Creative Solution of Problems*

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Abstract. Creative solution for a problem depends on its proper representation. For a systematic search for a new representation we introduced Semiotic Introspection Principle (*SIP*). The resulting representations are compared with other attempts to find a solution, borrowed from the paper on creativity published by McCarthy and related to his "Tough Nut Problem". It is also shown in our paper how to obtain a good representation for an orthogons version for the same problem. At last, a theorem is demonstrated, which gives the necessary and sufficient conditions for the perfect coverage of an arbitrary array of cells, which generalizes the above problem in another way.

Keywords: Creative Problem Solving, Problem Representation, Semiotic Introspection Principle, Tough Nut Problem.

1 Introduction

It will be shown that the choice of problem representation made prior to its solution may provide a ground for so-called creative problem solution, i.e. the solution that does not follow from the knowledge of the area to which the problem belongs. For elucidation of this situation some practical examples of creative solutions where the sources of origination are difficult to find will be demonstrated.

For a systematic choice of the appropriate representation we propose a new concept named Semiotic Introspection Principle (*SIP*). Its use opposes the some irregular tools discovering of creative solutions.

The usefulness of *SIP* is demonstrated in the paper for examples which are related to the "Tough Nut Problem" that was brought to the Artificial Intelligence field by Prof. J. McCarthy [1] and became quite popular in the field of AI.

In conclusion an opinion is expressed that a combination of the heuristic *SIP* and some traditional for AI heuristics would provide the most serious advance in solution of various intellectual problems encountered in AI.

2 Logic Problem Solving

Computer solving of logic problems has been well studied in AI [2]. There are various tools for logical analysis of a situation. Some logical means were used in organization

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of a complex enough behavior of robots. For instance, the system Strips for the robot Shakey was based on a logical decision making.

There are many theorem proving systems. Various logic systems to solve applied problems have been described [2]. It seemed that only “some minor AI problems” has been left to be resolved.

However, quite a different situation was discovered in the area of search for creative solutions for some problems.

One may say that for many researchers it is the *Creativity* that differs of Human Cognition from artificial modeling of our mind with a computer. Sometimes a thought is expressed that the creativity is the property intrinsically belonging only to people and, probably to some mammals. And even more: theses abilities does not belong to all the people, but only to some subset of the people.

Indeed, only a few great artists became famous in the World. Some more artists of a decent level remain unknown to general public. Also we have a lot of people who does now how to use a brash and the oil for painting.

Some great mathematician of nowadays are also quite known. Yet, the total number of such names is not terribly great. And this is despite of the fact that famous universities throughout the World, like Math Department of Moscow State University, prepare hundreds of qualified mathematicians each year.

From above it becomes obvious that the creativity problem in the frames of AI may be raised only with some outstanding representatives of AI, such as the founders of Artificial Intelligence Prof. John McCarthy or Prof. Marvin Minsky and similar outstanding AI persons, who are brave enough to start a new AI issue and to reach a postulated goal.

In the figure 1 we show the definition of creative solution given by J. McCarthy.

> *“Definition (informal): A solution to a problem is creative if it involves concepts not present in a statement of the problem and the general knowledge surrounding it. Don’t identify creativity with difficulty although they are usually correlated”*

Fig. 1. The definition of a concept of creative solution [3]

3 Problem Representation

Participating in international conferences on Artificial Intelligence IJCAI-II IJCAI-III, IJCAI-IV, we provided the papers on the topic of Problem Representation using examples following “Tough Nut Problems” by John McCarthy [1]. Prof. John McCarthy had returned to his example of the problem some years later referring to this area as *creative problem solving* area [3].

Before going further, please note that the recognition of creative solution obtained by people usually comes across with some obstacles.

The main two barriers are:

- Ignoring from the start.
- Citations are missing.

As an example we will mention ignoring in the West the translation of the book by M.L.Tsetlin [4] and ignoring all the publications on collective behavior and games of automata, that have been published in the USSR long before the multi-agents appeared in some countries.

The detailed discussion of negative role of non-citation and the positive influence of proper citation were considered in [5].

Presently it is difficult to predict how these pictures would change if some features of creativity will be attributed to computers. At least it is clear that the problems of copy-write ignorance or non-citing are to be reconsidered a new as the role of personality is reduced due to computer.

4 Definition of Creative Problem Solving

The definition in figure 1 belongs to J.McCarthy and was taken from his publication [3] of the year 1999. In this publication it was stressed that this definition is not formal, and simplifications comes from substitutions of the concept of *creative problem solver* with the concept of *creative problem solving*.

In the present paper we start to speak on the creative problem solver considering creative solutions as only some illustrations of the creative ability of such a solver, realizing however that we are making only the first steps in this direction. Our illustrations are, in this way or another, related to the Tough Nut Problem [1], which is demonstrated in the figure 2.

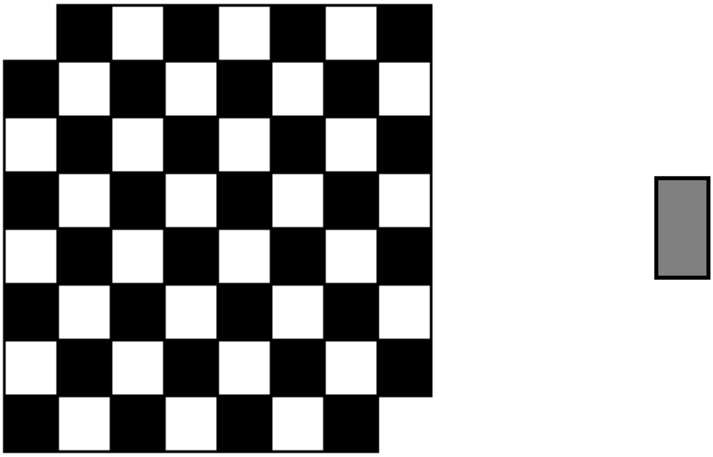

Fig. 2. Tough Nut problem formulation

The problem is to show that the left array in the figure may not be perfectly covered with domino pieces shown to the right. It means that there no uncovered cell and there is now domino piece that produces itself outside the board.

Actually this problem is widely known among AI experts, and it has been mentioned in a number of publications.

In the paper [1] its author noted that the solution with the full search algorithm leads to the large number of computer steps, and this procedure was completely impossible to perform using computers of those days.

In the same time a nice solution is known to the people. It is proposed in this solution to note that each domino, being put on the left array, covers exactly one black and one white cell. As the total of black cells exceeds the total of white ones then the perfect coverage is impossible.

In the publication [1] the importance of this problem for AI was stressed as the full search procedure is the only way to solve problems if no other additional knowledge on the problem available.

Some researches decided that the idea of the *black and white invariant* is a very important topic and may be developed further on its own [6]. However, we used another possibility, namely we have proposed to search for an *appropriate representation* to the problem.

In what follows, first we will bring in some figures of the citations taken from the publication by John McCarthy [3], where he demonstrated examples of creative solutions of the Tough Nut Problem obtained by various experts:

The first "non-creative" solution was prposed by Shmuel Winograd of IBM. He claimed it was non-creative? because it didn't involve coloring.

Assume a covering. The number of dominoes projecting from the top row to the second raw is odd. Likewise the number from the second to the third is odd, etc. Therefore, the total number of vertical dominoes is the sum of seven odd numbers and hence odd. Likewise the number of horizontal dominoes is odd. Odd + odd is even so the total is even, but the total is 31. There is apparent mathematical induction here in the "ets.". We will see later that the idea itself does not include the induction.

Surely Winograd's proof is creative, but we can ask whether there is one creative idea in it or several. My guess is that there was one creative idea, and the rest was straightforward for a good mathematician like Winograd.

Fig. 3. Discussion of solution reached by Sh. Winograd [3]

The second was by Marvin Minsky of M.I.T.

Start with the 2-diagonal next to an excluded corner square. 2 dominoes must project from it to the adjacent 3-diagonal. Subtracting, one domino projects from the 3-diagonal to 4-diagonal. 3 project from 4-diagonal to 5-diagonal, 2 project from 5-diagonal to the 6-diagonal, 4 from 6-diagonal to the 7-diagonal and finally 3 project from the 7-diagonal to the 8-diagonal. coming from the opposite excluded corner also only covers 3 squares of the 8-diagonal, leaving 2 uncovered squares. Minsky's proof gets high pints for non-creativity, because it is specific to the 8 by 8 board.

Fig. 4. Discussion of solution reached by Marvin Minsky [3]

The third method is by Dmitri Stefanuk of Moscow, Russia. He suggested 62 proofs – 17, taking into account symmetries.

Choose an arbitrary square and mark it 1. Mark its rectangular neighbors 2, their unmarked neighbors 3, continuing until every unexcluded square is marked. Then proceed as in Minsky's proof, counting the number of dominoes projecting from the 1-squares to the 3-squares, etc. We got a proof if there not enough dominoes projecting from (n-1)-squares to n-squares. Every attempt at a Stefanuk proof succeeds. Stefanuk proofs are just as uncreative as Minsky proofs.

Remark: Counting colors shows that Stefanuk proofs and Minsky proof proofs always work on any even board. However, this argument is at a meta-level to the Minsky and Stefanuk proofs and therefore can't claim to be non-creative.

Fig. 5. Discussion of solution reached by Vadim Stefanuk [3]

Then J.McCarthy concluded:

In fact, the Winograd, Minsky and Stefanuk proofs are all creative? and we will try to identify the creativity involved and give a concise expression of the ideas.
I suppose they count as creative, but maybe as one creation rather then two.
In a future article, we hope to put the Winograd and Stefanuk proofs in a logical form that isolates the creative part from the routine part.

Fig. 6. On creativity [3]

Unfortunately, John McCarthy was not able to finish his important research on creativity started in [3] due to his premature death.

5 Problem Representation Methods

The *problem representation* was a topic listed in the conference IJCAI-IV due to our initiative [7]. Unfortunately, this topic has gradually been forgotten and replaced with the *knowledge representation*, which is only slightly related to the topic mentioned above.

Now, speaking on creative solution some people refer to the property of insight or "the mystics of a proper guess".

Trying to reduce the "mystics" let us remind that in the logic the most popular decisions are made using either induction, or deduction, or abduction.

It may be said that the change of the problem representation is related to the abductive reasoning. Indeed, the change of *problem representation* does not give a solution to the problem by itself.

In what follows the abduction stage or the change of representation for the problem will be illustrated with the following versions of "Tough Nut".

Case A. The array of cells has a chess coloring and the notion of the invariant is provided.
Case B. The array of cells is painted but no advice is given with respect to the problem solution.
Case C. The array of cells is not painted.
Case D. The square type figures are presented called orthogons.

These examples have been described in a number of our publications [8] and collected together in the book [9]. In the present paper they are given in order to make a complete exposition of the important role of problem representation for problem solving.

6 Semiotic Introspection Principle

For solution of such problems we propose to use *Semiotic Introspection Principle (SIP)* to stress the similarity and to demonstrate the difference [V.L. Stefanuk, 1973].

The similarity is stressed with the use of same name for the elements of the problem. The difference is demonstrated with different names to the elements. (The usage of names explains the term semiotic in the definition of *SIP* [8].)

Case A. As the notion of invariant is given the solution is obvious.

Case B. The array is painted appropriately
Using numbers for the cell array one would have for any coverage the following sequences of domino positions:

$$path_1 = [a_{12}, a_{13}], [a_{14}, a_{15}], [a_{16}, a_{17}], \ldots, [a_{85}, a_{86}], [a_{78}, -], [a_{87}, -]$$

$$path_2 = [a_{12}, a_{22}], [a_{13}, a_{23}], [a_{14}, a_{15}], \ldots, [a_{77}, a_{87}], [a_{87}, -], [a_{78}, -]$$

$$\ldots \qquad \ldots$$

$$path_k = [a_{12}, a_{22}], [a_{13}, a_{14}], [a_{15}, a_{16}], \ldots, [a_{85}, a_{86}], [a_{87}, -], [a_{78}, -]$$

$$\ldots \qquad \ldots$$

Fig. 7. All the possible coverage

Using the names black and white one will see that any of the covering will be converted to the one:

$$path_i = [B,W][B,W][B,W], \ldots, [B,W][B,W][B,-][B,-] \qquad (1)$$

for any value of i from figure 7[1].

Hence, if one of the coverage is successful, the following equation would be hold

$$n_i(\mathrm{B} + \mathrm{W}) = 32\ \mathrm{B} + 30\ \mathrm{W} \qquad (2)$$

Obviously, this equation is not valid for any value of n_i.

Case B. The array cells are not painted

Applying *SIP* to this array of cells one obtains two versions, shown in the figure 8. Giving name “1” to an initial cell in the left version we see that we have four similar possibilities for positioning domino starting with the cell named “1” in the left version, or three similar possibilities in the right version. In accordance to the Semiotic introspection Principle this neighboring cells are similar and obtained the same name.

In the first case we use only two names, in the second case we have a numbering that will spread over the array. In both cases it is seen that coverage is impossible.

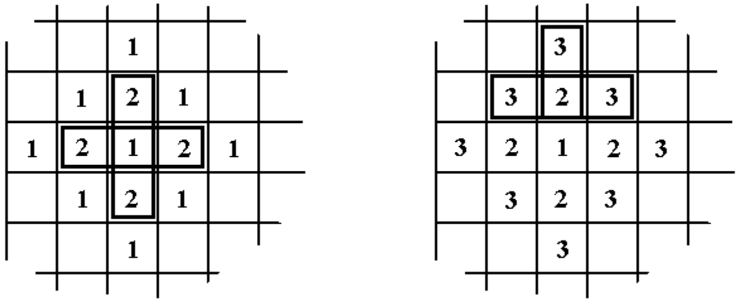

Fig. 8. Coloring the array of cells with two names (left figure) and with arbitrary number of names (right figure)

Case B. Orthogons

An orthogon is a multiangular plane figure with all sides either parallel or collinear. In the figure 9, the problem of Tough Nut is shown in the language of orthogons.

[1] B stands for each cell painted black in the figure 2, while W stands for each white cell in the same figure.

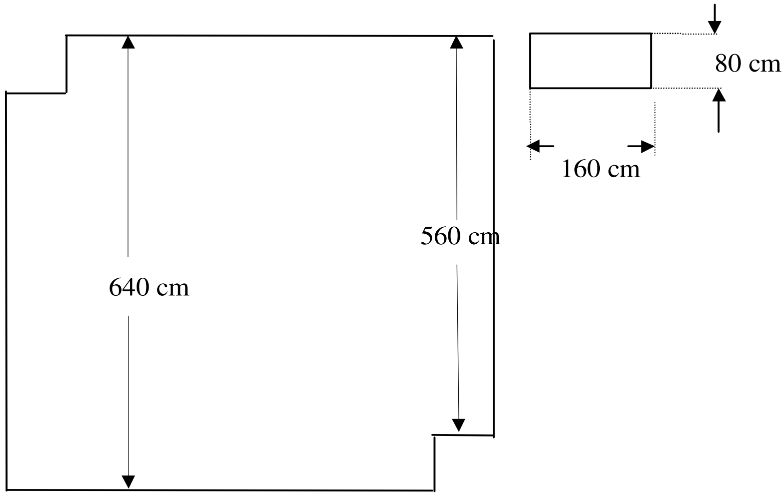

Fig. 9. Tough Nut Problem with the orthogons

Theorem 1. Left orthogon in figure 9 may not be covered with collection of small orthogons shown in the right of figure 9.

The proof

First note, that the left orthogon may not be perfectly covered with small orthogons from the right if at least one of them is not parallel to the sides of the bigger one.

Hence, the locus (geometric positions) of the borders of all the small orthogons in the figure 9 (if the coverage is possible) must be collection of lines in the large orthogon that is demonstrated in the next figure.

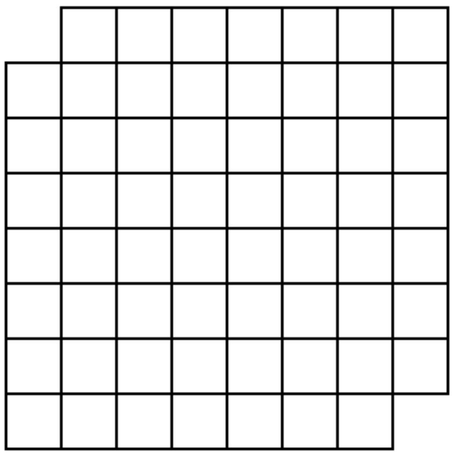

Fig. 10. The locus of all the possible positions of the borders of "domino pieces" when the coverage is successful

In other words the problem with orthogons is reduced to the **Case C.** Thus, theorem has been proved.

In the publication [9] it was shown that the orthogons formulation of the Tough Nut problem may found some application in Japanese Homes.

Arbitrary Array of Square Cells

In the paper [3] it is also mentioned, that presently there are some solutions of the Tough Nut Problem obtained with a full search procedure as the speed of processors had increased considerably since the time of publication of the very first paper on this subject by J. McCarthy [1].

However, to our opinion, the importance of the problem for general Artificial Intelligence is not reduced as the some minor increase the number of cells in the array will give a problem that may not be solved with the full search even if one takes rather powerful modern computer.

At the present paragraph we will prove a theorem concerning a possibility of the perfect coverage with domino pieces of the array of arbitrary size. This theorem provides necessary and sufficient conditions for the possibility of the perfect coverage of the *arbitrary array* of cells.

For this theorem we will make use the problem representation shown in the right of figure 8.

Definition. For a connected array of square cells we will define the naming system or representation P by assigning names “1” to some subset of the cells of the array and the names 2, 3,… in the way providing that the names of any neighboring cells are different by one.

Let g_k be the set of cells with the name k, and let $|g_k|$ denotes the number of cells in this set. The naming system P is called *correct* if and only if the following relations are true

$$\begin{aligned} \blacktriangle_2 &= |g_2| - |g_1| \geq 0, \\ \blacktriangle_3 &= |g_3| - |g_2| \geq 0, \\ &\ldots \\ \blacktriangle_{s-1} &= |g_{s-1}| - |g_{s-2}| \geq 0, \\ \blacktriangle_s &= |g_s| - |g_{s-1}| = 0 \;, \end{aligned}$$

:

where s is the largest name in P.

Then the following theorem is valid [9].

Theorem 2. Any two-dimensional simply connected array of n square cells may be completely covered with two-cells domino pieces if and only if any possible for this array naming system (or representation) P is correct.

7 Conclusion

1. It was shown that computer may produce a creative solution for some problems.
2. It was demonstrated that the subject of problem representation is still actual and deserves further study.
3. It was shown that formally the change of representation is a kind of abductive reasoning.
4. A new universal principle (or heuristic) of semiotic introspection (SIP) was proposed and used for solution of several problems to overcome combinatorial complexity.
5. When there no combinatorial complexity one may use traditional for AI tools like GPS. It seems that combining these tools with Semiotic Introspection Principle would move computer intelligence closer to human intelligence.

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