tree** is one example; it can also illustrate processes rather than showing where decisions have to be made. The choice of which type of algorithm or flow chart to be used should be based on what the readers will be using it for. Standard symbols, e.g. ISO 5807 (1985), that are internationally recognisable should be used — for instance, rectangles for actions or processes and diamonds for decision points — though a key to the symbols should be provided. Arrowed lines should show the direction of flow, above the use of position of the page.

Macdonald-Ross (1977a) believed that algorithms could show rules, regulations, procedures and instructions in non-continuous prose — usually as flow charts, sometimes in list form. Purves (1987) termed the use of block diagrams to describe the flow of activities in a logical system as the **black box system**; flow charting improved on this by using symbols that acted as forms of instruction. Flow charts typically represent business or computing applications; **project network techniques (PNT)** are implemented in enterprises involving a number of interrelated activities. When time is taken into account, the procedure becomes known as the **critical path method (CPM)** or **critical path analysis (CPA)**.

Operational diagrams are technical diagrams associated with clear-cut operational tasks such as setting-up, operating, maintaining and repairing complex equipment. They are characterised by photographs or drawings of the equipment, functional block diagrams of the system, detailed circuit diagrams and algorithms. A circuit diagram, for example, is a drawing that illustrates the direction and path or circuit of a medium that is moving under pressure.

The **organisational chart** shows the interrelations, the responsibilities and the authority of various units of an organisation. The units may be officers or departments of a business. The names of the departments may be enclosed in boxes, eclipses or circles that are then joined by an line that shows the delegation of responsibility and authority. The diagram can be purely typographical or it can use symbols. The organisation chart does not show quantities. More emphasis can be given to certain boxes by size, weight of line and choice of typeface.

The **family tree** method has been adopted to show relationships outside the human family — languages, energy sources, evolution, etc. A **time chart** shows information related to a time scale. With historical time charts, the main problem is the small amount of information to be shown for the early part and the overcrowding for recent history. It is difficult to overcome this, but if the chart is shown in separate parts the simplest method is to change the time scale. This must be clearly labelled to avoid a misleading interpretation of information. Quantitative statements can be made on such time charts.

Pictorial Charts

Also called **ideographs, pictograms** or **pictographs**, these use iconic symbols in place of numbers; the subject matter of the chart is associated directly with the quantity. Neurath was probably most influential in promoting pictorial statistics. The format is mentioned for completeness; it is not examined in the thesis due to symbolic reliance on figurative analogy.

A2.4 The role of graphics

There are many conflicting opinions about the role of graphics. According to Anscombe (1973), graphs have two purposes: to help the reader perceive and appreciate the broad features of the data, and to help them look behind the broad features to see what else is there. Selby (1979) declared that graphs often were most effective for showing trends. In addition, graphs served to:

- bring out the main numerical points about a subject.
- uncover facts that might be overlooked in text or a table.
- summarise a cumbersome mass of data.
- add variety to text and tables, making material more interesting to look at and easier to read and understand.

Selby's first three reasons broadly concur with Anscombe's; however, the last alludes to other purposes to which graphics may be applied. Wainer (1980) examined the use of graphic techniques by the *news media*, maintaining that graphics used in this domain can:

- display complex data simply.
- provide evocative images that are remembered.
- lend scientific credibility or confirmatory evidence to a story.
- provide visual appeal, enlivening the layout of the page.

Wainer contended that the last reason was often the primary motivator for newspaper graphics. Henry (1995) believes that graphics can be used for more detailed description and decoration, in addition to their analytical purpose. For instance, presentation graphics are descriptive, allowing the audience to access data visually while they are communicated to them verbally. They contain a limited amount of data that allow the audience to retrieve the message in a quick scan. Presentation graphs often introduce material or make a specific point.

Fienburg (1979) developed a graphical *continuum of purpose*. It is anchored at one end by descriptive display of data and at the other end by analysis of data. Tukey (1988) pointed to two types of graphs with descriptive purposes: graphs that substitute for tables and graphs that show the result of some other technique. The trend line, which was found by Tufte (1983) to be the most popular graph, and the bar chart are two examples of graphs generally used for descriptive purposes. Other graphs go beyond description to encourage the reader to analyse the data contained in them; Tukey (1988: 38) described graphs further towards this end of the continuum as "graphs to let us see what may be happening over and above what has already been described". A generalised rule is that graphics displaying the relationship of the data and one variable tend towards the descriptive, while multivariate relationships tend to be analytical. Two-variable relationships are a mixture.

It is not only the form of the graph that determines its place on the continuum. The choice of graphical form can limit the sophistication of the information displayed. In addition, the amount and type of information displayed affects the viewers' ability to penetrate the data further. Most graphs in popular media present limited amounts of information, e.g. the bar chart and trend graph. Analytical graphs combine the attributes of presenting more data and using a form that reveals the data to the reader. Analytical displays "encourage the eye to compare different pieces of data" and "reveal the data at several levels of detail, from a broad overview to the fine structure" (Tufte, 1983: 13). Time-series graphs have some analytical capacity, especially when they include markers for significant events or multivariate trends. The greatest analytic potential is available with graphical formats that present data in more abstract forms, such as the bivariate plot.

Another purpose for graphical displays is to decorate the text. It is obvious that publications as diverse as *New Scientist*, *Business Week* and the *Financial Times* have not overlooked the decorative and entertainment value of graphics, including graphs in every issue. However, these type of graphics must compete for audience time with information generated by the surrounding text or images and, indeed, other media. Therefore they adopt broader entertainment values. But as Tufte (1983) found in a survey of social research graphics in daily newspapers, there is a lack of 'sophistication' in the choice of data presented and in the graphics used.

A2.5 Conclusion

Since the 1970s, graphics have re-emerged as an important analytical tool with recent innovations exploiting computer technology. Wainer (1992: 15) maintains that "graphs are so basic to our understanding that we cannot easily imagine the world without them". Graphs work well because people are good at seeing things (Robinson & Petchenik, 1976): the eye makes comparison of *length* more easily and surely than comparisons of *area* or *volume* (Brinton, 1914; Neurath, 1936). Even so, a child can judge that one-third of a cake is larger than a quarter before being able to judge that the fraction $\frac{1}{3}$ is greater than $\frac{1}{4}$. Graphics have certain advantages. They are:

- good for communicating non-specific quantitative comparisons.
- attractive to look at and make a report look more interesting.
- likely to appeal more to a general audience than a table of figures.
- general time trends can be shown and compared more effectively using line graphs than using tables.

Most people have the ability to retrieve data from a well-composed graphic: Wainer (1992) goes so far as to state that this ability is 'hard-wired' into the brain.

Unfortunately, producing a good graphic is not as easy as retrieving information from it. In recent years, the greatest change in graphic presentation has been the utilisation of personal computers and auxiliary equipment in the preparation of graphics. Although computerised techniques now occupy an essential place in graphic presentation, it should be recognised that they possess certain constraints and limitations. To rely on the default formats or 'Wizards' in some software programs demonstrates a lack of understanding of design since the resultant graphics often fail to improve insight or communication. Writing as a cartographer in 1976 — though the comment is applicable to graphics in general — Baxter alleged that computer-generated maps were either the creation of computer-*il*literate cartographers or cartographic-ignorant computer scientists. Holmes (1993: 7) goes further: a computer "absolves [designers] of the necessity of knowing what they are doing". The impact of new technology — computer hardware and software, and photocopiers and facsimile machines — is discussed in Appendix Three.

Appendix Three
THE IMPACT OF NEW TECHNOLOGY ON THE PRODUCTION OF GRAPHICS: COMPUTERISATION AND AUTOMATION IN THE OFFICE

Although most modern graphic formats have been available for 200 years, it is only in the recent past that graphics has changed from being seen as a specialist tool to being used as a more general medium of communication. Even in 1977, the use of graphics was seen as a "relatively costly" form of communication, a consequence of the "good deal of expertise ... needed to produce charts" (Macdonald-Ross, 1977a: 66). Chapman (1986: 64) similarly believed that "graphs are time-consuming and expensive to produce" and therefore must be used economically.

Wright (1991: 239) maintains that, for information design processes and people's understanding of information design factors, "the sea change came about in the 1980s when the micro spread re-designable information into offices, laboratories, workshops and home". Schmid (1983: vi) alleged that "the electronic computer has served as a significant catalyst in the development of a renascent interest in statistical graphics as well as facilitating an unprecedented production of statistical charts, and its potential future role in statistical graphics will be far greater than it has been in the past". Central to the change in status of graphics has been the spread of reasonably priced, yet sophisticated, software packages, extending the facility to produce graphics much more widely. The availability of the desktop or personal computer (PC) provided the hardware base on which this might be achieved: "the success of the IBM-compatible PC has resulted in computers becoming commodity items" (Key Note, 1992a: n.p.).

The process can be considered as a hybrid, analogous to both the impact of printing *and* the typewriter. Printing made possible the accurate and rapid multiple transmission of handwriting that transferred the accessibility of the written word in the 15th century. Yet the increasingly capital-intensive nature of the equipment necessary to undertake this has meant that its power has never been fully realised. The invention of the typewriter enabled 'production by individual', but never with the quantity or professional quality of design and production as print. Computing software and hardware have united to enable writing and printing to be produced by one individual as a single, combined unit.* Photocopiers and facsimile machines have aided its distribution.

Despite the time it has taken for the written word to be typed or turned into print, it has taken even longer for the similar process to be achieved for graphics; Appendix One refers to notable events. In spite of Hellemans and Bunch (1988) dat-

* Vince (1992) claims that the collective experience and knowledge accumulated over 500 years in the printing industry have been incorporated into software in just two decades.

ing graphic representation back to 4000–3501 BC, even in the 18th century Playfair's charts were scribed directly to copper plates for subsequent printing. Nearly 200 years later, the average person can replicate this process using computers and graphics packages. While it has been possible for someone to have their written words printed for over 500 years, it is only in the last 15 years or so that the same can be said for the production of graphics. Considering graphics long-established heritage, its common use and power is only just being fully realised.

The effect of computerisation is discussed immediately below. The impact and popularisation of office automation through the now-ubiquitous photocopying and facsimile machines, and the resultant effect on the dissemination of information, is also significant and examined in the subsequent section.

A3.1 Computerisation

In 1988, a *Computerworld* survey of 2,500 corporate microcomputer systems professionals in the USA reported that 30 per cent of the respondents cited the benefit of improved information flow from using microcomputers (reported in Key Note, 1988). There are two aspects to the impact of computerisation: the advances made in hardware that widened the base, and software development that deepened the penetration of the technology. The success of both is interrelated.

Hardware*

The microcomputer has been available since 1978 and it was the success of earlier models of personal computers — like the Commodore PET, the Tandy TRS-80 and Apple II — that prompted IBM to establish itself in that market in 1981. "The entry of IBM, the largest computer manufacturer in the world, was to establish the PC as a world product" (Key Note, 1992a: n.p.). By 1989, the ratio of PCs to employees had increased to one micro to every 11.3 employees and was expected to be one to every 8.3 in 1991 (Key Note, 1990). In 1991, personal computers accounted for almost 40 per cent of the world computer-market (Key Note, 1991a) with growth in Europe estimated to be around 25 per cent per annum.

Falling prices and increasing levels of technological innovation led to the increased diffusion of desktop computers. The availability of cheaper random-access memory (RAM) led to more sophisticated software being developed, that — in turn — required more RAM to operate. As silicon chips became more powerful and faster, programs made use of this to reduce calculation times and increase functionality. It also enabled more advanced printer and screen routines to be written — graphs could be viewed as hard copy or on a monitor.

Printers were developed from typewriter technology where a character was formed

* Myers (1980) presented an excellent review of printing and display devices, describing their functions and their operational limits. Its aim was to put the technology in perspective so that the capabilities and limitations of the devices available could be appreciated.

by a model hitting an inked ribbon onto paper. The model took various forms: daisy wheels (the industry standard for quality for some time), thimbles and single stalk — as in the typewriter itself. The idea of forming characters using an array of dots — the dot-matrix printer — came later. As dot-matrix printers became more popular, it was realised that the dots could be used to form images other than letters, and cheap computer graphics were born. However, early printers could not be used for high-quality printing since they were based on only seven- or eight-dot heads.

However, more sophisticated head technology and new software developments allowed finer control, e.g. allowing the print head to make multiple passes over each line of text. With 24- and 48-dot heads, dot-matrix printers could approach the resolution of modern laser printers. Printer drivers became more sophisticated at capturing screen images to produce less bitmapped lines and curves. Colour printers were originally developed from dot-matrix devices by using multicoloured ribbons. Ink jet ("DeskJet") or the more recent bubble jet printers use the dot-matrix principle with a special head enabling quality similar to that of laser printers.

Laser printers are more akin to photocopiers, a standard model producing output at a quality resolution of 300 dots per inch (dpi). More advanced models can produce output at 1,000 or 1,2000 dpi, which is close to that of typesetting machines (2,000 dpi), and it is argued that the human eye is incapable of perceiving the difference between them unaided. Laser printers have totally eclipsed the daisy wheel; the Hewlett-Packard LaserJet was launched in 1984 and "brought laser printing to the desktop, effectively sounding the death knell of the daisywheel" (Key Note, 1992a: n.p.). More recently, colour laser printers have been developed.

The development of display technology has been the pursuit of even better resolution (dot size) and the reproduction of more colours. This has required more sophisticated video graphics cards and screen drivers. The limitations are the focusing of the electron beam that forms the dot, the size of the phosphor dots and the memory required to store the information needed to form the picture. Each dot has to have information stored on how strong the beam has to be when it hits that dot. Since a colour screen has three times the number of dots than a mono screen has, for the same resolution, a colour picture needs at least three times the memory of a mono picture. While the human eye can perceive an almost infinite range of colours, the computer screen has to be limited or memory requirements would be similarly infinite. Thus colour systems use a palette system that reduces the choice of colours available, but makes for a workable screen within its limitations.

The requirements of the printing industry and CAD have driven the screen manufacturers to produce better resolutions. Even a modest desktop publishing operation needs a high-resolution screen if the operator is to see what the publication will look like when printed. As more publications made use of full colour, it became more desirable that the operator should see full colour on the screen to avoid clashes. Traditional printers and compositors had the experience to know what would match correctly, but the computer's role has been to lower the skill level and therefore reduce the wage bill — the computer's capabilities are used to replace the experience of the traditional artisan.

Software

VisiCorp's *VisiCalc* was the first spreadsheet package, appearing for use on the Apple II microcomputer in October 1979. It allowed the easy calculation of 'what-if' analyses. It was followed by *VisiTrend/Plot*, a statistical and graphics application that could receive data from *VisiCalc*. In January 1983, the Lotus Development Corporation released *Lotus 1-2-3*, initially for the IBM personal computer. The program became the industry standard for spreadsheets in the 1980s:

> The 1-2-3 spreadsheet can claim to be one of the most important software products of the 1980s. It was the availability of 1-2-3 which opened the corporate market to the personal computer and led businessmen to see the PC as a business tool (Key Note, 1992a: n.p.)

As the result of (and perhaps spurring) technical progress, a number of spreadsheet packages were developed.* Software, like Microsoft's *Excel*, Computer Associates's *SuperCalc*, *VP Planner*, Borland's *Quattro* (and later versions of *1-2-3*) featured the capability to produce basic analytical graphics, e.g. bar graphs, line diagrams and pie charts. As the technology progressed, spreadsheets became more powerful and added titles, keys and basic-level shading to the graphs. Developers began offering the basic functions of three programs (spreadsheet, word processor and database, sometimes with graphics creation and modem communication capabilities) combined in one application; this could be run with reduced memory — this was particularly important on early machines and again with portables. These programs, like Lotus *Symphony* and Microsoft *Works*, were termed integrated business (or software) packages (IBP/ISP) and did much to make graphs in word-processed documents commonplace, due to the interchangeability within the modules.

However, the graphics capabilities of spreadsheets were being used increasingly for business presentations. With the introduction of ink-jet printers and the falling price of laser printers, presentation or business graphics packages were developed. These enabled the production of charts specifically for business that enhanced the data and graphs with scalable fonts, straight (as opposed to jagged bitmapped) lines, three-dimensionality and the ability to import graphics and logos. Software like Lotus *Freelance*, Software Publishing's *Harvard Graphics*, Computer Associates's *Cricket Graph*, Lotus *Graphwriter II* and Microsoft *Powerpoint* could produce bar, line, pie and organisational charts, tables, and freehand and free-text graphics.

In the last few years, it has been recognised that there is a need for some type of graphical analysis software due to the more widespread usage of this communica-

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* The disadvantage with *VisiCalc* was that data was prepared in the spreadsheet and saved, and the program quit. *VisiTrend/Plot* was then loaded with the saved data. If there were any changes to be made to the data, the user had to quit and reload *VisiCalc*.

tion format (Donoho *et al.*, 1988). Data visualisation programs are fed with data so that different types of plots are produced, which may be viewed in a number of different ways; among their number is the *Spyglass* family of software (*Transform, Plot, Dicer* and *Slicer*), *PV-Wave* and *MacSpin*.* Statistical analysis programs, like *SPSS* and *SYSTAT*, perform a similar type of function, but are more statistically oriented; this software has been developed for its analytical functions and algorithms, but also features strong graphical capabilities to transform the data into information. Among technical graphics programs, Visual Numerics's *Stanford Chart* and *Stanford Graphics* are perhaps the most popular; their main task is the plotting and charting of technical data to present it as information, although it may be analysed graphically as well.

Clearly, this whole category is in its infancy, but its development is likely to be faster than was the case with spreadsheets, since a well-established use of the graphical format is to present certain types of data. Also, it is noteworthy that there is already the blurring of the boundaries and distinctions between the subcategories, and it seems that the software will 'look and feel' similar, sooner rather than later, than was the case with spreadsheets and IBPs/ISPs. In addition, with the acceptance of the network representation, software houses have not been slow to exploit this niche. The most notable of these new packages are Meta Software's *MetaDesign* and Visio Corp.'s *Visio*. Both allow the creation of all types of diagrams that represent flows and relationships, from flowcharts and block diagrams to organisational charts and network diagrams. Their ease of use for novices is stressed and they come complete with a wide variety of templates and stencils for nodes and links for fields as diverse as chemistry, information technology and mechanical engineering.

A3.2 Office automation

Electronic automation has improved the versatility, cost and productivity of the office. Basic office tasks involve the production of information, making copies of what is produced and transmitting it to other locations. This has been greatly aided by the photocopier and facsimile machine. The evolution and integration of office automation products are such that often the photocopying or facsimile functions in an office are not carried out by stand-alone photocopiers or facsimile machines; some facsimiles and laser printers offer a photocopying facility while many computers can be adapted to provide a facsimile facility. The sections below consider those models that can be considered as stand-alone photocopiers or facsimile machines.

The photocopier

Originally, of course, all writing was by hand and copies were made the same way. With the perfection of the typewriter in 1867, this process was speeded up greatly.

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* According to Donoho *et al.* (1988), *MacSpin* was only a *display* program, i.e. it was unable to process or analyse data, like its antecedent *VisiTrend/Plot*. The authors maintained that this was due to their focusing on the implementation of a good user interface, to the detriment of other development.

Within ten years, carbon paper had been invented to facilitate making copies as the pages were typed. In 1881, the stencil duplicator, or mimeograph, was invented, a copying machine that used a coated fibre-sheet through which ink was pressed. The need for carbon paper and stencils was reduced, if not altogether eliminated, by the commercial launch of the photocopier in 1959.

Xerography's ability to produce clear, stable copies on ordinary paper has made it the most popular method of office copying. Modern plain paper copier (PPC) machines range in size and speed from lightweight models that fit onto a desk top and produce about 12 copies per minute to models that take up whole rooms and produce 120 copies per minute. There are machines that can make full-colour copies of documents, photographs, slides, and transparencies; superimpose images; reduce or enlarge the copy image; copy on both sides of the paper; and sort, collate, and staple the copies.

The growth in the market in the middle of the 1980s for photocopiers was driven by desktop machines.* Towards the end of that decade and into the 1990s, the market has been sustained by low and mid-volume copiers. Until the beginning of the 1990s, photocopiers and facsimile machines existed as separate technologies and markets, stimulated in part by high levels of new product development. While the pace of new product development in the photocopier market has been slower than that of facsimile machines and personal computers in the last few years, full-colour and digitised technology may buck this trend.

For the most part, new photocopiers using existing technology provide a mix of greater flexibility, speed, reliability, easier operation and more functionality at lower prices. Users have proved to be less interested in colour and sophisticated editing features than manufacturers had hoped. Despite this, the full-colour photocopier market, while in its infancy, is probably one of the fastest growing product categories, reflected in the fact that Canon introduced a compact desktop full-colour copier for general office use. Product launches using digitised technology represent the conceptual change in document handling that has occurred throughout the 1990s. The way that information is created, structured, communicated, processed and moved through the office has remained largely unchanged and, until now, relatively untouched by information technology (IT).

According to Key Note (1992b), despite huge investments in IT, the gain in white-collar productivity in the 1980s was 3 per cent compared with 75 per cent in the factory. The reason for the discrepancy lies in the fact that 90 per cent of the investment in IT has gone into manipulating data, yet 90 per cent of information is held in documents. Document production is the biggest expense after payroll. On average, documents consume up to 60 per cent of office workers' time, up to 40 per cent of labour costs and around 8 per cent of revenue.

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* Desktop machines are defined as producing less than 12 copies per minute. Low-volume copiers produce 12–30 copies per minute, with mid-volume defined as those producing 31–70 copies.

With the development of integrated digital document management systems to capture, create, store-and-retrieve and distribute-and-print, the office productivity gains could be enormous. Publishing is an area of opportunity for vast reductions in organisational expenditure. It is estimated that companies spend between 6 per cent and 10 per cent of their annual gross revenues on it (Key Note, 1992b). In the past, bringing printed or publishing type work in-house was not viable for many companies. However, the advances made by companies like Xerox and Kodak in the area of electronic reprographics have meant that in-house publishing has become viable for more companies.

The facsimile machine

Sending documents, photographs and graphics from one location to another was speeded up greatly by the invention of facsimile transmission. The process requires a special machine that scans an image and represents contrast changes by an electric current. This is transmitted as a signal over telephone lines and received by a device that reproduces an exact image of the original. Due to their speed and the low cost of using them, facsimile, or fax, machines have become common equipment in many offices. Facsimile machines were first launched in the UK in 1982 and their increase in numbers has been so rapid that, within eight years of their introduction, one in three businesses in the UK had one installed (Key Note, 1992b).

While much of the growth of the photocopier market has come from the high-value end of the market, the same cannot be said of the facsimile market. This probably reflects that the perceived benefits of a fax machine have a broader appeal than photocopiers. In 1991, the UK installed base of facsimile machines overtook that of photocopiers. Low-end fax machines, particularly if they can act also as an answering machine and low-grade copier, have much more utility value than comparable photocopiers. In addition, many businesses are at a competitive disadvantage if they do not have a facsimile machine.

As with photocopiers, the fax market is similarly affected by the influence of a changing market potential and technological advance. The definition of stand-alone fax machines will become less precise as more multifunction copier/printer/facsimile machines are introduced onto the market. In 1991, Sharp announced the launch of the first full-colour fax machine. It could scan originals from either books or sheets, even if they had irregular surfaces. A data compression and expansion system allowed the data to be reduced to one-tenth of its original size before transmission, hence minimising distortion. Most significantly though, it was also a high-resolution colour printer, encompassing 26 million different shades of colour.

A3.3 Conclusion

Brainerd alleges that

> the microcomputer [has] evolved beyond its original role as a device for making calculations and storing data. It [has] assumed a place beside the printing press, the broadcast media and the telephone/fax as one of the most powerful communication tools in history. (1993: 15)

Undoubtedly, the importance of computerisation on information will increase; as technologies continue to converge, the computer's power as a communication tool is far from its limit. The 1980s saw people using technology to *originate* communication by the production of text and graphics. The 1990s has seen the enabling of the *reception* of communication as well: with the addition of a fax-modem connected to a PC, facsimile transmissions can be sent to appear on a computer monitor so that they may be further modified; electronic mail — e-mail — can be downloaded; World-Wide Web pages — the production of information by individual on a *global* scale — can be 'browsed'; and text, graphics and sound files can be received. The future will see the realisation of what Feiner (1985) terms as *interactive graphic documents* that combine the best features of books and new technology. Clearly the power and symbolism of graphics will increase in response to advances in technology.