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THE COGNITIVE SCIENCE OF IMMEDIATE INTERACTIVE BEHAVIOR or WHY MILLISECONDS MATTER FOR REALITY-BASED INTERFACES

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ABSTRACT
Reality-based interaction promises to tremendously expand the type of interactive behavior supported by computer systems [17]. However, care must be taken lest reality-based techniques become a trendy replacement of older interactive techniques, not a concomitant of good design.

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Immediate interactive behavior, interactive routines, Subjective Present.

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INTRODUCTION
A conundrum inherent to all human behavior is that the procedures we use to accomplish tasks that are important to us are often not optimal but lead us to a plateau of stable but suboptimal performance. In the human-computer interaction community we refer to this situation as *the paradox of the active user* [2, 7], the human factors [38, 39] and animal behavior [15, 16, 28, 37] communities call it melioration [15, 16, 22, 23], and the decision-making communities refer to this as satisficing [26, 33, 36].

Understanding this conundrum and its implications for reality-based interfaces requires understanding the concept of the *Subjective Present* [18, 27]. Our sense of self-awareness or Subjective Present spans a time interval of about 3-s in duration and can be thought of as a continuous stream of 3-s wide beads that lead from our past and extend through our future. Newell referred to this interval as the time span of *immediate behavior* [24]. Ballard and colleagues [1] referred to it as the *embodiment level*. Regularities at this level of analysis were reported by Schledit [29] in her examination of repetitive behavior across four cultures (European, Trobriand Islanders, Yanomami Indicans and Kalahari Bushmen. Referring to this interval as a "universal time constant", she reports that, "When the acting persons are engaged in a pattern of simple movements which are repeated, they alter this pattern strikingly after about 3 s, or they stop the complete repetitive behavior altogether" (p. 74). In his analysis of action and perception in tea making, Land reported finding that object-related acts took about 3 s to complete and added that it is "tempting to think that there is some universality to this figure: that it has something to do with the intrinsic time scale over which the brain prefers to operate" [20].

For current purposes, the interesting thing about the Subjective Present is that it divides Newell's time scale of human activity [25] (see Table 1) into three parts. Those time spans longer than 3 s for which we make plans and execute complex tasks (*such as writing a workshop proposal as a task in achieving the goal of attending the CHI2009 conference*), those at this time span (say from 3 to 30 s) that we are aware of doing now (*I will now have another sip of coffee*), and those below the Subjective Present, at the embodiment level, of which we are typically unaware (*my hand begins to move to my coffee cup about 120 ms before my visual attention begins to shift to it. Visual attention, however, arrives at the cup about 400 ms before my hand does. By the time my hand arrives at the cup, visual attention has shifted back to my computer screen and my hand, arm, and mouth complete their part of "drinking" while my Subjective Present is again fixated on my computer screen*). My colleagues and I [12, 13] refer to these latter patterns of cognitive, perceptual, and motor operations as *interactive routines* and claim that they hold the key to understanding the paradox of the active user and the successful design of reality-based interfaces.

In the rest of this brief paper I will introduce the Extended Mind hypothesis, the soft constraints hypothesis, Naïve Realism, and joint action. These four powerful ideas

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provide a Cognitive Science bases for thinking about reality-based interaction.

Scale (sec)	Time Units	System	Analysis	World (theory)
1000000000	decades	Technology	Culture	Social Band
100000000	years	System	Development	
10000000	months	Design	Education	
1000000	week	Task		
100000	days	Task	Traditional Task Analysis	Rational Band
10000	hours			
1000	10 min			
100	min	Subtask	Strategies & Procedures	
10	10 sec	Unit task	Procedures & Methods	Cognitive Band
1	1 sec	Interactive Routines	The Embodiment Level (1/3 to 3 s)	
0.1	100 ms	Production System	Elements (DME-MA-VA)	
0.01	10 ms	Atomic Components	Architectural	Biological Band
0.001	1 ms	Parameters		

Table 1: Newell's Time Scale of Human Activity (Newell & Card, 1985) with minor changes.

EXTENDED MIND

The philosopher Andy Clark has recently rejected the BRAINBOUND image of the mind in favor of the extended mind hypothesis [4-6]. The BRAINBOUND view (caps are Clark's not mine) holds that "just about everything to do with thinking . . . [is] accompanied by some kind of image of the brain" [6]. In this view the body is viewed as just the effector and sensor system of the brain. The rest of the world is simply the place where the brain-body system senses and acts; that is, "all human cognition depends directly on neural activity alone."

In contrast to the BRAINBOUND view, the Extended Mind hypothesis holds that "cognition leaks out into the body and world" [4]. This view captures the essence of the famous anecdote [9] in which the historian of science Charles Weiner referred to several hand-scrawled pages of the Nobel Prize-winning physicist Richard Feynman's notes as a "record" of his work. Feynman corrected Weiner by saying that the pages were not a "record" of the work, but were the "work itself." The work was not done in the head and then transcribed onto paper. Rather, the work was done by a cognitive system composed of mind, paper, and pencil.

Clark's ideas draw broadly on cognitive science research including the gesture work of Susan Golden-Meadows. Golden-Meadows argues [10] that body gestures (hand, arm, and whole body) are not simply (or always) a by-product of thought or a random accompaniment of thought, but are as much a part of the thought process as more central aspects such as memory retrieval.

By the Extended Mind hypothesis, reality-based interfaces are not simply influencing the style of human-computer interaction but are affecting the process and perhaps outcome of thought itself.

THE COGNITIVE IMPARTIALITY PRINCIPLE AND THE SOFT CONSTRAINTS HYPOTHESIS

A key component of Clark's argument is based on the *cognitive impartially principle* that was first articulated by Gray and Fu in a paper presented at the CHI2001 conference [11] and later expanded in [12] and [14].

> The central [cognitive] controller makes no functional distinction between knowledge in-the-head versus in-the-world or the means of acquiring that information (such as eye movement, mouse movement and click, or retrieval from memory) [14].

The cognitive impartiality principle follows from the *soft constraints hypothesis* [13] which argues that the nondeliberate or wordless selection of interactive routines (see Table 1) is influenced by three factors; (a) past utility, (b) the exploration/exploitation costs that take into account the costs of embodiment (e.g., the time needed to move a mouse to and click on a cell to uncover information), and (c) embodiment's uncertainties – noise in the decision maker's motor, memory, perceptual, and attentional systems.

Each of these three selection factors makes the wordless selection of interactive routines a local optimizer. Hence, the combination these factors provide a full account of the paradox of the active user [7].

It is clear that most, if not all, interactive routines are executed not for their own purposes but for the purposes of higher-level subtasks. This picture implies that deliberate strategies and conscious attention can oppose the allure of myopic shortcuts. However, this opposition requires the use of limited and costly cognitive resources and when this deliberate opposition is relaxed local optimization is the rule and small, quantitative optimizations at the interactive routines level will result in qualitative changes at the strategy level.

Designers of reality-based systems must become aware of the powerful allure of these factors on immediate interactive behavior and take care to design their interfaces so as to optimize, not suboptimize human performance.

NAÏVE PHYSICS OR NAÏVE REALISM?

The use of the term naïve physics by the reality-based interaction community [e.g., 17] is at odds with how the term is used by members of the cognitive science community who focus on science education [3, 19] where the term has negative connotations. As used by the reality-based interaction community, the term has more in common with some forms of ecological rationality [8, 35] or Gibsonian affordances than with the naïve physics community. Although terms, per se, may not matter, it is important that the reality-based interaction community not succumb to *Naïve Realism* [34].

Naïve Realism has been developed in the domain of visualization. The poster child for Naïve Realism has been the effort by the military to develop 3-D displays for Navy operators to use in making range estimates. Smallman's [34] work has shown that such displays subtly, but inevitably lead to erroneous range estimates when compared to lower tech, 2-D, *God's eye*, displays.

> Naïve Realism appears to stem from the folk belief that scene perception is simple, accurate, and rich, when, in fact, perception is remarkably complex, error-prone, and sparse. It results in the development of realistic displays that give users flawed, imprecise representations. Therefore, Naïve Realism offers a new account of why users sometimes prefer displays that subsequently under-perform. Naïve Realism also highlights a worrying disconnect between the zeitgeists of basic research (emphasizing the sparseness of perception) and applied display design (emphasizing the richness of visual experience) [34].

The examples that Smallman gives of Naïve Realism focus on visual displays. However, the folk belief in Naïve Realism appears to underlie the bolder claims made by the reality-based interaction community. As it is clear to me that there is much to be gained from the reality-based interaction movement, the call here is for caution and science as opposed to a blind faith in Naïve Realism.

SOCIAL AND PERCEPTUAL COMPONENTS OF JOINT ACTION

Work emerging from the cognitive science community (see the special issue of *Topics in Cognitive Science*, vol. 1, issue 2, 2009) is focusing on the cognitive, perceptual, motor, and social components of joint action [31]. Some cognitive researchers see human-to-human interactions as providing important social constraints for the architecture of individual cognitive processing [30]. Humans do not simply react to other human's behavior in cooperative tasks or competitive games, but they use that behavior to infer goals and to predict subsequent behavior. These nondeliberate observations and predictions occur at the 1/3 to 3 s time span of interactive routines; well under the time span of the Subjective Present. These nondeliberate observations and predictions permeate everything from the use of "the others" point of gaze as a guide to turn taking in speech or in coordinating joint physical action (such as the successful cooperative performance of two people putting sheets and blankets on a bed).

SUMMARY AND CONCLUSIONS

The emergence of Cognitive Science as a separate discipline not only parallels that of Human-Computer Interaction but in the early days was interdependent with it. As Allen Newell argued, "Nothing drives basic science better than a good applied problem" [25] and as Kurt Lewin long ago observed, "there is nothing so useful as a good theory" [21]. Recent advances in cognitive science, especially the ecological rationality approach, have focused on formal descriptions of the natural and artificial environment and formal descriptions of the ways in which the human cognitive, perceptual, and motor systems respond to these demands. Reality-based interaction designers will find a treasure trove of useful good theories in recent cognitive work and the cognitive scientist will find that the applied problems of this new movement provide good drivers of basic research in immediate interactive behavior.

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