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comRAT-C: A computational compound Remote Associates Test solver based on language data and its comparison to human performance☆

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ABSTRACT

Discovering the processes and types of knowledge organization which are involved in the creative process is a challenge up to this date. Human creativity is usually measured by psychological tests, such as the Remote Associates Test (RAT). In this paper, an approach based on a specific type of knowledge organization and processes which enables automatic solving of RAT queries is implemented (comRAT) as a part of a more general cognitive theoretical framework for creative problem-solving (CreaCogs). This aims to study: (a) whether a convergence process can be used to solve such queries and (b) if frequency of appearance of the test items in language data may influence knowledge association or discovery in solving such problems.

The comRAT uses a knowledge base of language data extracted from the Corpus of Contemporary American English. The results obtained are compared to results obtained in empirical tests with humans. In order to explain why some answers might be preferred over others, frequencies of appearance of the queries and solutions are analyzed. The difficulty encountered by humans when solving RAT queries is expressed in response times and percentage of participants solving the query, and a significant moderate correlation between human data on query difficulty and the data provided by this approach is obtained.

1. Introduction

In the quest to achieve human-like artificial intelligence, some of the attributes considered the hardest to replicate are creativity [14] and creative problem-solving. Humans might be biased against attributing creativity to machines [17], possibly because of considering it a highly defining human trait. However research on animal tool use [23] and frameworks for studying creativity in animals [5,21] show that creativity is not limited to the human realm alone.

The study of cognitively-inspired computational creativity can benefit both artificial intelligence and cognitive science. For artificial intelligence, it can show us the way towards more versatile, flexible and robust artificial agents and artificial cognitive systems. For cognitive science, it can provide us with the better understanding of our own creativity.

Various theoretical proposals have been made on the nature of creativity [8,18,19]. However, the field of computational creative problem-solving combines (i) the generative powers of creativity with (ii) the constraints and evaluative functions implicitly involved in problem-solving, thus providing a well-balanced tool to study computational creativity.

From the cognitive systems perspective, one of the major unsolved questions about creative problem-solving is what kind of knowledge organization and processes endow the human cognitive system with creative abilities. The particular characteristics of creative problem-solving in humans (e.g. remote association, functional fixedness, incubation, insight), together with data on such abilities (i.e. performance time, specific errors, quantity and domain of associations, quality of elaboration) can be used to try to understand and model such knowledge organization and processes. In order to refine hypotheses about which kinds of knowledge organization and processes enable creative problem-solving in humans and in the implementation of cognitive systems which manifest such creativity, such hypotheses need to be implemented in systems which can be tested with creativity tests comparable to the ones given to humans.

Various psychological tests have been used to measure creativity; some of the most widely used in the field are the Torrance Tests of Creative Thinking (TTCT) (for a critical review see [22]). Some tests reach up to empirically studying insight [16,25]. However, insight problems take a long time to administer to humans, and would need significant amounts of problem-specific common-sense knowledge to be given to artificial systems aiming at replicating the human performance.

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Thus, a good starting point for testing any assumptions about principles of knowledge organization and processes in creative problem-solving is to use a smaller task, which enlists abilities similar to insight problem-solving, though providing enough human data for a rich comparison between human performance and the performance of the automated solver. Such a task is the Remote Associates Test (RAT), initially proposed by Mednick and Mednick [28].

The following work is focused on the design, implementation and analysis of a computational solver which can answer RAT queries in a cognitively inspired manner. This automated RAT solver presents a specific type of knowledge organization and implements one of the processes in a previously proposed theoretical framework for creative problem-solving [30,31].

An artificial cognitive system or other computational system which solves the Remote Associates Test does not exist to our knowledge. Furthermore, computational creativity work, though having implemented a series of systems in a wide array of domains – e.g. poetry [13], painting [12], mathematics [24], magic trick making [33], etc. – does not generally focus on implementing systems capable of solving tasks used in the empirical assessment of creativity.

The rest of this paper proceeds as follows. The RAT test is presented in Section 2. The relationship between the RAT test and the principles of the CreaCogs theoretical framework is presented in Section 3, together with an explanation about how a process of this framework has been adapted for the RAT. The set-up of the proposed RAT problem-solver is presented in Section 4, where the knowledge used, the system's knowledge organization and the solving process are described. Section 5 presents a hypothesis on why some answers are chosen by humans when multiple answers are available. This hypothesis analyzes frequency data to propose an explanation for human preferred answers and define item contribution. Section 6.1 presents the results obtained with the computational RAT without using frequency data, and compares these to human normative data [10]. Plausible answers are also reached by the system and discussed. An empirical analysis on preferred answers using frequency data is presented in Section 6.2. The correlation observed between frequency results calculated using the hypothesis and difficulty of test items for humans (represented by response time data and percentage of people solving each test) is described in Section 6.3. A discussion of the results is presented in Section 7, followed by conclusions and further work in Section 8.

2. The Remote Associates Test (RAT)

The Remote Associates Test proposed by Mednick and Mednick [28] is meant to measure creativity as a function of the participant's ability to associate multiple remote items. Mednick believed that the creative process, independent of domain, has an associative basis [27]. He stated that the ability to *"bring mutually remote ideas into contiguity facilitates creative solving"* and believed that *"the organization of an individual's associations will influence the probability and speed of attainment of a creative solution"* [27]. In order to account for these theoretical assumptions, Mednick proposed and refined the Remote Associates Test [28] as an empirical tool for investigating creativity. The RAT has been amply used in the literature [2,9,15]. It takes the following form: given three word items, the participant has to find a fourth term, which is common or can be connected to all of them. For example, the following three items are given: COTTAGE, SWISS, CAKE; and the participant has to come up with a fourth related term. An answer considered correct in this case according to the studies by Mednick and Mednick [28] is CHEESE, because of the following associates: *cottage cheese, swiss cheese and cheese cake*.

In Mednick's opinion, the RAT requires the participant to *"form associative elements into new combinations by providing mediating connective links"* [27].

After Mednick's proposal, the RAT, originally implemented in English, has also been implemented in other languages, including Japanese [4], Jamaican [20], Hebrew [29] and Dutch [11].

Worthen and Clark [34] differentiated between two types of items which appeared in the test by Mednick and Mednick [28]: structural remote associates and functional remote associates. They posited that functional associates ellicit a non-language relationship (i.e. like the one between *bird* and *egg*) and structural associates triggered items previously associated in the same syntactic structure (e.g. *black* and *magic*). They proposed a remote associate test based on functional associates (FRAT). Bowden and Jung-Beeman [10] focused on obtaining normative data for compound remote associates (i.e. those obtained from a syntactical compound, like a phrase or a compound noun), which are similar to the structural remote associates from Worthen and Clark's categorization. Assuming that different types of knowledge will be necessary to solve the compound Remote Associates Test (cRAT) versus the functional Remote Associates Test, this paper chose to focus on a cRAT solver, and used the existing normative data [10] as a comparison point.

The stimuli given in the test are meant to be "remote" from each other, as Mednick considered their juxtaposition might enable the participant to *"draw a spark"*. This *"spark"* might be similar to something popularly known as *"the flash of insight"*. Indeed, the RAT is generally an interesting benchmark to initially test associative mechanisms used in creative problem-solving because performance in the RAT has been correlated with performance in insight problems [32]. Such a correlation might point to similar association-based search processes in both types of problems.

Results are thus available to the solver in a similar phenomenological manner when solving the RAT and when solving insight problems. When solving the RAT, the answer word seems to pop-up in the participant's consciousness in a similar manner in which a productive representation or a way of solving the problem appears in insight problems in the illumination phase. Thus, participants cannot report on their solving process [6] and the *"aha!"* experience is similar to that encountered when successfully solving insight problems [9]. In our opinion, this happens in both cases due to a search process based on associations to the initial items in the problem space. The *"aha!"* effect happens when a group of implicit associations converges upon a possible solution or a new representation structure (i.e. a different way to see the problem).

The following section explains the framework and mechanism this opinion is based on, after which such a mechanism is implemented and the assumption tested in a RAT solver.

3. The Creative Cognitive problem-solving theoretical framework (CreaCogs) and the convergence process of association

For a cognitive agent, the organization of its knowledge base is relevant as it can make computationally easier certain processes which help in creative problem-solving. Encountering items in a similar context can build associations in the agent's knowledge base that can be further used to: (i) search for a problem solution, (ii) transform the initial objects in the problem, and (iii) formulate or reformulate the problem in a way that makes it solvable for the agent [31].

For this purpose, the CreaCogs framework proposed [30,31] to use a knowledge organization system on three levels for modeling various creative problem-solving tasks:

- L1: a subsymbolic level, which encodes the various features of objects (shape, color, material, motion trajectory, etc.) in similarity based feature maps;
- L2: a concept level, at which each object known is encoded symbolically;
- L3: a structured representation level, which encodes larger representation structures and templates in the context of which the