Eliminate the Interface

Ted Krueger

School of Architecture
206C Vol Walker Hall
University of Arkansas
Fayetteville, Arkansas 72701
tkrueger@comp.uark.edu

Abstract

The design of an interface between two systems depends upon the way in which the systems are understood and characterized by the designer. Digital computation and the concomitant understanding of cognition as a computational process allowed the interface to be developed as a surface of contact between two symbol-processing systems. This paper suggests that as embodied, situated and to an increasing degree autonomous artifacts are developed and as cognition becomes understood as a dynamical process that new forms of interface will be required. It is suggested that direct actions in the world are the most robust means of means of communication. This eliminates the interface as an object or artifact of design and concentrates efforts on crafting the interaction that takes place between autonomous agents.

Our theories of computation have evolved and interacted with and informed our understanding of cognition. There is a strong tendency to see each in terms of the other. This reciprocal relationship has had a profound impact on the kinds of interfaces that have been developed to mediate between them. Transformations in this relationship will have corresponding implications for the kinds of interfaces that need to be developed and the way in which they are implemented. The shift from computational to dynamical models of cognition has tended to emphasize both the embodiment and situatedness of the agent and to bring the environment into an active role in the cognitive process. Simultaneously, the widespread distribution of embedded processors has allowed a measure of responsiveness and interactivity to be generated from within the environment itself. This condition requires that notions of interface be reconsidered.

The development of digital computation had symbolic logic as its foundation. Logic is an attempt to codify the proper structure of thinking independent of its content or context. This rule-based manipulation of symbols has enormous power and flexibility. Instantiations of this process have been shown to be equivalent whether implemented by mechanical, electrical, hydraulic, or other means. It was widely supposed that biological, and in particular, human cognition is based on computational principles as well. The independence of process from substrate suggested that software could be considered apart from hardware and so also the mind from the body. Hardware independence lent plausibility to the project of extracting and transferring human cognitive capabilities to machines. Wearn (1998) notes it is common to consider cognition only within the context of the mental processes of an individual using as a model the human as an information-processing machine. Interfaces within this perspective are surfaces of contact between two kinds of information processors -surfaces upon which the symbolic tokens reside and are manipulated. Text, graphic and speech interfaces attempt to capitalize on the richness of the modes of communication that have developed in the human social sphere. They suggest a humanness of the intelligent machine that is consistent with the traditional goal of A.I. - the duplication of human intelligence. They also accept an abstraction of humanness that is consistent with the cognitivist approach. But, the computational model of human cognition, especially in that it relies on notions of representation and logical operations, has been effectively challenged. We have come to understand ourselves as much more than this. But if the computational model is no longer convincing, then alternative interface strategies will need to be developed.

There has been a consistent trend toward the diffusion of computing resources into the environment. Initially all computing machinery was concentrated in a small number of machines of legendary size at work on problems of scientific or political import. The development of personal computing has put a large number of (for their time) relatively moderate processors to work on issues that are related to the individual or corporate user. While few of the problems addressed by these machines individually have the social significance of those that engaged the first machines, together they have produced significant social and cultural transformations. At the same time, the number of information processing machines of all sizes is dwarfed

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by embedded devices in products, equipment, appliances, and environments. It has been estimated that 25 billion of these devices have been produced. The scope of activities addressed by these devices is even more limited than personal computers, yet, as a group, embedded processors produce a transformation of the environment in which we live. No longer an inert physical container of human activity, the environment is becoming capable of responsive, adaptive, interactive and increasingly autonomous behavior. Embedded computation is more ubiquitous and transparent, but also less theorized than interfaces to information processing machines. The interface required for interaction with these environments is not likely to be a screen, and may have no reason to make use of symbolic tokens or other abstract devices. Interaction in this new condition must be founded on an understanding of activities that are grounded in the world rather than on the processing of symbols that have a relationship to that world only at some level of removal.

The human-machine interface issues that arise out of this new condition may be illuminated by reference to perspectives drawn from biology, robotics, dynamical models of cognition, and autonomous agents. These serve to characterize the agents involved and so enable an understanding of the constraints and opportunities of the interface. A comprehensive understanding of the relationship of cognition to the environment is required in order to craft an engagement with embedded devices and the material substrates through which they operate. These relationships have implications for how we understand the process of cognition relative to the organism and therefore how we might begin building interfaces to the media in which we exist.

Maturana and Varela (1980) have proposed that the distinguishing features of living organisms consist in their self-production and autonomy. They are essentially closed systems, self-organizing out of the gregariousness intrinsic to specific molecular organizations and the resources available to those processes. These entities are capable of maintaining a constant set of relationships, the processes of production that give the organism its definition, over a range of conditions that are obtained within the medium in which they exist. It is the continuous reconstitution of these processes that distinguish the living systems from their artificial counterparts. A failure to reconstitute these processes results in the dissolution of the organism.

Living systems can be defined relative to their media by the location of a membrane or boundary within which the life processes occur. This bounding condition allows for the definition of the organism and also for the definition of the 'process of living' as distinguished from all else. It is also this limit which defines the interaction that is available to the entity relative to its environment. The sensor-effector apparatus of the organism is the sole means by which this interaction can occur. An organism has internal states based on its sensory apparatus and realizes changes of state based on the operation of its effectors. It is from the regularities in the relationships of sensor states to effector states by which the organism 'brings forth the world'.

It is important to note that the possession of internal state is insufficient in itself. The internal state of the organism does not 'represent' the state of the world. Cognition develops not from a static internal representation of the environment as given by sensory data, the organism is not a state machine (van Gelder 1997), but by patterns of relations that develop between changes in sensory data in conjunction with changes in effector states. This leads Maturana (1985) to assert that "the mind is not in the head, the mind is in behavior".

Maturana and Varela (1992) employ the concept of structural coupling to define a process analogous to electrical induction by which the world of an agent becomes correlated with the internal states of the organism. In electrical induction no current flows between adjacent and parallel conductors, but the dynamic alternation of currents in one produce alternating currents in the other. In structural coupling, recurring structures of behavior may arise from the repeated interaction of agents with an environment which, in itself, becomes structured by this interaction (Agre 1995). " ... Internal state is externalized through products and behavior that select and organize the surrounding world" (Oyama, 1985:22). In this characterization, it is impossible to understand cognitive processes apart from both the specific physical constitution of the agent and the media within which it operates.

Over the course of the last fifteen years a substantial amount of research has been devoted to articulating a behavior-based approach to artificial intelligence. Brooks (1991) designates situatedness and embodiment as two of the primary concepts of this approach. Rather than attempting to build a cognitive machine by incorporating human-level intelligence in software programs that (may or may not) eventually guide a robotic device, this approach builds the body first and allows the behaviors to emerge from the interaction between the robot and the environment in which it is operating. The processors implemented in these robots tend to be small-scale distributed devices that are dedicated to the control of specific effectors, the collection of sensory data or the mediation between them. This is in contrast to the large, often remote, centralized computers of 'classical' artificial intelligence that collected and stored facts about the environment and then generated plans for the mechanism to carry out.

The behavior-based approach to intelligence and the general implementation of embedded devices owes more to the intellectual tradition of cybernetics than it does to information theory. While it is recognized that these are neither wholly distinct nor oppositional perspectives, the notion of a reciprocal interaction or feedback loop that may make no recourse to symbolic operations is especially useful. The emphasis on interaction focuses the analysis, not on the process that takes place within an individual, but on the relationship between entities. It encourages an examination of the interaction with and within a context. As such, it allows a discussion of the socio-cultural implications of cognition and a consideration of the place that artifacts play with in this process.

Varela, Thompson and Rotch (1991:173) identify cognition with 'embodied action'. In their view, cognitive capacity is rooted in the structures of biological embodiment, but are lived and experienced within the domain of consensual action and cultural history. Embodiment implies, "first that cognition depends upon the kinds of experience that come from having a body with various sensori-motor capacities and second that these individual sensori-motor capacities are themselves embedded in a more encompassing biological, psychological and cultural context". Cognition, then, is grounded in the organism's history of experience, in terms of its body and its social relations. (Varela 1992:253)

This reciprocal relationship between agent and its media suggests that the isolation of cognitive processes as phenomena of the brain is an oversimplification. Kirsh (1995) and Kirsh and Maglio (1994) have shown that an agent's environment may be actively restructured in order to facilitate perceptual and cognitive tasks. While clearly some actions in the world are undertaken in an effort to achieve functional or pragmatic goals, this work indicates that there is also much that is undertaken only to facilitate cognition. Indeed, there are levels of complexity where cognition can only occur by means of this structuring. Clark (1997) proposes that the concept of the mind be extended to include the environment in which cognitive operations are performed based on the active role that the environment plays in driving these cognitive processes. Much of the extensive modification of the environment undertaken by humans may be an effort to simplify cognitive tasks and to apply previously developed solutions in the pursuit of pragmatic goals. Kirsh (1999) notes that the boundary between the agent and the environment depends upon the nature of the explanation required and it's level of focus or analysis. In some cases it may be quite useful to think of the mind as extending into and incorporating parts of the world. Conversely, it is possible to consider just those sorts of cognitive operations to take place in the hybrid condition of agent and environment.

Hutchins (1995b) argues that the cognitive work that is required to land a plane takes place in part through the agency of the cockpit reference materials, markers and instrumentation. These serve not only a recording or memory function but, by their configuration, allow for the instantaneous calculation and processing of certain critical information relative to the operation of the craft. His analysis shows that the processing required takes place not within the individuals nor in the machine but by the agency of the socio-technical system that they comprise. It is concluded that the thinking that takes place during this activity resides in the hybrid condition of pilots and cockpit, not in one or the other. Here the unit of analysis has shifted from individual components to the conjunction of humans and artifact together. This translation of perspective is of more fundamental interest and wider applicability than the navigational situation discussed. It suggests that many human activities and the artifacts that support them, at a wide variety of scales, are deeply implicated in cognition.

Hutchins (1995a) considers cognition to be a cultural process and culture to be a cognitive one. As we come to develop our environments with increasing levels of autonomous, adaptive and intelligent behaviors, it becomes necessary to understand the nature of the relations that we structure into these environments. We can no longer consider ourselves, as individuals or as social groups, to be the sole locus of cognitive activities operating within an essentially inert physical context. Hutchins' analysis points out that at a social scale cognitive functions may be distributed and that the status of active participant in these processes must be attributed to machines as well as humans. Within the context of this analysis, then machines are no longer inert objects or artifacts in the physical realm but must be regarded as participants in the socio-cultural realm, as well.

The designation of an artifact as a co-participant assumes that there is some parity of stature within their relation. This equivalence, though perhaps not yet equality, becomes possible by virtue of the autonomous stature acquired by interactive machines. Krueger (1999) argues that increasingly complex behaviors on the part of an agent can not be met with brute force programming. The requirement that all possible states of interaction be anticipated and provided for sets a practical limit on what can be achieved. These limitations are simply a matter of mathematics. Repeatedly, as the combinatorial limitations become manifested, the designer is required to develop some means by which the agent can independently evaluate its context and take action. A measure of autonomy must be granted to the machine in order to be able to deal effectively with the complexity of its interactions with the environment.

Autonomy is a fundamental change in the nature of the artifact that in turn requires a re-evaluation of roles that objects play in both the cultural and cognitive processes. It is this aspect of embedded intelligence that most profoundly alters our relationship to the products of our material culture and requires an accommodation within the interfaces that we design in an effort to craft an interaction with them.

The production of intelligent behavior in synthetic constructions must begin with a reproduction of the necessary, though perhaps not sufficient, conditions from which cognition arises in biological systems. This implies that the cognitive capacities of artificial systems will develop out of the relations that are obtained between their physical architecture and their immersion in a dynamic context. Just as the cognitive capacities of humans depend upon both their sensory apparatus and their effectors, artificial systems will depend upon the specific sensor-effector functions that are enabled. There is no reason to expect, under these conditions, that if machines become capable of cognitive functions, that these would bear a close resemblance to the cognition of humans. Contact between human and machine agents will be most efficiently realized by direct operations in the world allowing the structural coupling of each organism to its medium to operate as both media and message. Issues of translation then need not arise.

(Stein 1997, Torrance and Stein 1997) propose that multiple interacting systems may extract structurally similar regularities from a shared environment and that these regularities form the basis for a shared grounding of their respective internal states which may be disparate. This understanding of shared grounding is consistent with and sympathetic to the notion of structural coupling of an autonomous entity and its medium as given above. It offers a framework in which to consider modes of communication that could be enacted between embodied autonomous synthetic agents and humans.

A direct interaction between embodied entities may have no need to make use of the layers of abstraction associated with symbolic and representational schemes. This interaction may proceed by a direct manipulation associated with and grounded in the shared task, whether this task is pragmatic or epistemic in nature. Brooks (1991), in discussing the merits of embodied and situated robots, notes that 'the world is its own best model'. He argues that it is unnecessary for the machine to contain explicit representations of its context if knowledge of the environment can be made available to it via its sensors. Information about the world is immediately and directly available in its current state. The robot may, in fact, communicate with itself via the environment. The results of an activity are given by changes to the robot's context and may be directly perceived and made use of by other sensors. This is more efficient than passing the projected consequences of the action to a centralized comprehensive model and then verifying the model relative to the actual context. The relationship between an action and changes of state in the medium can be perceived by other agent in the environment and may constitute a form of communication.

Kirsh (1995) argues that humans use space, that is their physical context, as a stable repository for both information and organization. Humans actively structure their environments in order to simplify and facilitate their cognitive tasks. When the task domain is shared by several autonomous entities, including humans, direct manipulation of the environment may be the most reliable and stable form of communication. Kirsh suggests that this is, in fact, a common occurrence during cooperative work. The structuring of the environment is often a clear indication of the nature of the task being undertaken and the manner or sequence in which it will proceed.

Novick and Perez-Quinones (1998) suggest that the notion of a 'situated act' may be used to directly describe goals of the activity domain rather than goals of the interface. They suggest that a fine-grained alignment between the nature of the real-world task and its representation in the interface is desirable. The purpose of this analysis is to 'abstract' from specific interface strategies to focus on the situational goals in an effort to open the possibilities for a variety of interface mechanisms that are capable of achieving those goals. It may also be possible to use the notion of 'situated act' to reduce or eliminate what is often considered to be the interface. Situated acts directly undertaken in the task domain may have no need for reference outside of the context of the interaction itself, but instead possess a high degree of situational meaning. Kirsh (1999) notes that in interfaces the objective should be a transparency that allows the semantics of the action to speak through the interface. This approach eliminates the surface between action and communication on which symbolic tokens exist and, by doing so, eliminates all errors and approximations of translation into and out of the symbolic medium. Perhaps most importantly it circumvents the problems associated with the relationship between symbolic structures and meanings for artificial systems.

Cooperstock (1995) suggests that since people can infer the intentions of others from their actions that technical systems might be crafted to do the same. The intent is to reduce the cognitive load on the user by allowing the system to make context sensitive reactions to the users conscious actions. The underlying design principle is to reduce complexity by enabling interaction based on skills developed by the user in everyday activity of a lifetime in the everyday world.

Penny (1999), in describing interaction with the robot 'Petit Mal', notes that this artwork trains its users. Significantly, this is an autonomous and interactive machine operating in relation to humans and so displays exactly the kinds of dynamics that arise between autonomous embodied agents. Here there is no recourse to symbolic structures, but the users and the work together negotiate the interaction in real-time and real-space by means of the activity that takes place there.

Embodied and situated actions in the world are both direct and immediate. Simultaneously productive, of epistemic and pragmatic goals, and communicative, they may also reduce the need for a metaphor. While interface metaphors allow for a relatively immediate accessibility to the means of accomplishing a task within a technical environment, they also become a limitation as interaction evolves. Interfaces are typically fixed environments for interaction. The notion that the interaction between machines and humans may proceed by means of a negotiation is a fundamentally different proposition.

This kind of interaction is not beyond human experience however. It takes place on a regular basis as part of our social intercourse. This does not remove the interface from the concerns of the designer but instead shifts its focus. Maes (1995) notes that emergent phenomena are not the result of unforeseen or accidental occurrences rather the designer must set an interaction loop between an agent and its environment that converges on the appropriate behavior. The equivalence of an interface, the negotiated understanding between autonomous entities, may be an emergent rather than a designed phenomenon. In this case, the location of the design effort moves away from a concern with the proximal detail and instead describes the parameters that shape the space or set of possibilities within which the interaction occurs. This kind of design does not have a long tradition and much of the work that needs to be done must be considered research and experimentation. There may be insights that can be drawn from ecology, social behavior, interactive arts and media, or a study of the choreography of improvisational dance.

This paper is not intended to argue that action in the world is the only viable interface strategy or to suggest that the symbolic approach is unnecessary. There is far too much evidence to the contrary. Rather the proposal is that interfaces to embedded systems need to be thought through in radically different ways from those for general information processing machines. Just as the computational metaphor provided a common frame of reference for systems concerned with symbol processing, so autonomous embedded systems may be brought into relation by means of embodied and situated actions.

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