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# A Dynamic Approach to Context Modeling

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**Abstract**

This paper presents the issues of dealing with context from the perspective of cognitive modeling. A dynamic theory of context is proposed which considers context as the set of all entities that influence human cognitive behavior on a particular occasion. As a consequence context is thought of as the dynamic fuzzy set of all associatively relevant memory elements at a particular instant of time. These memory elements might be both mental representations and operations. Some experimental facts about the influence of the perceptible environment as well as of the previous memory state on human problem solving are briefly presented. The dynamic nature of context influence on behavior is emphasized.

A general cognitive architecture, DUAL, is presented which consists of many small agents running autonomously in parallel with variable speeds depending on their current associative relevance. A model of problem solving, AMBR, based on DUAL is discussed where problem solving emerges from the collective behavior of the agents. The possibilities of AMBR for modeling context and priming effects are considered and some simulation results are presented.

## 1. Introduction

This paper presents the issues of dealing with context from the perspective of cognitive modeling, i.e. how *human* cognitive processes are influenced by context and how this could be modeled in computer simulations. The main focus of the paper is on problem solving, although most of the considerations could be still valid in modeling other cognitive processes.

The methodology of the current research is the following. Psychological experiments have been performed in order to discover the influence of context on real human behavior [Kokinov, 1989, 1990, 1994a]. The obtained data have been used for acquiring a better understanding of the concept *context*. A general cognitive architecture, DUAL, has been proposed with the specific requirement – being able to explain context effects [Kokinov, 1994b,c]. A particular model of reasoning in problem solving, AMBR, has been developed which accounts for the context-sensitive nature of human deductive and analogical reasoning [Kokinov, 1994a,c]. Simulation results have been produced which are in accordance with the psychological data [Kokinov, 1994a]. Moreover, some predictions have been made which are additionally tested in psychological experiments [Kokinov & Yoveva, to appear].

In the following section a dynamic theory of context is proposed. In section 3 the representation of knowledge and context in DUAL is described, while in section 4 the mechanisms of context computation and change are presented. In section 5 the usage of context in problem solving is discussed and some simulation results are outlined briefly. In section 6 a comparison to other approaches is presented.

## 2. What is Context? A Dynamic Theory of Context.

There is no universally accepted definition of context and that is why I will start with a definition specifying the term *context* in the context of this paper. Definition*: Context is the set of* <u>*all*</u> *entities that influence human (or system's) cognitive behavior on a particular occasion.*

Analyzing the above definition a number of questions arise. Some of them are discussed in the following subsections.

### 2.1. Is context a state of the universe or a state of the mind?

There are many things in the universe that do not influence human behavior in a particular moment and only very few that do influence it. Moreover, different people will be influenced by different elements of the same environment. So, all the entities in the environment which do influence human behavior are *internally represented* and it is the representations which actually influence the behavior. (This statement may be questioned from the point of view of the situated cognition approach but it allows for homogeneous treatment of all types of entities influencing human behavior.) That is why *context is considered as a 'state of the mind' of the cognitive system*.

Where do these context elements come from? Some of the elements come from the reasoning mechanism itself (e.g. goals, subgoals, and facts established by the inferential mechanism); they form what we call *reasoning context*. Others come from the environment through perception and they form what we call *perceived context*. In accordance with our statement that context is a state of mind, it is the representations of the objects which are part of the context, not the real objects in the environment. However, sometimes only for simplicity of the expression we will refer to the objects as being members of the context instead of the more accurate wording that their representations are part of the context. Finally, some elements are residuals from recent contexts (like previous goals, or previously perceived elements) and they form what we call *memorized context*.

No one has doubts that the elements of the reasoning context influence the behavior as the goals and the inferences already made play a crucial role in the further reasoning processes. That is why many people consider these elements as something in the foreground while the context is considered as the background which may or may not influence the behavior. However, according to the definition of context presented above these elements belong to the context (maybe to its core). The reasons for that might become clearer in the next section.

There are many experiments demonstrating the influence of elements from the external environment (usually called context effects) and of elements from recent contexts (usually called priming effects) on perception and language understanding (see, for example [Anderson, 1983] for a review of experiments on priming effects and [Rumelhart and McClelland, 1986] for a review of experiments on context effects on perception). However, little attention is paid on priming and context effects on high-level cognitive processes, like reasoning and problem solving. Some experiments performed by the author demonstrate similar influence on problem solving, e.g. [Kokinov, 1989] has demonstrated priming effects on question answering (fact retrieval), [Kokinov, 1990, 1994a] has demonstrated priming effects on problem solving, and [Kokinov & Yoveva, to appear] have demonstrated context effects on problem solving. These experiments provide evidence that both the perceived and memorized contexts are not empty sets.

## 2.2. What are the boundaries of context?

Everyone trying to perform experiments on context effects always faces the difficult problem of discovering which elements are part of the context and which are not. Let us consider some examples.

**Letter recognition**. The subjects' task is to recognize letters looking at a notebook full of handwritten text and the question for the experimenter is which other symbols from the text (or more precisely, the representations of which other symbols) form the context for that task. Suppose the subject sees the following symbols and is asked to recognize them.

**A 13 C**

Most often people recognize them as **ABC**. However, if they see the following string with the same instruction

**9 13 7**

most probably they will recognize them as the numbers **9 13 7,** the same symbols **13** recognized the first time as **B** and the second one as **13**, i.e. the neighboring symbols are part of the perceived context.

However, if the subjects see the following string

**9 M 7 9 N 7 9 A 7 9 13 7 9 C 7**

then probably they will spell it out as **9M7 9N7 9A7 9B7 9C7**, i.e. they will interpret **13** again as **B** in this larger context. This means that now all the elements in the string are elements of the perceived context.

This example demonstrates that it is difficult to specify what the elements of the perceived context are even for such a task as letter recognition: the neighboring symbols, the whole string/row, the whole page, or even the whole text (suppose the subject cannot read a word and scans the whole text in order to find similar symbols in unambiguous words), i.e. there are no clear-cut boundaries of context.

**Problem solving**. What are the context elements in a problem solving process? Typically problems arise in everyday life when people discover that they cannot directly achieve a certain goal. In such circumstances people use their reasoning mechanisms to formulate and define the problem: its goal and initial states, some explicitly stated restrictions, etc. All these elements of the produced problem description are part of the *reasoning context*. Even in cases where people receive the problem from other people they produce their own internal representation of the problem by a sophisticated reasoning process and therefore these elements are part of the reasoning context. On the contrary, the specific words, phrases and pictures used in the input description of the problem (when the subject is presented with it from somebody else) are part of the environment which can also influence the problem solving in one or another way [Kokinov, 1989] – that is why their internal representations are part of the *perceived context*. Moreover, even casual objects and pictures in the environment of the problem solver (which are not part of the input description) can influence the particular way in which the problem is being solved [Kokinov & Yoveva, to appear] and therefore their representations are elements of the *perceived context*. They can activate particular ideas about some specific instruments, about some specific facts or old problems. However, which particular objects in the environment will be perceived and will actually influence the process (and to what extent) is hard to say in advance. On the other hand, the concepts being active at the beginning of the problem formulation or problem understanding processes (i.e. having some residual activation as result of recently perceived objects or recently solved problems) can also influence the problem solving process [Kokinov, 1990, 1994] and therefore are part of the *memorized context*. Again, it is difficult to establish which the particular members of the memorized context are in a particular problem solving process.

As experiments have shown various entities influence the cognitive process to different degrees producing larger or smaller changes of the behavior. So, usually, the goal influences the problem solving process much deeper than a casual object in the problem solver's environment; an inference produced by the reasoning mechanism is likely to be used further, but can also be dropped. On the other hand, some of the problem representation elements are produced by the reasoning mechanism, while others might be produced by the perception process or retrieved from memory. That is why instead of defining clear-cut boundaries between problem representation and context, and between context and neutral elements (unaffecting behavior) it would be better to consider the context as a fuzzy set.

### 2.3. What are the criteria for context membership?

After the problem has been solved it is relatively easy to determine which entities have contributed to the problem solution (i.e. have been relevant to the problem solving task) and to explain why they are part of the context (what are the particular relations between them and the solution of the problem). However, what is needed is an *a priori* estimation of the relevance of the entities in order to consider some of them more extensively than others. That is why two different criteria for relevance can be defined and used (the first one provides an *a posteriori* estimation, while the second one provides an *a priori* estimation).

*Causal relevance* is defined *with respect to the goal* of the reasoner and the criterion for relevance of an element is whether a *chain* of *causal relations* connecting that element with the goal has been found by the reasoner. Causal relevance is of “all or none” type.

*Associative relevance* is defined *with respect to the whole context* and is measured by the *degree of connectivity* of the element in question with all other elements of that context. Associative relevance is by definition graded because it is clear that all elements are somehow related to each other, so it is the degree of connectivity that matters.

In a realistic problem solving situation the reasoner has to elicit the possible actions from memory and the possible instruments from the real-world environment. Thus it is impossible simply to test the causal relevance of all the possibilities since explicit knowledge about most (or all) of them will be unavailable *a priori*. People, however, have an intuitive idea (not always accurate) of the relevance of the elements of a situation even before there is any possibility of formal analysis of the situation and sometimes even before the goals are defined or made explicit. In other words, the reasoner will know that a particular element is somehow connected to other pieces of knowledge, presently considered as relevant, without being able to report the exact nature of these connections or a particular path followed. In this way associative relevance can be considered as a preliminary and approximate estimation of the relevance of all representations (all memory elements) to the whole context. This estimation guides the problem solving process and the higher the associative relevance of an element is the deeper is its influence on the reasoning process. That is why we consider the associative relevance of the representations as a measure for their membership to the context. The causal relevance plays a secondary role in problem solving - mainly for explicit reasoning about a particular, picked out possibility and in *a posteriori* explanation of the reasoning process.

### 2.4. When does the context change?

Changes in the environment as well as changes in the reasoning state bring new entities into consideration, decrease and increase the influence of the various elements of the context. When do such changes take place?

Context changes when the reasoning mechanism changes the reasoning context, for example, when it changes the goal or produces a subgoal. These changes are, however, relatively rare and occur in discrete steps. If only such changes are considered then the context can be thought of as being relatively static. However, the perceived and memorized contexts are much more dynamic. Thus, for example, the typical environment changes continuously (new objects appear, existing objects change their properties, relations between the objects change, the actions of the cognitive system change the environment) as well as the active perception allows for discovering new elements in it and therefore the perceived context changes continuously. The memorized context is also dynamic: typically, the influence of an element from the “previous” context on the behavior of the cognitive system in the “current” context decreases with the course of time (i.e. there is a process of “fading”). Thus, for example, the priming effects on problem solving discovered in experimental studies [Kokinov, 1990, 1994] decrease with the time course according to an exponential law and completely disappear after a certain period of time (20 minutes in the particular study), priming effects on perception and language understanding disappear even faster [Anderson, 1983]. That is why we consider context as *dynamic* and continuously evolving.

The two types of relevance considered above seem to have very different dynamic properties. For example, causal relevance appears to be static since it depends on the problem goal and is thus highly connected to the problem itself, i.e. whenever we present one and the same problem, the same elements are expected to be considered important as they will always be connected to the goal of the problem. On the contrary, associative relevance is highly dynamic and variable because of the continuously developing perceived and memorized contexts (note that it is impossible to replicate any particular context). This is another reason why we have chosen associative relevance as the criterion for context membership.

### 2.5. Main Principles of the Dynamic Theory of Context

The main principles underlying the dynamic theory of context are the following:

- ***context is a state of the mind;***
- ***context has no clear-cut boundaries;***
- ***context consists of all associatively relevant elements;***
- ***context is dynamic.***

As a consequence, *context is considered as the dynamic fuzzy set of all associatively relevant memory elements (mental representations or operations) at a particular instant of time.*

## 3. Knowledge and Context Representation in DUAL

### 3.1. DUAL – A Hybrid Multi-Agent Cognitive Architecture

The cognitive architecture DUAL [Kokinov, 1994b,c] consists of a large number of relatively simple agents (they are not intelligent agents but rather specialized computational devices) whose collective behavior produces the global behavior of the system. Each agent has a specific piece of knowledge associated with it: it may "know" some facts and may be able to perform some specific relatively simple tasks.

Each agent is a hybrid (symbolic/connectionist) processing device. Its symbolic part (*s-component*) takes part in the emergent global symbolic computation processes, while its connectionist part (*c-component*) takes part in an emergent global process of spreading activation.

All agents work in parallel. The *s-component* of each agent operates performing a specific symbolic task at its own speed which is proportional to the activation its *c-component* has computed. Inactive agents, i.e. agents with activation level below a certain threshold, do not perform any symbolic computation.

### 3.2. Long-Term Memory and Working Memory

All the agents form the Long-Term Memory of a DUAL system. They are connected in a network reflecting the typical patterns of interaction between them, each agent communicating directly only with its neighbors. Generally speaking both the *s-components* and the *c-components* use the same network for communication. However, the *s-components* recognize various categories of links giving them particular semantic interpretation, while for the *c-components* all the links belong to the same category but have weights associated with them.

The active agents in a particular instant of time form the Working Memory (WM) of the system. Some of these agents (existing permanently) are part of the LTM while others are temporarily constructed by other agents and are part only of the WM. The latter can disappear after a certain period of time or become permanent and part of LTM.

### 3.3. Knowledge Representation in DUAL

Knowledge is represented in DUAL by the *s-components* of the agents. Each *s-component* is a frame-like structure which represents both declarative and procedural knowledge about a particular concept, object, event, situation, rule, etc. The frame consists of slots (which are part of the same agent) and relations to the corresponding fillers (which are represented by other agents). These relations to other frames are represented by links between the agents each link having a semantic interpretation (like is-a, instance-of, co-reference, etc.).

### 3.4. Context Representation in DUAL

Context is represented in DUAL by the state of the WM of the system at a particular instant of time. This representation fulfills all the principles of the dynamic theory of context as outlined in section 2:
- WM is in a sense a complete description of the “state of the mind” of the cognitive system;
- WM has no clear-cut boundaries as the degrees of membership of the memory elements to the WM are measured by their activation levels which are real numbers in the segment [0,1);
- All the elements in WM are actually associatively relevant elements as their activation level reflects their connectivity with all other WM elements as it will be described in more detail in the following section;
- Finally, WM is dynamic as its contents (the set of its elements) and the degrees of their membership change continuously as described in the following section.

In other words, context has a dynamic and distributed representation in DUAL: the distribution of activity over the set of all memory elements (the set of all agents).

## 4. Context Computation and Change

### 4.1. Context Computation

The particular state of WM is computed by a connectionist mechanism of spreading activation which emerges from the local computations performed by the *c-components* of all agents. These computations are performed continuously and in parallel to all the symbolic processing done by the *s-components* of the agents.

All the links in the network are used for spreading activation. This includes both the semantic and the associative links between the agents. The semantic links are also used by the *s-components*, while the associative links are used only by the *c-components.* Associative links represent simply frequent co-occurrence of both entities.

There are two agents which are considered as permanent sources of activation: the *GOAL* agent and the *INPUT* agent. They continuously emit activation and pass it over to their neighbors connected by weighted links to them. The agents directly related to the *GOAL* agent represent the particular goals that the system is currently pursuing and are called *goal* agents. On the other hand, the agents directly related to the *INPUT* agent represent objects (or their properties and relations) currently being perceived by the system and are called *input* agents.

The particular state of WM reached on a particular occasion and computed by the above mechanism depends on the particular list of *goal* and *input* agents as well as on the initial state of WM which is the distribution of activation computed in the previous context. It is important to stress that there is a decay process which decreases the activation of each individual node (agent) with the course of time, however, the decay rate is relatively slow making it possible for the previous state to influence the new one.

### 4.2. Context Change

What causes the changes in the context? It is the interplay of many cognitive processes – the reasoning process producing new inferences, the perception process producing new representations of elements of the environment, and the memory processes “suddenly” bringing some old representations into consideration. All these are active processes running in parallel and interacting with each other. (Note that memory in DUAL is not considered as a store which is being searched and queried by other processes, but rather as an independently running process which stimulates and influences other processes).

Memory processes are continuously changing context by the connectionist mechanism described above and in parallel to the reasoning process emerging from the symbolic computations. These changes in the context are not a result of the reasoning process (although the reasoning process influences the context changes as described below) but are rather independent and they in turn influence the reasoning process by making some inferences possible and others impossible, giving priorities to particular inferences, etc. The dynamics of the connectionist computation produces continuous changes in the context.

However, more radical changes in context occur as a result of structural changes in the network or in the lists of *goal* and the *input* agents, i.e. in the sources of activation. This is performed by the processes of reasoning and perception, respectively. Both the reasoning and the perception processes in DUAL are emergent from the collective behavior of many agents.

Perception plays a crucial role in context changes. Most of the well known context effects in psychology are about how the changes in the outside world (the environment) influence human behavior, i.e. about the influence of perceived context. This is modeled in the following way. The perception process produces temporary agents corresponding to elements of the environment and connects them to the *INPUT* agent. Currently DUAL has quite simple perceptual abilities. The system receives both a formal description of the problem and its textual description as input and the formal description becomes a *goal* agent while the system produces *input* nodes for each word in the textual description. In this way the representations of the words (which are different from the representations of the concepts) form the perceived context and the effects of different wordings on the problem solving can be modeled. The perception of objects from the environment is simulated by directly implanting an *input* agent in WM. Currently the architecture is being extended in order to equip it with more elaborate perceptual abilities. It should be able to construct the internal representation of the problem by itself starting from an image of the scene: in our case a text-processing situation. For this reason the architecture is extended with a visual buffer.

The reasoning processes also influence the context changes. They produce new *goal* agents and link them to the *GOAL* agent thereby changing some of the sources of activation. They also generate inferences producing new temporary agents and connecting them to other agents in the network. This changes the topology of the network and influences the spread of activation in it. In this way the reasoning processes can change some of the sources of activation and some of the constraints on the flow of activation, however, the resulting context is computed by the memory processes which completes the pattern of activation by activating related agents from the Long-Term Memory.

## 5. Context Usage in Problem Solving

### 5.1. Advantages of Context Usage in Problem Solving

The use of context makes it possible to satisfy two traditionally considered as contradictory requirements to problem solving: flexibility and efficiency.

Flexibility is the ability of the cognitive system to solve a wide range of problems, to be able to solve problems in more than one way, to adapt easily to new and unforeseen situations. In order to achieve this the system should not be restricted in advance to very specific heuristic searches and domain-specific schemata.

Efficiency is the ability of the cognitive system to solve the problems at a low cost: spending minimal time and efforts. This is traditionally achieved exactly by using domain-specific heuristics and schemata which will restrict the search of the system and avoid combinatorial explosion.

The solution to this problem proposed by DUAL is the following. Keeping potentially unrestricted searches (i.e. non of the possible searches is excluded from the system's knowledge base and reasoning mechanisms in advance) the actual searches performed on a particular occasion are strongly restricted by the current context (i.e. only paths which are considered as relevant to the context are being actually searched). A dynamic and *a priory* estimation of relevance is needed for this reason and that is why the associative relevance is used as a measure for it.

In short, the proposed solution is restricting the search to a small part of the potentially huge problem space in a dynamic context-sensitive manner, i.e. the context guides the reasoning process in one or another direction depending on the previous memory state and/or on the perceived part of the environment. This solution is possible only when the context is not computed by the reasoning mechanism itself.

### 5.2. Context-Sensitive Problem Solving: Simulation Results

A computer model of human problem solving, AMBR, has been developed which simulates deductive and analogical reasoning and demonstrates some of the priming and context effects documented in psychological experiments [Kokinov, 1994a,c]. The problem domain chosen for the simulation is a small part of naive physics and common sense reasoning involving situations of boiling water, tea, coffee in the kitchen or in the forest.

Problem solving in AMBR is an emergent process. It emerges from the collective performance of many agents. Some of these agents are more general like *marker generator* agent, *semantic correspondence* agent, *structure correspondence* agent, *node constructor* agent, etc., while others are domain specific like *heating* agent, *water* agent, *heating water on a plate* agent, etc. Some of the agents cooperate like the *marker generator* agent and the *semantic correspondence* agent one of them enabling the other to do its job, while others compete like the *semantic correspondence* agent and the *structure correspondence* agent each of them extending the constraint satisfaction network adding contradictory constraints.

The general idea of context-sensitivity of problem solving in AMBR is the following. The contexts in which a particular problem is being solved may differ in their perceived and/or their memorized parts. The perceived context is established by activating from outside some agents corresponding to words in the problem description as well as some agents corresponding to objects in the environment (e.g. stone) simulating their perception. The memorized context is established by the initial distribution of activation as a residue of a previously solved problem. These different activation patterns result in different sets of agents contributing to the problem solving process as well as different distribution of their performance speeds. As a result different bases for analogy are found or different constraint satisfaction networks are built up and different correspondences between the same base and target are established. In other words in one particular context the system fails to solve the problem, in another one its solves it successfully, and in a third one it solves it in a different way.

One particular problem solved by the simulation is *"How can you heat up some water in a wooden vessel being in the forest and having a match box, a knife, and an axe?"*. The simulation experiments involved running the program several times in different conditions like different initial memory states of the system and different objects perceived from the environment. Thus in one memory state (a neutral one) the system failed to solve the problem, in another one (having just solved the problem of preparing tea in a glass involving an immersion heater) it found a solution involving heating up the knife and putting it in the water, and in a third situation (simulating the perception of a stone from the environment) it found another solution involving heating up a stone and putting it in the water.

The simulation results have replicated the experimental data about the dynamics of the memorized context influence on problem solving demonstrating the same pattern of decreasing priming effect [Kokinov, 1994a]. Moreover, these simulation results have predicted the influence of the perceived context on the specific way the problem is being solved and these predictions have been confirmed in successive psychological experiments [Kokinov & Yoveva, to appear].

## 6. Comparison to Other Approaches

There are many different approaches to context modeling, however, there is little agreement on what is context and what aspect of context is being modeled. A number of questions are listed below which differentiate the theories proposed so far.

*What is context?* There are at least three general types of answers to that question: the term context is used for the situation itself (the state of the universe), for a particular description of the real-world situation, or for the particular state of the mind of the cognitive system. Thus, for example, [McCarthy, 1990, Giunchiglia, 1991] treat context as a logical object representing a particular situation. Other approaches [Hendrix, 1979] treat context as a set of facts describing a particular situation from a specific point of view. Finally, [Giunchiglia, 1993] treats context as a temporary state of the reasoning individual. Moreover, similarly to our approach he includes in that state both the mental representations (the facts) and the mental operations (the inference rules).

Situations are represented in DUAL by a specific frame-like description associated with a particular agent and the facts associated with that description are represented by other agents which are slot-fillers of the first one. This allows for the existence of several descriptions for the same situation presented from different points of view. The agents corresponding to these descriptions are connected by co-reference link. Context, however, is treated as the particular state of the cognitive system in a way quite similar to Giunchiglia's [1993] treatment. In contrast to it, however, this state is determined not only by the reasoning process, but it is influenced also by the memory and perception processes.

*How is context represented: explicit or implicit, locally or distributed?* Again there are a number of approaches. McCarthy [1990] and Giunchiglia [1991] represent context as logical objects, i.e. explicitly and locally. Giunchiglia [1993] represents context as a logical theory, i.e. explicitly and distributed. Anderson [1983], Kintsch [1988], Hofstadter and his collaborators [Hofstadter & Mitchell, 1994, Mitchell, 1994, Hofstadter, 1995, French, in press] as well as the author of the current paper represent context in an implicit and distributed way by the distribution of activation and "urgencies" over the memory of the cognitive system. There are a number of differences between these latter approaches in what is the underlying knowledge representation (separated declarative and procedural knowledge bases, separated permanent and temporal knowledge structures in the first several approaches, and unified frame representation and common network connecting the permanent and temporal knowledge structures in our approach) and in how context is represented with respect to various types of knowledge (context is represented by activation over the declarative knowledge base only in Anderson's and Kintsch's approaches, by activation over the declarative knowledge and "urgencies" over the procedural knowledge in Hofstadter's approach, and by activations over the whole knowledge base in our approach). The unifying approach of DUAL allows for a common explanation of the priming effects encountered both for declarative and for procedural knowledge.

*What and how does the context change?* All logical approaches [Sperber & Wislon, 1986, McCarthy, 1990, 1991, Giunchiglia, 1991, 1993] rely completely on the reasoning mechanism for changes in the context, i.e. only conscious and voluntary actions may change the context. These treatments cannot account for the many context and priming effects demonstrated by psychological experiments. Moreover, all the changes in the context take place relatively rarely and in large discrete steps, i.e. when the particular context should be changed in order to cope with the problem from another point of view. Our approach as well as the approaches of Anderson and of Hofstadter & group are quite dynamic, they change in a continuous and automatic way. Anderson gives an account of the priming effects, while Hofstadter stresses the importance of perception. Our approach as well as Kintsch's approach tries to combine the influence both of the perceived and of the memorized contexts.

*For what purposes and how is context used?* Kintsch [1988] and [Sperber & Wislon, 1986] use context for text and communication interpretation. [Sperber & Wislon, 1986] construct *all* accessible contexts and than evaluate them and select the one that makes the utterance being processed maximally relevant. Kintsch [1988] uses the context to filter out the alternative interpretations of the text *after* the memory and reasoning mechanisms have produced *all* possible interpretations. Our approach as well as the one of Hofstadter's group uses context to guide the processes of reasoning and perception, respectively, i.e. to reduce drastically the number of generated alternatives (generating only the relevant ones) and to assign dynamically priorities to some of them. While Kintsch's approach can be modified by dynamically constructing only some of the nodes in the constraint satisfaction network

[Kokinov, 1994a], the approach of Sperber and Wislon cannot be adapted for that purposes because their definition of relevance is *a posteriori* one and is based on the logical inferences drawn from an explicitly generated context. Moreover, the assumption that the utterance being processed is intentionally produced to be relevant (the relevance principle of communication) has no analog in a problem solving situation where *the problem solver* himself/herself has to find the relevant objects, instruments and operations (except in the artificially designed problems in the textbooks where typically all explicitly mentioned elements are relevant).

## 7. Conclusions

A dynamic theory of context has been proposed which considers context as the set of all entities that influence human cognitive behavior on a particular occasion. As a consequence context is thought of as the dynamic fuzzy set of all associatively relevant memory elements (mental representations or mental operations) at a particular instant of time.

In the cognitive architecture DUAL the memory elements are called agents and they have variable availability determined by their activation level. Problem solving is modeled by an emergent computation produced by the collective behavior of the agents (the AMBR model). Context influences problem solving by changing the availability of the agents and in this way in different contexts different sets of agents take part in the computations running at different rates and that is why they produce different results. Moreover, context changes dynamically because of the inherent dynamics both of the memorized context (decreasing its influence with the course of time) and of the perceived context (continuously changing the perceived elements of the environment). The architecture is a hybrid one - each agent having both a connectionist and a symbolic processor. The connectionist aspect of the architecture dynamically restructures the knowledge base of the system represented by the symbolic aspect and makes some inferences more probable and others less probable or even drops them at all.

The proposed theory as well as the computer models need extensive experimentation both from psychological and simulation point of view. An extension of the perceptual abilities of DUAL will allow for much more elaborated influence of the external environment.

Both the architecture DUAL and the model of problem solving AMBR have been proposed as cognitive modeling tools, however, it turns out that they might be useful also in application areas where it is important to build up flexible systems which should have reasonable computational efficiency and should not require extensive searches.

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