

Simulating Context Effects in Problem Solving with AMBR

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Abstract. This paper presents a computer simulation of context effects on problem solving with AMBR — a model of human analogy-making. It demonstrates how perceiving some incidental objects from the environment may change the way the problem is being solved. It also shows that the timing of this perception is important: while the context element may have crucial influence during the initial stages of problem solving it has virtually no effect during the later stages. The simulation also explores the difference between an explicit hint condition where the focus of attention is drawn towards a context situation which is analogous to the target problem and an implicit context condition where an arbitrary object from the environment makes us remind an old episode.

1. Context Effects: Psychological Data and Cognitive Models

Imagine you are sitting at your desk struggling with a difficult problem with a roving look. At some point your eyes incidentally fall on a steaming cup of tea or on a drawing in an open book and you are suddenly reminded of an old analogous problem and its solution that might be adopted to the current case as well. You may not realize that there was a relationship between the cup of tea and the old episode, you may even not notice that you have perceived the steaming liquid, finally, it is possible that you even do not remember that there was a cup of tea on the desk, but still the very fact of perceiving it may have had an influence on your problem solving process. We call this “context effect” on problem solving and we are interested whether such effects really exist and if yes, what might be the mechanisms responsible for that.

Context effects on language understanding [39], perception [36], decision-making [38], memory [9, 10, 27], concepts and categorization [4], affect and social cognition [3, 16, 33] have been extensively studied in psychology. Context effects on problem solving and reasoning are still not well explored. Gestalt psychologies have first demonstrated such effects [11, 29, 30]. Gick and Holyoak [12] have demonstrated how an explicit hint may influence the problem solving process. Lockhart [28] and Schunn and Dunbar [37] discuss the influence context may have on accessibility of concepts and therefore on thinking. Recently, Kokinov and his collaborators have studied in a

systematic way the influence one incidental element from the environment may have on the problem solving process [25, 26].

In their first experiment Kokinov and Yoveva [26] have demonstrated that when solving a problem about boiling water in the forest in a wooden bowl, subjects, who have seen an illustration of a river by a forest with many rocks and stones around, tend to produce significantly more solutions using stones than control subjects, who have not seen the illustration. In a second experiment subjects received sheets of paper with two problems on each sheet, but they had to solve only the first one. The illustration accompanying the second problem and thus seeming to be irrelevant to the first problem played the role of an incidental environmental element. The results have clearly shown that this seemingly irrelevant picture may be crucial in the problem solving process and subjects may produce completely different solutions being exposed to different pictures, even though they claim they have not seen and used them. Being suspicious about participants' unawareness of the second picture on the page another experiment was carried out by Kokinov, Hadjiilieva, and Yoveva [25]. In this experiment the context condition described above was compared to an explicit hint condition in which the same picture was put on the sheet of paper, but an explicit instruction was given to subjects to try to use it when solving the target problem. The results were significantly different from the context condition which suggests that in the context condition subjects have perceived and used the picture unconsciously. Moreover, in some cases, the same picture had opposite effect when used explicitly as a hint. This supports the hypothesis that different mechanisms are responsible for the picture influence and use in the context and in the hint condition.

Computational models of problem solving suggested by AI researchers tend to focus on the later case: when the external stimulus is intentionally and consciously perceived and used in the problem solving process [1, 5, 7, 8, 13, 14, 31, 32, 40]. Thus context is typically explicitly represented, moreover a complex structure is used for its representation (e.g. a schema or a frame [40], a feature vector [1], a logical constant [31, 32] or even a whole logical theory [5, 13, 14]) and a complex organization of contexts is introduced (hierarchy of contexts, network of bridges between different possible contexts, etc.). This was described as the "box metaphor": context is considered as a set of propositions grouped together and embedded in a box [14, 24]. This approach was criticized for not taking into account the possibility for automatic unconscious context influence and for the continuous dynamic changes in the context as reviewed in [24].

In an attempt to build a cognitive model of human problem solving and how it is influenced by the dynamically evolving context Kokinov [21, 24] has put forward a dynamic theory of context. According to it context is considered as the dynamic state of mind of the cognitive system and thus is not necessarily explicitly represented. This state may be reflected by the system itself and thus partially represented, but as seen above, other parts of the context may still have an influence on our behavior without our awareness of that fact. The theory was implemented in a general cognitive architecture, DUAL, and a model of problem solving, AMBR, has been built on it. The current paper describes some simulation experiments with AMBR demonstrating context effects.

2. A Context-Sensitive Model of Problem Solving

2.1. Dynamic Theory of Context

The essence of the dynamic theory [21, 24] is that context is considered as the dynamic state of human mind which state is crucial for all cognitive processes. If we paraphrase this in computational terms, the algorithms that compute a particular cognitive process and the data they are using are changing dynamically with the changes in the state of mind. Since the state evolves continuously the algorithms and data are never the same. That is why we can never replicate a given act of human thinking, perception, or learning fully — since the context will have been changed and the processes will change as well. Of course, in many cases the changes might be small and even unnoticeable, but it can also happen that even small changes turn out to be crucial for the computation and the generated behavior becomes radically different. This is analogous to the theory of catastrophes developed in mathematics.

According to the dynamic theory the state of mind is determined by the content of human working memory (WM) and the relative weight each memory element has in it. The WM elements are both operations and structures — thus changing the content of WM may result in changing the operations available for application or in changing the data we are currently using in the computation.

The dynamic theory of context is not bound to a symbolic computational interpretation, it can possibly be implemented in connectionist or dynamic systems terms where no differentiation between data and operations will be necessary.

2.2. DUAL: A Dynamic Context-Sensitive Cognitive Architecture

DUAL [19, 20, 22, 35] is a general cognitive architecture which has been developed with the dynamic theory of context in mind and it provides a basis for modeling context-sensitive cognitive processes. This is a massively parallel and highly decentralized system consisting of micro-agents each of whom represents a small piece of procedural and declarative knowledge. Thus all operations in DUAL are performed by some agents. The agents are connected via links (which can be dynamically changed) and exchange messages via these links. The overall behavior of the system, or what is being computed at the particular moment, is an emergent phenomenon which reflects the collective behavior of the acting micro-agents. There is no central mechanism which controls which agents to act and in what sequence. On the contrary, each agent acts independently and in parallel to the acting of other agents and it uses only local information coming from its neighboring agents.

Each agent has an activation level which is determined by the incoming activation from neighboring agents and its residual activation from earlier stages. This activation level determines the degree of availability of that agent in that particular moment. If the degree of activation of a given agent is below a certain threshold than the agent is “sleeping”, i.e. it cannot take part in any computation. The higher the activation level, the more active the agent is and the faster its operations are performed. The connectionist activation is considered as a power supply for the symbolic operations performed by the agent [35].

Working memory in DUAL is considered to be the set of active agents in a particular moment of time. Thus the content of WM determines which agents will take part in the computation, how fast will each of them act, how they will compete, etc. and therefore it determines the outcome of the global emergent process that they generate. That is, in different contexts different sets of agents will act and with different levels of activation and therefore they will produce different outcomes. This is how context-sensitive behavior is implemented in DUAL.

The content of WM is determined by several factors: direct activation of agents from the environment via perception (modeled by connecting some of the agents to the INPUT node), direct activation of agents by internal motivational factors (modeled by connecting some of the agents to the GOAL node), residual activation of agents from previous memory states (modeled by a decay function of activation), and by receiving activation from neighboring agents via the links (modeled by a process of spreading activation).

Similar approaches to context modeling have been followed by John Anderson [2] where the semantic network has its internal dynamics, and by Douglas Hofstadter [15] where the Slipnet is also dynamically changing its structure as well as the codelets run with various probability depending on the context as represented in the workspace.

2.3. AMBR: A Context-Sensitive Model of Analogy-Making

AMBR [17, 18, 23, 34] is a model of human problem solving built upon the DUAL architecture. The program has semantic knowledge about various concepts and general facts as well as a number of past problem-solving episodes from everyday kitchen life. A target problem is presented to the program and it has to find its solution basically by analogy with one of the old episodes. There are many important differences between AMBR and other models of analogy-making. For example, mapping and retrieval are emergent processes based on the local computations and interactions of many micro-agents and thus they are running in parallel which makes it possible for mutual interaction between mapping and retrieval, including mapping guidance of retrieval. Since episodes are represented in a decentralized way (by a coalition of agents) they can be partially retrieved, they can be extended by intrusions from general knowledge or from other episodes, finally blending between episodes is possible. AMBR is sensitive to priming and context influences. The rest of this paper will present simulation data which demonstrate AMBR's context-sensitivity.

3. Simulation Experiments

The knowledge base (KB) of the system contains 570 agents representing about 270 concepts and 12 old episodes. Concepts include tea, milk, water, drinkable-liquid, liquid, temperature-of, high-temp, low-temp, made-of, color-of, cause, etc. The old episodes include the following ones (Table 1).

Table 1: Old episodes in the long-term memory of the system.

Short name of the episode	Short informal description of the episode
WTP	heating Water in a Teapot on a hot Plate
BF	heating water in a wooden Bowl on the Fire and burning the bowl
GP	heating water in a Glass on a hot Plate and breaking the glass
IHC	heating water by Immersion Heater in a Cup
MTF	cooling Milk in a Teapot in the Fridge
ICF	cooling Ice Cube on a glass in the Fridge
BPF	cooling Butter on a Plate in the Fridge
FDO	baking Food on a Dish in the Oven
STC	sweetening by putting sugar in the tea being in a cup
SFF	salting by putting salt into the food in the fridge
ERW	coloring an Egg put in Red Water
GWB	keeping a Glass in a Wooden Box

Here is a simple target problem HM: “How can you Heat some Milk which is put in a teapot?” This problem has to be solved by making analogy with one of the known episodes in the KB. A simplified propositional representation of this example is presented in Table 2. Each proposition is represented by a separate DUAL agent.

Table 2: Representation of the target problem HM — “heating milk”. Content of input list, goal list, and primary WM are described.

Agent	External Activation	Propositional representaion
	Goal List	
T-of-HM	1.00	(temperature-of milk-HM high-T-HM)
high-T-HM	1.00	(inst-of high-T-HM high-temp)
milk-HM	1.00	(inst-of milk-HM milk)
	Input List	
in-HM	1.00	(in milk-HM tpot-HM)
tpot-HM	1.00	(inst-of tpot-HM teapot)
made-of-HM	0.50	(made-of tpot-HM mmetal-HM)
mmetal-HM	0.25	(inst-of mmetal-HM material-metal)
	Just in WM	
goalst-HM	0.0	(goal-state T-of-HM high-T-HM)
initst-HM	0.0	(init-state milk-HM tpot-HM in-HM made-of-HM)
to-reach-HM	0.0	(to-reach initst-HM goalst-HM)

In order to get statistical data 100 variations of the initial KB have been generated by randomly changing some associative links and instance links. This reflects the possibility that various people even sharing the general knowledge about this simple domain may have different associations for the same concepts, objects, or events. Someone may have richer experience with immersion heaters while someone else may have recently broken a glass on a hot plate.

3.1. AMBR's sensitivity to context

In order to test AMBR's sensitivity to context 100 simulations (with the 100 KBs) have been done within each of 6 different contexts using the same target problem HM. The context is changed by only one element: we simulate the incidental perception of one single object from the environment. We have run the simulations in the following conditions and the results are displayed in Table 3.

- control condition — without perception of any context elements
- “egg” condition — the system perceives an egg while solving the target
- “fridge” condition — the system perceives a fridge
- “immersion heater” condition — the system perceives an immersion heater
- “oven” condition — the system perceives an oven
- “sugar” condition — the system perceives sugar.

Table 3. Statistical results from 100 runs of AMBR with the target problem “Heating Milk” in 6 different conditions. Numbers in cells are the frequencies of making the analogy with the corresponding situation.

Target: Heating Milk — Statistics of Solutions Found							
#	bases	no context	egg	fridge	immersion heater	oven	sugar
1	wtp	50	46	45	41	46	48
2	bf	3	1	0	0	0	1
3	gp	1	0	1	1	1	1
4	ihc	6	10	5	20	2	8
5	mtf	28	16	35	21	25	22
6	icf	1	1	0	1	0	1
7	bpf	0	0	0	1	0	0
8	fdo	6	3	3	2	13	7
9	stc	0	0	0	1	1	3
10	sff	1	0	1	0	0	1
11	erw	4	23	10	12	11	8
12	gwb	0	0	0	0	1	0
% Changes:		0%	32%	32%	37%	31%	24%
Total:		100	100	100	100	100	100

We can notice that in about one third of the cases we have changes due to the change of context element perceived, even when this element is not obviously related to the

target and potential base for analogy. On the other hand, no drastic changes happen in the statistics. The most obvious base for analogy “heating water on the plate” is dominating in all conditions. As we can easily notice in Figure 1 the biggest changes are a facilitation effect for some rare remote analogies which in this context become relatively more probable. For example, in the “egg” condition the old episode “coloring an egg in red water” is more often retrieved and mapped than normally. In the “immersion heater” condition the case of heating water with an immersion heater is much more often retrieved and successfully mapped (20%) than normally (6%). These results qualitatively correspond to the data obtained in an psychological experiment [17, 18] where subjects primed with “immersion heated” increased the solution of a target problem (a much more complicated one) involving an analogy to the immersion heater case from 14% to 44%.

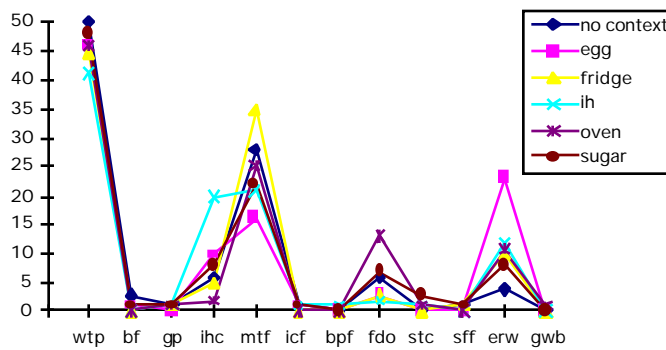


Figure 1. Statistical results from 100 runs of AMBR with the target problem “Heating Milk” in 6 different context conditions.

3.2. Control versus Hint versus Context Condition

The next simulation takes a closer look at the difference between a control condition (no perception of external elements), a context condition (perceiving a single incidental element from the environment without being aware of its relevance to the problem at hand), and an explicit hint condition (where a teacher provides another case and says it can help in solving the target problem — this may also be called a “forced-analogy” condition).

The target problem in this case was: “What will happen if you put an ice-cube in the coke which is in a glass?” In order to solve this problem the system should rely on its knowledge that “ice-cubes have low temperature” (a general fact which is part of the semantic knowledge of ice-cubes) and on an analogy with some of the old episodes in memory. All simulations are run with one single knowledge base — KB000 — one of the randomly generated KBs as described in the previous section.

In the control condition the system finds an analogy between the target situation and the situation “Heating Water in a Teapot on a Plate”. This is the most typical example of changing temperature (although it is heating instead of cooling) and is

most easily retrieved. Table 4 presents the analogy found by the system — details of the established correspondences are shown.

Table 4: Correspondences established by AMBR in the control condition.

Situation “Ice-Cube in Coke”	Situation “Water in a Tea-pot”	Activation level of correspondence hypotheses
ice-cube	plate	1.74 winner
coke	water	1.75 winner
glass	tea-pot	1.82 winner
in(coke, glass)	in(water, teapot)	1.80 winner
temperature-of(ice-cube, low-temp)	temperature-of(plate, high-temp)	1.76 winner
low-temperature	high-temperature	1.76 winner
init-state-ICC	init-state-WTP	1.77 winner
end-state-ICC	end-state-WTP	1.29 mature
follows-ICC	follows-WTP	1.44 mature

In a context condition where an immersion heater is perceived for a while, i.e. when an arbitrary instance of “immersion heater” is put for a while on the input list without any relations to the target, without marking it as a target, etc. The only result of this is that this instance becomes active for a short period of time (25 time units) and starts spreading its activation to the network of agents via its link to the concept “immersion heater”. As a result another base for analogy is found, namely — cooling water with an ice-cube is like heating water with immersion heater. The established correspondences are shown in Table 5.

Table 5: Correspondences established by AMBR in the context condition when perceiving an immersion heater.

Situation “Ice-Cube in Coke”	Situation “Immersion Heater in Water”	Activation level of correspondence hypotheses
ice-cube	immersion heater	1.82 winner
coke	water	1.80 winner
glass	cup	1.83 winner
table	saucer	1.72
in(ice-cube, coke)	in(immersion-heater, water)	1.81 winner
in(coke, glass)	in(water, cup)	1.79 winner
on(glass, table)	on(cup, saucer)	1.79 winner
temp-of(ice-cube, low-temp)	temp-of(imm-heater, high-temp)	1.78 winner
low-temp	high-temp	1.75 winner
Init-state-ICC	init-state-IHC	1.80 winner
End-state-ICC	end-state-IHC	1.28 mature
follows-ICC	follows-IHC	1.27 mature

In a hint condition we put a whole new situation of the type “heating water with immersion heater” on the input list and mark it as a target. This corresponds to an explicit hint to find an analogy between the two targets - a forced analogy case. The systems establishes the same correspondences as above, except that the elements are the ones provided by the input instead of the once retrieved from memory. The activation levels are a bit different, but the end result is the same.

Table 6: Correspondences established by AMBR in a context condition when perceiving “sugar”.

Situation “Ice-Cube in Coke”	Situation “Sugar in Tea”	Activation level of correspondence hypotheses
ice-cube	sugar	1.82 winner
coke	tea	1.80 winner
glass	cup	1.80 winner
table	saucer	1.72 winner
in(ice-cube, coke)	in(sugar, tea)	1.81 winner
in(coke, glass)	in(tea, cup)	1.79 winner
on(glass, table)	on(cup, saucer)	1.79 winner
temp-of(ice-cube, low-temp)	taste-of(sugar, sweet)	1.77 winner
init-state-ICC	init-state-STC	1.80 winner
end-state-ICC	goal-state-STC	1.31 mature
follows-ICC	follows-STC	1.31 mature

Another example we have tried is to put some sugar to be perceived, i.e. to put an instance of the concept “sugar” on the input list for a while. In this context condition the system finds another analogy: cooling the coke with an ice-cube is like sweetening the tea with sugar. The correspondences found by the system are shown in Table 6.

Again in a forced analogy case where an externally perceived situation of sugaring tea is provided we obtain very similar results (only the activation levels differ).

Finally, as a third example of context condition we used an instance of an egg in the input. In this case the activation of the “egg” instance turned out not to be enough in order to retrieve the ERW episode from memory and the WTP episode got the power, i.e. we obtained the same result as in the control condition.

In a hint condition when a “coloring egg” situation is provided by a teacher, AMBR was trying to establish the analogy “cooling coke with an ice-cube is like coloring an egg in red water”. In this case, however, AMBR failed to establish correct correspondences since in ICC the ice-cube is in the coke and it is the source of “coldness”, while in the ERW situation the egg which is in the water is not the source of “redness”, but the water is the coloring material in this case. This turned out to be too complicated for the system. AMBR was trying to color the water white using the color of the egg which contradicts the “follows” relationship in ERW. The established correspondences are presented in Table 7.

Table 7: Correspondence established by the system in the forced analogy case when presented with a coloring egg situation.

Situation “Ice-Cube in Coke”	Situation “Coloring Egg in Water”	Activation level of correspondence hypotheses
ice-cube	egg	1.79 winner
coke	water	1.66 winner
glass	tea-pot	1.08 mature
in(ice-cube, coke)	in(egg, water)	1.41 winner
temp-of(ice-cube, low-temp)	color-of(egg, white)	1.48 mature
low-temp	red	1.73 winner
init-state-ICC	init-state-ERW	1.80 winner
end-state-ICC	end-state-ERW	1.75 winner
follows-ICC	follows-ERW	1.75 winner

Finally, some of the others randomly generated variations of the KB have been tested. In the context condition when an egg is perceived it turned out that in many cases this context does change the solution found by the system. However, instead of making analogy with the “coloring case” AMBR found analogies to other episodes which somehow became available when “egg” is activated via the input list. Some of these analogies are, however, bizarre and inconsistent. With KB002 we obtained the following analogy: “cooling the coke with a ice-cube is like cooling the butter on the plate in a fridge” - this is a correct analogy, however, the correspondences found were inconsistent. With KB004 we obtained the analogy “cooling the coke with ice-cube is like putting a glass on the plate” which is extremely bizarre analogy. With KB006 we got “cooling the coke with ice-cube is like cooling the milk in the fridge” which is a fine analogy, but some of the correspondences were inconsistent. At the end, we tried

the hint condition with KB011 and we obtained a perfect forced analogy which is presented in Table 8.

Table 8: Correspondence established by AMBR in the forced analogy case when presented with a coloring egg situation (KB011 used).

Situation “Ice-Cube in Coke”	Situation “Coloring Egg in Water”	Activation level of hypotheses
ice-cube	water	1.76 winner
coke	egg	1.74 winner
glass	tea-pot	1.75 winner
in(ice-cube, coke)	in(water, tea-pot)	1.74 winner
in(coke, glass)	in(egg, water)	1.77 winner
temp-of(ice-cube, low-temp)	color-of(water, red)	1.60 mature
low-temp	red	1.73 winner
init-state-ICC	init-state-ERW	1.77 winner
end-state-ICC	end-state-ERW	1.75 winner
follows-ICC	follows-ERW	1.77 winner

The results from the simulation presented in Table 7 seem to correspond to the finding in [25] that when the presented forced-analogy base is not obviously isomorphic, the hint hinders the problem solving process instead of facilitating it. In this case, a context condition might be a more effective facilitator since it may activate a completely different base for analogy.

3.3. Timing of Context Element Perception and its Relation to the Context Effect

Another experiment aimed at understanding the most effective timing of the context influence. We varied the onset of presentation of the context stimulus thus simulating various timing of perceiving of the incidental environmental element. It turned out that the effect is to a certain extent stimulus-specific. Thus in the case of “perceiving” sugar it has an effect only when perceived at the very beginning of the problem solving process, while in the case of “perceiving” immersion heater the effect lasts longer. For onsets less than 5 time units it has the effect of making the “immersion heater analogy”, while for onsets greater than 5 time units it goes back to the “heating water on a plate” situation which is typical for the control condition. That is, when presented later than 5 time units after the problem solving process has started, the context does not have an effect.

This simulation makes a prediction that contextual clues can influence the problem solving process only if they are perceived at the very beginning, otherwise the reasoning process is too much preoccupied with its own commitments. We are not aware of psychological evidence in support of this prediction and are currently designing an experiment to test it. There is, however, an indirect support: Bransford and Johnson [6] have run an experiment on context effects on text understanding. They used a picture as a contextual element assisting the interpretation of a difficult paragraph. It turned out that the picture facilitates the understanding of the text only if

provided before reading the text, but not after that. This seems coherent with our prediction, but is in the area of text understanding, not of problem solving.

4. Conclusions

The simulation experiments reported in this paper have demonstrated that the AMBR model of problem solving is context-sensitive and finds various solutions to the same problem (or fails to solve it) in different contexts. Still the internal knowledge and experience of the system dominates the type of solution found and only about 30% of the changes are due to the variations in the context.

It was shown that incidental environmental clues influence the process of problem solving only at its very early stages, in the later phases it does not change the solution produced. This is a prediction that needs to be experimentally tested.

Finally, a comparison was done between the incidental perception of an environmental element (context effect) and an explicit hint provided by a teacher which results in a forced analogy between the target and the provided situation. In some cases, both have the same effect, in others, the context does not have an effect while the hint does change the solution, and finally in third cases, the explicit and implicit hints have opposite directions of influence. This is coherent with psychological data [25], but needs further experimentation as well. What is important here is that AMBR offers an explanation of these opposite directions of influence, i.e. different mechanisms are responsible for them. While only spreading activation is involved in the context condition, the full sets of mechanisms are employed in the hint condition and explicit hypotheses for correspondence are formed with the context elements.

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