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Fitts' Law as a Design Artefact: A Paradigm Case of Theory in Software Design

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Abstract: Fitts' law is described and discussed as an example of use of theory in human-computer interaction design. The dichotomy between academic theory and applied theory is rejected and replaced by a radical pragmatic notion of theories as design artefacts. Different roles of theory in design are discussed.

1 Introduction

In the early years of interactive computing, designers relied solely on their intuition, some rules of thumb and a few guidelines. As the users of interactive systems turned from programmers to non-computer professionals, this situation became a problem —the systems were too difficult to use. Some saw in this an urgent need for a scientific foundation for HCI-design. The classical contribution to this vision is formed by the works by Card, Moran and Newell [3, 4], who believed that the future science of HCI should be based on cognitive psychology. They saw their task as one of making the bulk of academic experimental results applicable for designers. The vision was that this science had to be guided by the requirements set by the interface engineers, i.e. the theory should be operational rather than true in a more academic sense. The basic components in this applied science of the human-computer interface were task analysis, calculation and approximation. The idea was that the performance of a future human-computer system could be calculated from an analysis of the job which the system was intended to do. The special need for approximation in this field, compared to e.g. electrical engineering, was that the human system component was too complex. The implicit epistemology underlying Card, Moran and Newell's vision is formulated with great clarity in Newell's last book:

> Theories are approximate. Of course, we all know that technically they are approximate; the world can't be known with absolute certainty. But I mean more than that. Theories are also deliberately approximate. Usefulness is often traded against truth. Theories that are known to be wrong continue to be used, because they are the best available. Fitts' law is like that. How a theory is wrong is carried along as part of the theory itself. Grossly approximate theories are continuous launching pads for better attempts. Fitts' law is like that too. The scientist does the best he can with what he's got - and the engineer, who has to have answers, even more so. [13, p.14]

Newell doesn't reject the existence of a universal truth about human cognition, neither does he claim in principle that it is impossible to know this truth. The world *is* out there, but we construct approximate theories because it is too cumbersome to build an exhaustive theory, and because in many practical situations we are better off with operational rather than true theories. We can't reach the truth so we have to live with the useful. Newell's pragmatism is based on a dichotomy between applied theory (that is wrong but useful) and the truth. This position could be called methodological pragmatism.

In the field of HCI, the most prominent result from cognitive psychology is Fitts' law [6]. In this paper, I will use Fitts' law as a vehicle for a discussion of the role of theory in human-computer interaction, viewing it as a design artefact. Design artefacts are employed in the design process in order to support (or mediate) one or more of three design functions: gaining knowledge and understanding about what is to be designed, communicating during the process, and affecting the world. Examples of design artefacts are programming languages, CASE-tools, specification standards, systems development methods, and the like. Theories are thus constructed to help us master the world we are living in. Here I look at Fitts' law because it plays various interesting roles in the game of science and design.

2 Fitts' Law.

The goal of Fitts' work [6] was to make sense of experimental results about human motor performance that seemed to be mutually contradictory.

> The need for a unifying concept of motor capacity is indicated by the apparent difficulty of reconciling many of the facts reported in the literature on motor skill. [6, p.382]

Thus Fitts' motivation was the purely academic one of making sense of some phenomena. Fitts' idea was that this could be obtained by realising that the capacity of the motor system (the relation between the movement-time, distance, and required precision) could be compared to the capacity of a communication channel [15], that is, a model where a sender codes signals onto a channel with a given bandwidth possibly perturbed by noise, after which a receiver gets the signal from the channel and decodes it. Fitts did not claim that mechanisms for coding etc. could be found in the motor system, but only that the limitations on performance had the same mathematical structure.

Fitts conceived the motor system as consisting of bones, muscles and nerves in the arm, as well as control mechanisms such as visual feedback. That is, the motor system consists of everything from "the signal in the brain" that initiates the movement to the resulting movement outside the subject. Fitts points out that one can only observe the total system of: receptor → neural channel (cognitive system) → effect, from the eye via the brain to the finger; you stimulates the eye and observes the resulting response in the hand. He works around this problem by applying a trick. By assuming that the neural channel consists of specific sub-channels in a chain, he sets up an experiment where everything except the motor system is eliminated. By using repetitive over-learned movements at the highest possible speed, he eliminates perception and cognitive processing from the chain, leaving the isolated capacity of the motor system (including the subjects' monitoring of the movement) to be measured. This was done in the so-called reciprocal tapping set-up.

Fitts defines the capacity of the human motor system as the ability to perform certain classes of movements in a uniform way. The time required to do a specific movement is inversely proportional to the capacity of the “motor channel”. This capacity can be described by an analogy to Shannon’s:

> Theorem 17: The capacity of a channel of band[width] W perturbed by white thermal noise of power N when the average transmitter power is limited to P is given by
>
> $$C = W \log \frac{P+N}{N}$$
>
> [15, p.100]

The obvious problem of this analogy is that it is impossible to get any information about the information capacity of the motor channel. Fitts does not see the information capacity of the motor system as a property of the motor system per se, but as a property of motor performance under given conditions. Thus the basis for Fitts’ analysis is the amount of information required to accomplish a given movement. This quantity he denotes as the index of difficulty I_d, described by:

$$I_d = -\log_2 \frac{W_S}{2A} \; bits/response$$

where W_S is the variability of the movement, and A is the amplitude (distance). Division by the time t it takes to do the movement yields a quantity that is constant for specific classes of movements. This is called the index of performance, $I_p = I_d/t$ Consequently, Fitts’ law has the following form:

$$I_p = -\frac{1}{t} \log_2 \frac{W_S}{2A} \; bits/\sec$$

where I_p corresponds to Shannon’s *C*, 1/t to the bandwidth of the motor system, and $W_S/2A$ to the signal to noise ratio, (P+N)/N in Shannon’s formula. The interesting point is that this equation is able to describe the empirical data. From this expression of I_p, it is simple to deduce an expression for the required time t, but Fitts did not do that. He only wanted to describe the empirical data in a consistent way.

The appearance of Fitts' law is historically situated in a time when academic psychology (in the US) was on its way back from the behaviourist dark ages. The appearance of the computer had made it possible to build testable models of human cognition. The channel idea has been central in the sciences of human cognition and performance. In the behaviourist version, the channel degenerates to a black box, but the basic view of the relation between subject and object remains. In human factors engineering, human-machine relations are seen as a circular composition of channels: Machine operation → displays → sensing → data processing → controlling → controls → machine operations → ...

3 Additive Models

From the viewpoint of experimental psychology, Fitts’ law is an unquestionable fact, due to the overwhelming amount of empirical evidence. When we move outside the laboratory, however, this fact appears to be questionable. The implicit assumption underlying Fitts’ law is that it is possible to decompose human performance into basic tasks and add up the times for all these tasks to get the total performance time. This strategy, known as additive models, is an old idea and has been questioned for at least the last hundred years [9]. Simplistically stated, the assumption underlying additive models is that e.g. a mouse operation is the same thing no matter what context it is performed in. In HCI additive models have been widely used (e.g. the GOMS- and keystroke level models by Card et al. [4])

An experiment reported in [9] shows that additive models cannot describe even simple and controllable tasks. The subjects were solving so-called “Sterzinger lines”, i.e. nonsense lines of letters and spaces. The task was to step from space to space, using the arrow keys on the computer console, until a space separating two equal letters was reached and then to indicate that by pressing the arrow-up key. In contrast to the studies by Card et al. [4], Gediga and Greif were able to monitor the performance of single keystrokes and thus discover that, although the total performance time could be described by an additive model, the time taken to perform the single key-press changed as the subject moved the cursor through the line.

The significance of these result with respect to Fitts’ law is that if it is impossible to build additive models, then we may expect that the parameters in Fitts’ law change according to changes in the (micro) context. Furthermore, the relevance of Fitts’ law as a prescriptive tool depends on the general validity of additive performance models.

The “Sterzinger line” experiments can be seen as a critique of additive models from within experimental psychology showing that the relation between the human being and the surrounding world is dialectical and not mechanical — while the subject changes the object, the object also acts on the subject. There is no stable engine inside the subject. A more fundamental critique can be made by questioning the validity of laboratory experiments as a source of design relevant knowledge. Chapanis [5] has pointed out that, due to the complexity of human beings, it is almost impossible to keep track of the variables. This critique can be radicalised from the point of view of activity theory by stating that the human being in the controlled environment of the laboratory, is fundamentally different from the human being in “the real world” [12]. Although some aspects of human performance are evident from a laboratory experimental point of view, these aspects may not exist outside the experimental setting.

4 Fitts' Law in HCI —some Examples

Fitts’ law studies expose great diversity in the way the law is used and the approach to the given (design) problem. Two general approaches can be identified. One tries to find general quantitative properties of the human motor system, constants of the human that are independent of the specific circumstances. In this group we find studies that have great resemblance to Fitts’ reciprocal tapping set-up, but no resemblance to any practical situation (e.g. [11]). These studies are based on the implicit assumption that Fitts’ law is part of a cognitive psychology that can form a universal framework for studies and design of HCI. At the other extreme, we find approaches more concerned with specific issues of specific (types of) interfaces, and thus more realistic in the experimental set-up (e.g. [7]), here we see studies that use Fitts’ law solely as a source of inspiration. We are dealing with two fundamentally different approaches to the possibilities of a HCI-science. Either you try to establish anthropometric laws based on a “theory” about human cognition, or you can, based on specific metaphors, study specific interface classes. The classic Fitts' law study in HCI by Card, English, and Burr [2] comparing the performance of various devices in text selection, can belong to both categories. Some see these experiments as the determination of I_p in the mouse version of Fitts' law, others see the studies as a concrete, although reductionist, investigation of specific input devices. I prefer the latter interpretation.

Gillan et al. [7] report that Fitts' law can account for some of the performance variations in text selection with a mouse, but that other variations can neither be predicted nor described by Fitts' law. Two cases that theoretically should have the same I_p were examined, nevertheless the two I_p appeared to be different. Gillan et al. conclude that a general theory of mouse performance in a direct manipulation interface has to include parameters for aspects not covered by Fitts law, e.g. cognitive processes and user strategies. They point out that development of design oriented metrics has to be based upon detailed investigations of what the user does in concrete situations. Thus they give up the efforts to find the parameters in the mouse version of Fitts' law, and view their studies as dealing with some concrete properties of direct manipulation interfaces.

The applicability of Fitts' law in a practical design task is illustrated by an example regarding the placement of "soft buttons" in a hypertext browser screen layout [10]. Fitts' law was utilised to minimise the time required for mouse operation.

> We probably saved tens of milliseconds per 5-minute browse. This really is not bad, as such things go; it's often not done in commercial systems, and is economical worthwhile in our expected applications, which have large multipliers. I think saving small fractions of a second by optimal button placement is probably a good illustration of the real but limited impact that traditional psychological theory can have if diligently applied. [10, p.65].

This indicates that artefacts like Fitts' law can be used to solve specific isolated design problems, whereas they are almost useless as general perspectives on human-computer interaction.

Laboratory experiments by Gediga and Wolff [8] confirm that target size influence movement time in "mousing", at the same time as the quantitative contents of Fitts' law are considered too unpredictable to be applied in design. They suggest a distinction between Fitts' law and a Fitts' effect that merely states that movement time is inversely proportional to target size, and proportional to movement length. They say that only the latter is relevant in HCI. This seems to preclude Fitts' law from being a part of the world of "task analysis, approximation and calculation".

5 Fitts' Law as a Design Artefact

Fitts made sense of a "chaotic" world by constructing a consistent predictive scheme. Although this scheme predicts and describes empirical data it provides no suggestions for an understanding of the observed phenomenon and its relations to its surroundings. Thus Fitts' law can be seen as a detached predictive metaphor. Fitts' law is basically a performance model in line with the time and motion study tradition founded by Taylor and Gilbreth. Together with this tradition it tends to reduce design of work environments, e.g. computer artefacts, to a matter of economical optimisation. No matter how much it is claimed that Fitts law is merely a useful metaphor, it will make us perceive the human being as a channel. The danger is that viewing the human being as a channel will make us treat her as a mechanical device. The significance of these basic assumptions about the human psyche depends on the part Fitts' law plays in the game of design.

The above examples show at least three different roles. In the HCI psychology by Card et al. [4], Fitts' law was part of the *world view.* To play this role, Fitts' law must be placed in a context where human beings are seen as mechanical devices, i.e. cognitive science. Landauer [10] used Fitts' law as a *tool* for specific calculations in the design process, without adopting cognitive science as his main perspective on HCI. Gillan et al. [7] used Fitts' law as a *metaphor* for research on specific aspects of acting with a mouse. In design this amounts to the use of the Fitts' effect as a thinking tool [8]. The borders between these three roles are not clear-cut. By thinking about interface problems in Fitts' law terms (the metaphor role), other views are excluded and one is led towards mechanistic reduction. The use of a specific performance calculation serves as a thinking tool, too. Theories always play different roles at the same time.

In Newell's implicit dichotomy between true and applicable theory the metaphor role could be added as a third distinction. I would rather prefer to view the three above roles as modes of acting with and developing understanding of the world. The methodological pragmatism expressed by Newell rejects that value statements can have any relevance in the real world of design, and that differences in the overall understanding of the use of computer artefacts can have any practical significance. A simple notion of theories as design artefacts, based on this view, would state that theories are tools for prediction, calculation, and generation of visions; and that sometimes they work and sometimes they do not. Furthermore, such an idea would claim that the only valid world view should be the collection of tools for calculation, or performance models, just like the Model Human Processor [4].

In contrast to this, I will claim that value statements must be the basis for every science no matter whether they are implicit or explicit. Performance models like Fitts' law are based on specific (implicit) assumptions about the human being and her relation to her surroundings. By applying such models as tools in design we will automatically share this world view, unless we strongly specify another one. We can not avoid this ontological discussion. Our implicit or explicit choice of world view is also a choice of the world in which we want to live; disinterested sciences do not exist [1].

The absence of value statements in the methodological pragmatism of Newell [13] and Card et al. [3, 4] leads to either a position saying that any statement is valid if you like it to be so (i.e. relativism), or a position saying that only statements that can be inspected are valid in science (i.e. logical positivism). In the latter case, the scientific method is installed as a substitute/proxy/go-between for the assessment of theories, as it is seen in the idea that the psychology of the human-computer interface should be a *hard* science [14].

When designers build specific computer systems they use what they have and what they know, no matter how incompatible from a theoretical point of view. Current social- and cognitive science tend to misunderstand the strengths of science and just collect everything that seems to be right together. Scientific theories are not one-to-one reflections of the world, but artefacts mediating understanding of, and action in the world, through reduction. By stuffing everything together, nothing interesting about the world will appear, powerful theories have to be based on cruel reductions.

6 Conclusion

The fact that cognitive science is able to predict and describe many phenomena relating to HCI, should not necessarily lead to the conclusion that cognitive science must be (part of) the scientific framework for HCI. I still agree with Card, Moran and Newell that HCI design might benefit from a tighter connection between science and design, but as the use of Fitts' law in HCI indicates it is not likely that mechanistic psychology will form a fruitful basis for this connection. A pragmatic science of HCI will have to take into account the context of the use of computer artefacts, and the context of design of computer artefacts as well as the relation between science and design.

In a way it is both too optimistic and too pessimistic to state that: "Scientific models do not eliminate the design problem, but only help the designer control the different aspects" [3]. Of course, no science will ever be able to see into, or build the future. Human beings are fundamentally contingent, one is never sure of their next moves, and thus science will never fully control any aspects of the interface. On the other hand, a radical pragmatic science of HCI, a science not based on ideal natural science, can yield design-knowledge and understanding that goes beyond technical control. Such a radical pragmatic science of HCI will necessarily be based on dialectical, as opposed to mechanical materialism.

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