On a Paradigm Shift in Design: Toward Constructivist Foundations

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Abstract

A paradigm shift has been observed across scientific, engineering, and other disciplines. While this shift also impacts design, the impact within the design profession has been rather sporadic without a clear recognition of a profound philosophical change. The purpose of this paper is to elucidate the transformation in design triggered by the emergence of new paradigms. For this, we contrast the old and the new paradigms and their impact on design. In particular, we look at the underlying epistemological and ontological assumptions and how they are reflected in design. The foundation for a new design philosophy sets new directions and goals.

Keywords: design philosophy, design cognition, design research, design education, design theory

Introduction

In the first half of the last century, new worldviews replaced old ones and new paradigms emerged in the natural and social sciences, as well as in the humanities. These changes were triggered by the discovery that widely accepted foundations of modern life, rooted in the nineteenth century positivist philosophy were inconsistent with new observations in a number of fields, including physics, chemistry, and the life and social sciences. They were successful in fostering industrialization and technological development, but inadequate for studying complex phenomena that became the focus of interest across disciplines. The quest for new foundations that became known as 'paradigm shift' spread eventually to all other areas of science and society, and impacted design as well. The paradigm shift in design is closely related to the proliferation of technology. Of all the rapidly evolving new technologies, computer technology had the largest impact on design. In particular, computer aided design (CAD) became pervasive in every aspect of design. CAD profoundly changed the design profession and called for new foundations. Seeking new foundations for design in the Information Age has been one of the main topics of Artificial Intelligence (AI). AI is symptomatic or characteristic of this development, as it is concerned with the cognitive processes of designing to push the envelop of CAD. However, these efforts have been plagued by inconsistencies and incongruence, as the paradigm shift occurred spontaneously and remained largely unnoticed and unrecognised in design, as well as in AI. In design, a more human oriented postmodern style started to gain territory, and the focus of the design process shifted from technology toward the user. From the 1980's on, user-centered and participatory design has become widely accepted and utilized. A similar shift is happening in AI, where current interest has turned to anthropocentric models. These models are based on new principles, such as situatedness, embodiment, emotions, and social interactions. One of the consequences of failing to recognize recent changes in design as part of a larger paradigm shift is the lack of explicit and systematic philosophical foundations. Without such foundations it is hard to develop a general program and directions in design. This also holds for CAD and design-related AI. To find new directions and develop a coherent program for

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the latter is particularly challenging, as classical and neo-classical AI are still dominating this field. The purpose of this paper is to outline such foundations.

How does design incorporate philosophy?

Everything we do is determined by our worldview or philosophy. Our philosophy determines *what* we do and *how* we do it. Since creating artifacts requires appropriate actions, our philosophy determines the properties of our creations. This means that any man-made object or artifact incorporates our philosophy. A classic example is Jeremy Bentham's Panopticon (Bentham, 1843). The Panopticon was a plan for an 'optimal' penitentiary that was never built. Bentham, the father of utilitarianism, published his plan (Figure 1) in 1791.

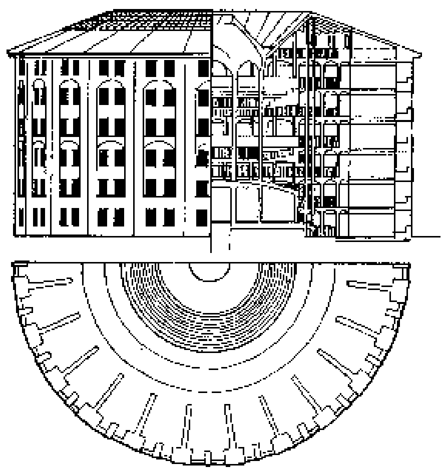

Figure 1: Jeremy Bentham's Panopticon

Utilitarianism was a philosophy of the blossoming Industrial Revolution the moral of which demanded to subordinate individual interests to those of humanity. Utilitarians believed that morality is about producing good consequences for the society at large, but not necessarily having good intentions. They also believed that studying and scientifically analyzing facts could reduce, or even eliminate moral disagreements. Their working hypothesis was that it is always possible to find a morally justified answer to the question of 'what we ought to do,' if we can scientifically assess various possible courses of action to determine which will have the greatest positive effect on the world. On the surface it was a humanitarian moral philosophy. In effect, however, it was the philosophy of the emerging new bourgeoisie seeking moral justification for their political and economic interests.

The Panopticon incorporates many of the utilitarian concepts. In particular, the layout maximizes economy and efficiency, the corner stones of the emerging industrialization. It was economical because it required few guards to control many inmates. It was also efficient because the inmates couldn't see the guards who randomly inspected them. Also the layout provided the shortest possible access to all cells. This was achieved by a semi-circular arrangement with an 'inspection lodge' at the center and with the cells around the perimeter. The guards had free view of each inmate placed in individual cells, but a carefully contrived system of lighting and the use of wooden blinds hid the guards from the inmates' view. "The occupants of the cells ... [were] isolated from one another by walls, and subject to scrutiny both collectively and individually by an observer in the tower who remains unseen. Toward this end, Bentham envisioned not only Venetian blinds on the tower observation ports but also mazelike connections among tower rooms to avoid glints of light or noise that might betray the presence of an observer" (Barton & Barton, 1999:139). Thus the inmates were subjected to the feeling of being watched constantly by unseen eyes. The clever design of the Panopticon, a Greek-based neologism for 'a place to see everything,' left the prisoners no other option as complete surrender and obedience.

The design also reveals many beliefs of the early industrial society in general and of the Utilitarians in particular. A basic belief was that information is the source of power. Facts, such as data and statistics are neutral and can be trusted; they speak for themselves. As all other utilitarian proposals to improve the social system, the idea of the Panopticon was also based on a careful study of social statistics. The Utilitarians were the first who used statistics as a political weapon to change the law, economics, education, welfare, the prison system, sanitation, etc. They gathered information on everything to support their case. In a sense they were forerunners of today's information society. A corner stone of their social philosophy was the belief that poverty is criminal and parasitism and the poor has to be forced to work.

The utilitarian invention of social statistics culminated in "the famous Victorian Blue Books, the densest collection of social statistics in human history" (Roszak, 1986:158). Another nationwide social statistics, the Survey of the British Poor Law in 1833 aimed at reforming the Old Poor Law that dealt with regulations and social programs of the time. The Old Poor Law evolved spontaneously over centuries and was plagued with inconsistencies and inadequacies. It was an easy task for the Utilitarians to take apart and discredit the Old Poor Law with their meticulous statistics and convince the government to reform it. "The result was the draconian workhouse system we find depicted in the novels of Charles Dickens. While the Poor Law Commission sought to make its survey look totally neutral ... it was shaped from the beginning by a well-structured social philosophy based, for example, on the assumption that poverty was a form of criminal parasitism which deserved to be punished and that too generous a system of relief will only corrupt the people's will to work" (ibid:159). The Panopticon also epitomized and symbolized the views of the eighteen-century French philosophes seeking radical social and cultural changes. Foucault (1979:170) connects the Panopticon with the social and cultural values of modernism and Lyon (1994:57-80) with the perils of today's information society.

From philosophy of design to design philosophy

The Panopticon is just one example of how a particular design object represents or embodies a philosophy. One can easily find other historical examples, such as Jacquard's loom, Babbage's Differential Engine, or Paxton's Crystal Palace, that are also clear 'statements' about the philosophy of their creators. Moreover, we can turn to any artifact and find that it is a rich source of philosophical 'statements.' For example, such a mundane object as a Styrofoam cup is a rich source of information about the philosophy of its creator: The material, shape, size, color, ornamentation, decoration, etc., all provide important clues about the designer's beliefs and values, intentions, and culture.[3] However, more often than not, designers would give you an incredulously blank stare if you asked them about their views about philosophical issues and how these views influence their designs. Unlike Bentham, designers are seldom aware of their own views and processes and how these are incorporated in their work.

Recently, however, there is a growing interest in the philosophy of design, as designers begin to recognize the relevance of philosophy for the profession. Although great designers often fancy philosophy and are concerned about ethical, esthetical, social, and other philosophical issues, the design profession lacks philosophical underpinnings that sciences, especially natural sciences, have always been seeking. While the philosophy of science has been a much-debated subject, philosophy of design is virtually non-existent. According to the Journal of Design Philosophy Papers (DPP, 2004), "As for philosophy, design itself hardly exist. Yet design is a crucial factor in the relation between beings and worlds as they shape each other. In this context it is not a matter of just asserting the need for design to be engaged philosophically, but rather that philosophy engage design for the sake of philosophy." As a few recent publications indicate, the need for studying philosophical aspects of design is starting to be recognized. In fact, the appearance of the Journal of DDP is a sign of this trend. Also a recent issue of the Design Studies (vol.23, 2002) was dedicated entirely to this subject. In his editorial paper of this issue, Per Galle (2002:211-218) proposes to study and discusses two major aspects of the philosophy of design: 1) understanding the nature of design and 2) improving design by integrating philosophy. He lists a number of philosophical issues the study of which can help to understand the nature of design, such as methodology, phenomenology, quality, cognition, language and communication. On the other hand, he suggests that philosophy could help to improve design in all three major areas: research, professional practice, and education.

The philosophy of design seeks answer to the question of *what* designers do and *how* they do it. The former raises ontological and the latter epistemological questions. However, designers might wonder: "Does [philosophical] 'insights' about design help us improve our products, increase our share of the market, or boost productivity of industry?" Galle's response is that "the philosophical insight into their profession may enable designers to take well-founded critical stance towards what they are doing, and may give them a conceptual and verbal tool kit *useful for thinking* about how to improve the practice of their profession" (ibid).

Yet philosophy provides much more than just insights. Any philosophy has not only analytical but also programmatic aspects as well. Understanding concepts and relations is just the first step toward a change of attitude and behavior. While the philosophy of design helps to clarify views regarding various design re-

[3] It is quite an interesting and educational experience to ask engineering or architecture students to identify the designer's (conscious or subconscious) assumptions, beliefs, and values based on the study of a particular design object, such as a teacup, a pen, or a cell-phone.

lated issues, design philosophy also provides behavioral guidelines. It is concerned with moral and ethical issues, seeks answers to social, legal, and political questions that are pertinent to design. Thus, beyond seeking explanations, design philosophy also *drives* what designers do and *determines* how they do it.

From Philosophy to Paradigm Shift

Design philosophy can be understood only in a larger context. As scientific, technological discoveries and social developments transform our world, our philosophy is also changing: old theories get revised, some of them are discarded while new ones emerge. To place design philosophy into this context, let's describe here some recent developments.

Shared views

Within each field or profession there are fundamental beliefs and values that are shared by the community. For example, in AI shared views of cognitive models lead to Computational Representational Understanding of the Mind (CRUM, Thagard, 1996:10-21) vs. dynamic system approach (ibid:169-181);[4] or views on goals to weak (Dreyfus, 1994; Gams, 2001; Penrose & Gardner, 2002) vs. strong AI (Minsky, 1994; Moravec, 1998; Kurzweil, 1999; Kurzweil et al., 2002).[5]

Regarding design, a shared view is, for example, functionalism characterized by Sullivan's slogan "form follows function" or user-centered and participatory design (Norman & Draper, 1986; Participatory, 1998; Participatory, 1998a; Gill, 1991). Functionalism was the dominant design philosophy of the Industrial Revolution, in particular of the Bauhaus. User-centered and participatory design originated in the 1970's in the Scandinavian countries in connection with the study of human-computer interactions. It became a widely accepted design philosophy in the 1980's and 90's.

These views or beliefs and values are often implicit and to make them explicit helps communication. This is particularly important for new, evolving fields or professions as it impacts their evolution. Both, design and AI are relatively new. Their marriage, design-related AI as an interdisciplinary field, is even younger. Although design has always been an integral part of professional activities, it emerged as an independent profession only at the turn of the nineteenth century with the Industrial Revolution. Establishing as an independent branch of computer science and laying the groundwork for the ongoing evolution of AI was born at the Dartmouth Conference in 1956. The foundations of Computer Aided Design were laid down by Ivan Sutherland's PhD thesis in 1963.[6] Design-related AI became a mainstream research area only in the 1980s.

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[4] The underlying assumption of CRUM is that the mind can be best understood and described in computational terms. This computational metaphor is based on the analogy between computer programs comprising data structures and instructions (algorithms) and mental processes comprising mental representations and computational procedures. According to the dynamic systems approach, the mind functions as a dynamic system rather than a computing device. Dynamic systems are nonlinear, which means that if e_i is the effect of the cause c_i within a system, then sum of the causes $c_1, c_2, \dots, c_n$ is not the sum of their effects $e_1, e_2, \dots, e_n$. This feature of a system gives rise to emergent properties that cannot be explained solely by the properties of its parts. The behavior of a dynamic system might be described by dynamic equations. This behavior is chaotic and unpredictable.

[5] The proponents of weak and strong AI see the mission of AI radically different. According to the 'strong view' the mission of AI is the understanding of human intelligence by building computer models of the mind. The 'weak position' is, however, that AI doesn't need to worry about how our brain internally works to develop computer programs or machines exhibiting intelligent behavior. The Supercomputer Deep Blue that beat the World Chess Champion Garry Kasparov in May 1997 illustrates the difference between these two views. The proponents of strong AI don't consider this as an accomplishment in AI, as Deep Blue doesn't 'think' as a human chess player, but weak proponents do, as it displays a proficiency in chess that we attribute only to highly intelligent people.

[6] Sutherland developed the hard- and software for the first graphic user interface. His thesis also laid down the foundations of object oriented programming and constraint satisfaction, that are techniques widely used today in software design in general and in AI in particular.

Paradigm

Shared views or philosophies are related to the Kuhnian concept of *paradigm*. In his seminal work on the philosophy of science, Thomas Kuhn defined paradigm as "a constellation of achievements—concepts, values, techniques, etc.—shared by a scientific community and used by that community to define legitimate problems and solutions" (Kuhn, 1962). In other words, a paradigm is a system of interrelated premises or presuppositions which gives rise to a fundamental worldview. It refers to a systematic set of assumptions or beliefs about fundamental aspects of reality. "Paradigms represent what we *think* about the world (but cannot prove). Our actions in the world, including the actions we take as inquirers, cannot occur without reference to those paradigms: 'As we think, so do we act.'" (Lincoln & Guba, 1985:15).

According to Lincoln and Guba (1985), paradigms address fundamental assumptions taken on faith, such as beliefs about the nature of reality (the ontology), the relationship between knower and known (epistemology), and assumptions about methodologies. As generally accepted assumptions are challenged and new assumptions emerge, old paradigms are replaced by new ones. The emergence of a new paradigm always starts with the critique of the current paradigm. An example in design is Donald Norman's critique of neglecting human factors and the user's interests (Norman, 1988; 1993), and an example in AI is Rodney Brooks' critique that AI has been long ignoring situatedness and embodiment (Brooks, 1999; Steels & Brooks, 1995). Brooks (2002:51-52) defines situatedness as being "embedded in the world [… that] directly influences the behavior of [a system]," while embodiment as having "a physical body and experiences of the world […] directly through the influence of the world on that body."

Paradigm shift

A new paradigm is emerging in many fields: mathematics, physics, biology, linguistics, education, sociology, literature, fine arts, etc. The emergence of a new paradigm is not an isolated event but a chain of events in many areas. It becomes apparent by observing general tendencies or directions in many fields simultaneously. Thomas Kuhn called this emergence of new tendencies or directions across scientific disciplines a *paradigm shift*. Kuhn also described how paradigms drive scientific inquiries and developments and how paradigm shifts occur discontinuously and cause radical changes or revolutions throughout the history of science. Gergen (1991:90) writes:

> [M]ainstream scientists of a given age are committed to a particular perspective of the world (along with associated practices)—a paradigm in Kuhn's terms. [...] At some point [... other] scientists will develop an alternative way of thinking about the world, one in which their findings make sense. The new theory cannot be compared with the old in terms of its empirical truth; it is simply a different way of viewing the world, wedded to a different realm of facts.

Thus paradigm shifts replace one scientific paradigm by another incommensurable one. They move across scientific disciplines and eventually impact the entire society. Or viewing from the point of view of a particular discipline, as the physicist Capra (1996:5) observes: "Today, [...] we recognize the paradigm shift in physics as an integral part of a much larger cultural transformation."

Although science and design play different roles in human development, they are intimately connected, so that paradigm shifts equally affect both. While scientific paradigms have become a focus of interest in the philosophy of science, paradigms have received little attention in design. In this paper we would like to shed light on a recent paradigm shift that is rapidly capturing the scientific world and influences design as well.

Postmodernism

Any new development in any domain is driven by the prevailing worldview (Weltanschauung) or philosophy. In particular, "[s]cience, research, and technology are all by-products of our philosophical reflections" (Gaarder, 1996:463). In the 19th and 20th centuries the prevailing worldview was objectivism, rationalism, or positivism. While modern science and technology are based on positivist paradigms, these paradigms have also set the trends and determined the predominant views and styles in design. New discoveries in particle physics (triggered by Planck's discovery of the quanta at the turn of the twentieth century) and the exponential increase of computational power allowing complex computer simulations (from the 1980's on) led to contradictions and raised questions about the adequacy of these paradigms. The quest for new foundations gave rise to postmodern, in particular to constructivist paradigms. While the positivist philosophy assumes that there exists an objective reality independent from the observer, according to the constructivist view, we are constrained by our perception so that we cannot access 'reality'—whether it exists or not—and so our 'reality' can only be constructed. The observer and the observed cannot be separated and what we call 'reality' is co-constructed by people in a social context through a dynamic process.

The term 'postmodernism' originated in design, in particular in architecture (Venturi *et al*, 1977; Galinsky, 1992; Jencks, 1996), but philosophers, such as Saussure, Derrida, Lyotard, Foucault, Habermas, and Rorty, gave the word 'postmodernism' different meanings in philosophy and science. Postmodern philosophy started initially as critics of the structuralist movement of the 1960s that was mainly concerned with patterns of relations among the many sign-elements of human culture. "Perhaps the most characteristic tenet of postmodern philosophy is that everything that European philosophy and science has held to be fundamentally true at an abstract or programmatic level (ontology, epistemology, metaphysics, logic) is in fact a contingent, historically specific cultural construction, which has often served the covert function of empowering members of a dominant social caste at the expense of others. It dismantles the most foundational procedures and assumptions whereby prior European philosophical traditions sought to establish universal truths or principles" (Lemke, 2000).

While the paradigm shift from modernism or positivism to postmodernism is taking place across many disciplines, it has not been widely recognized by the design community as a revolution sweeping through all aspects and segments of design. Consequently, changing views and attitudes in design remained often isolated or disconnected from other social and scientific developments. Unlike in social and natural sciences, there is a lack of general recognition of the larger context of this change and a lack of systematic (re)evaluation of design theories and methods. Although, the paradigm shift is clearly recognizable by the emergence of new concepts, such as participatory and user-centered design (Norman & Draper, 1986; Participatory, 1998; Gill, 1991), there is a lack of foundation and orchestrated effort to make this shift explicit. In particular, we are not aware of any attempt to study the impact of new paradigms on design and to establish a connection between the philosophy of science and design. Even studies about the impact of postmodern philosophies on design (such as Coyne, 1995), are rare with the notable exception of the educational field (Black & McClintock, 1995; Wilson, 1997) and systems engineering (Crowe *at al*, 1996). As a consequence of the lack of foundations, there is also a lack of explicit goals and direction in design. Such goals and directions seem particularly relevant for CAD and design automation shifting the focus to AI. We argue for making the paradigm shift explicit and consistent across the whole design spectrum.

Constructivism

Among the numerous postmodern philosophies, constructivism emerged as one of the most coherent and comprehensive ones setting a trend and defining a new paradigm.

History

Constructivism traces its origin back to Giambattista Vico's philosophical work, *De Antiquissima Italorum Sapientia*, published in Naples in 1710. However, Vico's work remained largely unknown until recently when interest turned to constructivism starting probably with the pioneering work of child psychologist Jean Piaget in the first half of the Twentieth Century. Another forerunner of constructivism was Immanuel Kant. According to Kant, if there is a real (in Kant's terminology 'noumenual') world, then it is unknowable to us, and the one we experience (the phenomenal world) is constructed through the imposition of concepts. While Kant believed that everyone imposes the same innate concepts, neokantists and constructivists dispute this belief. In particular, "where constructivists differ from Kant is in the origin and nature of the concepts that are used in constructing reality" (Crowe e*t al*, 1996:23). One alternative offered by constructivism is to substitute this Kantian fix-point by relativism: "These concepts differ from (linguistic, social, scientific, etc.) group to group, and hence the worlds of groups differ. Each such world exists only relative to an imposition of concepts" (Devitt, 1991). The above discussed scientific paradigms or worldviews introduced by Kuhn are also socially determined as the concepts associated with a given paradigm or worldview are developed and shared within social groups. These groups share the views on the domain of science, the choice of scientific problems considered to be relevant, the methods considered to be appropriate to investigate these problems and the solutions considered to be acceptable.

From the many shades and colors of constructivism, the probably most influential one is radical constructivism. Unlike the other strains of constructivism that have their roots in philosophy, radical constructivism originates from psychology (Piaget & Inhelder, 1969; Glaserfeld, 1976), physics (Foerster, 1998), biology (Maturana, 1980) and sociology (Luhmann, 1995). It maintains that our understanding of the world is based on making distinctions (or as Gregory Bateson (1972) formulated, "the difference that makes a difference"), and the function of our perception is to allow us to take actions rather than to create a representation of some independently existing external world. The pragmatic approach of the radical constructivists and their interest in the interaction of science and society influenced many other scientific and engineering areas (Radical, 2001). Joining this trend, designers and AI practitioners have been recently embracing constructivist ideas in general and radical constructivism in particular.

Constructivism in Contrast

Schwartz and Ogilvy (1979) provided an analysis of the concepts that were, at the time, emerging in a variety of disciplines and research areas, such as physics, chemistry, brain theory, ecology, evolution, mathematics, philosophy, politics, psychology, linguistics, religion, consciousness, and the arts. From their analysis, Schwartz and Ogilvy synthesized seven major characteristics of an alternative naturalistic or constructivist paradigm, that stand in contrast to those of the still-dominant positivist paradigm (Lincoln & Guba, 1985):

1. *Movement from simple to complex realities*: It is no longer possible to view systems as merely the sum of their parts; as systems become more and more complex, they develop unique properties that cannot be accounted for or predicted from the properties of parts.
2. *Movement from hierarchic to heterarchic concepts of order*: Emergent thinkers have come to believe that if there are orders, many of them exist side by side.
3. *Movement from mechanical to holographic images*: The earlier predominant mechanistic metaphors are too simple to complement related concepts of complexity and heterarchy. Instead, holographic images are emerging: "With the holographic metaphor come several important attributes. We find that the image in the hologram is created by a *dynamic* process of interaction and differentiation. We find that the information is *distributed* throughout—that at each point information about the whole is contained in the part. In this sense, everything is interconnected like a vast network of interference patterns, having been generated by the same dynamic process and containing the whole in the part" (Schwartz & Ogilvy, 1979:13-14).
4. *Movement from determinacy to indeterminacy*: Heisenberg's Uncertainty Principle demonstrated that, at subatomic levels, the future exact state of a particle is not predictable, and the act of observation to determine its state will influence the observed state.
5. *From linear toward mutual causality*: The concept of feedback is extended by the concept of feed-forward, which blurs the distinction between cause and effect, introducing the notion of mutual causality.
6. *From assembly to morphogenesis*: Morphogenetic change occurs suddenly and dramatically, operating in such a way that lower forms create higher order forms.
7. *From objective to perspectival views*: Objectivity is an illusion, but subjectivity in the usual (idealistic) sense is not the only alternative: "We suggest that perspective is a more useful concept. Perspective connotes a view at a distance from a particular focus. Where we look from affects what we see. This means that any one focus of observation gives only a partial result; no single discipline ever gives us a complete picture. A whole picture is an image created morphogenetically from multiple perspectives" (ibid:15).

Constructivism in Context

A sharp distinction between the positivist and the constructivist view is often impossible, as similar to constructivism positivist philosophy is also inhomogeneous with numerous shades and colors. An example is the various attempts to counter criticism and reconcile realism with the constructivist view on reality as it is discussed in (Harrè, 1986). Another example is the attempt of Hacking (1999) to define social construction in relation to scientific realism, about which Latour (2002) writes: "Hacking understood that the reason these disputes around the right mix of reality and construction trigger so much passion is that they are political: they seem to talk about epistemology but they are really about how we should go about living together."

Also, in spite of the sharp differences between the positivist and the constructivist views, we want to place particular emphasis on the fact that we do not see these two paradigms as antagonistic, but rather complementary in a certain sense. We see their relation similar to the one between Newton's theory of mechanics and Einstein's special relativity theory. In most phenomena of ordinary experience the results from the theory of relativity approximate those based on Newtonian mechanics, but the results deviate greatly for phenomena at cosmic scale with bodies moving close to the speed of light.[7] Just as Einstein's theory does not invalidate Newton's theory under normal earthly circumstances while it does in other settings, so has constructivism another domain of application than positivism. In any context where subjective experience is not the main issue, positivist or quantitative research methods can be applied very successfully. Such contexts involve what Paul Waczlawick calls "first order realities." This is "the universe of 'facts' which can be established objectively in as much as the repetition of the same experiment yields the same result independently of by whom, and where the experiment is being carried out" (Waczlawick, 1984:236).

However, positivist research methods fail in contexts that involve "second order realities" or "[t]he aspect of reality in the framework of which meaning, significance, and value are attributed […]. While it is sensible in the area of first order reality to examine, in the cases of differences of opinion, whose opinions do justice to the concrete facts and who is wrong, in the sphere of second order reality *it is senseless to argue about scientifically established 'truth' or to claim to have found it* [italics ours]" (ibid:237–238).

Problems arise when a system claims possession of absolute truth and consistency. "[T]he concept of an ultimate, generally valid interpretation of the world implies that no other interpretations can exist beside the one; or, to be more precise, no others are permitted to exist. For otherwise, we would find ourselves in a universe in which finally everything would be true, including its opposite. Where the ideology tries to refer back to itself in order to establish its validity and truth from within itself, a blind spot arises." (ibid:222).

Inseparability of Science and Design

The purpose of this section is to show how a change of a scientific paradigm has a strong impact on society in general and on design, in particular, as a result of the inseparability of science and design. Both science and design play a major role in human development. Science is responsible for acquiring knowledge, and design for creating artifacts. The two activities are inseparable and have been practiced together over centuries.[8] Only recently, with the advent of the Industrial Revolution, emerged a tendency to separate scientific and design activities.[9]

According to Kuhn (1962), the paradigm shift leading to the development of modern sciences was the Copernican "revolution." The work of Copernicus, Galileo, Tycho Brahe, and Kepler in the sixteenth century replaced Ptolemy's speculative planetary model by—what we call today—'scientific methods.' These methods, influenced by Aristotlean philosophy, led to the development of Kepler's laws of planetary motion, driving a wedge between science and theology. In the seventeenth and eighteenth century, Decartes,

[7] Moreover, as Barrow (2002:59) points out, a similar relation can be observed not only between classical mechanics and special relativity, but also between other established theories based on their inclusion or exclusion of the three main constants of physics; the gravitational constant, the speed of light, and the Planck constant. None of these theories invalidate the others within their application domain, but they do beyond it. In fact, physicists often apply theories outside of their application domain, for it would be impractical or even impossible to use only 'valid' theories. For example, Newtonian mechanics is often used in quantum domains simply because using quantum models would be just too cumbersome or such models are still unavailable. Physicists are, however, aware of the limitations of their models.

[8] A friend of us objected that nose rings and hair dues have apparently nothing to do with science. Yet, they do, for manufacturing nose rings, drying, coloring, and curling hairs are all based on physics and chemistry even if today this is fifth grade's science.

[9] Even the word 'design' is relatively new. Although its origin can be traced back to the art historian Giorgio Vasari (1511-74) and the Italian word 'disegno' for drawing, its common use for creating plans for new artifacts dates back only to the beginning of the 20th century.

Bacon, and Newton fueled this revolution by laying down the foundations of the nineteenth and twentieth century science. New scientific knowledge led to the development of new technologies and to the Industrial Revolution of the nineteenth century. The Industrial Revolution increased product development—qualitatively as well as quantitatively—and separated design from manufacturing. One of the results of the emergence of design as a new independent discipline was that the connection between science and design became less transparent. Today designers and scientists live in separate worlds divided by historic, cultural, linguistic, and even physical barriers. While Renaissance masters were scientists, artists, designers, and craftsman in one person, these are now not only separate professions exercised by different persons and groups, but it requires also efforts to bridge the gap between these professions.

In spite of the lack of transparency, the inseparability of science and design is quite obvious. Scientific knowledge is acquired by observation and testing whether the knowledge we acquired through observations can be generalized. However, for observations, as well as for testing, we need to create tools. Our perception is limited and without appropriate tools, phenomena that lie beyond our perceptional limits cannot be observed. Also, there are limits of what we can test without appropriate tools. Since creating tools requires design, science couldn't go very far without design. But the same holds for design: The creation of any tool or artifact requires knowledge that can be obtained only through science. A prime example is the relation between astronomy and clock design. The study of astronomical objects requires instruments for measuring time, but without astronomical observations and knowledge we would have no concept of time and thus no measuring apparatus.

Another even more important connection between science and design is the application of scientific knowledge in everyday life. Design uses scientific knowledge to create artifacts and using artifacts provides feedback or impulses to gain new scientific knowledge. For example, airplane design is based on aerodynamics, but the field of aerodynamics advances also by studying the properties of airplanes. Also, more often than not, problems or demands in the application domain prompt new scientific inquiries. According to Raymond Willem (1990), "it is *only* through design that science is made visible. It is only through design that science moves beyond the pure knowledge of laboratory experiment or textbook principle and acquires operational consequences." The cross-fertilization between science and design is also an interesting phenomenon. Design often employs scientific methods, and science often turns to design for inspiration, in particular to boost creativity.

Both design and science are concerned with our environment and co-evolve simultaneously. Both are concerned with *all aspects* of the environment—natural as well as man-made (such as social, economical, cultural, etc., environment). The fundamental difference between them is their purpose: While the purpose of science is to *understand* the environment, design wants to *change* it. The main reason for our quest for understanding is the need to satisfy our innate curiosity. However, understanding also serves the practical purpose of making predictions about the outcome of new events. On the other hand, the purpose of design is to satisfy our (physical and mental) needs by altering the environment. To serve its purpose, science is *seeking* patterns while design *creates* them. These fundamental differences between science and design give rise to different manifestations of the same paradigms.

Emerging New Paradigms in Science

As in design, in the first half of the twentieth century interests and views in science and philosophy shifted as well. The triggering event was probably Planck's discovery that the second law of thermodynamics was a statistical rather than an absolute law. His re-formulation of this law, that is Planck's radiation law, assumes that radiation is emitted, transmitted, and absorbed not continuously but in discrete packets or quanta of energy. Planck's quantum theory dates back more than a century, as it was first published in 1900. The implications of quantum theory that we can have only statistical knowledge of certain phenomena and—according to the Copenhagen interpretation—the observer cannot be separated from the observed phenomena changed the dominant Cartesian world-view. Science seized to be the ultimate objectivity to explore nature, or as Heisenberg formulated: "Natural science does not simply describe and explain nature; it is part of the interplay between nature and ourselves; it describes nature as exposed to our method of questioning."

The other major impact on the emerging paradigm was Einstein's special and general theories of relativity. While the special theory of relativity fundamentally changed the concept of time (by connecting it with the relative speed of the observer), the general theory changed the concept of gravity assuming that matter warps the space according to the amount or mass of matter in any given locality. Then, according to this theory, all motions along world lines in this vicinity must follow the warp. The theory of gravity resolved puzzling inconsistencies such as the difference between the calculated and actual path of the planet Mercury and made predictions like 'black holes' that Newton's theory of gravity could not account for. A significant aspect of Einstein's general (gravitational) theory is its nonlinearity, which implies that the whole is greater than the sum of its parts. Other leading physicists of the time, such as Max Born and Erwin Schrödinger, also recognized the importance of nonlinear theories for fundamental formulations of physics as they saw in them the possibility to explain the emergence of elementary particles from underlying nonlinear fields (Moore, 1989).

However, nonlinearity didn't receive much attention until the 1970s when it started to attract not only physicists but other scientists as well. "Earlier emphasis—in teaching and research—on linear dynamics has given way to a broadly based appreciation of the insights that are now collectively called nonlinear science" writes the physicist Alwyn Scott (2000).

> Evidence for this paradigm shift is provided, first of all, by the growing number of centers for nonlinear studies that have sprung up around the globe since the early 1980s. These new centers differ from previous research institutes by including a very wide range of activities: from biology to economics, from biochemistry to psychology, from condensed matter physics to electrophysiology. Second, many conferences and workshops in nonlinear science are now organized and attended by scientists from very different areas of primary interest. Finally, several new journals devoted to nonlinear science have appeared, again since the early 1980s. Broadly speaking, nonlinear science is characterized by its interdisciplinary nature, which will become of increasing importance in the research of the coming century (Scott, 1999) (ibid).

Both the quantum theory and Einstein's relativity theory raised questions not just about earlier methods, but also about the focus of scientific inquiries. These earlier methods were based on Descartes' reductionist views. According to these views, the world is an assembly of simpler physical entities and therefore one can successfully study complex phenomena by breaking them apart and analyzing the simple parts separately, mainly by mathematical modelling. This idea has been particularly successful in the so-called hard sciences such as physics, chemistry, or biology. This success produced useful theories and valuable applications, in particular a series of technological breakthroughs. The most important such breakthrough in the twentieth century was the development of computers. Ironically, however, computers also helped to undermine reductionism by playing a central role in the emergence of cybernetics and systems theory. Cybernetics and systems theory studied complex systems and soon recognized that any reductionist approach was doomed to fail.

"The great shock of twentieth-century science has been" writes Fritjof Capra (1996:29) "that systems cannot be understood by analysis. The properties of the parts are not intrinsic properties but can be understood only within the context of the larger whole." This came as a surprise to the entire scientific community because suddenly scientific interest turned to complex phenomena and found that systems are everywhere, not just in social and life sciences, but in hard sciences as well. In fact, it was discoveries in physics and chemistry, such as the Bénard cells or the laser that raised worldwide interest in complex systems. By studying systems, in particular complex ones, researchers recognized that similar nonlinear mathematical models could describe systems as diverse as the weather and the stock market for their behavior patterns are similar at some abstract level. As John Holland, a pioneer in the development of genetic algorithms, said in a lecture:

> Many of our most troubling long-range problems—trade balances, sustainability, AIDS, genetic effects, mental health, computer viruses—center on certain systems of extraordinary complexity. The systems that host these problems—economies, ecologies, immune systems, embryos, nervous systems, computer networks—appear to be as diverse as the problems. Despite appearances, however, the systems do share significant characteristics, so much so that we group them under a single classification […] calling them complex adaptive systems. (Horgan, 1995)

At the same time researchers also recognized that understanding the role of *humans* in scientific inquiries or the cognitive aspects of scientific endeavours is fundamental to understanding complex systems. The result was a paradigm shift across disciplines that also triggered a large number of inter- and cross-disciplinary researches.

> The focus of the natural sciences has begun to shift away from the search for new fundamental laws and toward new kinds of synthesis—'holism,' if you prefer—in order to understand complex systems. [...] No compelling

> reason has ever been offered why the same strategy should not work to unite the natural sciences with the social sciences and humanities. The difference between the two domains is the magnitude of the problem, not the principles needed for its solution. The human condition is the most important frontier of the natural sciences. Conversely, the material world exposed by the natural sciences is the most important frontier of the social sciences and humanities. (Wilson, 1998:267)

There seems to be no compelling reason for treating design differently from natural sciences or forgo applying the same methods and strategies that promise, "to unite the natural sciences with the social sciences and humanities." Brooks and Stein (1993) write about this paradigm shift:

> Recent trends in artificial intelligence, cognitive science, neuroscience, psychology, linguistics, and sociology are converging on an anti-objectivist, body-based approach to abstract cognition. Where traditional approaches in these fields advocate an objectively specifiable reality—brain-in-a-box, independent of bodily constraints—these new approaches insist that intelligence cannot be separated from the subjective experience of the body.

Emerging New Paradigms in Design

Design intentions are intimately related to social and cultural *values* that are the core of design paradigms. Design paradigms are more obscure than scientific ones, for the philosophy behind intentions is seldom explicit or well documented. Although designers and design theorists have often been interested in and elaborated on cultural, social, political, and other aspects of design, considering design from a philosophical point of view is a new, emerging phenomenon. In spite of these efforts, however, the impact of paradigms and paradigm shifts on design received little attention.

The concept of design can be traced back to the Greek philosophers, particularly to Aristotle, who "discovered a science of production directed toward an understanding of the differences among all of the arts and their products due to the specific *materials*, *techniques of production*, *forms*, and *purposes* that are relevant to each kind of making. [...] Aristotle also found it important to distinguish the element of *forethought* from the specific considerations and activities that are relevant to each kind of making" (Buchanan, 1995:30). However, Aristotle referred not specifically to design, but to 'poetics,' the science of making in general, using the example of literary arts, specifically the art of tragedy. The connection between design and the 'practical arts of making,' as well as to 'forethought,' has been made only recently. Until the first part of the twentieth century, design was not clearly separated from arts and sciences. With the advent of the Industrial Revolution and the emergence of a distinct design discipline, it became necessary to think about the *mission* of design, its nature and place in human development. As Buchanan writes: "The origins of design are reasonably traced to the early decades of the twentieth century because it was in this period that individuals began to formulate new disciplines of design thinking that would combine theoretical knowledge with practical action for new productive purposes" (ibid:35). A historical chart indicating this development is shown in Figure 4: The number of historically significant designs increased exponentially during the Greek and Roman empires and then again from the 19th century on.

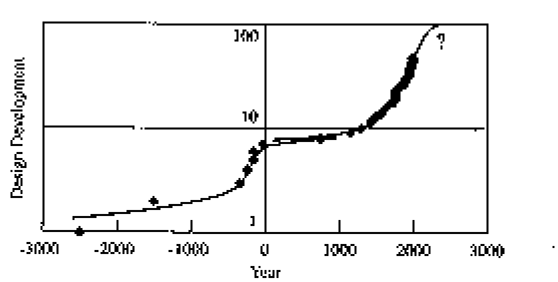

Figure 4: Design theory developments (Otto & Wood, 2001:46). The square dots represent milestones, such as the Ebers papyrus, the oldest design manual about manufacturing a soap-like substance in 1500 BC, or John Roebling's report of 1885 analyzing design failures.

The development of new technologies and the industrialized mass production conquering the world have lead to new paradigms that were probably first formulated by the Chicago architect Louis Sullivan. His famous dictum, "form follows function" (from a magazine article he wrote in 1896 with the title: "The Tall Office Building Artistically Considered") became a maxim for architects and designers of the modernist movement. By the mid 19th century, mass production already advanced to the point of setting new design trends. Manufacturing constraints required much simpler designs stripping products from decorative elements. Around the turn of the century, a number of design centers, such as the Vienna Werkstätte, the Glasgow School, and the German Werkbund were established promoting this new kind of designs. They all subscribed to the functional superiority concept where form emerged spontaneously changing established aesthetical norms. Form became the expression of moral principles uniting ethics and esthetics.

Functional priority became also a leitmotif of the Bauhaus, a movement of prominent designers such as Walter Gropius, László Moholy-Nagy, Marcel Breuer, and Ludwig Mies Van der Rohe. The Bauhaus of the 1920s and the New Bauhaus (later, Institute of Design) of the 1940s embraced the "Zeitgeist," focusing on technology and industrial production. "By 1910 the design oriented arts and crafts movement of Ruskin and Morris had been reconceptualized" writes Gergen (1991:37). "It was now 'a movement for stamping out of [crafted designs] by sound production on the one hand and the inevitable regulation of machine production and cheap labor on the other,' (Ashbee, 1908:9). For the Bauhaus group, familiarity with the machine was considered essential to all esthetic study. As Le Corbusier summarized the case of architecture, 'The house is a machine for living in' (Le Corbusier, 1931)." However, the pragmatic and functionalist design philosophy of the Bauhaus "lacked [...] a revolutionary vision of rhetoric to match its revolutionary vision of making. This would be rhetoric as a broad intellectual discipline, expanded from an art productive of words and verbal arguments to an art of conceiving and planning all types of products that human beings are capable of making. Without such a discipline for integrating design and making with science and practical action, the accomplishments of the Bauhaus were necessarily limited" (Buchanan, 1995:38).

After WWII, while Moholy-Nagy was working on the legacy of the Bauhaus in Chicago, another alumnus of the Bauhaus, Max Bill, founded the Hochschule für Gestaltung (HfG) in Ulm, Germany. In the 1950s, the HfG under Max Bill's successor, Tomás Moldonado, ventured beyond the limitation of the Bauhaus by seeking scientific foundations and developing systematics for a new science of design. Although his approach was based on the same pre-war positivist paradigms as the Bauhaus, it also embraced the emerging systems theory and cybernetics. The aim of systems theory and cybernetics was to understand complex systems that were beyond the grasp of any positivist science. Herbert Simon went even a step further by emphasizing the cognitive aspects and presenting a systems theory view of design (Simon, 1969:193-229) as well as the role of emotions in thinking and problem solving (Simon, 1967)—a rather contrasting position to his leading role in the development of computational psychology and traditional (reductionist) AI.

In the second half of the twentieth century, designers turned against the functionalist trend. Pop-Art and the Italian anti-design of the 60-s used new forms as cultural criticism of the faceless consumer society. In the 70-s and 80-s a hodge-podge of design styles emerged experimenting with various materials and shapes to find a new identity. One example is Memphis Design, a shocking cultural experiment of Ettore Sottsass. Sottsass and his collaborators rehabilitated kitsch and décor as means of questioning established cultural values and provoking debates. Designers of this time also revived and mixed traditional forms and styles, especially Egyptian, Greek, and Roman motifs, as a reaction to the sparse and expedient designs of the previous era. The bizarre mixture of new and old styles became known as postmodern design. It originated in architecture, with prominent architects such as Charles Moore, Louis Kahn, Aldo Rossi, James Sterling, and Frank Gehry, but it was also quickly adopted in other design fields, such as interior and industrial design. At the same time a new environmental friendly, technology oriented design emerged. High-tech was embraced to incorporate technological and social progress, and a minimalist style stripped design to the bone by using new materials and technologies. This was, however, contrasted by the appearance of a new sensual baroque style.

The (implicit) motivation for experiencing with a hodge-podge of techniques and styles was, however, more than just a swing of fashion. Designers found that the functionalist or modernist approach concentrates exclusively on economic values and fails to acknowledge *human* values. Without having any relation to postmodern design, system designers came to the same conclusion. In particular, they recognized that in the fastest growing field of information technology, computer systems have been developed mainly under economic considerations often bypassing or entirely ignoring the user.

Originating in the Scandinavian countries, from the 1980's on, *participatory* and *user-centered design* became an integral part of system design (Schuler & Namioka, 1993). Also, the design of user interfaces has changed significantly: Participatory methods and human factors such as ergonomics have come into the forefront. Human factors play a central role in other areas of system design as well. Donald Norman (1993:253) captures the essence of this new development:

> Remember the motto of the 1933 Chicago World's Fair [...]: 'Science Finds, Industry Applies, Man Conforms'? That was the machine-centered view of the world—unabashedly, proudly machine-centered. It is time to revolt. We can't conform. Moreover, we shouldn't have to. It is science and technology—and thereby, industry—that should do the conforming. The slogan of the 1930s has been with us long enough. Now, as we enter the twenty-first century, it is time for a person-centered motto, one that puts the emphasis right: People Propose, Science Studies, Technology Conforms.

In fact, today's technology can conform effortlessly by eliminating earlier design limitations. For example, since the mid 80-s microelectronics advanced to the point that many product-functions became invisible. The design of the 'housing' of a device became separated from the design of internal functions, as it is the case e.g. with computers or cellular phones, opening the door to entirely new ways in design. According to Tom Kelley, general manager of IDEO, the legendary international design company that helped develop Apple's first mouse, the world's first laptop computer, and the Palm V handheld device, after the current era of pocket-size devices, the company's design team saw some hardware disappearing, so that in his view, the hardware should become increasingly woven into clothing or worn as a fashion accessory. Thus, there is much more freedom today to mould designs according to the user's taste and needs. Due to the digital revolution, designers can pay more attention to form or aesthetics to address emotional concerns that has long been neglected by functionalism and its 'relatives.' All these developments are part of a larger social and cultural transformation reflecting a new way of perception and thinking. Or, as an exhibition (June-August, 2003) poster in the Museum für Angewandte Kunst in Frankfurt formulated, "New forms, new technologies and materials, as well as new functions are part of social change —the change of things reflects the change of thinking. Today design is part of our everyday life, an intrinsic element of culture."

Emerging New Paradigms in AI

As mentioned earlier, AI is at the forefront of the current developments in design, as it is concerned not only with the automation of design tasks, but first and foremost with the underlying cognitive processes. Consequently, current trends are characteristic and indicative for future developments across the entire design spectrum. These new trends evolved in a relatively short time, as AI itself can be traced back only til the late 1950's. After WWII the controversy between the positivist and constructivist views split the cybernetics movement and led to the emergence of AI. As Lynn Hoffman (1985) writes:

> Early cybernetics research was connected with experiments with guided missiles and rockets. There was a sense of Faustian expansion, as the new technology was used to investigate the brain and to create brain-like prostheses for the brain. Over the ensuing decades, a division began to build in the field of Cybernetics between engineers involved in research in robotics and artificial intelligence, often underwritten by the military, and a group of visionary researchers that included not only Bateson but colleagues like Heinz von Foerster, Humberto Maturana, Francesco Varela, and Ernst von Glasersfeld.

The two probably most influential fathers of the cybernetics movement, Norbert Wiener and John von Neumann, also went in two separate directions. Wiener with Claude Shannon developed information theory and influenced Bateson as well the others of his group "to understanding the mind as a systems phenomenon and became the first successful attempt in science to understand the Cartesian division between mind and body" (Capra, 1996:55). Von Neumann, on the other hand, developed the foundations of today's computer technology and used it as the conceptual basis for the scientific study of the mind. His "invention of the computer and his analogy between computer and brain functioning are so closely intertwined that it is difficult to know which came first" (ibid:66). For the rest of the twentieth century this analogy became the prevalent view—called cognitivism—in cognitive science and the foundation of the emerging field of AI.

Since the mid 1950s the defining paradigm of AI has been the Cartesian division between hard- and software and the belief that the human mind is a problem-solving machine operating on symbols. Although this paradigm resulted in a number of successful applications and provided valuable insights into the functioning of the mind, it is currently under attack from all sides as it runs against new developments and trends in science and philosophy. One of the early vocal critics, Hubert Dreyfus (1995:72) wrote:

> Artificial Intelligence and then cognitivism as a generalization of Artificial Intelligence is the heir to traditional, intellectualist, rationalist, idealist philosophy. That is what fascinates me: that they took up the tradition at almost exactly the moment when people in the Anglo-American world stopped believing in it. Wittgenstein's *Philosophical Investigations* were first published in 1953, shortly before Newell and Simon started to believe in

> symbolic representations. Of course, Heidegger had already criticized this devastatingly in 1927, and Merleau-Ponty had applied Heidegger to criticizing what he called intellectualism in 1945. So people in cognitivism have inherited a certain research program—which seems to me a fascinating but wrongheaded and ultimately abandoned direction in philosophy.

Problem-solving as symbol processing has been particularly relevant for design related AI. This paradigm provided numerous successful AI applications, in particularly expert systems, in the design domain. However, they were successful only in solving specific problems within a limited domain, but not in understanding and modelling the designers' mind. Thus the success was more in the realm of economics than of cognitive modelling. According to another vocal and critically inclined philosopher, John Searle (1995:210), the inherent problem with symbolic computation is that "[o]nly an observer, user, or agent can assign a symbolic interpretation to something, which becomes a symbol only by the act of interpreting it as symbol. So computation exists only relative to some agent or observer who imposes a computational interpretation on some phenomenon. […] But if the question is whether consciousness is intrinsically computation, then the answer is that nothing is intrinsically computational; it is observer-relative." Searle concludes that, "without the computer, there would have been no discipline of cognitive science as we know it. However, one of the most important results of the development of cognitive science has been the refutation of the computational model" (ibid:205). John Haugeland (1995:106), on the other hand, points out that even basic "skills—the ability to get along in the world, manage things, deal with things, […]—are embedded in people, in the brain, in some way quite different from symbolic structures […]. It is because skills are embodied in this other way that the background implicit in the collection of skills and practices will not succumb to a symbol processing treatment." Since design requires complex skills, cognitivism or the symbol processing AI paradigm is inadequate for capturing any of the relevant cognitive aspects of design.

Such external critics that "often viewed AI models through philosophical lenses and found scandalously bad" (Agre, 1997:xi) were either ignored, rejected or dismissed by the AI community: "AI people [...] often do not recognize their methods in the interpretations of the critics, and as a result they have sometimes regarded [them] as practically insane" (ibid). This is currently changing as a growing number of AI-practitioners share Agre's view "that the substantive analysis of human experience in the main traditions of AI research is profoundly mistaken" and "that people are intimately involved in the world around them and that the epistemological isolation that Descartes took for granted is untenable" (ibid).

It seems that after the split in cybernetics, the maturing AI came back full circle as many of the original ideas of cybernetics are being now rediscovered and pursued vigorously in AI. One of these ideas is the modeling of neural networks. As early as 1943, neuroscientist Warren McCulloch, the Chair of the Macy Conferences, and mathematician Walter Pitts proposed a neural network model by using binary switches (McCulloch & Pitts, 1943). Based on their proposal, other scientists began to build artificial neural networks in the 1950s. The probably most relevant one was Frank Rosenblatt's Perceptron (Rosenblatt, 1962) that was attacked by two prominent researchers of AI, Marvin Minsky and Seymour Pappert (1969). As a consequence, the entire neural network research was discredited until the second half of the 1980s. Only after the ground-braking work of David Rumelhart, James McClelland, and Geoffrey Hinton on parallel distributed processing (Rumelhart & McClelland, 1988) gained artificial neural networks slowly acceptance by the community and became part of mainstream AI. This and other developments indicate that cognitivism is on the decline and neural based cognitive models are on the rise in AI. We believe that cognitive aspects of design and their relation to the positivist and contructivist views—as it will be discussed below—is a fundamental part of this development.

Design scenarios occur in a social context with multiple *agents* playing various roles. The concept of "agent" is generic; it includes all kinds of agents such as humans, robots, or computer programs. Since the early 1990s agents became the focus of interest, and autonomous agents have been playing a central role in computer science in general and in AI and robotics in particular. According to Leonard Foner (1998), an agent is *autonomous* in the sense that it can initiate and execute actions spontaneously. It is also *capable of adaptation* by learning personal preferences of people it is engaged with. It can *communicate* with other agents *intelligently*. One can *delegate* a *task* to an agent by taking a certain risk of letting the agent do the job, but at the same time *trusting* the agent that it will do the job right, i.e., there is a trade-off between risk-taking and trusting. Each agent has its domain of interest or *expertise* that is important to know when dealing with this agent. An agent should *gracefully degrade* when stepping outside of its expertise, i.e., to trust an agent, the agent needs to be able to communicate outside of its own domain, or in other words, it is not an idiot savant. Finally, an agent should be able to cooperate with other agents by communicating about its needs and by reasoning about the specific tasks it has to accomplish. Even though the domain of an agent should be defined explicitly and agents should degrade gracefully, expectations regarding the capabilities of the agent need to be realistic.

Although this characterization of Foner was meant for computer/software agents, it obviously applies to arbitrary intelligent agents. In fact, problems in current software agent technology, such as information discovery, communication, ontology, reasoning, planning, co-ordination, monitoring, and evaluation (Nwana & Ndumu, 1999) are the same as the problems dealt with in any intelligent multi-agent system. Agent technology is moving into new territories and its interest in psychology, cognitive and social sciences is increasing. This development is particularly relevant for socially intelligent agents that are also playing a major role in design. However, many of the emerging cognitive and social theories are either constructivist or strongly influenced by constructivist ideas (see e.g. Vygotsky, 1978; Glaserfeld, 1983; Latour & Callon, 1981; Luhmann, 1995).

Impact of Constructivism on Design: Contrasting Paradigms

The current paradigm shift from positivism to constructivism across disciplines influenced design. This is clearly recognizable by the fundamental changes described below.

The focus of interest moved from the design object and the designer to the user. Thus, perfecting the design object is a goal under consideration of the user's and not the developer's or the manufacturer's needs. The user's parameters and needs play a central role in the specification and evaluation of the design product. Examples are abundant in every walk of life; however, the need of user involvement in the design process was recognized and implemented first in the design of human-computer interfaces (HCI).

One consequence of user involvement was that professionals or experts ceased to be the sole authority setting the stage for an antiauthoritarian environment. This means that design decisions are made not exclusively by professionals or experts but by all involved parties—as far as they can be identified and integrated into the design process—in a democratic manner. Even companies, like Boeing, with a hierarchical organization and authoritarian tradition turn increasingly to customers and suppliers for feedback. For example, the whole philosophy leading to the development of the new 7E7 still on the drawing board is the result of intensive cooperation with airlines. Boeing's future hinges on the success of the 7E7, so it makes sense for the company to involve all relevant parties into the design process. Failing to consult partners and customers early in the design process was probably the reason for Boeing to scrap the plans for the Sonic Cruiser, a radically new airplane design. In 2002, halfway through the development, Boeing realized that the innovative tail-first jet, that supposed to fly 100 miles per hour faster than today's airplanes, would probably have the fate of the Concord. Thus, innovation and technology themselves are of no guaranty for success.

Although economy continues to play an important role in the development of new products, ecology became the dominant factor driving the design process. There is a general sentiment that economical considerations should not override environmental, health, and other important aspects of the quality of life. This is an almost complete reversal of previously held doctrines. For example, the US Interstate Highway System was hailed as the "best investment a nation ever made" just a few years ago. Conceived in the 1920's and 30's and built in the 1960's and 70's, this system was and still is a major chapter in the economic success story of the US. It provided jobs, created new business opportunities and markets, and shaped urban development. It is probably no exaggeration that this system helped propelling the US to the top of the world-economy. However, the US Interstate Highway System is also responsible for the proliferation of vehicles with internal-combustion engine that is the single largest contributor of carbon-dioxide pollution, and thus, a major reason for the greenhouse effect and global warming. Thus, pushing the development of super-highways and neglecting a national railway system—in contrast to France, Germany, or Switzerland—was economical, but hardly ecological.

The social context became integral part of design, and machine orientation moved to human orientation. A prime example for overlooking the social impact of a design object is cellular phones. In the past few years, cell-phones quickly conquered the world and now successfully compete with traditional phone networks. Being used practically everywhere in all kinds of situation often in ways no one expected, cell-phones are now ubiquitous. People conduct private conversations loudly in public, while strolling on the street, traveling, attending public events, waiting in line, and even in public bathrooms. In fact, cell-phones ringing in public places became a common nuisance so that they are now banned in theaters, lecture, and concert halls. Cell-phone use distracting people while driving or working became a hazard and is often prohibited by law. However, cell-phones also save lives in emergency situations and are an integral part of today's business world. A prime example for the enormous economic impact of cell-phones is their use by third-world countries to skip the costly development of wired communication networks. Cell-phone designers might have thought of many applications, but hardly anticipated such a wide range of social impacts.

While significant design objects, like cell-phones, trigger a whole range of cultural and behavioral transformations, social developments also have a large impact on design. One example is the cell-phone itself, as its popularity and widespread use cajoled designers to add new functions not associated with telephones, such as taking pictures or exchanging messages and e-mails. Now, there is a trend of cramming more and more computer functions into cell-phones. There are already a number of "smart" handheld devices on the market incorporating phone, phone-book, calendar, organizer, web-browser, e-mail, and camera functions. Since the tiny, pocket size cell-phones are with their users almost all the time, other functions, such as personal identification, medical database, and tele-banking, might also be added soon. Another example is the SwissMemory pocketknife by Vitronix. This Swiss army knife comes with a removable USB memory key that is convenient for computer dependent business travelers. Detaching the USB key became an important design requirement only because of the social development following the 9/11/2001 terrorist attacks in the US. One consequence of this development is the strict security regulations for air travel prohibiting boarding a plane with a pocketknife. These and other examples for the intricate relationship between design and social development show that technology itself is not the ultimate measure of design success.

The main goal of the design process used to be the development of products that are functional and efficient, nothing more and nothing less. An example is the above-mentioned US Interstate Highway System connecting all major urban centers across the nation. Function and efficiency required that these connections reach deep into the heart of cities. In the name of efficiency, the urban highways cut often through low-income neighborhoods where land was cheap and residents didn't have the resources to fend off this development. The consequence was an efficient and well-functioning highway system that is not sustainable, for it became a major obstacle of urban development. Due to this system, community efforts to improve such low-income neighborhoods failed and many of them became slums. To change the system now is nearly impossible, as the urban landscape that evolved since the 1960-s prohibits rerouting highways, and mitigating the impact of the urban highways by noise barriers, tunnels, etc. is costly and often impractical. To sum this up, Table 1 compares the positivist and constructivist view of these subjects.

	positivist	**constructivist**
Focus:	design centered	user centered
Authority:	professional	no one
Priority:	economy	ecology
Social context:	excluded	included
Orientation:	machine	human
Goal:	high performance, efficiency	sustainability

Table 1: Paradigm shift in design

This paradigm shift impacts AI too: In the 70-s and 80-s, cognitive models in AI were based predominantly on symbolic representations viewing the human brain as a symbol-processing machine. Connectionist models that are based on the neurological structure of the brain did not belong to mainstream AI. Recently, however, the tide has turned and connectionist models receive a lot of attention. Reasoning moved from purely formal, logic-based ones to those that also include informal reasoning modelling experiential based hunches or gut feelings. Regarding the mind-body connection, AI is abandoning the concept of disembodied systems to embrace embodied ones. While this is quite a natural trend in robotics, other areas in AI are also recognizing the relevance of the body-awareness in our intelligence. While traditional AI emphasized pure reason as opposed to emotions, currently, there is wide interest in the role of emotions in decision-making. Emotions also play a central role in user interfaces or man-machine communication. AI is slowly recognizing (what cognitive science and psychology always knew) that emotions are an integral part of human intelligence, and the acceptance of AI systems depends on whether and to what extent they can emulate or have a notion of emotions. Traditional AI disregarded the context, in particular the social one, in which intelligent systems operate. Now, there is a trend to develop situated systems in a social context capable to interact socially. Situatedness also means that AI is recognizing the pitfalls of simplifying the environment and it is moving toward systems that operate in a realistic environment with all its natural complexity (Table 2).

	positivist	**constructivist**
Cognitive model:	symbolic	connectionist
Reasoning:	formal	informal
Mind/body:	disembodied	embodied
Emotions:	disregarded	fundamental
Social context:	excluded	included
Environment:	artificial/simplified	natural/complex

Table 2: Paradigm shift in AI

Philosophical Assumptions

The new developments or movements described by (Lincoln & Guba, 1985) are the consequence of a few fundamental philosophical assumptions. Objections can be raised, as these assumptions fail to reflect the diversity of the many views; instead they lump these views together as either positivist or constructivist. Nevertheless, these assumptions or axioms provide a useful framework for characterizing the paradigm shift that is taking place in design and AI.

Is there a need for such a characterization? We think so. Currently designers and AI practitioners live with contradicting paradigms either without being aware of them or ignoring them, as well as all of their consequences, entirely. The issue of the AI Magazine (Vol. 22, No.3, Fall 2001) that is dedicated to the topic of creativity illustrates this point quite convincingly. On its last pages reports about the AAAI 2000 Fall Symposiums describe increased interest in situated and embodied agents. In connection with socially intelligent agents, AI-researchers talk about the importance and relevance of human intentions, emotions and beliefs. This seems to be at odds with most of the creative AI-systems described on pages 13-28 by one of the AI-pioneers, Bruce Buchanan. Creativity is at the heart of design and we all know from experience that creativity is a social concept that requires a stimulating environment and bodily experience. How can anyone be creative without having clear intentions, emotions and beliefs? And yet so far mainstream AI seems to overlook or dismiss entirely this aspect.

Even such renowned scientists as one of the founding fathers of AI, the Nobel-laureate Herbert Simon couldn't escape such contradictions. He was intensely interested in and studied design as one of our most intriguing cognitive functions that has been playing a major role in human development. While he was keenly aware of the social and psychological aspects of design rendering the mental process involved as intrinsically private, he advocated an objective, third person perspective borrowed from positivist sciences (Simon, 1969). An example is his work on protocol analysis (Ericsson & Simon, 1984) recognizing that complex mental processes, such as designing artifacts, are accessible only to introspection. Nevertheless, this was part of his efforts to develop computer programs, specifically expert systems, within a framework of an objective 'science of design.'

A more recent and perhaps more significant example is Rodney Brooks' paradigm consciousness. His case is more relevant than the previous examples, as he is at the forefront of today's AI and robotics research and a vocal critic of the traditional AI. He is behind numerous innovative robot designs, such as Gengis, and Kismet, setting a new trend in AI. He also represents a new generation of AI researchers seeking a better understanding of human intelligence with all its complexity. However, when he is looking for an answer to questions about life and intelligence, he is trapped between two paradigms. He turns adamantly against traditional, reductionist AI, yet he takes many of its assumptions for granted. He doesn't accept all the claims of strong AI, yet he seems to accept most of its assumptions. In particular, he doesn't seem to recognize that strong AI is chasing an elusive dream, as its fundamental concepts such as *intelligence* and *machine* are ill-defined and undergo permanent changes.

The concept of ‘intelligence’ has been used to draw the line between species, in particular to distinguish between humans and animals. However, as we learn more about the cognitive abilities of animals, the line is getting blurred, so that we are starting to doubt our preconceptions and looking for new ones. Measuring human intelligence is also a dubious endeavor as there is no consensus of what and how should be measured. Similarly, the concept of a ‘machine’ is traditionally a mechanical device made of wood, stone, ceramics, or metal powered by external forces provided by animals, water streams, wind, or burning fuel. First, with the steam and combustion engine the external force became internal similar to living creatures. Then machines became composed mostly of electrical components, some of them, like certain computers or digital devices, even without visibly moving parts.[10] Now, there is wide range of new energy sources, such as nuclear, and solar power, biologically generated gases, and hydrogen powered fuel cells. We also have nano-machines traveling in the arteries powered by the blood stream and biological computers using sugar as their power source. Moreover, new nano-machines are coming out of biotech laboratories that are made of DNA, use DNA as their power source, and can even replicate themselves (Seeman, 2004).

Brooks (2002:164-180) dismisses the critics of strong AI, such as Hubert Dreyfus, Roger Penrose, David Chalmers, and John Searl, who argue that the assumptions of strong AI are flawed and its goals are principally unachievable. But he readily admits that today’s AI models are a far cry from the ideals of strong AI because something substantial is missing from our understanding of human intelligence. He seems to believe that to achieve the goals of strong AI all we need is to find this missing something. He hypotheses that we either need to change a few parameters in our systems, or change our assumptions about the complexity of the environment, or increase the computing power. Yet, he himself doubts that such developments would provide the expected results and he is rather betting on the discovery of a ‘new stuff’ in biology. What this ‘new stuff’ might be is left to the imagination. Brooks’ “hypothesis is that we may simply not be seeing some fundamental mathematical description of what is going on in living systems. Consequently we are leaving out the necessary generative components to produce processes that give rise to those descriptions as we build our artificial intelligence and artificial life models” (ibid:188). While some arguments of the strong AI critics might not be convincing, it is hard to dismiss their point that AI needs new perspectives or new paradigms rather than, as Brooks suggests, ‘new stuffs.’

The only way to identify the discrepancies between two paradigms is to make the underlying philosophical assumptions explicit and compare them. This can also shed light on inconsistencies and contradictions. In a separate follow up paper, the authors are doing just this: compare the underlying assumptions of the positivist and constructivist paradigms and how they impact design.

Conclusion

Our philosophy, i.e., our beliefs and values, determines our intentions, behaviour and ultimately their outcome. One rather important outcome of our intentions and behaviour is the creation of design objects or artifacts. Philosophies seek the answer to fundamental questions about us humans and our environment. A systematic set of assumptions, presuppositions, and beliefs about our world give rise to paradigms. What and how designers do that they do is closely related to the paradigm they live in. Presently, we are witnessing a paradigm shift from modernism or positivism to postmodernism in general and constructivism in particular. This paradigm shift is widely recognized in social and natural sciences. Although design has also been impacted, this recognition has been rather sporadic. The emergence of a new paradigm is particularly relevant to CAD and design related AI, as in the last few decades CAD drastically transformed almost all design areas, and AI pursues the understanding of the design process to revolutionize CAD. In spite of the many obvious symptoms of a new paradigm in design, there is a lack of paradigm consciousness among designers. Making underlying assumptions explicit helps communication, setting goals, and evaluating progress. The purpose of this paper is to call attention to the relevance of the prevailing paradigm for design, and to foster communication about the philosophy of the participants of the design process.

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[10] Certainly, anything called ‘machine’ is based on some kind of motion. However, many machines today apply motion that is not motion in the classical 19th century sense.

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