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THE FOCUS OF CONTENT-BASED APPROACH TO DESIGN ENGINEERING – A REPLY TO EDER

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1. Introduction

Without going too far back to the history of psychology one can point out two immediate predecessors for content-based approach: the early attempts to define content-oriented psychological thinking by Newell and Simon [1972] and Alan Allport [1980] called attention to the fact that cognitive psychology had missed the phenomenon of mental contents.

Newell and Simon's [1972, 1976] solution to the problem of coping with contents was building of simulation models. This idea is based on Turing's [1936, 1950] classic models of human mind as a computing machine. Models of mind such as General Problem Solver or ACT-family have been and are still being regarded as important openings in this direction. As is well known, such problems as match and exponential growth, among others, posed substantial problems to this way of thinking.

Allport's [1980] solution was different. He called attention to modular subsystems of human mind and the way mental contents are encoded. A little later, this idea became well-known in philosophy thanks to Fodor's [1983] efforts. The core question is to specify the cognitive processes and physiological units which enable human mind to have mental contents. The objective of this content-specific cognitive psychology is to link neural resources with mental contents.

Content-based analysis is the third way of looking at mental contents [Saariluoma 1990, 1995, 2003]. In this approach, the information contents of mental representation are taken as the starting point of the psychological research. Of course, one could say that this is what mental models, schemas and perceptual symbol systems have always wanted to capture [Barsalou 1999, Johnson-Laird 1983, Neisser 1976]. However, there is an important difference. In content-based thinking, mental content forms the explanatory ground. The focus of analyzing mind is not on mental representations, schemas, or mental models, but their information contents. In content-based analysis, the explanations for the relevant psychological phenomena are searched from the elements and other properties of involved mental contents [Saariluoma 1990, 2003].

2. From perception to apperception

Content-based thinking uncovers a number of conceptual inconsistencies in the mainstream psychological thinking. We have been ready to think that our mental representations have their origins in perception [Newell and Simon 1972]. However, this intuitive conception is not theoretically consistent from a content-based point of view [Saariluoma 1990, 1995]. For example, when people design, they rely on such notions as friction, electrons, earning logic, and maintenance schedules, which they cannot perceive. To be exact, designers seldom see what they think when they design, because the objects of design have not yet been constructed.

The conceptual problems with the traditional empiricist way of thinking are evident. The basic theoretical notions do not capture all the aspects of the process of forming representations. We simply cannot perceive the non-perceivables and therefore it is illogical to assume that the construction of mental representations is perception. To come up with a more effective system of theoretical concepts it is logical to assume that the process of integrating conceptual knowledge together and with perceptual knowledge, i.e., apperception, has a central role in forming mental representations. Otherwise, there remains an oversimplifying conceptual gap in the system of theoretical notions, which was noticed already by Leibniz [1704] and Kant [(1787].

Apperception when defined as the process of constructing mental representations entails such processes as “seeing something as something”, apprehending, conceiving and understanding [Saariluoma 1995]. These and other respective processes can be seen as sub-processes in apperceiving. Of course, one could adopt a different term for the process of constructing representations, but this would not necessarily be consistent with the classic tradition. Even such dictionary meanings as mind’s perception of itself can be subsumed under the presented definition: from a third person’s point of view, one can see self as a part of human conceptual knowledge and the system of beliefs.

3. Limited capacity of mental content

Content-based thinking does not pretend to provide answers to all kinds of psychological questions. It offers a way of looking at human mentality in a way an analysis or the theory of automata does in mathematics. Content-based thinking opens up a certain perspective to mind and thus it defines a set of questions which can be investigated within its concepts. For example, neural issues or the issues of limited capacity are outside its scope.

There are many psychological questions relevant to investigating design which can be explained on the grounds of humans' limited capacity. In his paper, Eder [2006] pointed out a number of such issues. If an ongoing task occasionally demands processing, in the short term working memory, more than four units or chunks of information, the risk of forgetting something immediately increases [e.g., Anderson, Farrell and Sauers 1984, Covan 2000, Johnson-Laird 1983]. However, there are many thought errors, which cannot be explained on the ground of limited working memory capacity but which are due to incorrect beliefs and other mental contents [Saariluoma 1992].

Already, Gestalt psychologists were able to show how people may be mislead by their false presuppositions. Fixation, einstellung and the related phenomena do not have anything to do with overtaxed cognitive capacity [Duncker 1945, Wertheimer 1945]. These must be explained in terms of false presuppositions which make subjects incorrectly conceptualize and encode their tasks. Apperception makes it possible to generalize these results to any domain in a natural manner (Saariluoma 1990).

It is important to notice that capacity is not a theoretical term with a sufficient power of expression for considering issues of mental contents [for power of expression, see Saariluoma 1997]. We can fill the capacity of working memory or attention with any imaginable contents as long as we do not overdo its limits. Therefore, capacity does not express the differences between mental contents, and consequently, capacity-based explanatory languages do not allow us to analyse the contents of mental representations.

A typical example of the problems involved in using capacity-based language in analysing the construction of mental representations and their transformation can be found in Eder [2006]. He is absolutely correct in arguing that “reconstructing means retrieving many different chunks, and bringing them together.” However, this does not explain why some chunks are joined and some are not.

It is possible to chunk any types of things together. Unfortunately, linking whatever to whatever else does not provide us with a clear understanding of what happens in constructive thinking. It is not chunks per se but their contents in our minds, which explain why some designs are better than some other. As a matter of fact, we need to understand the mental contents of chunks to understand the logic of design solutions.

4. Sense-making mental contents

The problem of associating chunks with each other, which was raised by Eder [2006], is particularly telling with respect to the differences between the content based and capacity based perspectives [Saariluoma 1997]. Chunking is a capacity notion, because no references to the contents of knowledge are required. We ignore here the fact that the notion of chunk itself as a memory unit is under a critical scrutiny [Gobet 2005], and instead concentrate on issues of mental contents.

In chunking terms, any engineering construction is an extensive system of chunks as was pointed out by Eder [2006]. However, this gives rise to a number of design related questions. Under which conditions can we join different representational elements to each other? Does it make sense to transmit energy by linking a gearwheel directly to a smooth roll? Is it not better to connect two gearwheels to each other instead? Of course, the latter resolution would make better sense. The example here is not applicable to this singular case only; it is possible to develop endless number of examples about senseless technological solutions. As a matter of fact, designers create poor solutions every now and then, though unintentionally [Perrow 1999, Norman 1988]. Therefore, we may inquire about the role of sense-making or sensefulness in human thinking.

Saariluoma [1990] found that chess players can limit their search processes into small compact problem subspaces, because they apply a small set of functional rules telling them what kinds of moves would make sense. These functional rules are tacit but they enable chess players to limit their search spaces within thirty to fifty moves, whereas computers need to generate hundreds of thousands moves per second when solving the same problems.

Saariluoma and Maarttola [2003] investigated architectural design and found that architects guide their design thinking also by sets of functional rules. They orientate a bedroom window towards west *because the sun rises in east.* All of architectural design is guided by reasons that are not always explicit but nevertheless mostly explicable [Saariluoma and Maarttola 2003].

We can find similar reasons also in engineering design. Extended nip, in paper machine, the design process of which we have been reconstructing, was initially designed to increase the press impulse on wet paper web and thus improve water removal and eventually make paper production faster [Saariluoma, Nevala and Karvinen 2006]. Functional rules or reasons apparently have an important role in explaining how chunks are linked to each other.

Unfortunately, the phenomenon of having reasons does not find any expression in capacity-based theory languages. We can associate anything together in chunks, but merely associating anything to anything else does not make much sense. To appreciate why it might make sense to make a certain kind of construction, we have to keep in mind what the design elements and their properties are. We must know how these properties and elements are mentally represented by designers, because designers may make false assumptions with respect to the crucial objects and their properties.

5. Formal and non-formal mental contents

Eder [2006] raises also the question about the role of deductive thinking. This is a question of primary importance. Much of human thinking is deductive and in a wider sense follows some formal principles such as modus ponens or modus tollens. There is very little doubt that generate-test behaviour, in Newell and Simon's [1972] sense, or trial-and-error, in Thorndike's [1931] sense, is based on these two logical principles. We generate alternatives following modus ponens and refute those following modus tollens. Generate-test is essentially a modus ponens-tollens schema.

However, the extent to which human thinking is explainable on this deductive ground is problematic. Formal schemes do not take any positions with respect to the contents of

premises and conclusions. It is fully logical to infer “if the moon is cheese then Napoleon is the emperor of Rome; moon is cheese and consequently Napoleon is the Emperor of Rome”. This inference, although it does not make any sense, is logically correct.
The example illustrates why one cannot exclude the analysis of mental contents from the analysis of design thinking. Formal schemes give a correct structure to thoughts and their transformations, but content-based analysis is required to investigate whether thinking makes sense and concentrates on essential issues rather than on issues of secondary importance.
This point is vital also when we think of formal modelling and simulating human thought processes. Turing [1936, 1950] machines such as Physical Symbol System by Newell and Simon [1972] are basically abstract mathematical machines. Therefore, they must be interpreted if one wishes them to model real life processes. Interpretation means that the elements on the tape as well as the transformation rules are given a form and contents which map them to reality. This interpretation cannot be carried out using mathematical concepts, but must be based on real world knowledge. In the case of Newell and Simon [1972], for example, the interpretation was based on empirical analysis of thought processes.
One may naturally ask why it is not possible to use mathematical concepts in interpretation. The answer is that mathematical concepts do not have sufficient power of expression. We cannot say about a member of a mathematical set whether it is relevant or irrelevant. This means that we do not know, in case of formal sets, what is essential and what is inessential. This, in turn, means that we have to use non-formal theory-languages to describe what we think to be essential in any particular case. And this presupposes content-based analysis.

6. The nature of creative thinking

In research, much depends on the system of selected theoretical concepts. Theory language defines the questions we can ask and therefore also the hypotheses we can test (Saariluoma 1997). All the hypotheses must be constructed by using the concepts a theory language offers us. A good example is the Wallas [1926] problem about the phases of human thinking. There is nothing in Newell and Simon’s [1974] conceptualizations that could effectively be used to ask why people need periods of incubation. Wallas [1926] describes overall human behaviour, which very probably also has some dynamic aspects. On the other hand, computational models do not easily lend themselves to the investigation of dynamic aspects of mind, as they are built on knowledge and not on affective phenomena. Simply put, computers do not have emotions, do not suffer from exhaustion, and do not have subconscious processes. Wallas [1926], on the one hand, and Newell and Simon [1972], on the other, therefore, investigate very different types of phenomena.
Another important consequence of basic theoretical concepts is that they may change the way we regard some earlier notions. Moving away from external and behaviourist concepts to the internalist systems of theoretical concepts due to the perceived cognitive revolution has tacitly changed our thoughts in some related areas.
If we think about the creativity along the lines of Guilford [1959], it is indeed important to see creativity in terms of free associations and remote associations. However, it is well-known that completely free associating proves to be rather a poor description of creativity, and brainstorming can be an inefficient method (Weisberg 1986) towards that end. This is why there is more convergence in creativity than was assumed in classic conceptions, which is not intended to say that there would not be invention of new things.
What we propose here is that in industrial creativity the problems seem to be linked to each other by the nature of their contents. Solving one problem (A) defines a new set of linked problems, which are presuppositions for the final solution of problem A. Thus, it is possible to design extended nip press only if such preconditions as suitable materials can be found. In other words, the idea of an extended nip press immediately begs a solution to the problem of finding the materials for its construction. In this way, industrial creativity is converging and far from relying on free associations. This emphasis of convergence should not be taken to

mean that there is no divergence in finding new solutions. One could call our way of relating the two traditional approaches as “divergence by convergence”.
The research in chess players’ thinking has illustrated that divergence by convergence is typical to human thinking [Saariluoma 1990, 1995]. Chess players abstract small problem subspaces and then they search within these spaces. The important thing here is that the contents of the problem subspace and the contents of relevant elements can explain the economy of creative process.

7. Conclusions

We have outlined here some of the main ideas behind content-based design analysis. While this work is still in its early phase, the basic assumptions of this approach nevertheless open up a new perspective for the investigation of design thinking. To make things clearer it is beneficial to summarise these fundamental assumptions.
Firstly, content-based analysis of human thinking assumes that mental representations (concepts, schemas, thoughts, mental models or scripts) have information contents. The main thing, however, is not the representational form but its information contents.
Secondly, it is assumed that human actions can be explained on the ground of mental contents. What we think and assume about the world explains what we do in life. While this may sound “folk psychological” to some people - and the notion of folk psychology is notoriously rhetorical [Churchland 1986, Stich 1983] -, it is one thing to use everyday beliefs and artistic intuitions to explain human behaviour and another to study mental contents scientifically and use the research results in explaining what people do. Unfortunately, these two aspects of mental contents have not always been kept apart.
Thirdly, content-based research concentrates on the types of scientific problems which belong to its scope. In design contexts, for example, all the problems do not require content-based analysis. There are questions for which it is simply inapplicable. Nevertheless, there are a number of problems which can best be formulated and solved by applying its concepts.
Fourthly, within design research, content-based design analysis is, in the first place, an approach to design thinking. We can get clarity to many issues concerning design tools, knowledge management, group work, leadership, communication etc., by analysing designers' thought processes - nevertheless, the main focus should be on how to best understand the mind of a thinking designer.
Finally, explaining in the ground of mental contents is different from content-oriented work, which rather models mental contents than explain on the ground of the properties of mental contents. The term content-based refers to this point.

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