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# Advances in Computer and Information Sciences: From Abacus to Holonic Agents

**Tuncer ÖREN**

*School of Information Technologies, Univ. of Ottawa, Canada and  
Information Technologies Research Institute of  
TUBITAK Marmara Research Center  
Gebze-Kocaeli-TURKEY*

## Abstract

*The shift of paradigm emphasizing the importance of the ability to process knowledge rather than being knowledgeable is stressed. A taxonomy of knowledge processing tools, machines, or systems is offered. Major possibilities for future achievements that the author would like to underline are listed with emphasis on agent technology, agent-directed simulation, holonic agents, holonic-agent simulation, and contribution of system theories for cognitive abilities such as understanding, learning, adaptation, and anticipation in computerization.*

**Key Words:** *shift of paradigm, taxonomy, system theories, agents, holons, agent-directed simulation, holonic-agent simulation*

## 1. Knowledge, Knowledge Processing, and the Shift of Paradigm

For a long time in the history of civilization, being knowledgeable was an important asset. Information age realities provide tools to store and interactively access a vast amount of knowledge. Hence, they challenge the value of being knowledgeable (in the sense of storing in human brain a vast amount of facts, alone).

For example, almost half of the books I have in my private library are on a single CD-ROM (Corel 1995). It contains over 3500 classical books that are searchable interactively. 32 volumes of Encyclopedia Britannica are on two CD-ROMs (EB). Recent announcements of some encyclopedia include, for example, Encyclopédie Hachette 2001 which comes in three CD-ROMs or one single DVD-ROM (Hachette 2000). Similarly, Encyclopedia Universalis, planned for release at the end of October 2000, will come in five CD-ROMs or in one single DVD-ROM (Universalis 2000). In the beginning of the advent of notebook computers, we had a transition period during which the volume of the documentation of the software loaded on the computer was much larger than the volume of the computer itself. Nowadays, the documentation resides on the hard disk. Similarly, all the knowledge we get through formal education can reside on a single CD-ROM where the knowledge can be stored for interactive search without any loss. Libraries were places to work as repositories of human knowledge. Now, information technology shrinks drastically the storage requirements and offers interactive search capabilities. Furthermore with Internet, geography became history;

with a single search command we can collect information from sources that we do not need to know their geographic locations.

Independent of the medium on which knowledge resides—paper, CD-ROM, DVD-ROM, or hard disk—information age has brought its own shift of paradigm: knowledge processing ability became more important than knowledge itself. Indeed, knowledge is necessary but not sufficient to solve problems. For example, no library or no CD-ROM can solve a problem. Therefore, knowledge processing and especially cognitive knowledge processing have to be explored to get the benefits of computerization. A taxonomy of over 500 types of knowledge and knowledge processing knowledge was given by Ören (1990).

## 2. Knowledge Processing Everywhere

Knowledge processing is done by two types of machines or systems: machines for knowledge processing and machines with knowledge processing abilities. Each group can further be divided into three categories, namely, fixed-wired tools or machines, variably-wired tools or machines, and stored-program tools or machines.

### 2.1. Machines for Knowledge Processing

These types of tools or machines are built for the sole reason of knowledge processing.

*Fixed-wired tools or machines for knowledge processing* have existed for a long time and the archetype, the abacus still exists. The relationship of the elements are fixed. As an abacus would inspire, they are indeed fixed-wired tools. Some other examples of fixed-wired knowledge processing tools are: astrolabe (Nasr 1976, Bott 1983), Al-Biruni's gear calendar computer and odometer (Price 1984), and bar-linkage computers (Svoboda 1965).

*Variably-wired tools or machines for knowledge processing* include unit record machines (also called punched card machines), analog computers, and hybrid computers (de Beauclair 1968, Fröschl et al. 1993). When I started to work for a computer company in Turkey in 1963, unit record machines were in use as there was only one computer in the country at the time.

*Stored-program tools or machines for knowledge processing* are basically digital computers with all the variants: personal computers, notebook computers, digital assistants, palm computers, and wearable computers. Paraphrasing Kay (1984) who stated "Computers are to computing as instruments are to music," we can define a computer as an instrument to execute programs. Computers are already used extensively. But it seems this is only the beginning. (Ören 1990, Denning and Metcalfe 1997).

### 2.2. Machines with Knowledge Processing Abilities

Primary goal for machines with knowledge processing abilities is not knowledge processing; however, with their knowledge processing ability they can perform their task much better.

*Fixed-wired tools or machines with knowledge processing abilities* include several types of historic automata (al-Jazari 1205). Akman (1976) re-introduced Turks to the works of al-Jazari.

The archtypical example to *variably-wired tools or machines with knowledge processing abilities* is the Jacquard loom. The machine under the control of punched 'cards' could weave different patterns. Furthermore, the punched cards used by the Jacquard looms were the inspiration for the punched card knowledge processing machines: first the unit records and afterwards the punched card computers.

*Stored-program tools or machines with knowledge processing* abilities are the most important applications. They can be computer-embedded machines (CEM) or computer-embedded systems (CES). When the emphasis is on the computer, they can be referred to as embedded systems. CEMs or CESs are the essence of intelligent machines (Kurtzweil 1990) and can automate functions at different degree of sophistication:

1. In some systems, parameters and some other values can be set based on some automatically measured/computed values (e.g., in a camera, to set film speed, to measure and set distance, to measure light and to set the lens aperture and shutter speed, and to automatically fire the flash); another example is reprogrammable pacemakers that existed since a long time as a forerunner of implantable computers.
2. Intelligent cars, utilities, and buildings can have several functions performed by the embedded computers.
3. Optimizing systems such as a tracking missile can perform its mission with a high degree of effectiveness.
4. Knowledge-based, rule-based, or agent-directed systems can benefit from their advanced knowledge processing abilities.
5. Simulative systems can evaluate, via embedded simulation ability, the outcome of different alternatives and can automatically select most desirable one.

### **3. Energy Transducers, Programs, and Their Synergy**

Perceiving the similarities of energy transducers and computer programs may offer new vistas and may facilitate the comprehension of their synergy (Ören 1990).

#### **3.1. Energy Transducers**

An energy transducer, commonly used in engineering, is a device which can perform three possible types of function. In all the functions, the input to an energy transducer is energy. An energy transducer can perform one of the following functions:

1. It can convert one type of energy into another type. For example, a piezoelectric crystal can convert pressure into electric current.
2. It can provide knowledge about the input energy. Some measuring devices use this feature. For example, a tire gauge can accept as input pressure in the tire to provide a read-out of the pressure.
3. It can process an input signal based on a secondary signal to perform one of the above mentioned two functions (to either convert the signal into another one with different characteristics or to provide knowledge about it).

#### **3.2. Knowledge Transducers**

Similarly, a computer program-as a knowledge transducer-can accept (different types of) knowledge as input and can perform one of the three functions:

1. It can convert the input knowledge into output knowledge. For example, a translator can transform a program written in a high level language into a program written in a lower level language.
2. It can provide knowledge about the input knowledge. For example, a compiler can generate data dictionary of an input program.
3. Based on some knowledge, another body of knowledge can be processed. For example, based on a query, a data base can be searched to provide either the documents and/or knowledge about them.

A cognitive program (an AI program) may have three types of input and two types of output (Ören 1990): The inputs can be forced input, actively perceived input, and endogenous input.

1. *Forced input* is customarily called “input” in conventional programming.
2. *Actively perceived input* is basically knowledge actively perceived, filtered, and accepted as input by the knowledge processing system.
3. Endogenous input is generated by the knowledge processing system and is accepted as stimulus or input to trigger knowledge processing. Examples of endogenous input can be based on anticipation of future, generation of questions, and formulation of hypotheses.

Outputs of a knowledge transducer can be primary and auxiliary outputs.

1. *Primary output* is generated based on the knowledge processing goal of the system.
2. *Auxiliary outputs* can provide guidance, advice, explanation, and certification.

### 3.3. Synergy of Energy and Knowledge Transducers

The second characteristic of energy transducers make them a good source of data. Therefore, energy transducers in sensors, can provide data to knowledge processing systems. Sensor fusion refers to multi-channel input when there are more than one type of sensor. Especially, systems/machines with knowledge processing abilities can have on-line input from their environment.

## 4. What’s Next?

Computers are still very young. For example, Konrad Zuse’s computer dates back 1936 (Dorsch 1989). We can expect to have advancements on many fronts. An excellent book prepared on the 50th anniversary of the field of computing provides a review of past achievements and future projections (Denning and Metcalfe 1997). Some major possibilities for future achievements that I would like to emphasize are:

1. Software *agents* provide a solid computational paradigm to implement software assistants working (quasi-) autonomously and having perception abilities to observe the existence or lack of some characteristics or events and other abilities to affect their environments. Furthermore, they can process goals and can perform goal-directed knowledge processing. Types of agents and agent-related terms are given in appendices 1 and 2, respectively, to show the many aspects of the field. To appreciate agents, one can consider different software engineering paradigms: batch processing software, interactive software, event-based software, and agent-based software. In agent-based software, agents can trigger events to perform knowledge processing on behalf of the user.

2. *Mobile agents* and distributed computing extend the concept of computational platform to whole or part of the net on intranets and on the Internet.
3. System theories provide strong backgrounds for cognitive, i.e., intelligent, computerization. For example, systems with *understanding* abilities (Ören 2000a), systems with *learning* abilities (Osherson et al. 1986), systems with adaptation abilities, and systems with *anticipation* abilities (Dubois 2000) would provide bases for cognitive knowledge processing. Agents are natural candidates for the implementation of systems with cognitive abilities.
4. *Cooperation* is becoming an important paradigm for both civilian and military applications. Holonic systems are excellent candidates to conceive, model, control, and manage dynamically organizing cooperative systems. A *holonic* system is composed of autonomous entities (called *holons*) that can deliberately reduce their autonomy, when need arise, to collectively achieve a goal. A *holonic* agent is a multi-agent system where each agent (called a holon) acts with deliberately reduced autonomy to assure harmony in its cooperation in order to collectively achieve a common goal.
5. *Agent-directed simulation* is very promising and consists of agent simulation, agent-based simulation, and agent-supported simulation. *Agent simulation* allows simulation of natural or engineered entities with cognitive abilities. Therefore, agent simulation is very appropriate for the simulation of intelligent entities. *Agent-based simulation* is use of agent technology to generate behavior of models. (Parallels with AI-based simulation are knowledge-based simulation, qualitative simulation, and rule-based simulation.) *Agent-supported simulation* is use of agent technology to support simulation activities; they comprise front-end and back-end activities of a modelling and simulation environment, agent-supported validation and verification, as well as agent-supported program generation, program integration (as it would be the case in the formation of federations using HLA), and program understanding for documentation and/or maintenance purposes.
6. *Holonic agent simulation or holon simulation*, in short, is an important type of agent simulation where agents represent holons. Some military application include use of simulation for preparedness for conflict management including conflict avoidance, conflict resolution, and conflict deterrence. Civilian applications include modelling and simulation of cooperation of different business entities.

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## APPENDIX 1 - Types of Agents

adaptive agent	endomorphnic agent	pro-active agent
animated agent	errant agent	purposeful agent
antagonistic agent	ethical agent	rational agent
anticipatory agent	fixed agent	reactive agent
application agent	fuzzy agent	reliable agent
application suite agent	global agent	remote agent
authorized agent	goal-directed agent	resident agent
autistic agent	goal-oriented agent	retrieval agent
autodidactic agent	holonic agent	root agent
autonomous agent	independent agent	rule-based agent
autoprogrammable agent	individual agent	scriptable agent
believable agent	information agent	search agent
bot	information filtering agent	self-motivated agent
broker	information gathering agent	self-replicating agent
client agent	information spider	semi-autonomous agent
cognitive agent	intelligent agent	service agent
co-located agent	interface agent	sociable agent
communication agent	Internet agent	software agent
competent agent	itinerant agent	spider
competitive agent	knowledge-based agent	stationary agent
complete agent	learning agent	system latency agent
computational agent	local agent	task-specific agent
computer interface agent	long-lived agent	teachable agent
computer-controlled bot	loosely coupled multi-agents	temporary cookie
contractee agent	mail agent	tightly coupled multi-agents
contractor agent	message transfer agent	tracking cookie
conventional agent	messaging agent	transient agent
conventional software agent	mobile agent	transportable information agent
cookie	mobile agent	trusted agent
co-operating agent	model-based agent	trustworthy agent
co-ordinator agent	multiple agent	unauthorized agent
coupled multi-agents	multiple mobile agent	understanding agent
deliberative agent	network agent	uniform resource agent
desktop agent	neural net agent	user agent
diagnosis agent	notification agent	user interface agent
digital agent	offline delivery agent	user-programmed agent
dispatched agent	pedagogical agent	vivid agent
dispatched mobile agent	persistent cookie	wanderer
distant agent	personal agent	Web search agent
distinguished agent	personal digital agent	Web site agent
domain-specific agent	personal software agent	
emotional agent		



## APPENDIX 2 - List of Agent-related Terms

absolute autonomy	agent-based holon	holonic agent simulation
agency	agent-based software	inter-agent communication
agent architecture	agent-based software engineering	inter-agent communication language
agent autonomy	agent-based software provider	inter-agent knowledge processing
agent behavior	agent-directed	interface autonomy
agent class	agent-enabled	message-based agent communication
agent cloning	agent-enabled feature	mobile agent paradigm
agent code	agent-oriented	mobile code
agent communication	agent-oriented CASE tool	mobile object
agent communication language	agent-oriented problem solving	multi-agent architecture
agent completeness	agent-oriented programming	multi-agent design-system
agent efficiency	agent-oriented requirements engineering	multi-agent learning system
agent implementation	agent-oriented tool	multi-agent learning technique
agent interactivity	animated agent technology	multiagent software
agent language	anticookie software	multi-agent system
agent security	community	multi-agent understanding system
agent software	cookie management	remote procedure
agent system	design autonomy	remote programming
agent user	design-system for multi-agent	social autonomy
agent/place interface	ethics for agents	
agent/user interface	execution autonomy	
agent-based		