Matching the Infoverse:
About Knowledge Networks, Knowledge Workers, and Knowledge Robots

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Humans are not able to cope with the exponential growth of information and the increasing speed of information and business processes fostered by information and communication technologies. Technical support not only for information storage and retrieval but also for information selection, process planning, and decision support is needed. Moreover, the use of a (desktop) computer is restricted in many ways. In this paper, it is predicted that smart and mobile computing units embedded in a variety of things, such as TV sets and cars, will bring computing power close to their users. It is also predicted that users will get closer to computing power by using natural language and by using their social skills in computer mediated communication. A holistic architecture of knowledge robots (knowbots) is described based on multi-agent platforms and distributed computational intelligence. Knowbots consist of a self-learning artificial brain, speech recognition and synthesis, direct access to other software agents and computer programs, and direct connections to networks of human users. It is pointed out that a newly defined partnership between men and machine is a possible way to keep control of the exploding 'infoverse'.

Reasoning and simulation mechanisms of currently unthinkable complexity will take over the control of process planning and information exchange. Fourth generation robots with the capability of performing more than 30 million instructions per seconds (MIPS) will be the heart of a company's knowledge base. This is the vision propagated by Hans Moravec, Principal Research Scientist at the Robotics Institute and Director of the Mobile Robot Laboratory of Carnegie Mellon University, Pittsburgh (USA).

The global economy gets accustomed to the idea of the 'new economy' where the knowledge workers' creativity and skills are the companies' most important capital and competitive advantage. If only parts of Moravec's vision come true, however, it will certainly mean that the relevance of human expertise and experience will diminish. Current developments seem to support this point of view: A supplier of computer storage systems reports that especially banks are consuming more storage space within six months than has been used during the last twenty years; the increasing speed of product innovation and life cycles depreciate technological knowledge and skills within one to three years.

The 'infoverse' stored in the worldwide Internet starts to exceed the amount of information that has been stored in more than 60,000 years of human culture before: It has been estimated that in the years 1972 to 1980 more information has been collected than in the 2000 years before. Fifty years after the publication of the first Gutenberg bible about two million books had been published; today, more than 3000 books are published per day, more than one million per year. Some authors, therefore, are discussing the advent of the 'age of knowledge'. Others, however, argue that the Internet is not more than a gigantic heap of information garbage.

Recent studies show that we are not able to remember more than one to two percent of all the information we perceive in the mass media, such as radio, TV, or newspapers. A single search engine covers not more than about twenty to thirty percent of the World Wide Web pages, meta-search services using more than one search engine comprise about fifty to sixty percent of the WWW pages. Even the best text searching and indexing techniques do not come up with more than 25 percent of relevant links or search results, that is, an optimal search process accesses a quarter of a half of the information in the Internet - and one or two percent of this information can be remembered. Thus, we have to state that we have lost control over all the information gathered in technical systems.

Exponential growth of information, information access at light speed and the increasing speed of business processes and the decreasing value of human knowledge force to re-focus the development of information and communication technologies (ICT). Information accessibility is no longer the main concern, but navigation, orientation and selection of relevant information. As computers and robots provide us with incredible capabilities to process increasing amounts of data within decreasing periods of time, it seems clear that we can only master the self-made 'information overload' if we manage to enhance our skills by developing a real computer-man dialogue and partnership.

The key topics of this new level of CMC (computer-man communication) is a mobile, ubiquitous and selective information access enabled by smart software agents based on multi-agent platforms using distributed computational intelligence. We are now at a turning point in our cultural development where sustainable progresses can only be made if we are able to delegate information retrieval, process planning and decision support to technical systems. We have to decide whether we want to become garbage collectors within heaps of information - or the human masters of smart agent systems which we do not fully understand.

If it works, it's not AI

Up to now, the progresses of the so-called Artificial Intelligence (AI) have been disappointing. A recent study about the commercial success of AI startup companies comes to the conclusion: 'If it works, it's not AI'. This assumption has been reflected in the revenues of AI corporations during the last decades (cf. figure 1). The strong position of AI is to develop machines that are intelligent in a human way. The weak position of AI is to implement programs that can be viewed as 'partly intelligent' because they are able to perform actions that used to be dedicated to human workers. This mode of AI is now referred to as 'Computational Intelligence' (CI). Patricia Churchland pointed out that we are at a stage where the strong AI position tries to mimic human intelligence in the same way the first pioneers of flight tried to mimic the birds' way of flying. As no modern airplane or helicopter is flapping its wings, it is clear that solutions enabling flight are not relying on flapping wings but on a proper lift. So, what might be a way to lift the weak position of AI to a higher level?

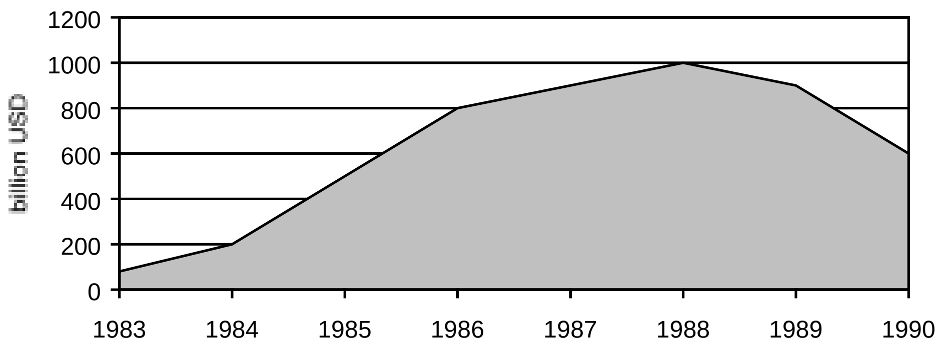

Figure 1: Approximate AI revenues (Philipps, MIT, 1999).

In 1998, the non-profit association 'Institute of New Media' and Bank Academy, a non-profit educational institution of the German bank associations, formed a joint venture to implement and test new ways of autonomous software agents which could help learners and knowledge workers in information intensive industries, such as banking and finance. At the beginning of the year 2000, Knowbotic Systems Inc. Ltd. was founded by the Institute and the Bank Academy. The purpose of this company is to develop and to examine knowledge robots or 'knowbots' which help to fully exploit the knowledge capital of a company by facilitating information selection, planning and decision making. The mission of Knowbotic Systems relies on two basic assumptions: (1) As long as key concepts, such as 'learning' and 'intelligence', are not fully understood and clearly defined, computers won't be intelligent learners. Therefore, a formal learning theory has to be deduced from recent theories and empirical studies in order to set up a virtual testing environment for knowbots which helps to measure their adaptability and to extend their learning capabilities. (2) The critical lift of CI will not come if a system is intelligent in itself, but it comes from the human capability to communicate with such a system in a intelligent and social way. Thus, knowbots have to mimic intelligent communication behavior in order to transfer the results of machine learning and machine reasoning to human users (cf. figure 2).

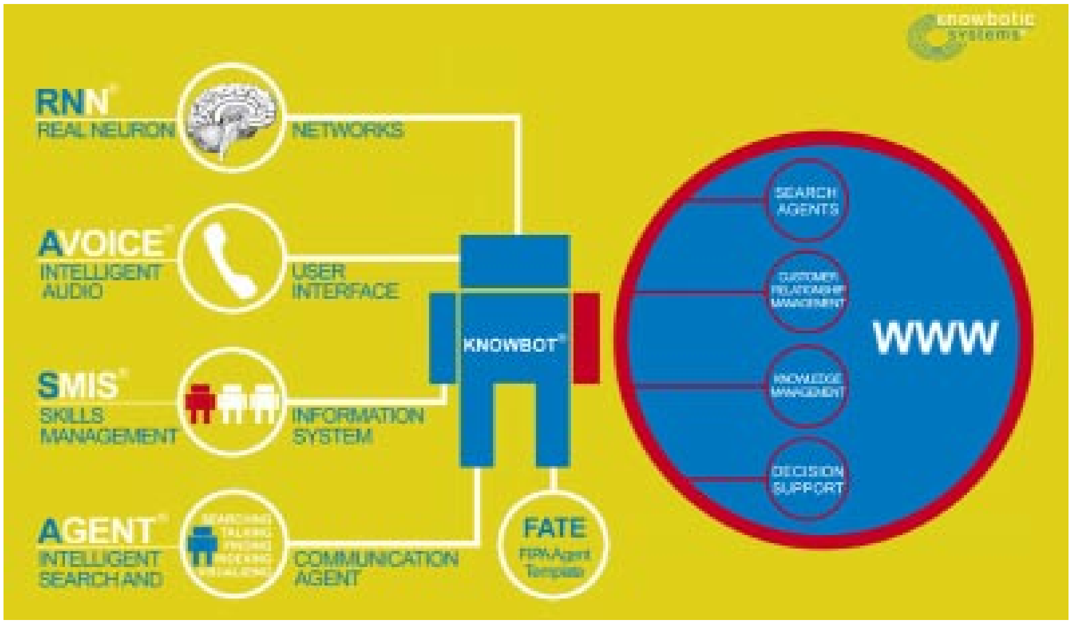

Figure 2: Knowledge robots (knowbots) are bridging the gap between technical information and data collections (right) by using artificial brains (RNN), ears and voice (AVOICE) and connecting information (AGENT) and people (SMIS) based on the multi-agent platform FATE.

The artificial brain

Most programs which mimic intelligent behavior are based on logical oriented knowledge-based techniques which proved to be too inflexible to represent even primitive forms of learning. Moreover, they elicit a number of paradox behavior when applied to support human learning. In classical AI different forms of logical based representational schemes are used and in connectionism researchers adhere to different types of artificial neural networks (ANN). ANNs have achieved some success in non-linear forecasting, pattern matching and in artificial life paradigms. But ANNs still lack many of the vital features of biological neural networks (BNN), such as the ability of real neurons to allow self-modification with regard to short term and long term learning. The simulation of BNNs developed by neurobiologists does not seem to be promising either because recent attempts have shown that exact simulations of neuron brain cells consume a vast amount of computer resources. For instance, 18 hours of computing time on five connected Sun Sparc workstations is needed to simulate one second of the activity of a single neuron.

Knowbotic Systems combines the behavioral perspective with the physiological perspective, both embedded in concepts of learning and sign based communications (or Semiotics). We call these self learning and sign-using systems 'knowbots'. The physiological structure is the main cause for observable behavior. Thus, we have to find a model of the human brain neuron which should be empirically more sound than the classical ANNs and should also be still practically feasible on 'ordinary' PCs. Knowbotic Systems' RealNeurons® almost perfectly simulate human brain cells with respect to the height of the potentials, the timing of the processes and the concentrations of chemical substances involved. Moreover, our neural networks can model the local and global influence of hormones and psycho-pharmaceutics on brain cells. We are modeling only those properties of biological cells which are most likely underlying learning of new behavior patterns.

Only a few BNNs underlying learning, however, have been identified yet. As a first test case we have chosen a classical conditioning circuit and several candidates that might be responsible for operant conditioning. In first experiments we implemented the network which represents the eye blink reflex of a rabbit. The network matches the neuropsychological data almost perfectly (cf. figure 3): The connection of the unconditioned stimulus (US = air flow) and the conditioned stimulus (CS = sound) is learned in a few trials, if the CS is given slightly before the US. Several runs presenting the CS without the US extinguish the connection. It is re-established very quickly, if the CS and the US are displayed together again. This means, that not only the neuro-biological structure of brain cells can be simulated on a PC, but also basic learning behavior which perfectly matches empirical data.

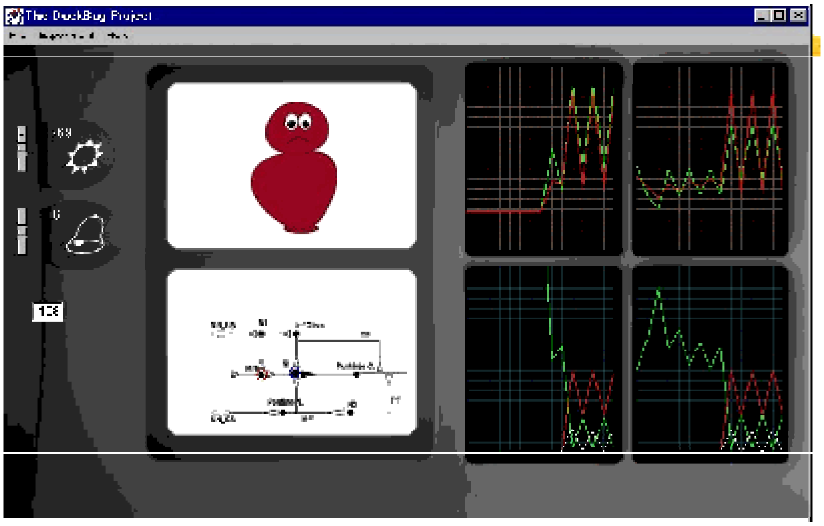

Figure 3: Test environment for (classical and operant) conditioning experiments with Knowbots based on artificial biological neural networks implemented with Java.

The artificial body

The artificial brain cannot communicate to humans and environments without a body. Robotics' research has shown that intelligent or adaptive behavior is based on a close interaction with the outside world. Moreover, the measure of learning or intelligence clearly depends on observable behavior corresponding to well defined learning tasks and environments. Knowbotic Systems, therefore, concentrates its technical developments on interface technologies which facilitate the access to knowbots by human users. The most important way to communication is speech. Knowbots are equipped with the speech recognition and synthesis system *AVOICE*. The speaker independent speech recognition is able to identify about fifty words in five different languages at a time. As the word recognition can be adapted according to the actual context, this small amount of words is sufficient to implement small navigational or command systems. The speech recognition unit may also be trained to understand a specific user and it is then capable to handle dictionaries of several hundreds or thousands of words. The speech synthesis can read any text, such as HTML pages, tables or documents. The user can choose between several 'speakers' with different pronunciation or intonation. In summary, AVOICE equips knowbots with a - still limited - human ear and voice. Knowbots, therefore, connect their users directly to all the information stored in the Internet, regardless whether they hook onto the Internet via a computer, a telephone, or a mobile phone.

Knowbots can also move around in the Internet, access data bases and organize their user dialogues. This is done by *AGENT*, an intelligent search agent and dialogue manager. The search agent is able to act as a search robot and a crawler in the World Wide Web. It can also get access to data bases or transform graphical information into text information. Thus, AGENT provides knowbots with a variety of ways to 'perceive' the virtual infoverse of the Internet.

The artificial environment

Up to now, there is much more talking about the irreplaceable value of the human capital and knowledge than taking actions to maintain and support the development of this capital. Most technical systems concerning the human capital of a company focus on the administration of personnel and training, such as SAP Human Resource modules, Peoplesoft or SABA - just to mention a view of them. An US-American study lists about 300 systems for training administration and delivery. But finding matches of needs and demands in the infoverse certainly means more than matching keywords to indices or user profiles to software agents. The knowledge economy is not so much about information, it is about people. Knowbotic System is, therefore, engaged in a jointly initiative of several partners to implement a Skills Management Information System called 'SMIS'.

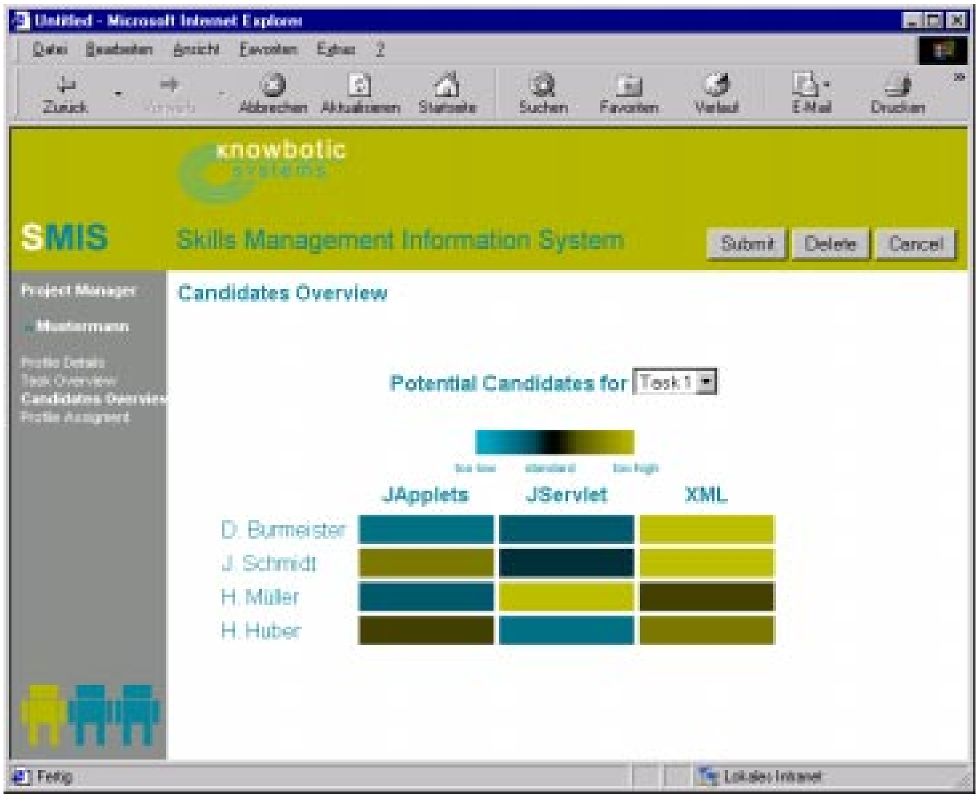

Figure 4: Screen shot from the Skills Management Information System 'SMIS' - the candidates overview lists possible candidates for a project tasks in acolored table indicating skills below or above the standard.

Human users, the users of information systems, visitors and creators of the infoverse, are the main 'component' of a knowbot's environment. Additionally, other knowbots or standardized software agents may also enrich the knowbot environment. For this purpose, Knowbotic Systems has developed one of three worldwide available multi-agent platforms based on the FIPA standard (FIPA = Foundation of Intelligent Physical Agents). The platform *FATE* (FIPA Agent Template) comprises templates or suits which allow programmers to convert nearly any computer program into a software agent, that is, the knowbot technology provides easy-to-use ways to introduce a large variety of programs into the virtual learning environment. FATE also allows to run several platforms on different Web sites. This enables knowbots and other agents to communicate, move or replicate themselves all over the World Wide Web.

The (artificial) future

We envision future developments in networked computing and distributed computational intelligence where the users are no longer forced to adapt to the computer. The computers will adapt to the human capabilities to perceive and process data. The communication between and with computers will adapt to the human way of communication, namely natural language. And computers will be accessible at any time from any point with any device, such as handhelds, laptops, or mobile phones. Computer networks will also become people networks, taking into account specific deficits and potentials of computers and humans.

Knowbots are one of the few holistic visions of a man-machine dialogue in its actual sense, dedicated to support humans where they need help to access and select information - and to learn from them. But knowbots are not the only development in this field. A new level of smart agents and self-learning machines will develop in the near future. Figure 5 summarizes some major developments which are expected in the near future. Among them are software agents, mobile computing, and speech control. But, most of the forecasts of technological growth and development turned out to be too conservative.

2004	2005	2006	2007	2008	2009	2010
Ubiquitous online learning in universities	Online learning in schools (K12) Interactive communities in the WWW Increasing use of eCommerce	Software agents to search and select information Interactive TV for big audiences	Increasing use of speech recognition and synthesis Central remote control station for 'intelligent buildings'	Increasing use of electronic cash Broadband access to information	Mobile computing and eCommerce	Self-learning software agents 3D virtual reality

Figure 5: Some major developments in interactive media in the next ten years according to a recent study of the Fraunhofer Gesellschaft (Institut für Systemtechnik & Innovationsforschung).

Up to now, many individuals and companies are fascinated by the potentials and the exponential growth of the Internet. We do not think that future generations will be too enthusiastic about slow networks, unstructured information heaps and poorly equipped online shopping malls. Smart computers will be part of our every-day life, will be part of houses, cars, TV sets, refrigerators, bags, and suits. As a matter of fact, many ordinary machines are based on so-called embedded systems, that is, a small specialized computer. So, the things start to become computational things - and they will be smart things in the future. Knowbots and other smart agent technologies will support work, leisure and even cultural or social entertainment. Computers in the form of smart things will make computational intelligence as ordinary as cars or TV sets. But if the computers get nearer to their users, at the same pace the humans will get nearer to the computers: Not individual human beings nor software agent platforms will be the masters of the infoverse, but partnerships of robots, knowbots, and humans.

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