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Empirical Evidence for Kahneman's System 1 and System 2 Thinking in Design

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Abstract

This paper analyses design protocols of professional engineers and engineering students using the FBS schema, testing two hypotheses related to the use of system 1 and system 2 thinking. These two modes of thinking are characterised as: one that is fast and intuitive (system 1), and one that is slow and tedious (system 2). Their relevance for design thinking has already been shown conceptually. This paper provides empirical support for the existence of system 1 design thinking and system 2 design thinking.

Keywords: Design cognition, Human behaviour in design, Design process, Dual-system theory

1 Introduction

Dual-system theory is an established model of human thinking with a long tradition in cognitive psychology [13], which has more recently been popularized by Daniel Kahneman in his book *Thinking, Fast and Slow* [8]. It is based on the concept that there are two systems responsible for different modes of reasoning: system 1 for fast, intuitive and effortless reasoning, and system 2 for slower, analytic reasoning that requires greater cognitive effort. In the last few years, a number of studies have examined how dual-system theory can explain the use of intuition and heuristics in design [1], including phenomena such as fixation and creativity [11]. One of the studies mapped system 1 and system 2 thinking onto Gero's [5] function-behaviour-structure (FBS) ontology of design, augmenting the eight fundamental processes postulated in the FBS ontology with a ninth process – representing system 1 thinking in design [9]. This process is a direct transformation of function into structure, which is a result of learning the most efficient pathway from the interpretation of requirements to a synthesised structure. The authors of that work show the use of system 1 in a number of design processes taken from the literature, including design fixation, case-based design, pattern-language based design and brainstorming. However, no empirical validation was provided to support the additional process in the FBS framework.

This paper aims to close this gap by analysing design protocols of professional engineers and engineering students using the FBS coding schema. This analysis is driven by two hypotheses:

Hypothesis H1: Design thinking comprises system 1 and system 2 thinking.

Hypothesis H2: Design professionals use system 1 thinking more often than design students.

Hypothesis H1 is based on the work cited above. Hypothesis H2 is based on the assumption that professionals have developed more experience than students, and with it a wider range of heuristics available for fast design thinking.

The remainder of the paper is laid out as follows. Section 2 introduces dual-system theory based on Kahneman's [8] account. Section 3 describes the FBS ontology and how it is extended to represent system 1 thinking. Section 4 presents the empirical studies carried out, including their coding and analysis. Section 5 shows the results of the empirical validation. Section 6 concludes the paper.

2 Kahneman's Dual-System Theory of Thinking

Dual-system theory originates from the 1970s and can be seen as well established with a large amount of experimental evidence in cognitive psychology and neuroscience. It classifies human thinking in two distinct types: one type is fast, automatic and effortless, and the other type is slow, analytic and effortful. Kahneman [8] refers to them as "system 1" and "system 2", respectively, even though they are not linked to different areas in the brain [4]. This is to enable his readers conceptualising them as two different characters with distinct "personalities" rather than as abstract concepts, and thus to facilitate understanding. In this paper, we will also use Kahneman's terms. Most of *Thinking, Fast and Slow* is about system 1. This is because it has more influence on human reasoning than many people would believe. Our beliefs, decisions and actions are shown to be systematically biased rather than to be rational and objective.

It is often difficult to use system 1 in the right "dosage". Kahneman illustrates this with a well-known optical illusion of the kind depicted in image 1. As printed on the page, the three human figures are of equal size. However, the one on the left appears larger than the one on the right. This is because the image contains cues that afford a 3D interpretation, so that system 1 automatically substitutes the question "Are the three figures, as printed on the page, of different size?" with the question "How tall are the three people?" [8, p. 101].

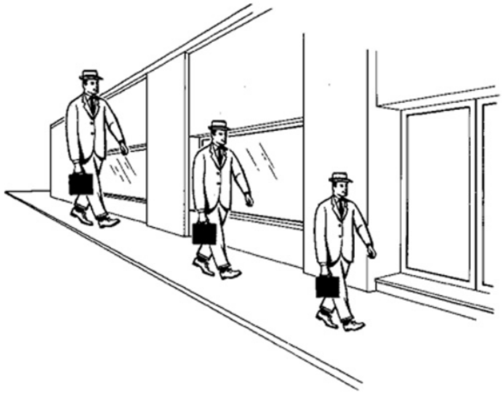

Image 1: Optical illusion: Are the three figures of different size?

This example shows that another characteristic of system 1, that it performs many computations at once, many of which are dependent on the context and cannot be consciously controlled. Kahneman [8, p. 95] uses the notion of a "mental shotgun" to describe this phenomenon.

3 System 1 and 2 in Design Thinking

Design thinking is often viewed as a complex activity that is different from other kinds of human thinking. If design thinking as an elementary process was to be classified into one of Kahneman's modes of thinking according to Table 1, many of its characterisations would suggest it to be system 2 thinking: It is neither associated with an effortless mode of thinking, nor can it be seen as very fast, given that most design processes in industry take place within timeframes of weeks and months, and in some cases several years. Yet, at least for parts of the design process a fast mode of thinking consistent with system 1 does play a role in design.

3.1 The FBS Ontology

The function-behaviour-structure (FBS) ontology [5] has been proposed as a design ontology that describes all designed things, or artefacts, irrespective of the specific discipline of designing. Its three fundamental constructs – function (F), behaviour (B) and structure (S) – are defined as follows:

- *Function* is the teleology of the artefact ("what the artefact is for"). It is ascribed to the artefact by establishing a connection between one's goals and the artefact's measurable effects.

- *Behaviour* is defined as the artefact's attributes that can be derived from its structure ("what the artefact does"). Behaviour provides measurable performance criteria for comparing different artefacts.

- *Structure* is defined as its components and their relationships ("what the artefact consists of").

Humans construct connections between function, behaviour and structure through experience and through the development of causal models based on interactions with the artefact. Specifically, function is ascribed to behaviour by establishing a teleological connection between the human's goals and the observable or measurable performance of the artefact. Behaviour is causally connected to structure, i.e. it can be derived from structure using physical or other causal-type laws or heuristics. There is no direct connection between function and structure. The FBS ontology defines the processes of designing as transformations between function, behaviour and structure. In a simplified view, designing consists of transformations from function to behaviour, and from behaviour to structure: $F \rightarrow B$, and $B \rightarrow S$.

In this view, behaviour is interpreted as the performance expected to achieve desired function. Usually it is unclear whether the structure produced exhibits this behaviour. It must be checked through a separate process whether the artefact's "actual" performance, based on the structure produced and the operating environment, matches the “expected” behaviour. As a result, two classes of behaviour are distinguished: expected behaviour (Be), and behaviour derived from structure (Bs). This extends the set of transformations as follows:

F → Be, Be → S, S → Bs, and Be ↔ Bs (comparison of the two types of behaviour)

The observable input and output of designing include requirements (R) that come from outside the designer and a description (D) of the artefact, respectively. The FBS ontology subsumes R in the notion of function and defines D as the external representation of a design solution: S → D.

Designing is often seen as a process of iterative, incremental development that frequently involves focus shifts, lateral thinking and emergent ideas. Consequently, there are transformations in designing that reformulate previously generated design concepts. This is accounted for by the following transformations: S → S′, S → Be′, and S → F′.

The eight fundamental transformations or processes are shown and labelled in image 2:

1. Formulation (R → F, and F → Be)
2. Synthesis (Be → S)
3. Analysis (S → Bs)
4. Evaluation (Be ↔ Bs)
5. Documentation (S → D)
6. Reformulation type 1 (S → S′)
7. Reformulation type 2 (S → Be′)
8. Reformulation type 3 (S → F′)

3.2 Including System 1 Thinking in the FBS Ontology

According to the FBS ontology, there is no direct transformation from function to structure. Yet, Gero [5] states that it "does occasionally exist" in the form of a "catalog lookup". Using system 1 thinking can be considered as equivalent to such a catalog lookup, because it is fast, effortless and does not require any verification of results. The only difference to the common notion of a design catalog [12] is that it is not external but internal to the designer. Kannengiesser and Gero [9] have modelled this view of system 1 by commencing with a simplified view of designing as an input-output transformation: The designer takes requirements as input and produces a design description as output. What happens inside the transformation is hidden inside the designer that is viewed as a "black box".

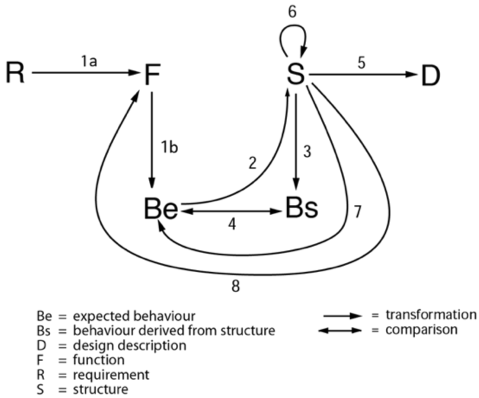

Image 2: The FBS ontology [5]

In image 3 this black box is expanded to show possible pathways from R to D, using the processes defined in the FBS ontology. The entry and exit paths of this process system are the transformations of R into F (part of formulation, process 1) and of S into D (documentation, process 5), respectively. They correspond to activities of interpretation and action that are executed by the designer. In addition to the eight fundamental processes in the FBS ontology, a ninth process (2') is depicted that transforms F into S. This additional process allows distinguishing two basic pathways between the interpretation of R and the action producing D: (1) a direct pathway provided by process 2', and (2) an indirect pathway that involves at least four processes: 1b, 2, 3 and 4.

Since process 2' establishes a direct link between interpretation and action, it can be seen as a reflex – an immediate response to a stimulus without involving any form of reasoning. This corresponds to system 1. The reflex represented by process 2' is based on learning a connection between stimulus and response through previous experiences of the designer. Whenever a pattern in the environment is interpreted that matches a previous stimulus, the associated response is executed as an instant reflex. Examples of pattern matching in architectural design include designing using precedents [3], which can be seen as design catalogues.

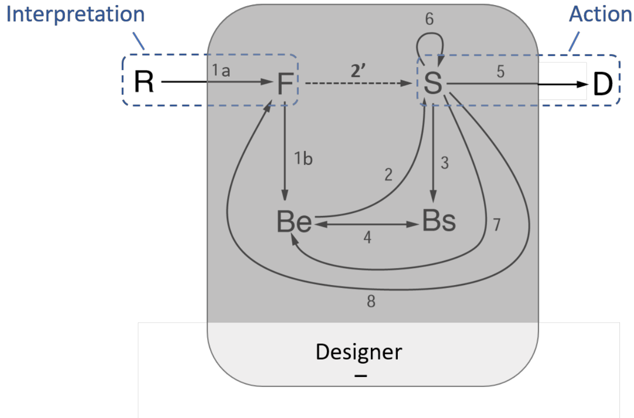

Image 3: Expanding the transformation of R into D, based on the FBS ontology [9]

Process 2' can be thought of as subsuming the set of processes 1b, 2, 3 and 4. It provides a "shortcut" for these processes, using a learned connection between F and S. This increases cognitive efficiency when performing design tasks that address similar Fs. Learning the connection between F and S involves eliminating all intermediate processes that were previously used for transforming F into S.

4 Empirical Studies

4.1 Experiments

Evidence for the existence of system 1 thinking in design (i.e. F→S) has been found when re-reviewing some previous empirical studies [14]. Here we present the results of analysing data from a complete experiment. As part of a project examining differences between professional designers and student designers, sets of design sessions were collected of juniors, seniors and professionals designing to the same set of requirements [2]. Thirteen teams of two freshmen, eleven teams of two seniors and thirteen teams of two professionals formed the source data for the resulting protocol analysis. Since they are collaborating, the team members naturally verbalized without prompting. The student participants were drawn from a convenience sample from undergraduate engineering students at Utah State University. The professionals were drawn from a convenience sample from multiple engineering design firms. Each session was videoed and the participants' utterances were transcribed. The results from this experiment form the basis for the empirical testing of Hypothesis H1 and Hypothesis H2.

4.2 Coding and Analysis

The FBS ontology is used as the basis for a coding scheme for segmenting the transcription of the design protocols and coding every segment as one of the six FBS design issues. An arbitration method was used to increase the reliability of protocol segmentation and coding. It consists of a phase of individual codings by two independent coders, and a subsequent arbitration session to resolve any disagreements in the codings. The arbitrated result, in the form of a sequence of design issues, is then taken as the input for the current analyses.

Relations between two consecutive segments are interpreted as transformations of the respective design issues. They may include design issue transformations that are not defined in the FBS ontology; for example, B→D and R→S. Given the model of system 1 and system 2 in design thinking described in Section 3.2, we are interested in the occurrence of F→S relative to two baselines in the data:

1. Syntactic baseline: Occurrence of any F→X, where X ∈ {R, F, Be, Bs, S, D}

2. Semantic baseline: Occurrence of any F→Y, where Y ∈ {Be, S}

The semantic baseline is a subset of the syntactic one, taking into account only those transformations of F that correspond to processes defined in the FBS ontology extended by system 1 thinking: F→Be and F→S. The occurrence of F→S relative to the semantic baseline is a direct measure for the distribution of system 1 thinking (represented by F→S) and system 2 thinking (represented by F→Be as part of the set of processes subsumed by system 1) in design.

The relative occurrences are then compared using ANOVA, pairwise t-tests and effect sizes.

5 Results

5.1 Occurrence of System 1 Thinking

The average occurrences of F→X, F→Be and F→S for juniors are 16.6 (std dev 5.6) 1.8 (1.5) and 6.9 (2.3), for seniors are 14.5 (4.9), 2.2 (1.6) and 5.2

(3.0) and for professionals are 12.9 (5.6), 3.5 (2.3) and 4.9 (1.6). The percent occurrences of F→S relative to the syntactic and semantic baselines are shown in Table 1.

Table 1: Percent occurrences of F→S relative to syntactic and semantic baselines (standard deviations in brackets)

	F→S relative to the syntactic baseline (%)	**F→S relative to the semantic baseline (%)**
Juniors	45.0 (15.6)	80.7 (10.4)
Seniors	33.1 (15.9)	66.0 (27.9)
Professionals	40.5 (7.8)	64.1 (17.7)

The results show that system 1 thinking, in the form of F→S transformations, is used substantially in all three cohorts. For the syntactic baseline its relative occurrence is at least 33.1% (in the "seniors" cohort). With respect to the semantic baseline, the majority of design thinking is system 1 thinking, with a minimum of 64.1% (in the "professionals" cohort).

This confirms Hypothesis H1, stating that design thinking comprises system 1 thinking and system 2 thinking.

5.2 Differences in the Use of System 1 Thinking between Students and Professionals

A one-way ANOVA shows that there are no significant differences between the three cohorts, neither with respect to the syntactic baseline ($F(2, 32) = 2.297$, $p = 0.117$) nor to the semantic baseline ($F(2, 32) = 2.519$, $p = 0.096$).

No significant differences were found between the cohorts except for juniors vs. professionals regarding the occurrence of F→S relative to the semantic baseline, using a pairwise t-test.

The effect sizes, calculated using Hedges' g [7], between the three cohorts resulted in large effect sizes between the juniors and versus seniors for both syntactic and semantic baselines, and for juniors versus professionals for the semantic baseline. The effect size was small or medium elsewhere.

Professionals use system 1 thinking less often than juniors, with an average of 64.1% for professionals against 80.7% for juniors and 66.0% for seniors for the semantic baseline. All other comparisons between professionals and students (including seniors and juniors) reveal no significant differences. These results contradict Hypothesis H2, stating that design professionals use system 1 thinking more often than design students.

6 Conclusion

The empirical results presented in this paper show that system 1 thinking is used in design and plays an important role based on its relative occurrence. It confirms previous observations and characterisations of design processes that led to the formulation of Hypothesis H1, which stated that design thinking comprises system 1 and system 2 thinking. Further analyses of existing protocols or results from new experiments are needed to have robust support these two conclusions.

Obtaining empirical evidence for system 1 and system 2 thinking in design addresses a number of research issues relevant for design researchers and practitioners:

- It fills a gap in current models of designing that do not account for, and even discourage, the use of system 1 thinking in design.
- It substantiates claims about the locations of system 1 and system 2 thinking, respectively, in the design process.
- It indicates where new methods and tools potentially to be drawn from cognitive psychology may be useful in the design process.
- It contributes to research in design expertise, by clarifying whether system 1 thinking is an effect of growing design experience.

The last issue in this list is associated with Hypothesis H2, which stated that professionals use system 1 thinking more often than students. This hypothesis was not supported by the empirical data. This is an unexpected result, because professionals are assumed to have grounded more experience that they can readily use to get from F to S by default. A possible explanation could be that the chunks of knowledge professionals build up are much bigger than students' chunks [10], in combination with the ability to generalise from specific experiences [6]. As a consequence, professionals need less cognitive processing and therefore fewer transformations including from F to S. Using Kahneman's [8] terms, professionals have a bigger "mental shotgun" with larger pellets, which might not need to be fired as often to have the same effect as that of a student. More research is needed to explain the connection between system 1 thinking and the role of expertise in design.

The research method used in this study can potentially be applied to a large set of existing design protocols coded using the FBS design issue schema. This means that new insights can be gained without having to run new experiments. Possible comparisons can be made regarding the use of system 1 and 2 thinking across different design disciplines, tasks and methods.

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