REFLECTIONS ON MAX WERTHEIMER`S "PRODUCTIVE THINKING": LESSONS FOR AI[1]

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Introduction

The aim of this article is to reflect on the influence of the seminal text by Max WERTHEIMER on the area of inquiry related, in general terms, to psychology, but concerned with computer technology, namely artificial intelligence (AI). The time period in which WERTHEIMER wrote *Productive Thinking* coincided with the appearance of other important works. One in the computational domain, another one in a biological one: both dealing with abstract mental constructs. Both also embody the first steps in the development of two streams of ideas concerned with AI. These are: TURING's work on the nature of universal calculator (TURING's machine) and models of neural nets (McCULLOCH and PITTS, 1943). One stream influenced discrete, reasoning based, sequential methods of AI, the other, parallel methods, encompassing the whole (that is Gestalt).

The physical base of AI - the computer - embodied a rough model of the brain that utilized various psychological concepts used by mathematicians and engineers. For example: receiver of the information, central processing unit, short term and long term memory, mechanisms for information withdrawal, and so on. Even such a coarse imitation of psychological notions turned out to be adequate, more so than previous models (for example, mechanical metaphor of tubes and vital juices, telephone metaphor of wires and switchboards). And in psychology, the computer metaphor was also used: psychological models were constructed using computer simile. The problem was, however, that those who constructed these models did not have, as yet, an awareness that they have been finding their own distorted image in them.

The generation of scientists who worked on problems of AI almost 30 years ago, by the most part, are now not active in AI and abandoning 'the stage,' so to speak. Perhaps it is time to reflect on this. The golden age, which cybernetics (as a component of AI) promised in the area of production management and the conduct of the

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1 Early version of this paper was presented during European Systems Science Congress in Valencia, Spain, September 1999.

daily life, turned out to be a mirage. Cybernetics itself disappeared, and what is more important, changed its name to escape the responsibility. Now it is called informatics, which promises nothing. It is our contention that an analysis of the text *Productive Thinking* can help us greatly in analyzing this problem. The book pleads the Gestalt point of view against other two perspectives dominant at the time, namely, traditional logic and the theory of associations.

Traditional logic method

Let us review, in brief, WERTHEIMER‘s position on the essence of logic when investigating the nature of thinking. As long as thinking is concerned with truth, and truth and false are qualities of expressions and judgments, they form the foundation of thinking. Assemblage of true judgments leads to new true judgments. Traditional logic defines criteria that guarantee the truth as well as congruity of judgments and conclusions.

Let us recall that the logic method goes back to the ARISTOTLE‘s "Organon". Processes of this method were stable for centuries. The new process - the method of induction, with its emphasis on experience and experimentation, was introduced 2000 years later, during the Renaissance.

The logic method formed the basis of AI work from the start. The assumption was, that proving theorems, playing chess, cards or performing similar activities demands logical methods of thinking. Computer models that where capable of carrying out these functions were the same as models used at the time to explain the working of the mind.

Rather odd phenomenon was discovered in some medical and geological applications: the specialist accepts a given outcome as truth not when it satisfies all formal criteria of truth (according to rules of logic), but when it is plausible (when it satisfies common representations and adheres to standards of actions accepted in a given professional context). Naturally, some of the logically correct judgments may be unacceptable, and some of the judgments that appear to be right are false.

The modeling of logic systems has its significant peculiarity. For these systems it is known a priori that the set of axioms and the rules of deduction hold all the information needed for solving the problem under study. The program "Logic - theoretic" by NEWEL, SHOW and SIMON (1956) pioneered this approach. GSP - the *universal problem solver* (described at a time as " the new powerful arms for creating the theory about man's thinking") was also the product of such approach. However difficulties soon became apparent. The big number of logically correct chains of conclusions did not necessarily lead to the goal. There where more ways and it became less possible to reach the goal. Even in the situations when computer found the right conclusion, the way of getting to the solution was very disappointing:

namely, efforts taken at the intermediate steps were often incredibly silly, and essentially non-human. There was no intellect exhibited in the models. Thus the new understanding emerged: intellectuality can be defined not only by the goal, but also by the way one reaches it. Nevertheless, at that time, many psychologists used the AI computer metaphor applying terms such long-term memories, multi-dimensional space and parallel processing of facts in their models. That was precisely the position of the practitioners of AI in the 60th and 70th. (It should be noted that if these practitioners have paid attention to WERTHEIMER's warnings, lots of time and effort could have been saved when developing AI applications.)

Let us now list all of its positive aspects (as WERTHEIMER had perceived them) before we examine WERTHEIMER'S critique of the logical approach. These are: 1) commitment to the truth, 2) awareness of the difference between a belief, a statement, and a correct judgment, 3) underscoring the difference between fuzzy and solid definitions, 4) understanding the significance of the proof, 5) insisting on the correctness of each step of the thinking process. Computer paradigm conveys all these to a broad field of ”soft” sciences (medicine, geology, psychology etc). In other words, the approach applied in practice was the logical approach. And as it is always the case, it embodies its power as well as its weakness.

WERTHEIMER was rather sarcastic about the method of logic. On page 6 of his book he stated: ”*Some psychologists would hold that a person is able to think, is intelligent, when he can carry out operations of traditional logic correctly and easily.*

He observes that: ”T*raditional logic is not so much concerned with the process of finding the solution. It focuses rather on the question of correctness of each step in the proof”* (p. 70). And this is its weakness when applied to the study of the intellect. Unfortunately, practitioners of AI did not pay attention to this profound statement and lots of time was wasted on constructing diverse correct decisions and on selecting sensible ones among them. Perhaps the alternative should have been this: construct "sensible" decisions, check their correctness, and when not correct endeavor to make them correct.[2]

WERTHEIMER‘s profound idea was that when considering thinking, logic plays normative role, not the constructive one. It is important to note that this is confirmed by the whole history of the AI and it still did not loose its essence, even now, with so vigorous interest in the multi-valued and non-monotonic logic. The other consequence of the exclusively logical approach to thinking that concerned WERTHEIMER was a wide acceptance of the notion that "*thinking is successive by na-*

[2] For example, when playing chess it is worthwhile to analyze the incorrect moves, to make two moves in a series instead of one (all according chess rules). The result can happen to be so alluring that one ought to think how to do this combination the correct way (for example, having parried the defense actions, which the partner could use, to use the right move). So one gets the combination, which allows for desired action into two steps, without hindrance.

ture" (p. 107). This, in turn, created "*axiomatic assumption that thinking is, must be, verbal by nature, that logic is a matter of language, both of which assumptions are blind generalizations*" (ibid.). WERTHEIMER strongly disagreed with this position.

Let us examine, in brief, consequences of acceptance of such notions in the construction of AI systems, especially, for expert systems. In expert systems, the base of the logical construct is formed through the use of "if - then". In reality, when this construct is applied to problems of, for example, medical diagnosis, or geological exploration, it becomes very quickly apparent that the more comprehensive knowledge and experience of physicians and geologists is not utilized. The nonverbal nature of thinking becomes especially evident when the image analysis is contemplated. For such types of problems the method of knowledge representation through logical constrains (for example, statements "if border's curvature is more than …, and the length is less than … , then...") is very inadequate. It turns out that it is more effective to retain the knowledge about the images in the form of images [3].

We conclude this section of the paper with WERTHEIMER`s reflections concerning conversations he had with Albert EINSTEIN about the process of intellectual creation of the theory of relativity. These reflections demonstrate clearly that WERTHEIMER recognized the strengths and limitations of use of methods of logic to comprehend, in its totality, the process of thinking and of the intellect.

"If we were to describe the process in the way of traditional logic, we would state numerous operations, like making abstractions, stating syllogisms, formulating axioms and general formulas, stating contradictions, deriving consequences by combining axioms, confronting facts with these consequences, and so forth.

Such procedure is certainly good if one wishes to test each of the steps with regard to its logic correctness. But what do we get if we follow such a procedure? We get an aggregate, a concatenation of a large number of operations, syllogisms, etc. Is this aggregate an adequate picture of what has happened? What many logicians do, the way they think, is somehow like this: A man facing a work of architecture, a fine building, focuses, in order to understand it, on single bricks and also on the way in which they are cemented by the mortar. What he has at the end is not the building at all but a survey of the bricks and of their connections" (p. 227).

Associative method

[3] For example, in his talks with WERTHEIMER EINSTEIN mentioned "the direction" of thinking: "Of course, behind such a direction there is always something logical; but I have it in a kind of survey, in a way visually " (p. 228).

Another theory of thinking is centered on the classical theory of associations. Thinking is considered as a chain of ideas (or, in more modern terms, a chain of stimuli and responses, or a chain of behavioral elements). An "idea" is therefore some remnant of perception, a copy, in more modern terms, a trace of stimulation.

What is the fundamental law of the connections between these elements? The answer is given in a very elegant way in its theoretical simplicity. If two items, "a" and "b", have often occurred together, a subsequent occurrence of "a" will call forth "b". Basically the items are connected in the way in which my friend's telephone number is connected with his name; in which nonsense syllables become reproducible when learned in a series; in which a dog is conditioned to respond to a certain musical sound. Habit, past experience, in the sense of items repeated in contiguity – inertia rather than reason, are considered to be the essential factors. Applying the theory of associations, psychologists may state that the ability to think is the management of associative bonds. Although WERTHEIMER admitted that there are merits to this approach, he criticized it sharply, nevertheless.

Let us now consider this approach as it influenced AI. It turns out that the search for adjacent elements that repeatedly occurred in the past informed one of the more fruitful streams in AI, namely learning of pattern recognition by examples. The idea was brought forth by ROSENBLATT and he expressed it in his pioneering paper on the *perception* (ROSENBLATT 1958). That approach was used in the multiple attempts to imitate, on the computer, the human ability to recognize speech and handwriting, faces, ships, fingerprints, and so on. Some programs devised for character recognition used 200 examples of each handwritten character. However, this approach did not work: the level of recognition was still low. A lot of effort was put into the development of sophisticated algorithms for pattern recognition. This approach did not work either.

The true progress was made when the adequate language for object description was put to use. Finding this adequate language was non-trivial. Though the pattern recognition approach did not succeed in perception modeling it became useful in other applications (medical diagnosis and geological exploration may serve as examples). WERTHEIMER foresaw such an outcome. He wrote (p. 27):

> "Modern science, while often based on induction, does not like to stop at induction. It goes on to search for a better understanding then induction alone provides. An important instrument in its right place, induction is a start rather than an end in itself. But here it is not even justified as a start, being unnecessarily, arbitrarily blind to the issue."

On the problem of pattern recognition

We wish also to point out that an important problem arises in pattern recognition. It involves the emergence of bias in the decision rule: appearance of false associations when generalizing from a small number of empirical data. In the context of the associative approach it seems that the only way to deal with such bias is to increase the number of examples put to use in learning [4].

Let us consider an example in the geological domain. Pattern recognition is a powerful tool used in the well log data interpretation (needed to distinguish between the layers containing oil or water). Most often the number of identified objects (layers) is small and the number of layers, subject of interpretation is large. When the volume of data used in learning is small, it is easy to obtain biased generalizations and thus wrong decision rules. The decision rules become unstable; it becomes impossible to choose a good rule from a number of different ones. Placing the problem in a wider geological context can rectify this situation. It is well known that within the oil deposit water containing layers are located in lower strata then oil containing layers (water is heavier then oil). This constraint dramatically decreased the number of possible decision rules. As a matter of fact, we are left with only one decision rule. This wider geological context is so valid that in many cases the number of examples for learning could be reduced to zero.

Moreover, the expression "*the brain is a machine for processing symbolic information*" lead to a fallacious and unsuccessful use of AI. Useful AI work came about when abstract entities were replaced by physical entities. The problem of handwriting recognition may serve as an example. Many papers were published and funds were used in an attempt to create minimally acceptable programs to be used in a free-form handwriting recognition. None succeed. What was accomplished at a maximum was the recognition of individual characters. It turns out that the problem resided in the approach taken. The initial data was considered the bitmap and the basic operations, thinning, normalizing and comparing with provided written sample. Acceptable solution emerged only when the process of writing was connected to the reality of how it is accomplished. The movement of the pen became the focus of concern. Thus the 'thinning' was substituted by 'path extraction', for example. What transpired is that it is essential to consider close relationship between the intellect and the formulation of movement. It is worthwhile to note that accepted AI paradigm at the time excluded pattern recognition (as well as the study of robotics) as not worthy of AI concern. At this juncture let us note that WERTHEIMER insightfully objected to such narrow mode of thinking. On page 197 of his text he states:

> "Generally speaking, it is an artificial and narrow view which conceives of thinking as only an intellectual operation, and separates it entirely from questions of human attitude, feeling, and emotion just because such topics belong to other chapters of psychology."

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[4] That is why in the handwriting recognition task the number of learning examples for each character reached 200.

Solutions to the pattern recognition problems can utilize not only objects and classes of objects but also notions. We posit that the definition of a notion as a generalization of objects of a given class is too narrow. Such approach supposes extraction of common features from given set of objects, which belong to one class. WERTHEIMER (p. 42) already proposed a novel way of forming notions and finding essential features based on the inner property of a single example.

> ”In associationism the question of many cases, of many repetitions showing some constant connection, is fundamental. In line with this, the ugliness of our cases of induction was viewed a due to their lack of general validity. But the issues of sensible structurization, organization, of fitting of items into each other, of completion, etc., are not necessarily connected with thinking of other cases; they may be envisaged, realized in the single concrete case, viewing it structurally, sensibly. This does not of course give assurance of universality in factual questions; but it often leads to reasonable understanding and to genuine discovery of essential features, in contrast to performing operations on the basis of blindly generalized features common to many or all cases.”

It took 25 years until these notions penetrated AI. It turns out, for example, that the grammatical structure of the utterance contains the information on the hierarchy of features of the object described by that utterance. As deeper the position of the word representing a certain feature, the less important is that feature. We maintain that this holds true for the natural language, for programming languages, for a specific language of description of an image (EKG, for example), and so on.

To illustrate, let us consider the situation described by the sentence ”The black horse jumped over the fence”. The ”horse” and ”jumped over” occupy top level in the grammatical structure of that sentence; ”black” and ”fence” are subordinates. Changes on the low level change the situation in small measure (”The white horse jumped over the fence” or ”The black horse jumped over the tree”). Changes on the higher level change the meaning of the situation dramatically (”The black fly jumped over the fence” or ”The black horse kicked the fence”.) Such approach allows one to create the notion of ”an arc” by providing a single example: to create the notion of an ”X-ray chest picture” by providing a single picture, to create a notion of ”a character” by providing a single example of a written character (‘a’ or ‘b’ or ‘c’ etc.).

Let us ponder this: such approach allows us to understand how was it possible that the remarkable physicians of the XIX century were able to describe a particular sickness by observing a single patient. The essence of this phenomenon is the following fact: from the grammatical structure of the description of the sickness proceed important features of the sickness and establishment of the description of the class (sickness); less important features represents the individual variations. Perhaps this allows us to explain why physicians need to know well the language in which they conduct their practice. This holds also for other practicing specialists.

Holistic approach

Although WERTHEIMER criticized logical and associative approaches, he did not deny the role of logic and associations in the process of thinking. He insists on examining their limitations and contends that productive thinking is impossible if based on logic and associations exclusively. In his opinion, the crucial point in the investigation of thinking is the use of the Gestalt (holistic) approach.

The essence of the Gestalt approach is described by WERTHEIMER as follows:

"The basic thesis of gestalt theory might be formulated thus: there are contexts in which what is happening in the whole cannot be deduced from the characteristics of the separate pieces, but conversely; what happens to a part of the whole is, in clear-cut cases, determined by the laws of the inner structure of its whole."

It makes sense to compare this statement with ARISTOTLE's expression of completeness: "The whole is more then the sum of the parts." Note that WERTHEIMER uses in his statement two notions: the element and the part. If one will cut the whole into elements and then tide them together one will not succeed in reconstructing the whole. If one divides the whole into pieces (in the agreement with the structure of the whole) then that will constitute pieces not elements, that allow to model the whole. Exactly that kind of algorithm was developed in the 1970 in order to identify objects that make up curves or images. This algorithm examines a limited number of possible partitions of the curve (or image). In each partition all parts occur at the same time. From all possible partitions the most stable partition is chosen. As a result the final partition becomes really non-local (that is holistic). It means that the existence and location of each object depends on the existence and location of all other objects.

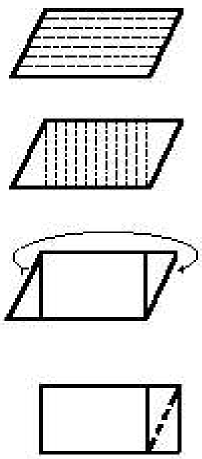

Fig. 1

It is important to recognize, that this specific algorithm attempts to imitate human ability to recognize objects (especially in certain domains: geological mapping, medical image processing, psychological tasks). In his book WERTHEIMER demonstrates the holistic approach to thinking by providing several examples.

Let us consider one of these: the problem of calculating the area of a parallelogram. After a number of observations on children and adults WERTHEIMER identified the following steps (fig. 1):

a) recognizing the notion of an area of the rectangle

b) connecting the appropriate points on the opposite sites of the parallelogram does not work

c) it is possible to cut the parallelogram into rectangular stripes but it works only for a part of the parallelogram

d) recognizing that the rest of the figure is composed of two triangles; these can be put together and constitute a rectangle.

Would AI approaches arrive at this strategy? Most probably not, with only one exception: when connecting the appropriate points creates stripes. The idea of appropriate points comes from Bongard (Bongard, 1971): the best way to describe an object is to describe the process of its creation.

WERTHEIMER used the same problem to demonstrate the limitation of the commutative law: A + B = B + A. That statement is true if *A* is the area of a triangle AFB and *B* is the area of rectangle FBCD (fig. 2). But if *A* and *B* are the triangle AFB and rectangle FBCD then *A + B* is a parallelogram and *B + A* is a rectangle.

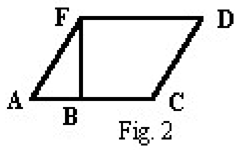

Fig. 2

The same applies to the celebrated case of recognizing an arch trough a single example. It turns out that the adequate description of a single arch contains in its grammatical structure the essence of the arch structure. The following expression represents this grammatical structure.

The digits before the closing brackets indicate the level of the term in these brackets in the hierarchical grammatical structure. Changes in the description on the lowest level (level 3) do not distort the notion of the arch. It means that the description in which the term ”black” will be substituted by the word ”white” and/or ”4-sided” will be substituted by 3-sided will still be a description of an arch. If one will substitute the term ”prism” by ”pyramid” on the higher level (level 2) the idea of an arch will be substantially destroyed and become more likely a caricature of an arch. Changes on the top levels (levels 1 and 0) destroys the notion of the arch completely (substitute ”apart” by ”side-by-side” or ”on” by ”nearby”).

{ { {black $_3$} { 4-sided $_3$} prism $_2$} lays $_1$}
on
{ { { {black $_3$} {4- sided $_3$} prism $_2$} stays $_1$}
apart
{ *The same* $_1$} $_0$}

One important feature of the arch is stability. Usually that feature is not mentioned explicitly, nevertheless it enables one to restrict the number of possible constructions. This demonstrates once more the productivity of broadening the context of the problem, the productivity of involving the real world.

The essence of all examples in WERTHEIMER's book that demonstrate productive thinking is the ability to look at the situation from a fresh point of view. More precisely, the ability to describe the situation in new terms, in a new language. That particular idea of the new language of description embodies successful applications of AI in medicine, geology, geophysics. The first who understood it as crucial for AI was GELFAND (GELFAND and TSELIN, 1966).

Lessons learned

Computing models implement main procedures of associative and logical approaches with ease (correlation function, logical functions). Holistic procedures are more difficult and it was difficult to implement them on the computer (for current von Neuman design). It is worthwhile to note that it took decades until psychology as well as AI became aware of the indispensability of the holistic approach. Perhaps the fact that the general systems theory was not able to define the notion of integrity is a culprit here (GUBERMAN and WOJTKOWSKI, 1996, 1998). Although the theory has its roots in the Gestalt-theory, its creators tried 1) to generalize the Gestalt approach, and 2) develop a solid physical theory. On the way they ceased to consider the integrity as associated with perception, instead attributed it to the object.

One of the most common tricks in use consists of substitution of the system (holistic) approach by the structural one. The difference is that, when solving problems using the structural approach it is necessary to discover the structure of relations in the set of given elements. When solving a problem using the holistic approach one first divides the object into appropriate parts. Each of these parts has to be coordinated with other parts and with the whole. Only then it is possible to consider the structure of relations between these parts.

Let us now consider a fundamental notion of Gestalt psychology, the notion of "vision". This notion is used in the context of "changing the vision", "moment of comprehension of the true (the solution)". One may note that the change of vision becomes apparent when one considers the change of description. Thus the notion "vision" can be substituted by the more definite notion of "description". Change of description can occur under the same language of description or when the language of description is completely changed. For example, for the task of establishing the area of the parallelogram, one possible "vision" is the description of the parallelogram as a set of stripes parallel to the base line. Another "vision" may consider parallelogram as a sum of a rectangle and two triangles.

The similar situation applies to the notion "Gestalt". In WERTHEIMER's book. This word is used in two ways, as a label (Gestalt theory, Gestalt logic) or as a notion. As a notion it is used only in the conjunction with words "good" or "bad" -

”good Gestalt” or ”bad Gestalt”. Invariably, when used as a notion, it means ”the good (bad) description”.

Such interpretation of the notion of ”Gestalt” does not contradict the basic meaning of the word – shape. The good shape is the shape that can be described in brief, or easily reproduced created. For example, the line, the circle, the rectangle are described in brief, and can be recreated easily.

In our opinion, AI can add to the list of holistic operands of thinking an operation of rough description (”Damn the Details” - DD algorithm may serve as an example). The DD operation (GUBERMAN, 1983) finds in the description of the object the hierarchy of stable levels and removes the low levels in the description. The DD operation differs, for example, from filtering.

The AI still confronts unsolved hard problems. Sophisticated speech recognition programs still cannot differentiate between **b** and **d**. On the chess field the battle between David and Goliath ended with the win of the stupid Goliath. It seems that we are moving in the wrong direction. It is obvious that we have to turn to psychology and learn from it.

In closing, let us quote WERTHEIMER again (page 2).

> ”Much has been achieved. In a large number of special questions solid contributions to understanding have been made. At the same time there is something tragic in the history of these efforts. Again and again when great thinkers compared the ready answers with actual, fine thinking, they were troubled and deeply dissatisfied – they felt that what had been done had merits, but that in fact it had perhaps not touched the core of the problem at all.”

Zusammenfassung

In diesem Beitrag diskutieren wir den Einfluß der für die Psychologie zukunftsweisenden Arbeit von Max WERTHEIMER über das produktive Denken auf die Entwicklung der Künstlichen Intelligenz (Artificial Intelligence). Wir kommentieren die Lehren, die aus der Gestalttheorie gezogen werden können und ihre Bedeutung für das Verständnis der Beziehung zwischen Denkprozessen und Computer-Modellen.

Summary

In this article we reflect on the influence of Max WERTHEIMERs seminal work “Productive Thinking” on the developments in artificial intelligence. We comment on lessons learned from Gestalt theory and their relevance to understanding of the relationship between thinking processes and computational models.

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