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Research article

Semantic-map-based analysis of insight problem solving

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A R T I C L E I N F O

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A B S T R A C T

Intelligent agents and co-robots, or cobots, become increasingly popular today as assistants of creators of arts. They can be also expected to become popular in the near future as assistants in other creative work, including research and, in particular, insight problem solving. Arguably, the success of such tools is linked to their social-emotional intelligence. This work continues the previous study of the concept of a cobot-assistant of an insight problem solver (Kuznetsova & Samsonovich, Procedia Computer Science 123:258–64, 2018). The concept is based on a semantic map, that represents cognitive and emotional states and attitudes. The previously constructed semantic map is used here to study the dynamics of human cognitive and emotional states during insight problem solving. It is found here that subjects solving an insight problem become more excited and try to take more radical approaches, and also become slightly more confident, as they approach the insight moment, regardless of whether they actually succeed. This finding should help to formulate rules and cognitive schemas to be tested in future studies of the proposed insight problem solver assistant. The expected impact is on the anticipated emergence of general-purpose virtual cobots-assistants, unleashing higher creativity in their users.

Introduction

Background and significance

Intelligent cognitive assistants in the form of physical or virtual human-friendly collaborative robots (cobots) will become ubiquitous in a near future (Samsonovich, 2018; Veloso, Biswas, Coltin, & Rosenthal, 2015). They will serve as extensions of human minds and bodies into physical and virtual worlds, together facing challenges that today only humans can solve. One such challenge is represented by the domain of *insight problems*, the solution of each of which involves the "Aha!" moment (an insight experience). Insight problem solving is traditionally linked to general fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008): the ability to successfully deal with new, unexpected challenging situations, where prior knowledge does not help. Contrary to common belief, this natural human capacity can be enhanced by training of working memory (Jaeggi et al., 2008). It can also be augmented by scaffolding and guidance, provided by artificial intelligence (AI) tools such as computer-based learning environments (Azevedo, 2002; Desmarais & Baker, 2012; Roscoe, Segedy, Sulcer, Jeong, & Biswas, 2013) and cobots (Timms, 2016). The latter built for this purpose are frequently based on self-regulated learning (SRL) frameworks (Winne & Nesbit, 2009; Zimmerman, 2008) couched in a cognitive architecture framework (e.g., Samsonovich et al., 2008). It remains to add that many data from psychological studies suggest that emotionality plays a key role in development of insight (Malekzadeh, Mustafa, & Lahsasna, 2015; Wen, Butler, & Koutstaal, 2013). This observation encourages thinking of a potential for application of emotional cognitive architectures (Eidlin & Samsonovich, 2018; Hudlicka, 2011).

Toward a creative cobot-assistant: Previous work and the present task

Our general approach to designing the creative cognitive assistant of an insight problem solver in the form of a virtual cobot was outlined in the previous work (Kuznetsova & Samsonovich, 2018). In essence, it is based on a simplified form of the emotional Biologically Inspired Cognitive Architecture eBICA (Samsonovich, 2013, 2018) with a weak semantic map (Ascoli & Samsonovich, 2012; Samsonovich, 2018; Samsonovich, Goldin, & Ascoli, 2010) at its heart. For the present purposes, the semantic map is built as a two-dimensional vector space, used to represent the cognitive-emotional flavor of the momentary psychic state of the problem solver. The same space is also used to map a database of available general cognitive strategies, that are potentially applicable to a cognitive problem of any sort. The cobot does not know the problem and its solution, and does not perceive the line of reasoning of the user whom it assists. All the cobot receives on input at each time step is the choice of a general strategy currently made by the user and the user's self-evaluation of own progress and attitude toward the

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problem (with the possibility to add real-time psychometric and neuroimaging data). This information is processed and used to represent the current position of the user on the semantic map. The result in turn can be used to select map coordinates of the short list of strategies that will be offered to the user as a guidance. The process of selection is governed by the currently active *cognitive schema* in the cobot. The ultimate choice is made by the user, who can accept or reject the cobot advice. One of the goals for the cobot is to maintain a socio-emotional contact with the user, based on a mutual understanding and trust. The main objective for both, the cobot and the user, is to find a solution to the problem.

This conceptual model has not been implemented yet. As the first step to its realization, in the previous work (Kuznetsova & Samsonovich, 2018) a list of strategies was collected from various sources. Then, the *semantic map* was constructed from them as follows. Each strategy was evaluated by human subjects on 10 different semantic scales: *conservative-revolutionary, passive-aggressive, concrete-abstract, easy-difficult, detail-level vs. meta-level, condition-oriented vs. solution-oriented, weak-strong, opening-closing, basic-extra, prospective-retrospective*. The resultant ten-dimensional distribution was reduced to two main principal components, that were selected as map coordinates. Semantics of these coordinates was evaluated by experts and used to interpret the map data (Fig. 1).

The second step, which was the main task for the present study, was to accumulate and analyze phenomenological data on human behavior during insight problem solving, interpreted in terms of the semantic map. This study is necessary to formulate a set of cognitive schemas (see above) as hypotheses, that will be tested in future experimental studies with cobots-assistants. The second-step study was performed, yielding an interesting finding about human insight problem solving, and is presented below.

Materials and methods

Semantic map

The list of SRL strategies borrowed from various sources together with the weak semantic map built of them were constructed in the previous work (Kuznetsova & Samsonovich, 2018). The resultant semantic map is represented in Fig. 1.

Strategies: 1. Understand what is given. **2.** Understand the statement of the problem. **3.** Understand and separate the conditions. **4.** Try to reformulate the problem (once again). **5.** Try to prove the impossibility of solution. **6.** Find a contradiction in the problem statement. **7.** Understand whether the given data is sufficient. **8.** Reject an intuitive interpretation/solution. **9.** Divide the problem into parts. **10.** Set an intermediate subgoal. **11.** Solve a particular case of the problem. **12.** Examine particular cases in sequence. **13.** Try to achieve a bigger goal. **14.** Try to solve a more general problem. **15.** Try to solve an analogous problem. **16.** Use a similar problem with known solution. **17.** Use a known formula. **18.** Apply a given means in an unconventional way. **19.** Visualize the given situation/statement. **20.** Use a symmetry or mirror reflection. **21.** Use a known mathematical fact. **22.** Introduce variables. **23.** Write down an equation or system of equations. **24.** Get rid of redundant data. **25.** Could additional data lead to the solution? **26.** Try to use all given information. **27.** Enumerate all possibilities. **28.** Find a pattern. **29.** Make a list. **30.** Make a table **31.** Introduce convenient notation. **32.** Try to solve the problem backwards. **33.** Use logical reasoning. **34.** Draw a diagram. **35.** Introduce additional elements. **36.** Read the statement attentively once again. **37.** Make a plan. **38.** Follow the plan. **39.** Validate every step. **40.** Recall definitions. **41.** Analyze the result of each step. **42.** Could the result be obtained in another way? **43.** Can the obtained result solve the problem? **44.** Understand the causes of failures of problem comprehension/solution. **45.** Get ready to take it easy.

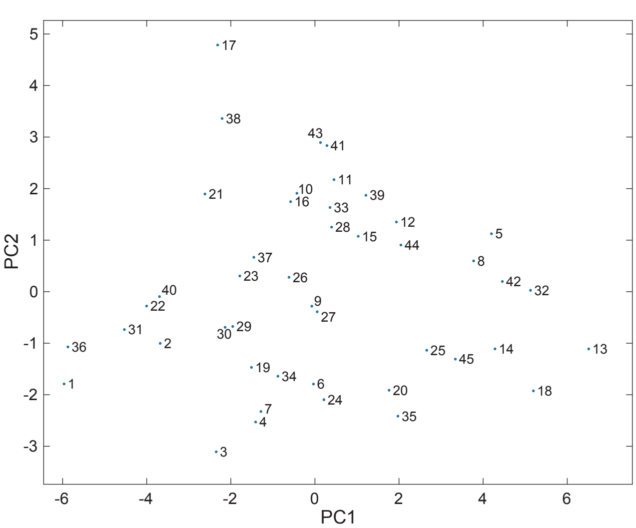

Fig. 1. Semantic map constructed of the 45 strategies (Kuznetsova & Samsonovich, 2018). Coordinates are main principal components of the distribution. The semantics of PC1 can be interpreted as *Aggressiveness, Arousal, Activity*. PC2 can be interpreted as *Valence, Confidence*. Strategies are represented by numbered dots and listed in text according to their numbers.

Semantic interpretation of coordinates PC1, PC2 in Fig. 1 is approximate and to a large extent subjective. PC1 can be interpreted as *Aggressiveness, Arousal, Activity*. PC2 can be interpreted as *Valence, Confidence*. Parameters of the distribution in PC1, PC2 are evaluated as follows. The center of the distribution is set to zero by the Principal Component Analysis. The standard deviations are: 2.94 in PC1 and 1.78 in PC2. Units are determined by the units of the original Likert scale (Kuznetsova & Samsonovich, 2018).

Insight problems

In total, eight insight problems presented below were offered to participants in this study, plus several additional, simpler problems not presented here were used for warm-up. Problems were acquired from various known sources, as indicated. Some of the problems were modified to match the level of difficulty used in this study, and are presented here as they were used in this study. All problems are known to be difficult for an average adult, yet they do not require for their solution any special knowledge beyond the high school program, and can be solved without any mathematical calculations. Solutions are intentionally not included here, except for one problem, for which the expected solution may be disputable. The rest have a clearly acceptable, valid solution each (while this fact cannot be used as a part of the reasoning scheme in finding the solution to the problem).

Problem 1: Two string problem (Fig. 2)

Given: a subject (a boy) in an empty room, where two strings are hanging from the ceiling at a distance from each other, so that the subject cannot grab them simultaneously. There are also a dome light, a chair, and plyers on the floor in that room. The subject holds an end of one string in one hand and tries to reach for the other string with the other hand, but cannot succeed. The original figure caption says: *"As hard as the subject tries, he can't grab the second string. How can he tie the two strings together? (Note: Just using the chair doesn't work!)"* (Goldstein, 2015; Maier, 1931).

Problem 2 (Fig. 3A), based on (Dawra, 2017): The line

Given: a line on the plane and a line segment parallel to the line. The task is to divide the segment into two equal parts.

Conditions: you are not allowed to perform any measurements or calculations, to copy objects, distances or angles. Only the following actions are permitted: