The Maturing of AI: from Science to Technology and Back

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Artificial Intelligence used to be just a science, or a branch of computer science. It is now becoming a technology for the real world. This is happening at the right time, when the complexity of today's business environments increases faster than the human skills. In all industries or government bodies events happen at a pace requiring that the information infrastructure be adapted very quickly. This cannot be done with conventional techniques.

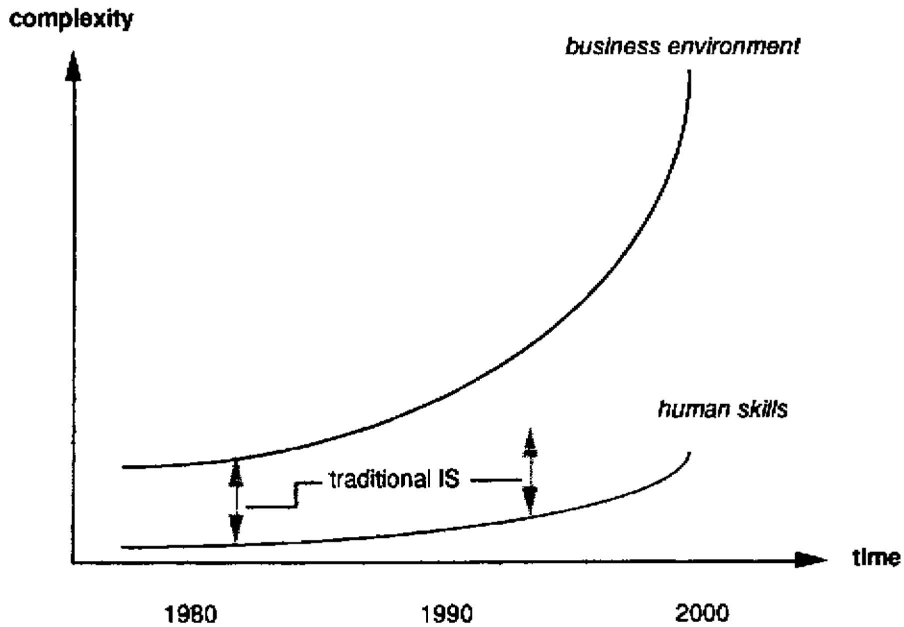


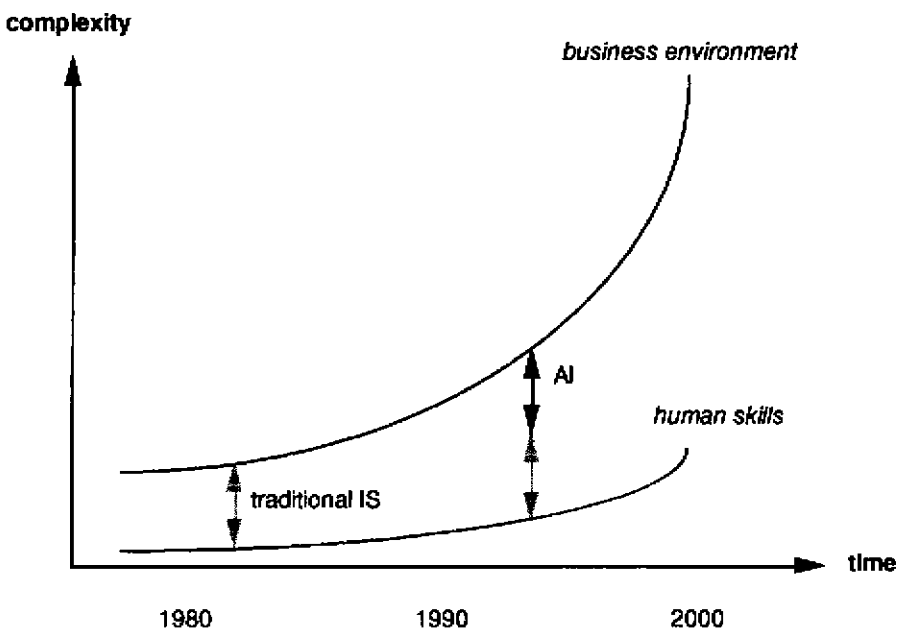
Figure 1. Evolving complexity of the business environments
(IS = Information Systems).

Until recently, modern information systems could withstand the demand of the users by somehow bringing more power than could be used, more languages and tools that could be learned. The remarkably rapid adoption of those new techniques, from computer-aided design to databases and personal computing software has generated complex environments requiring now a new level of computing. The infrastructures need to be managed, the software need to be glued, the productivity of application development needs to be increased, the development cycles need to be reduced. It is a combination of the systems complexity and the fluidity of today's business contingencies (that those systems help establish) that requires a new generation of software. Human skills simply cannot evolve fast enough, and need to be better used.

One can view most of the software written so far as extensions of the human's motor abilities. Even a computer-based transaction is a faster way to exchange goods or funds. A computer-aided design tool is an extension of the ability to draw. We have globally reached, across many tasks, a significant level of those motor extensions. They have changed the nature of the human acts, for instance from actually drawing to manipulating graphic objects.

It is clear that the environment we create evolves far faster than those limited resources. Undoubtedly, we need to either manage this environment or have it manage itself. This can only be done by manipulating knowledge; it is not just a research perspective for some future world; computing with knowledge has become a *natural* need arising from the complexity of the world we have built.

Many examples now illustrate that it is not *only* a need and that it is also becoming a reality. AI has emerged as the technology that allows us to bridge the gap, to adapt our existing environment to the rapidly changing conditions , and to create new software applications designed to be not only an extension of the physical body but also of the mind.



Furthermore, as shown in figure 2, the place of this new technology is on top of the existing one. There cannot be an "AI-centric" view of the world just as the mind without the body is meaningless.

Following are some examples of this evolving complexity. It is remarkable how fluid the world is, how small changes can have great impacts. If those global issues are not being addressed now by AI technology they are obvious candidates to its use. Indeed, they are directly part of the definition of today's business problems.

• Competitiveness: requires tools for better, enhanced productivity. For example, software design is a critical aspect of high technology, industrial design where the shape of the product is part of the product; there are also applications in design for manufacturability - expressing manufacturing constraints at the design level, reducing the manufacturing-design cycle.

• Deregulations: deregulations increase the degrees of freedom and the complexity of many businesses . In finance, the notion of automatically monitoring that foreign exchange transactions are within the right fiscal, legal and other boundaries is a very new type of application.

• Regulations: the natural counter-part of deregulations. The evolution of the health system and environmental concerns make the latter important candidates to the use of AI, but there are many other areas such as insurance, finance, telecommunications. The regulation/deregulation

• Geopolitics: political, economic and military contingencies are also rapidly changing, affecting policies, changing the directions of programs towards monitoring and verification for instance, re-assessing local and global issues. AI is being used already to measure the impacts of policy changes. But this also means in general an overload of information for the decision maker: classifying telexes or selecting news stories are now applications of AI which directly help in coping with vast amounts of information and bring them down to a manageable level by decision-makers.

It is important to convey the actual emergence of this technology as a major component in a broad spectrum of activities, as an invasive process demonstrating and increasing participation of AI in our information infrastructure. To illustrate this point, I have used a knowledge acquisition tool, NEXTRA (Rappaport and Gaines, 1990) on the data provided by this second IAAI international Conference. The interviewing module allows to identify and focus on important and in this case rather general characteristics of applications at this innovative frontier of AI.

For instance, an application can be made for very specialized processes while another one can apply to a more common or everyday task, or to a task likely to impact more people. An application can be either in a well known domain or illustrate the penetration of AI in a totally new domain. The applications of this conference were thus rated along those dimensions. Figure 3 shows an example. The various applications are named by topic and the dimension spans from very specialized types of applications on one end to more general ones, more likely to be used (whether they know it or not) by many people.

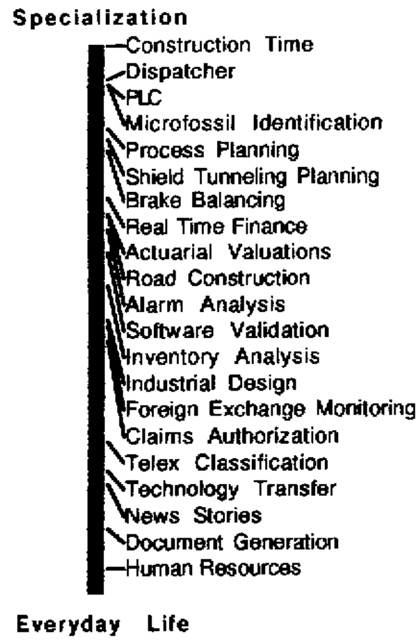


Figure 3. Scaling of applications along one attribute

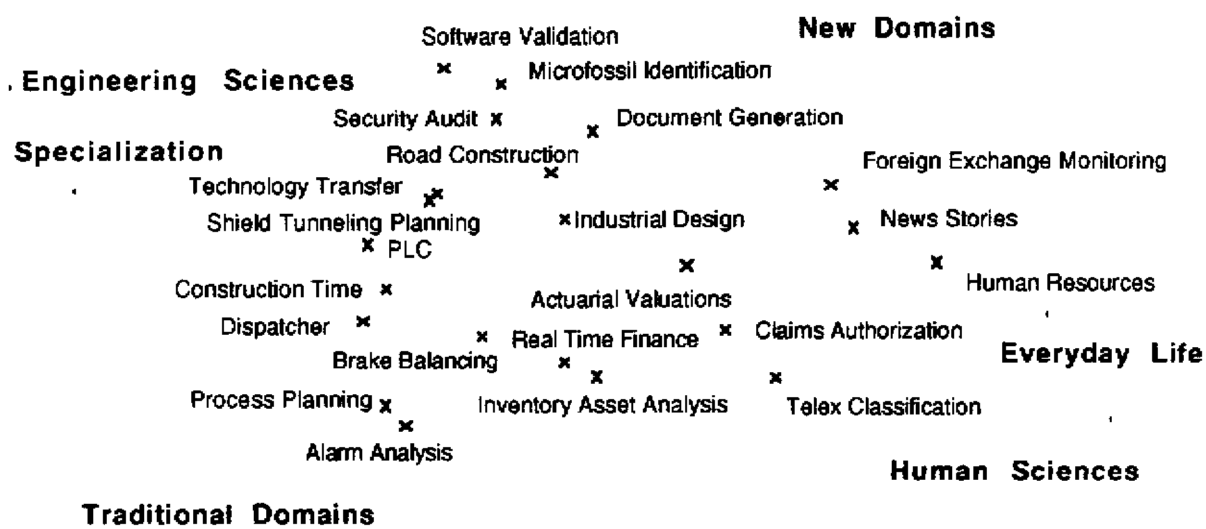


Figure 4. Map of applications (topics) and their dimensions

From such ratings, an actual map of how these applications relate to each other as a function of those dimensions can then be generated, by means of a multi-dimensional scaling operation, using the same interactive tool. The result is shown on figure 4. It represents a *space* of applications with regions characterizing the applications they contain. Naturally, such a map is dependent upon the ratings provided by the user. The existence of different maps obtained from different experts or interviewees can be the source of a consensus analysis. We will consider and discuss here the map we obtained.

The knowledge acquisition tool acts as an *information lens* on the data. The process of analyzing such maps is what we call "topological induction", i.e. the notion of interactively deriving knowledge by manipulating data and deriving inferences from changes in the representation of the space. Our purpose here is simply to observe the data through that lens. We can now distinguish clusters of applications and their relative meaning or positioning.

Most important, the uniform distribution of applications on the map indicates this continuous use of AI techniques along a wide spectrum of industries and services.

Furthermore, the diagram also shows that developments in AI are not merely tactical anymore, they are not the simple offshoots of some margins of the computer industry. Rather, they are strategic; before there is even a large population of such applications one can find them in virtually all domains of the industry, commerce and government. It is a global process, even if still very local within each sector of activity.

By focusing more closely on the new domains region we can observe domains that AI has penetrated in light of those new applications (figure 5).

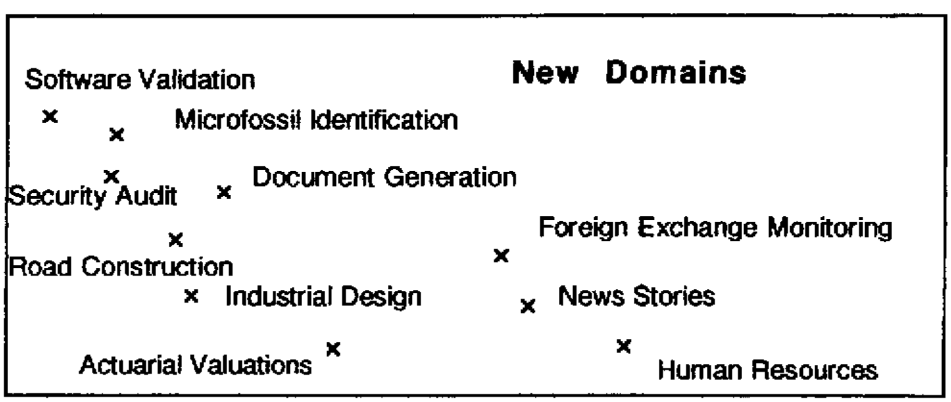


Figure 5. One region of the map, characterized by New Domains

Following are some brief details about some examples of the above region of the map.

- **Foreign Exchange Monitoring**

  This application's novelty (Byrnes et al., 1990) lies in both its implementation aspects and its professional implications. It is an embedded system which performs a safeguard role in the background of the international trading activities involving from small to very large transactions. This is also an example of AI techniques integrated with other standard technologies. The payoffs are also unusual: they are mainly preventive, but a single discovery is likely to be worth many times the investment in building the system.

- **Software validation**

  Comparing text output by regression testing programs is the subject of this application (Jechart et al., 1990). The comparison criteria, instead of being left to the expert are now embedded in the comparison software, enhancing productivity. This is a precursor application of what will be the increasingly important role of AI techniques embedded in software engineering tools.

- **Microfossil Identification**

  This domain is certainly new to most people; it is well known, however, to the oil industry where it is critical for oil exploration. The application helps to visually and rapidly identify what type of microfossil is present at a drilling site (Swaby, 1990). It is a good illustration of how very specialized and narrow scientific domains can be of critical importance to a whole engineering process.

These three applications illustrate the issue of AI to help reduce the complexity of a domain or task. Focusing now on another corner of the map, here are some domains where AI is obviously making its way and which are more likely to affect some aspects of our daily life:

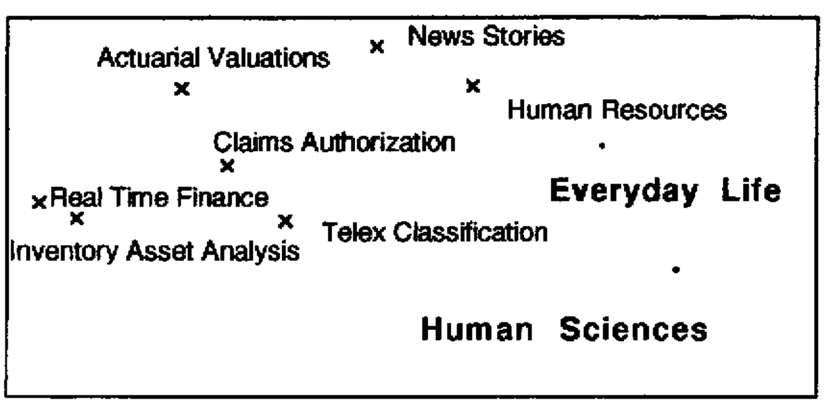


Figure 6. Region of the Map

- **Human resources**

An application in human resources (Tokuda, 1990) allows the intelligent dispatching of resumes sent to a firm to the right individuals who have the needs for that individual. We all know how human resources and hiring is critical to many companies. The combination of search, OCR systems and other office automation tools is indicative again of this component role that AI systems are taking in either existing or new computing infrastructures.

- **News stories indexing**

Streams of news, indicators and other numbers or images have become part of the daily business environment (Hayes, 1990). Electronic text volume increases and it becomes critical to those using such information to correctly classify and index it. These on-line systems are used by an increasing number of professionals who rely on rapid access to information, from details to global events or trends, to make decisions. They could easily face and unmanageable amount of information.

- **Telex classification**

Other techniques are now put to use to help in this general problem-solving framework. Case-based reasoning is one such recent technique efficiently put to use to classify telexes according to their content (Goodman, 1990) This is another case of AI as a technology put to use to manage interactions and the flow of information.

Concerning the addition of AI to a large spectrum of existing technologies and products, there is little doubt that many of those technologies such as databases, document processing or CAD are under-used; they require to be adapted to the mental model of the user or the organization in order to be efficient. These applications reflect this trend. They also reflect, like the foreign exchange and the resume systems or others in this conference, the close integration of AI with existing products that are established traditional technologies. There is even less doubt that the needs and the expectations we have as citizens, individual consumers, or organizations have shifted towards a *customization* of the products we want to use. That is the need to have things function the way we want, the desire to almost design the products ourselves, be they hardware or software.

Incidentally, we are also witnessing a rapid extension of some basic definitions. Only a few years ago, hardware meant chips for computing and software meant lines of code. Hardware now covers a much broader spectrum going from the computers to the video-cameras to HDTV broadcasting and smart cards or teller machines. Software is also extended from code to sound, movies and knowledge bases. AI will play a major role in the integration and expansion of these technologies. We are already witnessing a transition in AI, from the traditional problem solving where the problem is pre-defined to a looser, no less complex however, problem solving where it is simply an extension of the mind, from the perceptual to the executive levels, that is needed to carry out activities. We like to call this the "injection" of knowledge in existing computing environments. Systems can have those new resources, extending their capabilities to applying chunks of knowledge, to adapting to new situations or to perceive new patterns.

Basically, there is a lot of excitement in AI these days. Different AI paradigms and architectures turn out to be very complementary with the expert system's approach. There are new approaches based on integrating different AI techniques (Smith, 1990). In general one should expect important developments in the areas of machine learning and knowledge acquisition as well in the future. In machine learning it has become important to design with the notion of operationality in mind. In knowledge acquisition it has become critical to build practical techniques which can stand the trial of real developments. We should soon see significant applications including machine vision and speech as well as making use of AI for program synthesis.

What is changing is the definition of progress in the field. It now includes real world testing and integration. Fundamental research results need to undergo a software engineering process that turns them into technologies that can be tested within real environments, much like the process of being able to clinically test a drug. The clinical trial of AI is proving most successful. This is why we can speak of going from science to technology and back. Examining the designs, results and impacts of real-world applications are fundamental for the good design of future software technologies in AI. This feedback is important, like in all mature scientific and technological fields, to the scientific progress. It is time to close this loop, from the science to the technology and from its applications back to the science.

We are certainly still in this interesting zone where different concepts and perspectives are still tried out while important application are nevertheless being developed, fielded and assessed as part of the competitive arsenal of major companies. There are still some applications which will be too hard to replicate while others are showing the way. There are also good indications that it will be difficult to design future software without embedding this new dimension in them.

To doubt that AI, in all its different facets, is rapidly becoming a basic technology critical to address the complexity we have generated and that we must manage efficiently, is, in our view, to speak against all evidence.

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