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# Expert Systems and Geographical Information Systems for Impact Assessment

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# Contents

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# Part I

# GIS and expert systems for impact assessment

This book started as a research project[1] to investigate the potential of integrating Expert Systems (ES) and Geographical Information Systems (GIS) to help with the process of Impact Assessment (IA). This emergent idea was based on the perception of the potential of these two technologies to complement each other and help with impact assessment, a task that is growing rapidly in magnitude and scope all over the world. Part I discusses these three fields, their methodology and their combined use as recorded in the literature. In Part II we discuss the potential – and limitations – of these two computer technologies for *specific* parts of IA, as if replicating in the discussion what could be the first stage in the design of computer systems to automatise these tasks.

1 Funded by PCFC from 1991 and directed by Agustin Rodriguez-Bachiller and John Glasson.

# 1 The potential of expert systems and GIS for impact assessment

## 1.1 INTRODUCTION

Impact assessment is increasingly becoming – mostly by statutory obligation but also for reasons of good practice – part and parcel of more and more development proposals in the United Kingdom and in Europe. For instance, while the Department of the Environment (DoE) in Britain was expecting about 50 Environmental Statements each year when this new practice was introduced in 1988, the annual number soon exceeded 300. As the practice of IA developed, it became more standardised and *good practice* started to be defined. In the early years – late 1980s – a proportion of Environmental Statements in the UK still showed relatively low level of sophistication and technical know-how, but the quality soon started to improve (Lee and Colley, 1992; DoE, 1996; Glasson *et al.*, 1997), largely due to the establishment and diffusion of expertise, even though the overall quality is still far from what would be desirable. And it is here that the idea of expert systems becomes suggestive.

The idea of expert systems – computer programs crystallising the way experts solve certain problems – has shown considerable appeal in many quarters. Even though their application in other areas of spatial decision-making – like town planning – has been rather limited (Rodriguez-Bachiller, 1991) and never fully matured after an initial burst of enthusiasm, a similar appeal seems to be spreading into IA and related areas as it did in town planning ten years earlier (see Rodriguez-Bachiller, 2000b).

Geographical information systems are visually dazzling systems becoming increasingly widespread in local and central government agencies as well as in private companies, but it is sometimes not very clear in many such organisations how to make pay off the huge investment which GIS represent. Early surveys indicate that mapping – the production of maps – tends to be initially the most important task for which these expensive systems are used (Rodriguez-Bachiller and Smith, 1995). Only as confidence grows are more ambitious jobs envisaged for these systems, which have significant potential for impact assessment (see also Rodriguez-Bachiller, 2000a; Rodriguez-Bachiller and Wood, 2001).

The proposition behind the work presented here is that these three areas of IA, ES and GIS are potentially complementary and that there would be mutual benefits if they could be brought together. This first chapter outlines their potential role, prior to a fuller discussion in subsequent chapters.

## 1.2 EXPERT SYSTEMS: WHAT ABOUT SPACE?

Although a more extensive discussion of expert systems will be presented in the next chapter, a brief introduction is appropriate here. Expert Systems are computer programs that try to encapsulate the way experts solve particular problems. Such systems are designed by crystallising the expert's problem-solving logic in a "knowledge base" that a non-expert user can then apply to similar problems with data related to those problems and their context. An expert system can be seen as a synthesis of problem-specific expert knowledge and case-specific data.

Expert systems first came onto the scene in America in the 1960s and 1970s, as a way forward for the field of Artificial Intelligence after its relative disappointment with "general" problem-solving approaches. This new approach also coincided with trends to develop new, more interactive and personalised approaches to computer use in their full potential. Jackson (1990) argues that Artificial Intelligence had gone, until the mid-1970s, through a "romantic" period characterised by the emphasis on "understanding" the various intelligent functions performed automatically by humans (vision, language, problem-solving). It was partly as a result of the disappointments of that approach that what Jackson calls the "modern" period started, and with it the development of expert systems, less interested in understanding than in building *systems that would get the same results as experts*. In this context, the power of a problem solver was thought to lie in relevant subject-specific knowledge. It is this *shift from understanding to knowledge* that characterises this movement and, with it, the shift to relatively narrow, domain-specific problem-solving strategies (Hayes-Roth *et al.*, 1983a).

Although in the early days many of these systems were often suggested as capable of simulating human intelligence, this proved to be more difficult than at first thought. Today, a safer assumption underpinning expert systems work is that, while to "crack" the really difficult problems requires the best of human intelligence beyond the capabilities of the computer, *after* the solution to a problem has been found and articulated into a body of expertise, expert systems can be used to transfer such expertise to non-experts. This view translates into the more modest – but all the more achievable – expectation that ES can help solve *those problems that are routine for the expert but too difficult for the non-expert.*

Following from this lowering of expectations, when textbooks and manuals on expert systems started to appear – like the early one by Waterman

(1986) – the range of problems to which ES could be realistically expected to be applied with some degree of success had been considerably narrowed down, and it is instructive in this respect to remind ourselves of the main "rules of thumb" suggested by Waterman to identify the kind of problem and circumstances for which the use of expert systems is considered to be practicable:

- The problem should be not too large or complicated, it should be the kind that would take an expert only a few hours to solve (hours, rather than days).
- There should be established procedures to solve the problem; there should be some degree of consensus among experts on how the problem should be solved.
- The sources of the expertise to solve the problem (in the form of experts and/or written documentation) should exist and be accessible.
- The solution to the problem should not be based on so-called "common sense", considered to be too broad and diffuse to be encoded in all its ramifications.

In addition to this, a good reason for using ES is found in the need to replicate expert problem-solving expertise in situations where it is *scarce* for a variety of reasons: because experts are themselves becoming scarce (through retirement or because they are needed simultaneously in many locations), because their expertise is needed in hostile environments (Waterman, 1986), or simply because experts find themselves overloaded with too much work and unable to dedicate sufficient time to each problem. In this context, expert systems can be used to liberate experts from work which is relatively routine (for them), but which prevents them from dedicating sufficient time to more difficult problems. The idea is that overworked experts can off-load their expertise to non-experts via these systems and free up time to concentrate their efforts on the most difficult problems. This aspect of expert systems as instruments of *technology transfer* (from top to bottom or from one organisation to another) adds another more political dimension to their appeal.

Although classic reference books on the subject like Hayes-Roth *et al.* (1983b) list many different types of expert systems according to the different areas of their application, practically all expert systems can be classified in one of four categories:

- *diagnostic/advice* systems to give advice or help with interpretation;
- *control* systems in real time, helping operate mechanisms or instruments (like traffic lights);
- *planning/design* systems that suggest how to do something (a "plan");
- *teaching/training* systems.

Most of the now classic pioneering prototypes that started the interest in expert systems were developed in the 1970s – with one exception from the 1960s – in American universities, and it is instructive to note that most of them were in the first category (diagnostic/advice), with a substantial proportion of them in medical fields. This dominance of diagnostic systems has continued since.

With the advent of more and more powerful and individualised computers (both workstations and PCs) the growth in expert systems in the 1980s was considerable, mostly in technological fields, while areas more concerned with social and spatial issues seemed to lag behind in their enthusiasm for these new systems. In town planning, the development of expert systems seems to have followed a typical sequence of *stages* (Rodriguez-Bachiller, 1991) which is useful to consider here, given that there are signs that developments in fields like IA seem to follow similar patterns:

- First, *eye-opener* articles appear in subject-specific journals calling people's attention to the potential of expert systems for that field.
- In a second *exploratory* stage, differences seem to appear between the nature of the exploratory work in America and Europe: while European research turns to *soul-searching* (discussing feasibility problems with the new technology and identifying unresolved problems), American work seems to plunge directly into application work, with the production of *prototypes*, often associated with doctoral work at universities. Sooner or later, European research also follows into this level of application.
- In the next stage, *full systems* are developed, even if these are few and far between.
- In what can be seen as a last stage in this process, expert systems start being seen as "aids" in the context of more general systems that take advantage of their capacity to incorporate logical reasoning to the solution of a problem, and they tend to appear *embedded* in other technologies, sometimes as intelligent interfaces with the user, sometimes as interfaces between different "modules" in larger decision-support systems.

What is interesting here is the parallel with IA, as ES started attracting fresh interest in the early 1990s following a similar process, and we can now see the first stages of the same cycle sketched above beginning to develop. Articles highlighting the potential of ES for IA started to appear early in the Environmental literature (Schibuola and Byer, 1991; Geraghty, 1992). The first prototypes combining ES and EIA – leaving GIS aside for the moment – also started to emerge (Edwards-Jones and Gough, 1994; Radwan and Bishr, 1994), and we shall see in Chapter 5 how this field has flourished (see also Rodriguez-Bachiller, 2000b).

This fresh interest in ES may be interpreted in rather mechanistic style as a new field like IA following in the steps of older fields like town planning – similarly concerned with the quality of the environment – developing similar expectations from similar technologies, and in that respect maybe also doomed to be a non-starter in the same way. Another possible interpretation is that IA is (or has been until now) a much more *technical* activity than town planning ever was (where the technocratic approach advocated in the 1960s never really caught on), concerned with a much narrower range of problems – specific impacts derived from specific projects – more likely to be the object of technical analysis and forecasting than of political policy-making and evaluation.

One of the limitations that ES showed in trying to deal with town planning problems lay in the difficulty that traditional expert system tools have had from the start in dealing directly (i.e. automatically) with *spatial information*. Some rare early experiments with this problem apply to a very local scale, dealing with building shapes (Makhchouni, 1987) or are confined to the micro-scale of building technology (Sharpe *et al.*, 1988), and all involved considerable programming "from scratch". It is in this respect that other off-the-shelf technologies like GIS might prove productively complementary to expert systems.

## 1.3 GEOGRAPHICAL INFORMATION SYSTEMS: MORE THAN DISPLAY TOOLS?

As opposed to expert systems – discussed in detail in Chapter 2 – we are not going to discuss GIS in detail beyond this introductory chapter, and interested readers are directed to the very good and accessible literature available. In the GIS field we have the good fortune of having two benchmark publications (Maguire *et al.*, 1991; Longley *et al.*, 1999)[2] which summarise most of the research and development issues up to the 1990s and contain a collection of expert accounts which can be used as perfectly adequate secondary sources when discussing research or history issues in this field. Also, Longley *et al.* (2001) contains an excellent overview of the whole field at a more accessible level.

Computerised databases and "relational" databases (several databases related by common fields) are becoming quite familiar. GIS take the idea of relational databases one step further by making it possible to include spatial positioning as one of the relations in the database, and it is this aspect of GIS that best describes them. Despite the considerable variety of definitions suggested in the literature (Maguire, 1991), GIS can be most simply seen as *spatially referenced databases*. But what has made these systems so popular and appealing is the fact that the spatial referencing of

2 Although Longley *et al.* (1999) is presented as a "second edition" of Maguire *et al.* (1991), it is an entirely new publication, with different authors and chapters; so the two should really be taken *together* as a quite complete and excellent source on GIS.

information can be organised into maps, and automated mapping technology can be used to perform the normal operations of database management (subset extraction, intersection, appending, etc.) *in map form*. It is the manipulation and display of maps with relative speed and ease that is the trademark of GIS, and it is probably fair to say that it is this graphic efficiency that has contributed decisively to their general success. A crucial issue for the development of this efficiency has been finding efficient ways of holding spatial data in computerised form or, in other words, how maps are represented in a computer, and two basic models of map representation have been developed in the history of GIS:

(a) The *raster* model is cell-based where the mapped area is divided up into cells (equal or unequal in size) covering its whole extension, and where the attributes of the different map features (areas, lines, points) are simply stored as values for each and everyone of those cells. This model can be quite economical in storage space and is simple, requiring relatively unsophisticated software, and for these reasons the first few generations of mapping systems all tended to use it, and the importance of raster systems research cannot be overestimated in the history of GIS (Foresman, 1998). Raster-based systems tend to be cheaper, but this approach has the drawback that the *accuracy* of its maps will be determined by the size of the cells used (the smaller the cells the more accurate the map will be). To obtain a faithful representation of maps the number of cells may have to grow considerably, reducing partially the initial advantages of economy and size.

(b) The *vector* model, on the other hand, separates maps from their attributes (the information related to them) into different filing systems. The features on a map (points and lines) are identified reasonably accurately by their co-ordinates, and their relationships (for example, the fact that lines form the boundaries of areas) are defined by their "topology", while the attributes of all these features (points, lines, areas) are stored in separate but related tables. From a technical point of view, GIS are particular types of relational databases that combine attribute files and map files so that (i) attribute databases can be used to identify maps of areas with certain characteristics and (ii) maps can be used to find database information related to certain locations. The accuracy of these systems does not depend any more – as it does in raster-based systems – on the resolution used (the size of the smallest unit) but on the accuracy of the source from which the computer maps were first derived or digitised. Despite vector systems being more demanding on the computer technology (and therefore more expensive) their much improved accuracy is leading to their growing domination of the GIS market. However, raster-based systems still retain advantages for certain types of application – for instance when dealing with satellite data – and it is increasingly common to find vector systems which can also transform their own maps into cell-based representations – and *vice versa* – when needed.

The development of GIS has been much more gradual than that of expert systems (full prototypes of which were developed right from the start), probably due to the fact that, for GIS to be practical, computer technology had to take a quantum leap forward – from raster to vector – to handle maps and the large databases that go with them. This leap took decades of arduous work to perfect the development in all the directions in which it was needed:

- *Hardware* to handle maps had to be developed, both to encode them at the input stage, and to display and print them at the output stage. On the *input* side, the digitiser – which proved to be one of the cornerstones of GIS development – was invented in the UK by Ray Boyle and David Bickmore in the late 1950s, and Ivan Southerland invented the sketchpad at MIT in the early 1960s. *Output* devices suitable for mapping had started to be developed by the US military in the 1950s, and by some public and private companies (like the US oil industry, also some gas and public-service companies) in the 1960s, while universities – who couldn't afford the expensive equipment – were concentrating on software development for the line printer until the 1970s.

- It is argued that the development of map-handling *software* can be traced back to when Howard Fisher moved from Northwestern University to chair the newly created Harvard Computer Graphics laboratory in 1964, bringing with him his recently created thematic mapping package for the line printer (SYMAP), which he would develop fully at Harvard. While this is true of cell-based mapping – most systems in the 1950s and 1960s belonged to this type – interactive screen display of map data was being developed at the same time for the US military. Computer Aided Drafting was being developed at MIT, and Jack Dangermond – a former researcher at the Harvard Graphics laboratory – produced in the early 1970s the first effective vector polygon overlay system, which would later become Arc-Info.

- Also crucial was the development of software capable of handling large spatially referenced *databases* and their relationships with the mapping side of these systems. The pioneering development of some such large systems was in itself a crucial step in this process. These included the Canada Geographic Information System started in 1966 under the initiative of Roger Tomlinson, the software developments to handle such spatial data, like the MIADS system developed by the US Forest Service at Berkeley from the early 1960s to store and retrieve attributes of a given map cell and perform simple overlay functions with them, and the new methods for encoding census data for the production of maps developed at the US Census Bureau from 1967.

Good accounts on the history of GIS can be found in Antenucci *et al.* (1991) and also Coppock and Rhind (1991), and the latter authors argue that four distinct *stages* can be identified in the history of GIS, at least in the US and the UK:

1 The first stage – from the 1950s to the mid-1970s – is characterised by the pioneering work briefly mentioned above, research and developmental work by *individuals* – just a few names like those mentioned above – working on relatively isolated developments, breaking new ground in the different directions required by the new technology.

2 The second stage – from 1973 to the early 1980s – sees the development of formal experiments and government-funded research, characterised by *agencies and organisations* taking over GIS development. The New York Department of Natural Resources developed, from 1973, the first State-wide inventory system of land uses, the first of many States in the US to develop systems concerned with their natural resources and with environmental issues. The US Geological Survey developed, from 1973, the Geographical Information Retrieval and Analysis System (GIRAS) to handle information on land use and land cover from maps derived from aerial photography. Jack Dangermond had started ESRI (Environmental Systems Research Institute) in 1969 as a non-profit organisation and, with the development in the 1970s of what would become Arc-Info, ESRI turned into a commercial enterprise with increasing environmental interests. At the same time, Jim Meadlock (who had developed for NASA the first stand-alone graphics system) had the idea of producing turn-key mapping systems for local government – which he implemented for the first time in Nashville in 1973 – and he would later go on to found INTERGRAPH. This is a period that Coppock and Rhind characterise as one of "lateral diffusion" (still restricted mostly to within the US) rather than innovation, with the characteristic that it all tended to happen (whether in the private or the public sector) outside the political process, with no government policy guidance.

3 The third stage – from 1982 – can be characterised as the *commercial* phase, still with us, and characterised by the *supply-led* diffusion of the technology *outside* the US. GIS is becoming a worldwide growth industry, nearing a turnover of $2 billion per year (Antenucci, 1992), with the appearance on the market of hundreds of commercial systems, more and more of them being applicable on smaller machines at lower and lower prices. Even if the market leaders are still the large organisations (like ESRI and INTERGRAPH) which grew out of the previous stage, smaller and more flexible systems like SPANS (small, for PC computers) or Map-Info (with a modular structure that makes its purchase much easier for smaller organisations) – to mention but a few – are increasing their market presence.

4 Coppock and Rhind see a new stage developing in which commercial interests are gradually being replaced by *user dominance*, although an alternative interpretation is simply that – rather than commercial interests being displaced – increasing competition among GIS manufacturers is letting the needs of the users dictate more and more what the industry produces, in what could be seen as a transition to a more *demand-led* industry. Also, this new stage can be seen as characterised by the transition from the use of individual data on isolated machines, to dealing with distributed databases accessed through computer networks, with increased availability of data (and software) through networks in all kinds of organisations and at all levels, including the World Wide Web.

Although British research was at the very heart of GIS developments, it is probably fair to say that, after the first "pioneering" stage mentioned, the second stage in GIS development and diffusion of use has been largely dominated by developments in the US. Subsequent growth of GIS outside the United States can be seen as a process of *diffusion* of the technology from America to other countries – the UK included – despite the continuation of GIS work at academic British institutions like the Royal College of Art (where David Bickmore had founded the Experimental Cartography Unit in 1967) and later at Reading University and its Unit for Thematic Information Systems since 1975, as well as those resulting from the Regional Research Laboratories in the 1980s (see Chapter 5).

Apart from isolated developments in the early 1980s – like the SOLAPS system developed in-house in South Oxfordshire (Leary, 1989) – Coppock and Rhind underline the importance in the UK of three *official surveys* that mark the evolution of GIS: (i) the Ordnance Survey Review Committee (1978) looking at the prospect of changing to digital mapping; (ii) the Report of the House of Lords' Select Committee on Science and Technology (1984) investigating digital mapping and remote sensing, which recommended a new enquiry; (iii) the Committee of Enquiry into the Handling of Geographical Data, set up in 1987 and chaired by Chorley, which launched the ESRC-funded Regional Research Laboratories (RRL) programme (Masser, 1990a) from February 1987 to October 1988 and then to December 1991, with funding of over 2 million pounds. This programme tried to diffuse the new GIS technology into the public arena by establishing 8 laboratories spread over 12 universities: Belfast, Cardiff, Edinburgh, Lancaster, Leicester, Liverpool, London-Birkbeck, London School of Economics, Loughborough, Manchester, Newcastle and Ulster. Research and application projects were to be undertaken *in-house*, with the double objective of spreading the technology to the academic and private sectors and, in so doing, making the laboratories self-financing beyond the initial period supported by the ESRC grant by increasingly attracting private investment. While the first objective was fully achieved – as a result, a new generation of GIS experts was created in the academic sector, and numerous GIS courses started to appear, diffusing their expertise to others – the private sector never became sufficiently involved in these developments to support them after the period of the ESRC experiment.

In the US there was a parallel experience of the National Centre for Geographic Information and Analysis funded with a comparable budget by the National Science Foundation. Concentrated in only three centres for the whole country (Santa Barbara, Buffalo and Maine) and financing research projects done both inside and outside those centres, it had mainly theoretical aims (Openshaw *et al.*, 1987; Openshaw, 1990).

## 1.4 GIS PROBLEMS AND POTENTIAL

It is also productive to look at the development of GIS in terms of typical problems and *bottlenecks* that have marked the different stages of its progress, problems which tend to move from one country to another as the technology becomes diffused:

1 First there is (was) what could be called the *research bottleneck*, mainly manifest in the UK and mostly in the US, where much of the fundamental research was carried out during the 1950s and 1960s, taking decades to solve specific problems of mapping and database work, as mentioned above.
2 Next, the *expertise bottleneck* – the lack of sufficient numbers of competent professionals to use and apply GIS – became apparent especially outside the US, when the new technology was being diffused to other countries before they had developed educational and training programs to handle it. In the UK this was evident in the 1980s and it is this bottleneck that the ESRC's RRL Initiative sought to eliminate. It is now appearing in other countries (including developing countries) as the wave of GIS diffusion spreads more widely.
3 Finally, the *data bottleneck*: beyond the classic problems or data error well identified in the literature (Chrisman, 1991; Fisher, 1991), this bottleneck refers more to problems of data quality discussed early by De Jong (1989) and – most importantly – data availability and cost, especially when GIS is "exported" to developing countries (Masser, 1990b; Nutter *et al.*, 1996; Warner *et al.*, 1997).

These general bottlenecks can be seen as the main general obstacles to the adoption of GIS in countries other than the US, but they work in combination with other factors specific to each particular case. *Organisational resistance* has been widely suggested (Campbell and Masser, 1994) as responsible for the relatively lower take-up of GIS in Europe than in America, and the magnitude of the *financial cost* (and risk) involved in the implementation of such systems may be another factor growing in importance even after the initial resistance has been overcome (Rodriguez-Bachiller and Smith, 1995).

In terms of what GIS can *do*, it can be said that these systems are still to some extent prisoners of their cartographic background, so that part of their functionality (Maguire and Dangermond, 1991) was initially directed towards solving *cartographic* problems related to the language of visualisation, three-dimensional map displays and, later, the introduction of multi-media and "hyper-media" with sound and images. Also, because the development of GIS has been largely *supply-led*, spearheaded by private software companies who have until recently concentrated on improving the "graphical" side of GIS – their mapping accuracy, speed and capacity – their analytical side has been somewhat neglected, at least initially. As Openshaw (1991) pointed out ironically some years ago, sophisticated GIS packages could make over 1,000 different operations, and yet, not one of them related to true spatial analysis, but to "data description". This impression feels now somewhat exaggerated and dated as more and more sophisticated analytical features appear in every new version of GIS packages, but was quite appropriate at the time and underlined the problems encountered initially by users of these supposedly revolutionary new technologies. Today, the list of operations that most GIS can normally do (see Rodriguez-Bachiller and Wood, 2001, for its connection to Impact Assessment) is quite standard.

### *General operations*

- Storage of large amounts of spatially referenced information concerning an area, in a relational database which is easy to update and use.
- Rapid and easy display of visually appealing maps of such information, be it in its original form or after applying to it database operations (queries, etc.) or map transformations.

### *Analysis in two dimensions*

- Map "overlay", superimposing maps to produce composite maps, the most frequent use of GIS.
- "Clipping" one map with the polygons of another to include (or exclude) parts of them, for instance to identify how much of a proposed development overlaps with an environmentally sensitive area.
- Producing "partial" maps containing only those features from another map that satisfy certain criteria.
- Combining several maps (weighted differently) into more sophisticated composite maps, using so-called "map algebra", used for instance to do multi-criteria evaluation of possible locations for a particular activity.
- Calculating the size (length, area) of the individual features of a map.

- Calculating descriptive statistics for all the features of a map (frequency distributions, averages, maxima and minima, etc.).
- Doing multivariate analysis like correlation and regression of the values of different attributes in a map.
- Calculating minimum distances between features, using straight-line distances and distances along "networks".
- Using minimum distances to identify the features on one map nearest to particular features on another map.
- Using distances to construct "buffer" zones around features (typically used to "clip" other maps to include/exclude certain areas).

*Analysis with a third dimension*

- Interpolating unknown attribute values (a "third dimension" on a map) between the known values, using "surfaces", Digital Elevation Models (DEMs) or Triangulated Irregular Networks (TINs).
- Drawing contour lines using the interpolated values of attributes (the "third dimension").
- Calculating topographic characteristics of the 3-D terrain, like slope, "aspect", concavity and convexity.
- Calculating volumes in 3-D models (DEMs or TINs) for instance the volumes between certain altitudes (like water levels in a reservoir).
- Identifying "areas of visibility" of certain features of one map from the features of another, for instance to define the area from which the tallest building in a proposed project will be visible.
- So-called "modelling", identifying physical geographic objects from maps, like the existence of valleys, or water streams and their basins.

Many of these capabilities have been added gradually – some as "add-on" extensions, some as integral components of new versions of systems – in response to academic criticism and consumer demand. However, when these systems were being first "diffused" outside the US, to go beyond map operations to apply them to real problems tended to require considerable amount of manipulation or programming by the user, as the pioneering experience in the UK of the Regional Research Laboratories[3] suggested over ten years ago (Flowerdew, 1989; Green *et al.*, 1989; Hirschfield *et al.*, 1989; Maguire *et al.*, 1989; Openshaw *et al.*, 1989; Rhind and Shepherd, 1989; Healey *et al.*, 1990; Stringer and Bond, 1990). The bibliography of GIS applications in Rodriguez-Bachiller (1998) still showed about *half* of all GIS applications involving some degree of expert programming.

3 Funded by ESRC to set up (in the late 1980s) laboratories to research the use of geographical information, intended among other goals to help diffuse the new GIS technology.

## 1.5 IMPACT ASSESSMENT: RIPE FOR AUTOMATION?

Impact assessment can be said – once again – to be a US import. It has been well established in the United States since the National Environmental Policy Act (NEPA) of 1969 (Glasson *et al.*, 1999), which required studies of impact assessment to be attached to all important *government* projects. The 1970s and 1980s subsequently saw the consolidation of its institutional structure as well as its methods and procedures, and the publication of ground-breaking handbooks (e.g. Rau and Wooten, 1980) to handle the technical difficulties of this new field. Later, this nationwide approach in the US has been supplemented with additional statewide legislation ("little NEPAs") in 16 of the 52 states.

In the meantime, similar legislation, and the expertise that is needed to apply it, has been spreading around the world and has been adopted by more and more countries at a growing rate: Canada (1973), Australia (1974), Colombia (1974), France (1976), The Netherlands (1981), Japan (1984), and the European Community produced its Directive to member countries in July 1985, which has since been adopted in Belgium (1985), Portugal (1987), Spain (1988), Italy (1988), United Kingdom (1988), Denmark (1989), Ireland (1988–90), Germany (1990), Greece (1990), and Luxembourg (1990) (Wathern, 1988; Glasson *et al.*, 1999).

The European Directive 85/337 (Commission of the European Communities, 1985) structured originally the requirements for environmental impact assessment for development projects at two levels, and this approach has been maintained ever since. For certain types and sizes of project (listed in Annex I of the Directive) an "Environmental Statement" would be mandatory:

- crude oil refineries, coal/shale gasification and liquefaction;
- thermal power stations and other combustion installations;
- radioactive waste storage installations;
- cast iron and steel melting works;
- asbestos extraction, processing or transformation;
- integrated chemical installations;
- construction of motorways, express roads, railways, airports;
- trading ports and inland waterways;
- installations for incinerating, treating, or disposing of toxic and dangerous wastes.

In addition, for another range of projects (listed in Annex II of the Directive), an impact study would only be required if the impacts from the project were likely to be "significant" (the criteria for significance being again defined by the scale and characteristics of the project):

- agriculture (e.g. afforestation, poultry rearing, land reclamation);
- extractive industry;

- energy industry (e.g. storage of natural gas or fossil fuels, hydroelectric energy production);
- processing of metals;
- manufacture of glass;
- chemical industry;
- food industry;
- textile, leather, wood and paper industries;
- rubber industry;
- infrastructure projects (e.g. industrial estate developments, ski lifts, yacht marinas);
- other projects (e.g. holiday villages, wastewater treatment plants, knackers' yards);
- modification or temporary testing of Annex I projects.

In the UK, the Department of the Environment (DoE, 1988) adopted the European Directive primarily through the Town and Country Planning Regulations of 1988 ("Assessment of Environmental Effects"). These largely replicated the two-tier approach of the European Directive, classifying EIA projects into those requiring an Environmental Statement and those for which it is required only if their impacts are expected to be significant, listed in so-called Schedules 1 and 2 respectively – which broadly correspond to the Annexes I and II of the European Directive (Glasson *et al.*, 1999). In turn, the expected *significance* of the impacts was to be judged on three criteria (DoE, 1989):

1 The scale of a project making it of "more than local importance".
2 The location being "particularly sensitive" (a Nature Reserve, etc.).
3 Being likely to produce particularly "adverse or complex" effects, such as those resulting from the discharge of pollutants.

The European Directive of 1985 was updated in 1997 (Council of the European Union, 1997) with the contents of Annexes I and II being substantially extended and other changes made, including the mandatory consideration of alternatives. The new Department of Environment, Transport and the Regions (DETR) set in motion a similar process in the UK (DETR, 1997) to update not just the categories of projects to be included in Schedules 1 and 2, but also the standards of significance used, which has recently resulted in new Regulations (DETR, 1999a) with a revised set of criteria, and also in new practical guidelines in a Circular (DETR, 1999b). This represents in reality a shift to a *three-level* system, in that for Schedule 1 projects, there is a mandatory requirement for EIA, and for Schedule 2 projects there are two categories. Projects falling below specified "exclusive thresholds" do not require EIA, although there may be circumstances in which such small developments may give rise to significant environmental impacts (for example by virtue of the sensitivity of the location), and in such cases an EIA may be required. For other Schedule 2 projects, there are "indicative criteria and thresholds" which, for each category of project, indicate the characteristics which are most likely to generate significant impacts. For such projects, a case-by-case approach is normally needed, and projects will be judged on: (i) characteristics of the development (size, impact accumulation with other projects, use of natural resources, waste production, pollution, accident risks); (ii) sensitivity of the location; (iii) characteristics of the potential impacts (extent, magnitude and complexity, probability, duration and irreversibility).

## 1.6 THE IA PROCESS

IA can be seen as a series of processes within processes in a broader cycle that is the life of a development project. The life of a project usually involves certain typical stages:

1 decision to undertake the project and general planning of what it involves;
2 consideration of alternative designs and locations (not always);
3 conflict resolution and final decision;
4 construction;
5 operation;
6 closedown/decommissioning (not always present, some projects have theoretically an eternal life).

Within this cycle, IA is a socio-political process to add certain checks and balances to the project life, within which more technical exercises are needed to predict and assess the likely impacts of the project, sometime involving social processes of consultation and public participation. IA can be seen as a process in itself (Glasson *et al.*, 1999), with typical *stages*:

1 *Screening*: deciding if the project needs an environmental statement, using the technical criteria specified in the relevant IA legislation and guidelines, and often also involving consultation. Beyond this first stage, IA as such should be (but often is not) applied to all the main phases in the physical life of the project: *construction, operation, decommissioning*.

2 *Scoping*: determining which impacts must be studied (using checklists, matrices, networks, etc.), as well as identifying which of those are likely to be the *key* impacts, likely to be the ones that will "make or break" the chances of the project being accepted, often involving consultation with interested parties and the public. Both the "screening" and "scoping" stages require a considerable amount of work directed at the *understanding*

of the situation being considered: understanding of the project, understanding of the environment, and understanding of the alternatives involved.

3 *Impact prediction* for each of the impact areas defined previously, involving two distinct types of predictions:

3a *Baseline prediction* of the situation concerning each impact without the project.
3b *Impact prediction* as such, predicting the differences between the baseline and the project impacts using models and other expert technical means, and differentiating between:

- *direct* impacts from the project (from emissions, noise, etc.);
- *indirect* impacts derived from other impacts (like noise from traffic);
- *cumulative* impacts resulting from the project *and* other projects in the area.

4 *Assessment of significance* of the predicted impacts, by comparing them with the accepted standards, and often also including some degree of consultation.

5 *Mitigation*: definition of measures proposed to alleviate some of the adverse impacts predicted to be significant in the previous stage.

6 Assessment of the likely *residual impacts after mitigation*, and their significance.

7 After the project has been developed, *monitoring* the actual impacts from it – including monitoring the effectiveness of any mitigation measures in place – separating them from impacts from other sources impinging on the same area. Hopefully, this may lead to, and provide data for, some *auditing* of the process itself (e.g. studies of how good were the predictions).

The different stages of the IA process are "interleaved" with those of the project life and, in fact, the quality of the overall outcome often depends on how appropriately – and timely – that interleaving takes place. In general, the earlier in the design of a project the IA is undertaken, the better, because, if it throws up any significant negative impacts, it will be much easier (and cheaper) to modify the project design than applying mitigation measures afterwards. In particular, if alternative designs or locations are being considered for the project, applying IA at that stage may help identify the best options. Also, because the public should be a key actor in the whole assessment process, an earlier start will alert the public and will be more likely to incorporate their views from the beginning, thus reducing the chances of conflict later, when the repercussions of such conflicts may be far reaching and expensive for all concerned.

## 1.7 ENVIRONMENTAL STATEMENTS

In turn, Environmental Statements (the actual IA reports) represent a third process within IA – also interleaved with the other two – involving two main stages: (i) statement *preparation* by the proponents of the development, and (ii) statement *review* by the agency responsible. In fact, the structure of Environmental Statements should reflect all this "interleaving", which often determines also the quality of such documents. The structure and content of Environmental Statements are defined by the legislation, guidelines and "good practice" advice from the relevant agencies (Wathern, 1988; DoE, 1988, 1994 and 1995), and is usually a variation of the following list:

1 Description of the project:

- physical and operational features;
- land requirements and layout;
- project inputs;
- residues and emissions if any.

2 Alternatives considered:

- different processes or equipment;
- different layout and spatial arrangements;
- different locations for the project;
- the *do nothing* alternative (NOT developing the project).

3 Impact areas to be considered:

- socio-economic impacts;
- impacts on the cultural heritage;
- impacts on landscape;
- impacts on material assets and resources;
- land use and planning impacts;
- traffic impacts;
- noise impacts;
- air pollution impacts;
- impacts on soil and land;
- impacts on geology and hydrogeology;
- impacts on ecology (terrestrial and aquatic).

4 Impact predictions:

- baseline analysis and forecasting;
- impact prediction;
- evaluation of significance;
- mitigation measures;
- plans for monitoring.

In addition to these substantive requirements, other formal aspects can be added – in the UK for instance – including for example a non-technical summary for the layperson, a clear statement of what the objectives of the project are, the identification of any difficulties encountered when compiling the study, and others (see Chapter 11).

Early experience of Environmental Statements evidenced several problems, including the number of statements itself. All countries where IA has been introduced seem to have had a "flood" of Environmental Statements: in the US, about 1,000 statements a year were being processed during the first 10 years after NEPA, although the number of statements processed in the US dropped afterwards to about 400 each year, and this is attributed to impact assessment having become much more an integral part of the project design process and impacts being considered much earlier in the process. In France they had a similar number of about 1,000 statements per year after they started EIA in 1976, and this has subsequently risen to over 6,000. In the UK, more than 300 statements on average were processed each year between 1988 and 1998 (Glasson *et al.*, 1999; Wood and Bellanger, 1999), a much higher rate than in the US if we relate it to the population size of both countries. The number of environmental statements in the UK dropped during the 1990s to about 100–150 a year (Wood and Bellanger, 1999), probably related to a fall in economic activity, and the number of statements went back up to about 300 with the economic revival towards the end of the decade. With the implementation of the amended EU Directive in 1999, the UK figure has risen to over 600 Environmental Statements p.a., and there have been substantial increases also in other EU Member States.

The *quality* of the statements also seems to be improving after a relatively poor start: improvements were noted first from 1988/89 to 1990/91 (Lee and Colley, 1992), and also from before 1991 to after 1991 (DoE, 1996; Glasson *et al.*, 1997), even though it seems that the overall quality is still far from what would be desirable. After the teething problems in the 1980s, mostly attributed to the inexperience of all the actors involved (developers, impact assessors, local authority controllers), better impact studies seem now to be related to (i) *larger* projects of certain types; (ii) more *experienced* consultants; (iii) local authorities with customised *EIA handbooks*. Central to this improvement seems to have been (as it was in the US in the 1970s and early 1980s) the increasing dissemination of good practice and expertise – in guides by the agencies responsible (DoE, 1989 and 1995) and in technical manuals (Petts and Eduljee, 1994; Petts, 1999; Morris and Therivel, 1995 and 2001) – that show how the field can be broken down into sub-problems and the best ways of solving such sub-problems.

Glasson *et al.* (1997) believe that, had the European Community not insisted on the adoption of EIA, the then Conservative Government would not have introduced it in the UK, arguing at the time that the existing planning system was capable of dealing with the consideration of undesirable impacts from developments. This was despite their repeated attempts to streamline and in some cases dismantle the planning system as part of their general strategy of "rolling back the State" without any need for additional controls. In the UK Planning system, each development application is evaluated "on its own merits" as part of the general development control process, and the consideration of impacts could have been seen as just another set of "material considerations" to contribute to the decision, not requiring special guidelines, processes and legislation. But the European Directive *was* implemented in the UK, and there is now considerable debate in the UK about the possibility of extending the environmental impact assessment approach further, including:

- To broaden IA to include more fully under its umbrella the area of *socio-economic impact assessment*, already practised to some extent in the UK and more fully in other countries (Glasson *et al.*, 1999), but not always with the appropriate legislative recognition. Such widening of scope may lead to more integrated IA, with decisions based partly on the extent to which various biophysical and socio-economic impacts can be "traded".
- To move from a concern with projects to include "higher tiers of actions", structured into policies, plans and programmes (Wood, 1991). This has become known as *strategic environmental assessment* (SEA) with a growing literature and legislation around it. In 2001, the European Union agreed an SEA Directive for plans and programmes – although, unfortunately, not for policies (CEU, 2001). This must be implemented by Member States by 2004. Plan SEAs would define acceptable standards for an area that projects would have to adhere to, and ideally after such an assessment individual developments would not need to re-assess their impacts each time, but only to demonstrate their compliance with those standards.

## 1.8 INTEGRATION: THE WAY AHEAD?

The main purpose of this chapter has been to point out the potential complementarity of the three areas of IA, and the building blocks of the argument can be summarised in a final list of points:

- IA practice is growing at a fast pace, and many of the actors involved are finding it difficult to cope.
- The quality of impact assessment (although improving) is still far from satisfactory.
- One reason for the low quality of IA is still the relative scarcity of expertise.
- IA expertise is mostly legal, technical and specific, rather than "common-sensical" and diffuse.

- IA expertise and good practice exist, and are beginning to be articulated in good sources (guides, manuals, etc.) by good experts.
- The problem in many countries – including the UK – is not the existence or the quality of IA expertise and good practice, but its dissemination.
- Expert systems are particularly suited for "technology transfer" from experts to non-experts when dealing with *not-too-difficult* problems of the kind that some parts of IA pose.
- Expert systems are also increasingly becoming useful tools for interfacing in a logical and friendly way with other systems.
- Interest in the application of expert systems to IA has already started to take off as reported in the literature, and it seems timely to take a closer look at this possibility.
- Expert systems handle logical information well, but the handling of spatial information can be a problem, and GIS can help in this respect.
- GIS are efficient map-manipulation systems, and their analytical capabilities are being continually improving.
- GIS applications can require considerable programming and customising by the user.
- Expert systems technology can possibly provide the programming power and friendliness that GIS need to interface with the user, and combined together they can help IA take the leap forward that current institutional pressures are expecting of it.

These two computer technologies may be able to help with IA, each in their own different way: GIS may be able to *support* IA good practice, expert systems may be able to *spread* it. The potential for articulation of these three technologies is now clear. Chapter 2 discusses expert systems in greater detail, and the following Chapters 3–5 include a bibliographical review of IA applications of expert systems and GIS as documented in the literature.

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# 2 Expert systems and decision support

## 2.1 INTRODUCTION

This methodological – and to some extent historical – chapter focuses on the nature and potential of ES beyond the brief introduction to these systems in Chapter 1, by looking back at their early development and some of their most relevant features. It is structured into four sections: in Section 2.2, the emergence of expert systems is discussed in the context of the development of the field of Artificial Intelligence; in Section 2.3, the typical structure of expert systems is discussed; in Section 2.4 we discuss the "promise" of expert systems and the extent of its fulfillment and, in Section 2.5, we expand the discussion to cover the wider area of so-called Decision Support Systems (DSS).

## 2.2 EXPERT SYSTEMS AND ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) has been defined in a variety of ways, primarily by its *aims*, as reflected in a number of well-known AI manuals and textbooks:

- to *simulate* intelligent behaviour (Nilsson, 1980);
- to "study of how to make computers *do* things at which, at the moment, people are better" (Rich, 1983);
- "to *understand* the principles that make intelligence possible" (Winston, 1984);
- to *study* human intelligence by trying to simulate it with computers (Boden, 1977).

Definitions of AI such as these tend to be based on some degree of belief in the provocative statement made by Marvin Minsky (MIT) in the 1960s that "the brain happens to be a meat machine" (McCorduck, 1979) which, by implication, can be *simulated*. The main difference between these definitions is in their varying degree of optimism about the possibility of reproducing human intelligence mechanically: while the first two seem to put the emphasis on the *simulation* of intelligence (reproducing intelligent behaviour), the last two – more cautious – put the emphasis rather on *understanding* intelligence. In fact, the tension between "doing" and "knowing" has been one of the driving forces in the subsequent development of AI, and has also been one of the root causes of the birth of expert systems.

Many antecedents of AI (what can be called the "prehistory" of AI) can be found in the distant past, from the calculators of the seventeenth century to Babbage's Difference Engine and Analytical Engine of the nineteenth century, from the chess-playing machine of Torres Quevedo at the time of the First World War to the first programmable computer developed in Britain during the Second World War, together with the pioneering work of Alan Turing and his code-breaking team at Bletchley Park, part of the secret war effort only recently unveiled in its full detail and importance (Pratt, 1987) – and popularised in the recent film "Enigma". However, the consolidation of AI as a collective field of interest (and as a *label*) was very much an American affair, and AI historians identify as the turning point the conference at Dartmouth College (Hanover, New Hampshire) in the Summer of 1956, funded by the Rockefeller Foundation (McCorduck, 1979; Pratt, 1987). Jackson (1990) suggests that the history of AI after the war follows *three periods* (the classical period, the romantic period, and the modern period) each marked by different types of research interests, although most lines of research have carried on right throughout to varying degrees.

### 2.2.1 The classical period

This period extends from the war up to the late 1950s, concentrating on developing efficient *search* methods: finding a solution to a problem was seen as a question of searching among all possible states in each situation and identifying the best. The combinatorial of all possible states in all possible situations was conceptualised and represented as a *tree* of successive options, and search methods were devised to navigate such trees. Search methods would sometimes explore each branch in all its depth first before moving on to another branch ("depth-first" methods); some methods would explore all branches at one level of detail before moving down to another level ("breadth-first" methods). The same type of trees and their associated search methods were also used to develop game-playing methods for machines to play two-player games (like checkers or chess), where the tree of solutions includes alternatively the "moves" open to each player. The same type of tree representation of options was seen as universally applicable to both types of problems (Figure 2.1).

Efficient "tree-searching" methods can be developed independently of any particular task – hence their enormous appeal at the time as universal problem solvers – but they are very vulnerable to the danger of the so-called

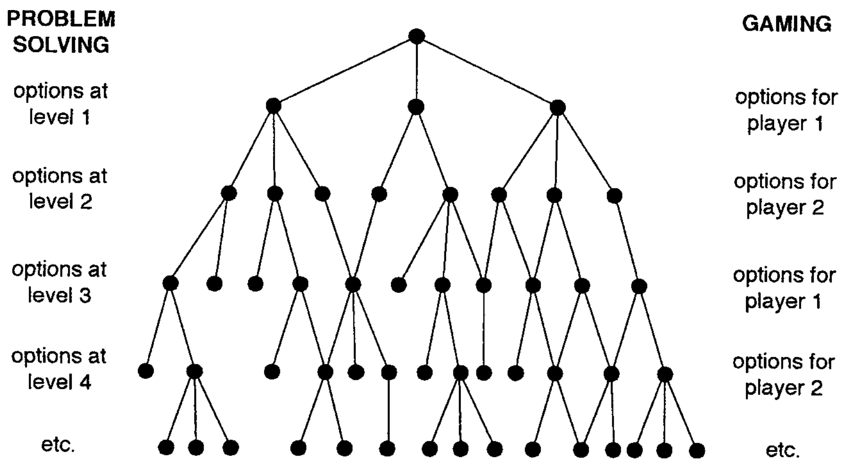


*Figure 2.1* Options as trees.

"combinatorial explosion", the multiplication of possible combinations of options beyond what is feasible to search in a reasonable time. For instance, to solve a chess game completely (i.e. to calculate all $10^{120}$ possible sequences of moves derived from the starting position) as a *blind* tree search – without any chess-specific guiding principles – would take the most advanced computer much longer than the universe has been in existence (Winston, 1984). It is for reasons like this that these techniques, despite their aspiration to universal applicability, are often referred to as *weak* methods (Rich, 1983). On the other hand, they do provide a framework within which criteria specific to a problem can be applied. One such approach adds to the search process some form of evaluation at every step (an "evaluation function"), so that appropriate changes in the direction of search can shorten it and make it progress faster towards the best solution, following a variety of so-called "hill-climbing" methods.

## 2.2.2 The romantic period

This period extends from the 1960s to the mid-1970s, characterised by the interest in *understanding*, trying to simulate human behaviour in various aspects:

(a) On the one hand, trying to simulate *subconscious* human activities, things we do without thinking:

- *Vision*, usually simulated in several stages: recognising physical edges from shadows and colour differences, then reconstructing shapes (concavity and convexity) from those edges, and finally classifying the shapes identified and determining their exact position.

- *Robotics*, at first just an extension of machine tools, initially based on pre-programming the operation of machines to perform certain tasks always in the same way; but as the unreliability of this approach became apparent – robots being unable to spot small differences in the situation not anticipated when programming them – second-generation robotics started taking advantage of *feedback* from sensors (maybe cameras, benefiting from advances in vision analysis) to make small instantaneous corrections and achieve much more efficient performances, which led to the almost full automation of certain types of manufacturing operations (for instance, in the car industry) or of dangerous laboratory activities.
- *Language*, both by trying to translate spoken language into written words by spectral analysis of speech sound waves, and by trying to determine the grammatical structure ("parsing") of such strings of words leading to the understanding of the meaning of particular messages.

(b) On the other hand, much effort also went into reproducing *conscious* thinking processes, like:

- *Theorem-proving* – a loose term applied not just to mathematical theorems (although substantial research did concentrate on this particular area of development) but to general logical capabilities like expressing a problem in formal logic and being able to develop a full syllogism (i.e. to derive a conclusion from a series of premises).
- *Means-ends analysis* and planning, identifying sequences of (future) actions leading to the solution of a problem, like Newell and Simon's celebrated "General Problem Solver" (Newell and Simon, 1963).

### 2.2.3 The modern period

In the so-called *modern* period, from the 1970s onwards, many of the traditional strands of AI research – like robotics – carried on but, according to Jackson (1990), the main thrust of this period comes from the reaction to the problems that arose in the previous attempts to simulate brain activity and to design general problem-solving methods. The stumbling block always seemed to be the lack of criteria specific to the particular problem being addressed ("domain-specific") beyond general procedures that would apply to *any* situation ("domain-free"). When dealing with geometric wooden blocks in a "blocks world", visual analysis might have become quite efficient but, when trying to apply that efficiency to dealing with nuts and bolts in a production chain, procedures more specific to nuts and bolts seemed to be necessary. It seemed that for effective problem-solving at the level at which humans do it, more problem-specific knowledge was required than had been anticipated. Paradoxically, this need for a more domain-specific approach developed in the following years in two totally different directions.

On the one hand, the idea that it might be useful to design computer systems which did not have to be pre-programmed but which could be *trained* "from scratch" to perform specific operations led – after the initial rejection by Minsky in the late 1960s – to the development in the 1980s of *neural networks*, probably the most promising line of AI research to date. They are software mini-brains that can be trained to recognise specific patterns detected by sensors – visual, acoustic or otherwise – so that they can then be used to identify other (new) situations. Research into neural nets became a whole new field in itself after Rumelhart and McClelland (1989) – a good and concise discussion of theoretical and practical issues can be found in Dayhoff (1990) – and today it is one of the fastest growing areas of AI work, with ramifications into image processing, speech recognition, and practically all areas of cognitive simulation.

On the other hand, and more relevant to the argument here, the emphasis turned from trying to understand how the brain performed certain operations, to trying to capture and use problem-specific knowledge *as humans do it*. This emphasis on knowledge, in turn, raised the interest in methods of *knowledge representation* to encode the knowledge applicable in particular situations. Two general types of methods for knowledge representation were investigated:

(a) *Declarative* knowledge representation methods which describe a situation in its context, identifying and describing all its elements and their relationships. *Semantic networks* were at the root of this approach; they were developed initially to represent the meaning of words (Quillian, 1968), describing objects in terms of the class they belong to (which itself may be a member of another class), their elements and their characteristics, using attribute relationships like "colour" and "shape", and functional relationships like "is a", "part of" and "instance of" (Figure 2.2).

Of particular importance is the *is a* relationship which indicates class membership, used to establish relationships between families of objects and to derive from them rules of "inheritance" between them. If an object belongs to a particular class, it will inherit some of its attributes, and they do not need to be defined explicitly for that object: because a penguin is a bird, we know it must have feathers, therefore we do not need to register that attribute explicitly for penguins (or for every particular penguin), but only for the class "birds".

Other declarative methods like *conceptual dependency* were really variations of the basic ideas used in semantic networks. *Frames* were like "mini" semantic nets applied to all the objects in the environment being described, each frame having "slots" for parts, attributes, class membership, etc. even

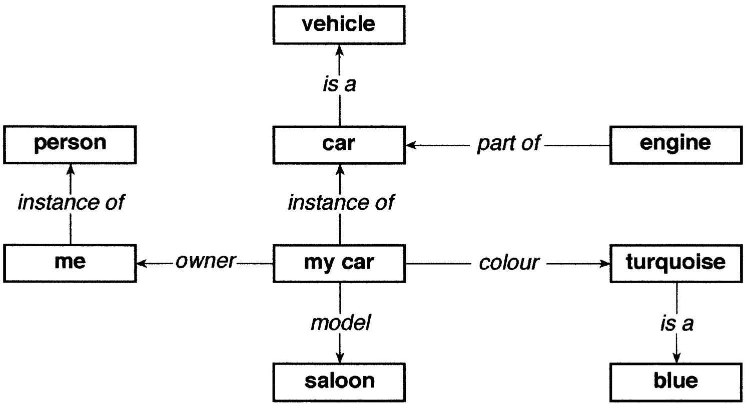


*Figure 2.2* A semantic network.
Source: Modified from Rich, 1983.

for certain procedures specific to them. We can trace the current emphasis on "object-oriented" approaches to computer technology to these frames and networks of the 1970s. Also, *scripts* were proposed to represent contextual knowledge of time-related processes, standard sequences of events that common knowledge takes for granted, like the sequence that leads from entering a bar to ordering a drink and paying for it. As with the rest of these methods, the emphasis is on common-sense knowledge that we take for granted, and which acts as backcloth to any specific problem-solving situation we encounter.

(b) *Procedural* knowledge representation, on the other hand, concentrates not so much on the description of a situation surrounding a problem, but on the articulation of how to use the knowledge we have (or need to acquire) in order to solve it. The most prominent of these approaches has been the use of *production rules* to represent the logic of problem-solving, "if-then" rules which can be used to express how we can infer the values of certain variables (conclusions) from our knowledge of the values of other variables (conditions). By linking rules together graphically, we can draw chains ("trees") of conditions and conclusions leading to the answer for the question at the top. These *inference trees* do not describe the problem but simply tell us what we need to know to solve it, so that when we provide that information, the solution can be inferred automatically. For example, a rudimentary tree to work out if a project needs an impact assessment might look like Figure 2.3.

A tree like this is just a representation of a set of "if-then" rules which might be worded like this: