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## **Enaction and Enactive Interfaces: A Handbook of Terms**

Walter Aprile, Federico Avanzini, José Barbero, Benoit Bardy, Ronan Boulic, Nicolas Bullot, Heinrich Bülthoff, Claude Cadoz, Antonio Camurri, Marcello Carozzino, et al.

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ENACTION AND ENACTIVE INTERFACES:  
A HANDBOOK OF TERMS

EDITED BY ANNIE LUCIANI & CLAUDE CADOZ

Enactive Systems Books

**Enaction and Enactive Interfaces: a Handbook of Terms**

Edited by Annie Luciani and Claude Cadoz

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## EDITORS' FOREWORD

Enaction is a recent approach in psychology and in cognitive sciences and it remains not easy to understand and to situate. Its introduction in the field of Computer Technology and Multimodal Interfaces has been initiated explicitly in the FP6 Enactive Interfaces Network of Excellence. It is nothing less than a conceptual revolution, an important paradigm shift.

This leads to necessary confrontations between several disciplines in order to bridge gaps, understand different ways of thinking, plunge within unfamiliar definitions, rub up with different schools, and work to extend each domain by new concepts, methods and results.

*Enaction and Enactive Interfaces: an handbook of Terms* aims at overcoming the interdisciplinary gap inherent to this new paradigm. It has been designed as a tool to constitute a common vision on Enaction, Enactive Interaction, Enaction Knowledge and Enactive systems, allowing students and researchers to reach, *at a glance*, a sufficient interdisciplinary level, in order to tackle efficiently the new question of « Enaction and Technology ».

Through a wide panel of words, terms, expressions, presented in a synthetic form, shorter than scientific papers or disciplinary books, it aims at creating a global understanding of the Enactive paysage, and stimulating new researches at the cross-point of disciplines, and ultimately at fostering a new generation of young researchers on Enaction and Enactive Systems.

Differently from dictionaries, the handbook includes debates, theoretical problems, controversies, expressions of complementary irreducible approaches. Terms are related to research in progress, addressing debates or schools differentiations, addressing other unfamiliar frameworks for laypersons of other disciplines.

Differently from several on-line encyclopaedia, it includes the names of the authors and contributors; the contents are certified by experts through consensus meetings, and they refer explicitly to their scientific context with a minimal set of sufficient references. And finally, relations with the field of Enaction are discussed.

In order to guaranty an optimal exploration of the Lexicon and to avoid the reader to be trapped within a sub-domain of expertise, the technique of related items has been used to stimulate interdisciplinary exploration with a sufficient internal connectivity.

The Handbook comprises about 200 terms covering the different fields necessary to explore the landscape of enaction and technologies: sensory-motor theories of interaction, multimodal integration, haptic and multimodal interfaces, instrumental interaction, virtual reality, design, human-computer interfaces, paradigms in cognitive sciences, robotics and teleoperation. Most of them have been written in collaboration by authors from different disciplines.

By nature of the contents closely linked to researches in progress, the process followed was original. It was an iterative process that accompanied the progress of the researches all along the Enactive Interfaces project. A restricted core group proposed a first list of terms from the initial expertise of the members of the Enactive network. The list was improved bit by bit from research documents provided within the Enactive network. Most of them are available on the website of the Enactive project. Most of the researchers of the Enactive network, seniors as well as young researchers, were involved actively in the process, exchanging and debating through web dedicated facilities. When scientific materials attained a certain amount, stabilized items have been improved, by merging, renaming, splitting, extending operations, leading to reach the expected level of convergence and balance between disciplines and approaches.

Among the chosen terms, some had already a long history. The text does not only provide a definition, but revisits the term in depth, emphasizing how its meaning and usages are questioned, transformed, or nourished, under the light of Enaction and Enactive Interfaces. Other terms are fully novel, in which case the text allows introducing the new concepts at hand. Some of them led to multiple definitions, whether because they represent stabilized different definitions in different disciplines whether because they underlie non-reducible schools and approaches. We respected these differences as representative of the vividness of the domain.

Many thanks are due.

In the first place, we wish to thank all the authors who contributed to this handbook, by proposing terms, selecting them, writing initial contents, exchanging and debating on contents proposed by each others, finalizing texts in a consensual way. It was a tremendous activity.

This book is a paper version of a web on-line lexicon on Enaction and Enactive Interfaces, designed and used within the Enactive network of Excellence. We thank the team of the Enactive Network website at PERCRO, especially Franco Tecchia and Danielle Ugoletti. As a matter of fact, no common web tool would have supported the original process on the Handbook. From our first specifications, this team was able to build a large database and web facilities that have been helpful throughout the process.

The process was first activated by a core group of the Enactive project headed by the editors of this handbook and composed by: Benoit Bardy, Roberto Casati, Antonio Frisoli, Georg Essl, Teresa Gutierrez, Kevin O'Regan, Elena Pasquinelli, Carsten Preusche, John Stewart. In the name of all the authors and contributors, we want to thank them for the setting-up of this enthusiastic challenge.

Finally, a deep friendly gratitude is due to our colleagues of the editorial board Armen Khatchatourov and Nicolas Castagné, who assist us all along the management of the project, in managing authors participations, reading and reviewing contributions, and designing the final printed version.

Annie Luciani  
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## NOTE

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ENACTION AND ENACTIVE INTERFACES:  
A HANDBOOK OF TERMS



# A

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## ACTION FIDELITY

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Speaking about action fidelity supposes to define two situations, to compare the actions undertaken in both of them to perform similar tasks or to reach similar goals: one that can be called a reference situation and one that can be called a represented situation, which is a new implementation of the first situation.

[Stoffregen et al., 2003] hence defines action fidelity in terms of relations between performance in a reference situation, called simulated system, and performance in a represented system, called simulator. Action fidelity exists then when performance in the simulator transfers back to behaviour in the simulated system. An appropriate measure of action fidelity is transfer of learning, or transfer of training. Action fidelity is measured in terms of task performance. Common metrics that could be used to compare performance in a simulator and in the simulated system are time to completion of a task, variance in performance across trials, and trials to criterion.

In tasks mediated by computerized technologies, the comparison is usually made between a task performed through instruments implemented in non-computerized technologies, mainly in mechanical technology, and similar tasks implemented by means of a computerized – or more generally electrified – instrument. For example, existing tools for non-invasive surgery used in real surgical performance, and virtual reality simulation platform to learn surgery practices. The first is then, more or less explicitly,

considered as the reference situation, and the second as the situation that have to guaranty more or less a fidelity principle. In the enactive framework, and more generally in the ecological approaches of action and perception, the focal point for the comparison is put on the fidelity of action rather than in the fidelity of the perception.

Referring to the history of the techniques and the *techné* developed by humans to face up to the necessities of the human life, tools and instruments have always evolved according to the properties offered by novel technologies, as assumed anthropologists such as Leroy-Gouran [Leroy-Gourhan, 1964]. There is no a priori reference situation and it is not possible to define fidelity, neither in action nor in perception. More generally, there is no case in which humans developed radically new tools in reference to an existing one. The basic reason is that a new tool is developed to cross over a new expectation. According to their needs, humans are creating new instrument (a screwdriver, a flight, and of course also computer) when it is necessary to perform new tasks; for these new tools, no comparison with existing tools is interesting.

Fundamental questions are then: is it truly possible to compare instrumental manipulations implemented on different instruments, for example instruments built from a previous technology (for ex. mechanics) and from today's technology (for ex. electrified technologies)? And is it really necessary?

This point of view is particularly applicable in the cases of artistic creation, computer tools and Virtual Reality based tools, etc. These tools are new instruments that are designed to extend the existing instrumentarium. But there are not new only because they are added to what existed previously, as for example piano was new after the harpsichord. They are new also because they allow new functionalities that did not exist previously.

In the framework of the instrumental paradigm developed by [Cadoz et al., 1984] [Luciani, 1993], there is no need of action

fidelity between playing a real violin and playing an Intel Xeon Violin, no more than we can talk about action fidelity between a Stradivarius and an anonymous violin. But what that has to be preserved is the “violin playing”, i.e. the conformity of the instrument as being a violin. Thus, the question of action (or perception) fidelity shifts to the conformity of the instrumental interaction, i.e. what are the minimal sensori-motor and cognitive conditions that an instrument – such as those including virtual objects - must guaranty to perform a task.

In other words, in the design of new instruments, the question is shifted from: “what are the conditions that will guaranty action fidelity” to “what are the minimal interaction properties (in action and perception) guarantying that, for example, a virtual violin, will be played as a violin”. In other words, the question to ask is: what is a violin and what does the modelling process of the violin has to take into account in order to build a computerized violin?

Thus, the question of the fidelity (in action and/or in perceptions) is shifted to the design of the new instrument (analysis, modeling, validation), starting from a causal level, with epistemic observation of what are the relevant invariant features able to define an instrumental violin, able to guaranty the conformity of the computer violin to the category violin.

Alternative concepts to action fidelity are those of: playability [O’Modhrain et al., 2000], Usability [→ *USABILITY*], believability of the instrument [→ *BELIEVABILITY\_1&2*], goal or task-based design, etc...

To conclude, in the design and use of new tools and instruments, at the theoretical level, action fidelity - and its mirror technological concept of transparency [→ *TRANSPARENCY\_2*] has to be considered as a limit concept. At the pragmatic level, it relates more to transitory situations, whether when testing technology, whether during which there is no novel practices that have yet emerged. Further, in the development of new practices,

the question of the learning of manual tasks by using simulators is an open issue, not yet solved, which still requires great efforts for evaluating the transfer between simulated situations (learning on simulator) and the situation in the real practices, and vice-versa. This corresponds to lively research in the field of technology enhanced learning, and a major centre of interest in enactive interfaces, related to the use of enactive systems in learning manual tasks.

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## RELATED ITEMS

*BELIEVABILITY\_1*  
*BELIEVABILITY\_2*  
*TRANSPARENCY\_2*  
*USABILITY*

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## ACTIVE PERCEPTION / TOUCH

Elena Pasquinelli [*INSTNICOD*]

The intrinsic connection between perception and movement, and the fact that the ability to perceive depends much more on the mastery of sensorimotor skills rather than on one’s own capacity for sensations is a widely recognized characteristic of the sense

of touch. This characteristic makes the sense of touch an exemplary model of active perception – though the expression active perception is classically declined for the visual modality. In this sense touch, more than vision, should be assumed as a model for the understanding of perception as an active process.

The necessity of assuming touch as a model for vision and perception in general had been affirmed by Merleau-Ponty [Merleau-Ponty, 1945] [Merleau-Ponty, 1964] who sustained that all visual experience only exists in the context of the movement of the eyes and gaze, thus all visual experience makes reference to touch. [Merleau-Ponty, 1945] illustrates this claim by describing the use of a cane made by a blind person as exemplary of perception in general. In virtue of the use of the cane, the blind person acquires new motor and perceptual skills which are equated with new pragmatic knowledge. Both the world and the body schema are thus enlarged to encompass the cane as an extension of the body and the distant objects which are now at reach.

More recently the paradigmatic role of exploratory movements in touch perception has been re-affirmed by two direct views of perception: the sensorimotor and the ecological approaches. The blind or blindfolded subjects again represent an exemplification of perceptual experience. The blind make contact with the world by exploring it; the cane of the blind person in particular receives no sensation at its end, so that the responsibility for the perception of the world that arises when the world is sensed by a cane is individuated elsewhere, in particular in the mastery of the use of the cane [Noë, 2004].

Even in the cybernetic context, touch has been indicated as a model for active perception (perception conceived as an exploratory activity) and contrasted with vision, assumed as a model of passive perception or recognition. In 1951-52 the cyberneticist D. MacKay had imagined an analogical intelligent machine capable of actively recognizing figures

and objects without necessarily possessing an internal model of the world (the possession of an internal model being considered by Mackay as a passive form of perception or reception). The mechanism on which this intelligent artefact is based is explained by the aid of an example: the actions performed by a blindfolded person. When seeking to recognize a solid triangular figure a blindfolded subject is required to move his fingers around the outline in a specific sequence. Hence, to the blindfolded person: *“the concept of triangularity is invariably related with and can be defined by the sequence of elementary responses necessary in the act of replicating the outline of the triangle.”* [MacKay, 1951-1952, p. 114].

When action is involved in the constitution of a percept or in the acquisition of a concept, touch is the model and tactile exploration is the exemplary case. On the contrary, vision represents the model for passive or merely receptive perception and concept acquisition. [MacKay, 1951-1952] describes the template-fitting method of recognition introduced by [Wiener, 1948] and [McCulloch & Pitts, 1943] as a passive system in which a typical pattern of the sample to be recognized is stored in the artefact as a template, an ideal model to which real triangles must be re-conducted, and indicates in visual studies the reference for this model.

The special role attributed to the touch modality hence depends on the evidence that exploratory movements constitute a fundamental condition for obtaining information about the tactile aspect of the objects. The role of movement in the touch modality was affirmed early by Katz: *“to study the sense of touch at rest is almost alike wanting to determine the capability of the leg musculature after the leg has been placed in a plaster cast.”* [Katz, 1989, p. 78] - original work published 1925.

According to Katz, movement plays a complex role in touch perception: it intensifies the action of static stimuli and prevents the habituation of the captors; it constitutes the objective pole of touch (the sensation of the external, distal object which causes the

experience as contrasted to the subjective sensation of the local stimulation); it creates tactile phenomena in that it allows for the perception of qualities such as texture and elasticity that are not available to static touch: “Every ongoing tactual activity represents a production, a creation in the true sense of the word. When we touch, we move our sensory area voluntarily, we must move them, as we are constantly reminded, if the tactual properties of the objects are to remain available to us [...] they remain mute until we make them speak.” [Katz, 1989, p. 242] - original work published 1925.

More recently, Lederman, Klatzky and colleagues (see for instance [Klatzky et al., 1985] [Lederman & Katsky, 1987]) have provided evidence for some specific connections between hand movements and the properties that are extracted by touch. The authors have described a set of exploratory procedures: stereotyped and recursive patterns of movement that perceivers perform with their hands when exploring different types of objects and surfaces, even if the perceivers are not necessarily aware of it. It seems that each of these patterns of exploration is associated with the extraction of one particular property by touch; for instance, lateral motion seems to be associated with the extraction of texture, pressure with hardness, contour following with precise shape, etc. In fact, when freely exploring different properties of an object, the subjects of the experiments tend to perform the corresponding exploratory procedures and, also, the relative speed and accuracy in the recognition of a certain property are greater when the corresponding exploratory procedure is performed. These studies prove one aspect of the integration of perception and movement in the case of touch where there is an effect on the perceptual performance of the recognition of object properties.

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## RELATED ITEMS

ACTIVE PERCEPTION / VISION  
 EXTERNALIZATION, PERCEPTUAL  
 HAPTICS, HAPTIC DEVICES  
 HAPTICS, IN COGNITIVE SCIENCES  
 PERCEPTION, MOTOR THEORIES OF  
 TACTILE DEVICE  
 TOUCH, DYNAMIC

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## ACTIVE PERCEPTION / VISION

Elena Pasquinelli [INSTNICOD]

Active or interactive perception approaches defend the idea that perception is not a pure and passive form of representation, in that the sensory systems are not simply hit by the external reality in its entirety, but actively contribute to the construction of its perception, and that this is done with the involvement of the motor systems. Active perception theories include a group of

approaches named “active vision” and “interactive vision”.

Active vision approach, for instance, insists on the fact that moving facilitates the interaction of the visual sensors with the environment [Blake & Yuille, 1992]. The active orientation of the sensors empowers the observer (which can be a human or a computer) to select the environmental information, thus to understand a visual environment more effectively and efficiently.

[Churchland et al., 1994] in the chapter *A Critique of Pure Vision* criticizes pure vision systems (those where the flow of information is only bottom up) and the assertions that we see a complete world; that is to say that the retina records a complete image which is further and at leisure analyzed; that information and representations follow a hierarchical organization; that information flows bottom up, with high-level and mid-level representations depending only on the low-level processes. The target of this description is the approach to vision that is contained in [Marr, 1982] and which constitutes the mainstream in computer vision research. In particular, of Marr’s three hierarchical levels of visual representations: the lowest level of the primal sketch, where an image represents intensity over an array of points in space, the 2½ D sketch and the higher level where the 2½-D sketch is converted into the 3-D view of the objects of the scene. Opposed to the idea of pure vision is the approach of interactive vision where information flows top-down. The main principles of the interactive vision approach state that perception evolved in order to satisfy distinct and variegated needs (and not only to provide a photorealistic image of reality). In fact, we see only a portion of the visible world, and movement redirects attention and then re-orientates the visual system; motion and vision are then strictly connected: movement allows the system to see more of the world. The role of movement is well illustrated by the existence of saccadic eye movements: the viewer cannot clearly see the entire scene, but he gradually explores parts of it. Instead of being

photorealistic, vision is interactive and predictive, since it builds models of the world and predicts what can be interesting for the system. The neurophysiological architecture finally is not hierarchical, and much information flows both ways; memory and vision for instance interact.

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## RELATED ITEMS

ACTIVE PERCEPTION / TOUCH  
ARRAY, GLOBAL  
DISPLAY, VISUAL  
EXTERNALIZATION, PERCEPTUAL  
PERCEPTION, DIRECT AND INDIRECT APPROACHES  
SHAPES AND CONTOURS  
VISUAL PERCEPTION

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## AFFORDANCES

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Behaviour consists of interactions with the environment. In the case of enactive interfaces, behaviour consists of interactions of the user both with the interface (the medium) and with the simulated world (the mediated). The success of behaviour (i.e., achievement of behavioural goals) is constrained by relations between the animal and the environment. A classical example is climbing stairs, where the maximum stair height that can be climbed is not an absolute quantity (e.g., 1.2 meters) but, rather, a relational quantity (for healthy adults, 88% of leg length). Affordances are these relational quantities; they are properties of the animal-environment system that constrain behaviour, that is, they are



relations between the person and the environment [Gibson, 1986]. Another way to put it is that affordances are properties of the environment scaled in commensurate properties of the animal, as in the stairs example, above. Sometimes they are also described as opportunities for action. Consider this other example: Is a given person tall enough to sit on a given chair? The metric height of the chair and the metric length of the leg are irrelevant; it is only the relation between leg length and chair height that determines “stability”. If the chair is  $<90\%$  of the person’s leg length, then they are tall enough to sit on the chair. This shows how affordances constrain behaviour. Affordances determine what behaviours are possible and impossible, but also what behaviours are easy/hard, efficient/inefficient, and so on. Therefore, affordances are directly relevant to enaction.

States of the world have affordances, for example, a fruit that is ripe affords eating, while a fruit that has rotted does not. But events in the animal-environment system can also have affordances. As an example, consider walking. Walking moves us from place to place. The affordances of one place often differ from the affordances of another place. Thus, by moving a person from one place to another, walking changes the layout of affordances for the walker. But the act of walking has affordances of its own, affordances that do not exist in either of the end-points. Walking affords getting lost, walking affords exploration of novel terrain, and many other things that are not afforded to a person standing at either the beginning or end of the walk. The affordances of walking often differ from the affordances of being at the beginning or end points of a walk, but the affordances of walking are, nevertheless, affordances.

For a given animal in a given situation, there are an unlimited number of affordances. These affordances exist in a nested structure. States of the animal-environment system have affordances, but events in the animal-environment system also have affordances. The animal may, at its discretion,

attend to the affordances of states, or the affordances of events (or both, simultaneously).

Baseball offers a good example of the multiplicity and multi-layered nature of affordances. Consider pitching. The pitch has end-points (i.e., before the pitch, and after the pitch), and these end-points have distinctive affordances. For example, before the pitch, when the pitcher still holds the ball, a pick-off attempt may be afforded (if there is a base runner). After the pitch, when the catcher holds the ball (that is, if the batter has not hit it, and the pitch is not wild), affordances include handing the ball to the umpire in exchange for a new one, throwing to a base to cut down a steal attempt, and so on. The pitch itself, as an event in the game, has its own affordances, such as being called a ball or strike, that do not exist when the ball is held by either the pitcher or the catcher. Above and beyond these affordances there are additional affordances that exist because individual pitches are embedded in larger contexts within the game. Each pitch occurs within the sequence of pitches that is thrown to a given batter, and the sequence has affordances that do not inhere in individual pitches (for example, a pitcher may elect to alternate pitches on the inside and outside parts of the plate, rather than repeatedly throwing to only one side). In addition, individual pitches are part of the larger sequence of pitches that constitutes an inning (e.g., the pitches that are thrown to a given batter often are influenced by the skill of the person who will bat next), and part of the larger sequence of pitches over the sequence of innings (e.g., pitchers often adjust their pitches as they become fatigued in the late innings). Thus, each pitch has affordances that exist at at least four levels; the level of the individual pitch, the level of the sequence of pitches for this batter, the level of the sequence of pitches for this inning, and the level of the sequence of pitches for this game. Each pitch changes the layout of affordances, but the layout of affordances is also changed by the group of pitches thrown

to each batter, and by the groups of pitches thrown in each inning, and by the aggregate sequence of pitches thrown over the course of the game.

In general, multiple levels of affordances exist at any given point in space-time, and have equal reality. The perceiver can choose to seek out information about any affordance at any level, and whether static or dynamic (or slow or fast, which is a better distinction). There does not appear to be any reason to single out some particular level in the ontology and claim that it constitutes a separate category of perceivables.

Affordances are real, that is, they are not mental constructs, images, or estimates. The fact that affordances are real means that they might, in principle, be specified in ambient arrays that stimulates our perceptual systems [→ ARRAY, AMBIENT ENERGY] [→ ARRAY, GLOBAL] [→ INVARIANT, PERCEPTUAL]. If affordances are specified, then they might be perceived directly. In the Ecological Approach to Perception and Action, knowledge about affordances, gained through direct perception, is used in the selection and online guidance of action [→ PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH].

An optimal enactive interface will be one that a user can explore to find out what they can do with a system, what their behavioural opportunities are. Enactive interfaces should be designed to provide information about affordances. In part, this means that the content of enactive interfaces should be influenced by properties of the user. New sensing technologies make this possible. Affordances are known to be perceived enactively, that is, people move in skilled, task-specific ways to pick up information about particular affordances [Oudejans & al, 1996]. Thus, affordances perception is part of embodied cognition. New research is needed on how people perceive and learn about affordances, focusing on the skilled movements that are used to generate and/or pick up information about particular (task-specific) affordances.

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## RELATED ITEMS

ARRAY, AMBIENT ENERGY  
 ARRAY, GLOBAL  
 CONTROL METAPHORS  
 ENACTIVE COGNITIVE SCIENCES\_1  
 INVARIANT, PERCEPTUAL  
 PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH  
 USABILITY

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## AGENT, AUTONOMOUS

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The expression autonomous agents, widely used in virtual reality [→ VIRTUAL REALITY AND VIRTUAL ENVIRONMENT], computer graphics [→ COMPUTER GRAPHICS], artificial intelligence and artificial life, corresponds to the simulation of autonomous creatures, virtual (i.e. totally computed by a program), or embodied in a physical envelope, as done in autonomous robots.

Intelligent characters [→ INTELLIGENT CHARACTERS] are a specific category of autonomous agents. The distinction between both comes from the difference between intelligence and autonomy, these two concepts being not synonymous.

Strictly speaking, autonomous and agent are redundant, in the sense that the basic definition of an agent is “an autonomous

adaptive entity”, having the following basic properties:

- Able to satisfy goals in a complex environment;
- Autonomous: able to do so by itself, i.e. without any external help, by controlling its actions and its internal states;
- Adaptive: able to improve its performance.

As a remark, autonomy is sometimes restrictively identified with the capability of perceiving the environment through sensors and act on it through effectors. By adding others properties to these three basic ones, especially the following, the autonomous agent goes toward the status of intelligent creature (or intelligent agent, or intelligent character):

- Social: interacting with other agents through a language ;
- Pro-active: able to define its own goals by itself;
- Able to learn: as an improvement of adaptive capabilities.

Two main types of autonomous agents are usually confronted, based on two different approaches on the nature of the autonomy: (1) Deliberative agents, cognitive agents, rule-based agents; and (2) Reactive agents or stimulus/reaction-based agents.

### **Deliberative agents, cognitive agents, rule-based agents**

Such agents lead to the Symbolic Artificial Intelligence paradigm, as founded by the Newell and Simon’s concept of symbol system [Newell & Simon, 1976]. They contain an explicit symbolic representation of the world, on the basis of which decisions are taken by logical symbolic reasoning. One of the most relevant implementation of this type of agent is the Believe-Desire-Intention of Rao [Rao & Georgeff, 1991].

The main difficulties on such approaches are:

- The need of a completeness of the system of rules
- The lack of reactivity, directly linked to the number of rules

- The maintaining of the coherence of the rules systems during their evolution

### **Reactive agents, stimulus/reaction-based agents**

Such agents are able to exhibit autonomous behaviours without any explicit symbolic representation nor abstract reasoning. Well-known implementations of those are Brooks’ robots [Brooks, 1991]. They are deterministic and passive systems, but they are not capable of defining their own goals and long lasting planning.

The software and hardware architecture implementing such concepts are called behaviour-based architectures. They are composed of modular behavioural blocks and perception-decision-action processes. Many hardware and software architectures have been proposed. The main three are based either on artificial neural networks, finite state automata, or logical rules systems.

### **Basic underlying assumptions**

Each of these approaches are grounded on specific hypothesis and philosophical enlightening on what are intelligence, autonomy, living organisms. Let us sum up some of the main assumptions.

- The principle of modularity.

Modularity is the principle according to which autonomous behaviours may emerge from a large collection of interacting simple and specialized behaviours. It corresponds to the ant paradigm, implementing the Taylorism organisation of labour, based on division of labour according to predefined task specializations.

- A modelling inspired by neural biological systems.

Especially, artificial neural networks, or finite state automata networks, are considered to model neural biological systems. These approaches are close to non-representationalist cognitive approaches. The behaviours emerge from the network structure. In neural networks, the data processed are “bits” (i.e. representing logical states)

while in finite state automata networks, they can be real and integers (i.e. representing analogical states).

- A pure logical interpretation of decisional and reasoning capabilities.

Especially, logical rules systems are usually used, based on deduction and inference processes, which are at a high level of abstraction [Jennings, 2000]. This approach is directly inspired by the computational theory of mind [→ COMPUTATIONAL PARADIGM]. The perception-decision-action process, supposed to be inspired by processes observed in human, is often implemented as a basic functionality. The main difficulty of this approach when implementing artificial creatures is that the specification of a complex performed behaviour is unwieldy because of a few numbers of rules compatible with a reasonable time of computation, and thus the method is strongly confronted to the automation of the creation of the rules, and thus it strongly depends on learning level.

### **Role of autonomous agents in enaction and enactive interfaces**

The mediations between humans and world through computerized representations can be split in five categories of interaction:

- Physical interaction between real human and the real physical world (such as is teleoperation).
- Physical interaction between real human and a virtual physical world.
- Symbolic or physical interaction between real humans and virtual agents.
- Interaction between real humans and the real physical world through virtual physical objects.
- Interaction between real humans and the real physical world through virtual agents.

Consequently, the assumptions on the nature of virtual autonomous agents as well as of the nature of real autonomous agent, intervene directly in the enactivity of the interaction:

- between real human and the real physical world through virtual agents;

- and between real humans and virtual agents.

This enables implementing situations from those that absolutely non-enactive (as those based on computational theory of mind for both interacting bodies) to those that are very close to the enaction paradigm (as those based on automaton networks).

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### **RELATED ITEMS**

AUTOPOIESIS  
COMPUTATIONAL PARADIGM  
COMPUTER GRAPHICS  
DYNAMIC SYSTEMS  
INTELLIGENT CHARACTERS  
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

### **RELATED DOCUMENTS**

[El\\_Enaction&ComputerTechnologies\\_Luciani.pdf](#)

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## **ALGORITHM**

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When mediated by computer, computation constraints and rules are introduced within the relation between humans and environment. This relation is no longer direct, in the sense that it no more depends only on hu-

man properties and external mechano-optical world, but it depends also of computation properties.

Computation constraints can be due to the hardware components such as when mechanico-optical objects are equipped by sensors and actuators. They can also be due to the formal aspects of the computation itself: a program that corresponds to a formal mathematical model able to be implemented on a specific computation automaton, called computer.

This specific mathematical model was called algorithm, from the name of the Arab mathematician Al-Huwarizmi. By his works, Al-Huwarizmi led to define a part of Mathematics, called nowadays the science of algorithms, or algorithmics, which aim is to *let* a mathematical problem, for which mathematical demonstrations have proved that a solution exists, find the solution under defined constraints.

Constraints can be various: number of steps, fixed time, memory occupancy, repartition of calculus over several computers, etc, leading to researches in computational optimization, parallel computation, real time computational techniques, etc.

The transformation of a mathematical expression of a problem - usually called model in experimental sciences as physics, biology, etc. - into an algorithm and, further, into a real computer implementation and real computation, introduces a cascade of causalities between the successive computed data, that further introduces non trivial transformations in the human-world interaction. Designers and users of virtual realities systems, human-computer interfaces and above all enactive interfaces, have to be aware of:

- First, the fact that algorithmic representation is very different than some other mathematical representations. The design of the algorithms consists in transforming the mathematical expressions of the model in a set of sequential mathematical computable actions.

- Second, the fact that to be computed by a computer, the algorithm needs to be transformed into a computer program that allows the mathematical actions to be automatically performed by the components of the computer (addition, multiplication, transfer, test, etc...). Designing a computer program consists in translating the algorithm into a programming language, so that the computer can perform the actions described by the algorithm.

A couple of examples can help clarifying the impact of these transformations in the domain of enactive interfaces.

First, let us consider a system that is not an algorithm. The Watt's centrifugal governor, considered as basic first cybernetics system [ $\rightarrow$  DYNAMIC SYSTEMS] [ $\rightarrow$  COGNITION, DYNAMIC SYSTEMS APPROACH] is a physical system that implements physically a control function [Clark & Toribio, 1994]. It is not an algorithm. To be computable, this function requires to be expressed in a formal set of sequential operations.

A more emblematic example is given by the case of a physically-based model used to create a physical virtual object, that is felt by humans through a force feedback device.

Let us consider the simple physical system made of two masses in elastic interaction. A usual physical mathematical representation is based on equations that link two expressions through an equal sign:

$$\text{Mass 1 (and 2): } F = M * a$$

*where a is the acceleration of each masses;*

$$\text{Elastic interaction: } F = K * d$$

*where d is the distance between masses.*

The equal sign implies that there is no causality between force and position; one cannot say that force causes position, nor the opposite.

Unfortunately, the equal sign does not exist in algorithmic representation. These equations have to be transformed into input-output expressions, each expression being a sequential action. For example:

First: *having a, compute F*  
Then: *having F, compute d*  
Then: *having d, compute a ...*

Hence, the transformation into an algorithm necessarily translates a physical non-causal representation into a causal representation. In this precise case of computation of physical rules, the physical principle of non-causality (for example between force and position) that is fundamental in physics, is impossible to satisfy.

Moreover, when this virtual physical object is linked to a force feedback, the causality cascade is worsened again by a temporal causality (the incompressible latencies) between data (positions for ex.) provided to the program by the external device and data (forces for ex.) sent back to the external device [ $\rightarrow$  CHANNEL, AFFERENT / EFFERENT] [ $\rightarrow$  FORCE].

Indeed, when computed by a machine, each step of the algorithm requires a certain time, not equal to zero. A temporal delay – which was not taken into account in the initial mathematical model - is introduced between the real inputs and outputs of the calculus. This distorts further the correspondence of the computed results with the real observed phenomena that was initially represented by the mathematical equations based on the equal sign.

There exist other transformations, such as numerical approximations, that are usually known by designers and users in virtual realities and human – computer interfaces. However, the transformations into an algorithm, which is studied by disciplines as real time simulation and robotics, are often less known in virtual realities and human – computer interfaces. In the domain of enactive interfaces, being aware of the effects caused by an algorithmic representation and implementation is of a central and critical importance.

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## RELATED ITEMS

CHANNEL, AFFERENT / EFFERENT  
DYNAMIC SYSTEMS  
FORCE  
SIMULATION  
STABILITY  
TURING MACHINE

## RELATED DOCUMENTS

EL\_Enaction&ComputerTechnologies\_Luciani.pdf  
EL\_InputOutputParadigm\_Luciani.pdf

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## ANTHROPOMORPHISM

Manfred Nüsseck [MPIT]

This term describes the phenomenon to attribute human characteristics, qualities, or thoughts to nonhuman organisms or inanimate objects. The most common behaviour is to misattribute animals as being psychologically like us [Mitchell et al., 1996]. Anthropomorphized animals are therefore often the subject in art and literature [Orwell, 1945] as well as in mythology and religion. This human-like characterization, however, can also be attributed to abstract, virtual and artificially constructed objects. Even a simple movement of a 2D geometric shape can give the impression of high-level properties such as causality and animacy [Scholl & Tremoulet, 2000]. Even Michotte [Michotte, 1963] could show that a simple motion can provide the foundation for perception of social behaviour in general. Such a form of personification consists of creating an imaginary entity that is presumed to have mental states, intentionality, cognition, emotion, consciousness, self-consciousness, and possibly is capable of having a language.

Consequently, one might say that one of the goals in computer graphics and animation for increasing the efficiency and usability of human computer interfaces is to achieve an anthropomorphization of computer agents

[→ INTELLIGENT CHARACTERS] and avatars [→ AVATAR]. One of the core problems in this context, however, is that in order to increase the believability of an animated agent all perceptual characteristics (including both visual and acoustic characteristics such as photorealism, motion, speech and action behaviour, etc.) need to be taken into account. It has been proposed that such an increase in behavioural and perceptual realism, however, might encounter the so-called uncanny valley [Mori, 1970] – an almost life-like character will be judged differently - and perhaps even more negatively - than a fully abstract one.

For developing enactive interfaces it is important to take this phenomenon into account. Often, research in Human Computer Interfaces concentrates only on reducing the computational cost, the usability, or other more technical or graphical issues. The factor, that when the animation (possibly an Avatar) is present a typical anthropomorphism takes place, is generally neglected. It is necessary for the optimal interface to investigate for both the best usability and the most believable presentation according to the task to fulfil without being distorted by high-level phenomena [Kim, 2005].

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## RELATED ITEMS

AUTOPOIESIS  
 AVATAR  
 BELIEVABILITY\_1  
 BELIEVABILITY\_2  
 COMPUTER GRAPHICS  
 HUMAN COMPUTER INTERACTION  
 INTELLIGENT CHARACTERS

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## ARRAY, AMBIENT ENERGY

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The ecological approach to perception and action stresses that the information available to perceptual systems lies in ambient energies of the environment (optic, acoustic, gravito-inertial, etc.) and more exactly in the invariant properties of these energies (i.e., invariant structures within energies [→ INVARIANT, PERCEPTUAL] [→ PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH]). Considered at a particular place in the environment, these patterns are formalised in terms of ambient energy arrays [Gibson, 1966] [Gibson, 1979].

An array is an arrangement. Traditionally, an array is a geometric arrangement, perhaps a grid, or a continuous spatial pattern. More recently, it was understood that an array could be a space-time arrangement. Examples of individual ambient arrays that have been investigated in research on perception and action include optic, acoustic or haptic array. When considering the entire perceptual experience individual energy arrays become dimensions of the Global array [→ ARRAY, GLOBAL]: the arrangement of spatio-temporal variations that extends across different forms of ambient energy [Stoffregen & Bardy, 2001] [Stoffregen & Bardy, 2004].

## Optic array

The optic array is the arrangement or pattern of variations, over time, in brightness (luminance) and frequency (hue) of light converging from different directions. At any given point of observation, light converges from all directions. There are differences, as a function of direction, in the intensity and frequency of the light, and these differences change over time. Variations in intensity and frequency are caused by all that that structure ambient light [→ INVARIANT, PERCEPTUAL], including the physical layout of the environment, the motion of objects (other than the point of observation) relative to the environment, and motion of the point of observation relative to the environment. The ambient optic array at the point of observation can be defined as the spherical projection of the ambient illumination at this point. The optic array can hence be capture with 3 dimensions: the two angles defining a direction in spherical coordinates and the time. Gibson [Gibson, 1966], who discovered the optic array, claimed that relations between the structure of the optic array and physical reality were lawful, such that the structure of the optic array was uniquely related to the system comprising the environment and the point of observation.

## Acoustic array

Similarly, the sound arriving at a given point in the environment exhibits properties in loudness and frequency that are specific not solely to the sound source and its spatial location, but that are also specific to the surrounding layout, including the shape of the listener's body if any, and to possible motions of any of these elements.

## Haptic array

Many studies (e.g., [Shockley & al, 2004]) have evidenced the role of inertial information in perceiving the weight of objects, their nature, etc. A given object when wielded is subject to rotational inertia that is constrained by the shape, mass and density of the object as well as by the forces exerted on

it by the wielder. These patterns of inertial information extending over time and space make up the haptic array.

Being space-time arrangements whose invariant features are directly related to invariant properties of the perceiver's movement, ambient energy arrays provide an adequate formalism for characterising the perceptual information that is enacted by the actor/perceiver (see related document for recommendations to designers).

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## RELATED ITEMS

ARRAY, GLOBAL  
INVARIANT, PERCEPTUAL  
PERCEPTION, DIRECT APPROACHES: THE  
ECOLOGICAL APPROACH

## RELATED DOCUMENTS

EL\_DRD212\_final.pdf

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## ARRAY, GLOBAL

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The global array is the ambient array [→ ARRAY, AMBIENT ENERGY] made up of spatio-temporal structure that extends across different forms of ambient energy [Stoffregen &



Bardy, 2001] [Stoffregen & Bardy, 2004]. These patterns are higher-order in the sense that they are superordinate to (and qualitatively different from) the patterns that exist within single energy arrays (e.g., the optic array, the acoustic array, the inertial array). In principle, information in the global array might be detected without prior or concurrent sensitivity to structure in single-energy arrays. The structure of the global array is influenced by all events, objects, and surfaces that influence the structure of single-energy arrays. In addition, the global array is influenced by events that do not structure single energy arrays, e.g., motion relative to different referents. Information about these relative motions is essential for many common behaviours, and so animals have a strong motivation for being sensitive to information in the global array. In the absence of such sensitivity animals would be forced to obtain this information through inferential processing, that is, through internal comparisons of the patterns in single-energy arrays (i. e., those picked up by individual perceptual systems). The relation between patterns in the global array and in single-energy arrays is the relation between wholes and parts. Patterns in the global array are emergent properties of relations between patterns in single-energy arrays, just as triangularity is an emergent property of an arrangement of three lines.

Within the enactive context, our general hypothesis is that perception consists of sensitivity to patterns in the global array, and that perceivers are not sensitive to patterns in single-energy arrays per se. To test this hypothesis, it is necessary to manipulate structure in the global array independent of structure in single-energy arrays. One way to do this is with the method of pairwise comparisons - e.g., [Fouque et al., 1999]. This method consists of fixing the structure in one or more single-energy arrays while systematically varying the structure in the global array (across experimental conditions), in situations that have consequences for behaviour. A reciprocal option is to fix parts of the struc-

ture of the global array while varying the structure of individual forms of energy - e.g., [Mantel et al., 2005]. This might be achieved if variations in different forms of energy were appropriately coordinated. Additional methods should also be pursued. It is essential that experimenters understand the physics underlying experimental work, and the physical reference frames relevant to the task. For instance, when a judgment task involves the detection of stasis or motion, instructions given to the subjects should be very specific with respect to the referents that are to be used for the perception of motion.

In the context of egocentric distance perception, [Mantel et al., 2005] have conducted research evidencing that (1) the reachability of objects (i.e., egocentric distance specified in intrinsic, affordance-based, coordinates) can be expressed in terms of a particular location of the global array, (2) human observers are sensitive to that global information, which (3) exist only through enactive exploration of the environment.

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## RELATED ITEMS

AFFORDANCES  
 ARRAY, AMBIENT ENERGY  
 INVARIANT, PERCEPTUAL  
 MULTIMODAL (MULTISENSORY) INTEGRATION,  
 IN COGNITIVE SCIENCES  
 MULTIMODALITY, IN COGNITIVE SCIENCES  
 PERCEPTION, DIRECT APPROACHES: THE  
 ECOLOGICAL APPROACH

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## ATTENTION, CROSSMODAL

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In spite of its controversial theoretical status, the notion of attention has played a major role in the history of cognitive science. It refers mainly to a variety of attentional systems underlying two mental functions:

- the mind's selective operations carried out within various cognitive domains (such as perception, identification, consciousness, learning, motor preparation)
- the coordination among these miscellaneous domains, particularly through the resolution of various binding or indexing problems [→ MULTIMODAL (MULTISENSORY) INTEGRATION: THE BINDING PROBLEM].

Focal attention is frequently assumed to link early sensory processing and memory-based operations such as object recognition or identification. Visual attention has controversially been described as object-based (in contrast to location-based or feature-based selection) in several respects. Crossmodal attention plays a crucial role in the deployment of spatial abilities based on multimodal perception.

Crossmodal attention is based on the fact that several modalities give different clues to the subject who maps it all together in order to try and reconstruct a coherent view of the world. The weight of the different modalities can be measured and is experience dependant. For example [Wu et al., 1999] and [Rock & Harris, 1967] tried to measure which modalities between haptic and vision predominates on the other, and they end up with different conclusions. Both of them are right and illustrate the fact that the weights of the modality are dependant of the experiments done and illustrate the importance of the

context. Indeed, as pointed by [Lederman et al., 1986], depending of the activity the subject is running, one modality is more trusted than the other and plays a more important role in the reconstruction. It should also be pointed that [Helbig & Ernst, 2005] recently pointed that attention does not affect multisensory cue weighting.

Study of crossmodal attention is essential to the design of interfaces that employ different stimuli, like touch and audio, simultaneously to convey information to the user. In this context it forms an essential aspect for the design of enactive interfaces.

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### RELATED ITEMS

CUES, SENSORY  
INTERFACE, MULTIMODAL / MULTISENSORY  
MULTIMODAL (MULTISENSORY) INTEGRATION,  
IN COGNITIVE SCIENCES  
MULTIMODAL (MULTISENSORY) INTEGRATION,  
IN TECHNOLOGY  
MULTIMODAL (MULTISENSORY) INTEGRATION:  
THE BINDING PROBLEM

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## AUDITORY FEEDBACK IN VR AND HCI

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We call auditory feedback the feedback generated in response to a subject gesture when performing an action, and perceived by the subject's or the auditor's auditory perception [→ AUDITORY PERCEPTION].

### **Auditory feedback in ecological environment**

In our daily life we use sounds:

- to get information from the environment: what things are, where things are, where things are, when something happens.
- and to inform the environment about our actions or intentions: what we are doing, where we are doing it, when we are doing it. This includes verbal communication.

Research in ecological acoustics [Gaver, 1993] demonstrate that auditory feedback can in particular effectively convey information about a number of attributes of vibrating objects, such as material, shape, size, and so on. In fact the information that can be extracted from the auditory feedback concerns both the nature of the sources involved (size, material and mass) and the action performed (speed, acceleration, force) [Gaver, 2005].

Auditory feedback is commonly used in everyday life for human interaction with the world: actions very often generate sounds that are informative about them. The generated sound is fed back to the auditory system and allows deeper monitoring of the action itself.

### **Auditory feedback and action/gesture**

In natural environment, sound/auditory feedback and actions are related in a number of different ways.

First, when sounds are generated externally, as those produced by autonomous sources (water falls, birds, wind, machines, etc.), they indicate, by themselves, what the objects that produced the sounds are, and where they are. The only auditory feedback that can be obtained in response to action is by moving our body or our head. In that case, there is obviously no relation between the physical properties of the objects that produce the sounds and our body. But the body plays the important role of a point of view that transforms the sound perceived without transforming the acoustic waves themselves.

Sound/auditory feedback can also be produced directly by action, when physically manipulating a physical object [→ ERGOTIC / EPISTEMIC / SEMIOTIC (...) LOOPS]. In this case, there is a physical energetic consistency between action and produced sounds: sounds can be produced by temporary object manipulation (the sound starts after the end of the action), or by continuous object manipulation (the sound continues during the manipulation). In other words, the sound properties can encode the physical gestures at the same time as it encodes the physical nature of the object. We can say that the sound is the trace of the gesture on the matter, or of both the two interacting bodies and their interaction. There is more or less a sort of genuine physical consistency between the action and the produced sound.

### **Auditory feedback in digitalized environment**

Most today's digitalized systems take into account only a few of the diverse, and precise features carried by auditory feedback in natural environment.

Apart in the special case of digital musical systems [→ MAPPING, IN DIGITAL MUSICAL INSTRUMENTS], the dominant paradigm is to trigger pre-recorded sounds, then apply various sound processing algorithms [→ SOUND ALGORITHMS]. With such a paradigm, the coupling of sound feedback to action is, very often, relatively relaxed.

For example, in virtual reality, one often use sound spatialization algorithms to provide the user with cues on sound source localization and sound propagation environment (room effects). The coupling to action is then mainly due to the movement of the subject's avatar in the environment, and to the triggering of sounds in case of various actions. Auditory feedback is also used to reinforce the user's feeling of immersion in the environment. An efficient mean to that aim is to compute spatialized auditory feedback in accordance with the subject's movement (by using a motion capture system), so that the sound sources apparently do not move in azimuth/elevation when the user moves his head.

In the human-computer interaction field, auditory feedback is used mainly for alarms, and more rarely for monitoring and status information [Brewster, 2002] [Kramer, 1994]. The coupling of auditory feedback to action is most often relaxed, at least due to the usually poor gesture device at hand (eg: a mouse, a keyboard...).

In the context of enaction, and in the light of embodied perception theories, developing enactive interfaces implies developing techniques for multimodal feedback and input, including sound, touch and gesture. Working on better coupling of gesture to auditory feedback allowing to close the perception-action loop in a continuous stream of information is, hence, a major research topic in the context of enactive interfaces. Toward that goal, various research directions are studied, including, but not limited to, ergotic interfaces [→ INTERFACE, ERGOTIC] that aim at respecting the energetic consistency of gesture and auditory feedback, physically-based modelling [→ PHYSICALLY-BASED MODELLING TECHNIQUES FOR SOUND SYNTHESIS], better gesture controllers and haptic devices.

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## RELATED ITEMS

AUDITORY PERCEPTION  
 ERGOTIC / EPISTEMIC / SEMIOTIC ACTION-  
 PERCEPTION LOOPS  
 INTERFACE, ERGOTIC  
 MAPPING, IN DIGITAL MUSICAL INSTRUMENTS  
 PERCEPTION, DIRECT APPROACHES: THE  
 ECOLOGICAL APPROACH  
 PHYSICALLY-BASED MODELLING TECHNIQUES FOR  
 SOUND SYNTHESIS  
 SOUND ALGORITHMS

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## AUDITORY PERCEPTION

Amalia de Götzen [DEI]

*Contributors: Matthias Rath [DEI], Nicolas Castagne [ACROE&INPG]*

### What is Auditory Perception?

A perceptual channel, or perceptual modality, can be defined following different approaches [→ CLASSIFICATION OF PERCEPTUAL MODALITIES]:

- by considering the sensory organs as physical entries for perception
- through a classification of forms of ambient energy
- by means of the sensory-motor laws that govern the relation of motor-actions of the perceiver and her/his percepts.

The fact that these approaches do not necessarily converge to identical results is well exemplified by the case of auditory perception.

The a priori most intuitive way of defining auditory perception is, following approach 1, to say that hearing is to perceive (whatever...) through our ears. In other words, auditory perception is the emergence of those percepts that we have when and only when our ears, including outer, middle and inner ear, are not deactivated through closure, damage or whatsoever.

Starting from a classification of types of ambient energy (approach 2), one might define auditory perception as that part of the human perceptual system that reacts on fluctuations of air pressure within a certain frequency range, typically 20 - 20000 Hz.

Finally a definition of auditory perception based on sensory-motor laws (approach 3) is surely a more complex task. The transduction processes in the middle ear, in particular the cochlear, are not simply one-way i.e. passive transformations of ear drum movements into nerve impulses but also active i.e. from nerve impulses to movement in the cochlear. Moreover, the connection of body, in particular head, movements to auditory percepts strongly depend on the range of the acoustic wavelengths/frequencies.

Air pressure waves of frequencies near the lower end of the sensitivity of the human ear can also be felt in other parts of the body if signal amplitudes are sufficiently high. If the auditory perceptual channel is defined only in terms of ambient energy, such sensation of low frequency tones in the body must be considered as part of hearing, but if auditory perception is defined in terms of the ear as the sensory organ, it is not. The latter standpoint may appear as closer to everyday intuition, since we rather say that a deaf person can "feel" low frequency tones rather than "hear" them.

In terms of sensory-motor laws, the border frequency between hearing and feeling, if it exists, should be probably much above the lower boundary of sensitivity of our ears, since we do not localize sources of acoustic signals with frequency components exclusively below around 100Hz. This last phe-

nomenon depends on whether the vibration is sensed purely in the ears or also in other parts of our body. From this viewpoint, low frequency tones are "felt" in the ear, rather than "heard".

Extreme cases can be useful to exemplify the dilemma of the different definitions and categorizations of perceptual channels: do bats "hear" trees, leafs and walls or do they "see" with their ears? However, from a pragmatic standpoint, we can note that in the case of human perception the problems do not occur for a large range of situations of perception. For example, the acoustic signal of a speaking voice is generally restricted to a frequency range were the various approaches coincide.

### **Every day listening / Musical listening**

Traditional psychoacoustic research has mainly focused on the study of the correlations of percepts with acoustic parameters of the sound (such as pitch/frequency, loudness/power, masking effects, perception of timber/spectrum...). In this context, the study of musical listening, and the connection to Fourier-related signal parameters, has received particular attention. The perception of everyday sound (sounds that are not music or speech, such as breaking and rolling sounds, elsewhere defined as environmental sounds [Gygi, 2001]) has received increased interest only since recently.

The distinction between everyday listening and musical listening has been proposed in [Gaver, 1993]. Gaver remarks that our auditory system is *first of all* a tool for interacting with the outer world in everyday life, that allows us to perceive "sound-producing events" (e.g. everyday listening) rather than sounds themselves (e.g. musical listening).

Indeed, we can listen to sound in two ways. We may focus on abstract properties such as a melody and ignore (or even not know) the physical nature of the sound source - this is often the case when listening to music - or we may hear sound sources without paying attention to sound attributes such as pitch; the latter has been remarked as

the usual response of average listeners towards everyday sounds. Indeed, everyday listening involve the direct perception and recognition of the distal stimulus, which is the sound source event, while musical listening less involve a recognition process, but rather a listening of the properties of the acoustic wave, i.e. the proximal stimulus.

Gaver distinguishes three categories of everyday sounds: solid, liquid and aerodynamic sounds. Each category is then divided according to the type of interaction between materials: sounds generated by vibrating solids are, for instance, divided in rolling, scraping, impact and deformation sounds. At higher level, he considers different complex events: basic events with a specific temporal pattern (i.e. bouncing), the overlapping of different basic level events, the interaction between different types of basic materials.

The knowledge on everyday listening, that rapidly develops today, is interesting for applications in interfaces, allowing to better focus the sound algorithms [→ SOUND ALGORITHMS] on the properties of perception.

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## RELATED ITEMS

CLASSIFICATION OF PERCEPTUAL MODALITIES  
ILLUSIONS, AUDITORY  
SOUND ALGORITHMS  
VISUAL PERCEPTION

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## AUTOPOÏESIS

John Stewart [COSTECH]

Autopoïesis is a fundamental concept in the conjoint epistemology of biology (as a fundamental theory of life) and cognitive science (as a basic element in the theory of enaction). As recounted in Maturana & Varela (1980), the key insight lies in recognizing a basic circularity, common to both domains. Concerning living organisms, their fundamental characteristic is that they are a set of processes which, in the last resort, do neither more nor less than to produce themselves (hence the term auto-poïesis). In the domain of cognition, the key insight is that the internal states of an autonomous cognitive system cannot be determined from the outside. Rather, the cognitive organism has its own structurally determined dynamics, which constitute the repertoire of all its possible internal states; from the point of view of the organism, interactions with the environment can only be perturbations, which will trigger the transition to one or other of this repertoire of internal states, but which cannot determine what these states are. This (difficult) concept is designated by the term operational closure, which has given rise to much confusion because, of course, cognitive organisms are thermodynamically *open* systems continually renewed by a flux of matter and energy.

The canonical definition of autopoïesis is given by Varela (1979): “*An autopoietic system is organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components that:(a) through their interactions and transformations continuously regenerate andrealize the network of processes (relations) that produce them and (b) constitute it (the machine) as a concrete unity in the space in which they exist byspecifying the topological domain of its realization as such a network*”.

A recent review of various definitions, together with a discussion, is given by Bourguine & Stewart (2004).

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## RELATED ITEMS

AGENT, AUTONOMOUS  
ENACTIVE COGNITIVE SCIENCES\_1  
ENACTIVE COGNITIVE SCIENCES\_2

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## AVATAR

Manfred Nüsseck [MPIT]

Contributors: Ronan Boulic [EPFL]

The function of an avatar is to allow communication between partners, which cannot contact with each other directly. The original term derives from the mythology and religion where an avatar is a bodily manifestation of a divine creature. An avatar can be everything and therefore this phenomenon is often referred to as an example of “antropomorphization” of non-human objects/entities, which start to speak and talk in a human language.

Since computer games started to simulate and create virtual worlds [→ VIRTUAL REALITY AND VIRTUAL ENVIRONMENT], the representation of the players in collaborative-networked environments (either human players or the computer and its artificial intelligence) was called an avatar. Nowadays, in technical fields, an avatar is used to personify an interface between two systems. The two systems interact with each other via the avatar(s). An avatar can be a facial or a full body animation for that the modern goal is to let it behave and look as human as possible. In a perfect

simulation as a high-level avatar, it should pass the Turing test for the represented system. It is also used in computer applications and for human computer interaction research as virtual character and is often synonymous with a virtual human [→ INTELLIGENT CHARACTERS].

Computer graphics [→ COMPUTER GRAPHICS] and perception research communities have come to realize the importance of working together both for improving the quality of computer generated simulations and for deriving insights into human perception [O’Sullivan et al., 2004]. Consequently, avatars have increasingly become employed in many experimental settings. In psychological and behavioural research, the advantage of using a computer generated character animation lies in having full control over the production of the animation. Experimental questions such as perception of facial expressions and influence of spatio-temporal characteristics [Wallraven et al., 2006] can therefore be clearly and systematically explored.

With a full body avatar, the perception and judgment of natural body motions can also be examined in detail. For instance, since humans never stand still but computer animations do, investigations of idle motions of standing people are important to let the animations behave more human like [Egges et al., 2004].

Conversely, using experimental methods from perceptual sciences it becomes possible to measure and identify perceptually meaningful and relevant parameters for improving the perceived realism and believability [→ BELIEVABILITY\_1&2] of the animation. In a coupled action-perception loop of the human with the avatar it is possible to look at self-recognition behaviours and transformations of own movements to a virtual equivalent. A perfect match between the human user and his/her avatar can lead to its internalization, by which the avatar would be felt as part of the human organism and the user consciousness focus would entirely shift on the task to

be performed by the avatar rather than focusing on the avatar control itself. This can be achieved at the full body scale through motion capture techniques [→ MOTION CONTROL, HIGH-LEVEL]. Recent investigations in the framework of enactive interfaces explore the possibility for a human subject to internalize avatar presenting important physical differences such as the body height, or that interact in a virtual environment constraining its posture [→ INTERACTION, FULL BODY].

Furthermore, avatars are used in studies of human-human communication. In the enactive research, the interaction of two persons is investigated via two avatars to find insights into the processes in collaborative situations.

In summary, interdisciplinary studies involving computer graphics and perception work to the benefit of both communities. Knowledge of these studies can then be used to improve enactive interfaces.

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## RELATED ITEMS

ANTHROPOMORPHISM  
BELIEVABILITY\_1&2  
COMPUTER GRAPHICS  
INTELLIGENT CHARACTERS  
INTERACTION, FULL BODY  
MOTION CONTROL, HIGH-LEVEL  
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT  
VIRTUAL REALITY THERAPY



# B

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## BELIEVABILITY\_1

Elena Pasquinelli [INSTNICOD]

In normal cases, one does not notice that the real world is going on in a believable fashion: the real world is trivially believable. But in some situations perceptual experience appears to be bizarre to the perceiver, i.e. when a paradox is perceived, when a conflict is experienced or when experience is inconsistent with acquired knowledge. These situations are associated with a reaction of surprise, which is more or less strong depending on the contents of the experience and on the attitude of the perceiver. Also, appropriate responses to the environment are suspended by a sort of paralysis of actions [Stein & Meredith, 1993].

It is hence when expectations are unfulfilled or coherence is violated that the problem of believability arises. In these circumstances, one is not disposed to form a (true) belief. One hence judges the experience as unbelievable.

Conversely, the judgment of believability corresponds to the condition of being disposed to hold beliefs susceptible of being true.

The notion of believability, however, is more in use in the characterization of virtual and fictional context than in the realm of natural experience.

Believability is an objective for experiences in mediated interactions with fictional or artificial environments, in analogy with Presence. Whether a film is judged to be non-believable, audiences are deceived and might want to stop the projection. A non-believable experience in virtual reality can produce a lack of the desired responses in the user.

Is believability in virtual and fictional contexts the same thing than believability in real ones? An influential current in philosophy states that the appropriate reaction to fictional contents proposed through different traditional media is not the production of beliefs, but the production of imaginings: an activity of imagination [Walton, 2001] [Currie, 1995].

This activity shares a number of analogies with the activity of believing, at the point that it can be considered as a form of simulation of having beliefs that preserves the connections within beliefs and between beliefs and behaviours [Currie, 1995].

The same consideration can be extended to virtual contents, since, as traditional media, virtual reality produces representations that are intended (by the authors or designers of the experience) to produce certain effects in the users or spectators. These effects are as varied as emotional involvement, appropriate perceptual responses (object recognition, patterns identification), appropriate motor actions (reaching, walking, exploring), and appropriate cognitive behaviours (learning, judging).

Believability in fictional and virtual contexts cannot hence be characterized in terms of the susceptibility to produce beliefs, but rather in terms of the susceptibility to raise imaginings that correspond to the intentions of the authors of the experience, or that put the user in the condition of behaving (at the emotional, perceptual, motor and cognitive level) in the way auspicated by the authors of the experience.

The reference to the intentions of the authors of the experience – in association with the possibilities that the medium makes available - helps defining the appropriate effects that are expected from believable experience (visual perceptual identification cannot be expected from radio, motor interactions cannot be expected from cinema, walking with its own legs cannot be expected from many virtual reality systems), hence designing suitable instruments for the evalua-

tion of believability in subjective and objective terms.

As in the case of believable or unbelievable experiences in the real world, violations of coherence and the frustration of expectations have a dramatic effect upon believability in fictional and virtual worlds, because they make it difficult for users and spectators to interpret what is happening [Bordwell, 1985] [Davidson, 1984].

For this reason, the fulfilment of users' expectations and coherence and the presence of appropriate reactions constitute the basic elements for a characterization of believability which is at the same time minimalist (it does not consist of a list of indications, but of two basic principles from which indications can be extracted in relationship to different contexts and contents), operational (it allows to provide indications for the enhancement of believability and for its evaluation) and general (it applies to real, virtual and fictional contents).

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## RELATED ITEMS

ACTION FIDELITY  
BELIEVABILITY\_2  
EXPECTATIONS  
OBJECTIVITY  
PRESENCE, IN COMPUTERIZED ENVIRONMENTS  
PRESENCE, THEORIES OF

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## BELIEVABILITY\_2

Thomas A. Stoffregen [HFRL]

What is it that the user believes?

In the literature on simulators and virtual environments, it is widely assumed that optimal interfaces will induce in the user an "illusion of reality". That is, the user may (erroneously) believe that a simulated or virtual environment is real [Ellis, 1991]. A common name for this idea is presence. Many researchers and designers regard the illusion of "being there" as a positive aspect of virtual environment systems, and even as a design criterion [Prothero, 1995]. However, we must distinguish between reality (inaccurate or illusory perception that the simulator is the simulated) and realism (accurate perception of resemblance between simulator and simulated); [Carr, 1995]. Awareness of a realistic simulation need not imply belief in the reality of that which is simulated. Moreover, the literal illusion of realism is likely to be very rare [Stoffregen, 2003]. Definitions of presence should focus on the perception of realism, not on the illusion of reality (the latter can be counterproductive [Stappers, 2003]). The subjective awareness of realism can be quantified. Rather than asking "how real does this seem", a better question might be "how closely does this resemble the real situation?"

While subjective awareness is important, it should not be the sole criterion for the design or evaluation of virtual environment systems. By itself, subjective experience often bears an uncertain relation to actual performance. In addition to assessing (and designing for) subjective experience, it may be appropriate to assess (and design for) optimal behavioural interactions between users and virtual environments. Action fidelity [Stoffregen, 2003] is defined in terms of relations between performance in the simulator and performance in the simulated system. Action

fidelity exists when performance in the simulator transfers to behaviour in the simulated system. An appropriate measure of action fidelity is transfer of learning, or transfer of training. Action fidelity is measured in terms of task performance. Common metrics that could be used to compare performance in a simulator and in the simulated system are time to completion of a task, variance in performance across trials, and trials to criterion [Flach, 1986] [Kozak, 1993]. Appropriate metrics for a telemanipulation task might include the accuracy with which users can position objects in a closed-loop 3-D video image [Smets, 1995].

Several partners of Enactive Interfaces network have worked jointly and severally for many years to understand relations between perception and action in real and virtual environments. This work includes both theoretical and empirical research. The arguments and experiments are developed from the Ecological Approach to Perception and Action. A central claim is that reality is specified in patterns of ambient energy in the Global Array. The specificity of the global array makes it possible, in principle, for perceiver-actors to differentiate simulations from the real-world events that they simulate. The ability to differentiate simulations from reality will depend upon perceptual exploration to detect the relevant information. Where exploration can be limited or prohibited, users may be unable to distinguish simulations from the corresponding reality. However, it will be difficult for limitations on exploration to be sustained, across time and across situations. Finally, one can argue that virtual environments (including enactive interfaces) should be evaluated (in most cases) in terms of perception-action metrics, rather than using metrics that are based on subjective awareness.

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## RELATED ITEMS

ACTION FIDELITY  
 ARRAY, GLOBAL  
 BELIEVABILITY\_1  
 EXPECTATIONS  
 OBJECTIVITY  
 PRESENCE, IN COMPUTERIZED ENVIRONMENTS  
 PRESENCE, THEORIES OF

## BIMANUAL INTERACTION

Joan De Boeck [UHASSELT]

We, human beings, naturally interact with both hands in the real world. As current virtual environment application often restrict the interaction to a single hand, it may be clear that this is a reduction compared to our natural feeling to interact.

In the context of bimanual interaction, two types can be distinguished. Symmetrical bimanual interaction and asymmetrical bimanual interaction. The first requires both hands to perform equally in the task (such as typing on a keyboard), but only a minority of our daily tasks require symmetrical bimanual interaction.

For the second type, asymmetrical bimanual interaction, both hands execute a specific part of the task. For instance while writing, the dominant hand writes, while the non-dominant hand holds the paper.

According [Guiard, 1987], in this context, the non-dominant hand creates a frame of reference for the dominant hand. Guiard has proposed a theoretical framework for the study of this asymmetry with the following principles:

- The dominant hand moves relative to the non-dominant hand. In other words, the non-dominant hand creates a frame of reference for the dominant hand. E.g., holding a sheet of paper while writing.
- The non-dominant hand's movements are low in spatial and temporal frequency, while the movements of the dominant hand are more precise and faster.
- The action of the non-dominant hand in the global bimanual task starts earlier than the dominant hand's movement. This is obvious since the non-dominant hand first has to create a reference frame before the other hand can start its task.

Hinkley found that as a task becomes more complex, the specialization between both hands becomes more important and pronounced. Hinkley also shows that in our every-day life, interaction with both hands creates a frame of reference that is strong enough, so that it is even independent of visual feedback [Hinkley et al., 1997], leaving opportunities to involve the user or the human's visual system in another task.

In the context of enactive interfaces, we can state that the frame of reference, provided by the non-dominant hand is experienced by the user's proprioceptive

knowledge, the knowledge humans have about the positions of their individual parts of their body. This is indeed important, as it establishes a first order (haptic) feedback loop.

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## RELATED ITEMS

FEEDBACK  
 HUMAN COMPUTER INTERACTION  
 INTERFACE  
 METAPHORS IN HUMAN-COMPUTER INTERACTION

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## BODY SCHEMA

Elena Pasquinelli [INSTNICOD]  
 Benoit Bardy [UM1]

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The performance of skilled motor actions involves different forms of knowledge or perception of one's own body. These forms of knowledge and perception have been addressed through different terms, the most diffused being the one of body schema. We try here to provide a terminological clarification.

In its first formulations, the body schema is conceived as a summary of the bodily experience: "*A combined standard against which all subsequent changes of posture are measured (...) before they enter consciousness*" [Head & Holmes, 1911].

Successively, the term has been used interchangeably with the term body image defined as a picture of the parts of the body consti-

tuted of conscious internal representations [Schilder, 1935].

Recently, [Gallagher & Cole, 1995] have made recourse to the notion of consciousness to solve the ambiguity between body schema and body image: “*a body schema involves a system of motor capacities, abilities, and habits that enable movement and the maintenance of posture. The body schema is not a perception, a belief, or an attitude. Rather, it is a system of motor and postural functions that operate below the level of self-referential intentionality, although such functions can enter into and support intentional activity.*” [Gallagher & Cole, 1995]

As a system of motor capacities and habits, the body schema guides movement and posture control in absence of awareness and is susceptible of expanding each time a new motor-perceptual habitude is acquired. [Merleau-Ponty, 1945] suggests that the prosthetic instruments that are skilfully employed become part of the body schema too.

On the contrary, the body image is conceived as a set of intentional states: perceptions, representations, beliefs regarding one own's body.

Finally, body percept refers to the particular body position that is being actually perceived at a certain point in time and updated by the various multisensory inputs.

The work performed on the inertia tensor (e.g. [Pagano & Turvey, 1995] [Bernardin et al., 2005]) can be put in relation to the notion of body percept. In this case, the perception of the dimensions and position of the arm is obtained in connection with information about a hand-held object which is actively manipulated: the eigenvalue of the inertia tensor (of the arm for instance) provides information about the length of the arm, and of an manipulated object. Similarly, the eigenvector of the inertia tensor provides information about the direction of the arm/object system.

Therefore, during active manipulation of objects in an enactive interface, the haptic system provides in the mean time relevant information, via the properties of the inertia

tensor, about exteroceptive properties of objects and proprioceptive properties of body parts. This proprioceptive specification of exteroceptive information may underly the concepts of body schema as a system of motor and perceptual function and of body image as long-term, organized knowledge (semantico-lexical and visuo-spatial) about the spatial characteristics of human bodies.

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## RELATED ITEMS

IMMERSION VS. VIS-À-VIS  
LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL  
APPROACH  
MOTOR CONTROL

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## CHANGE BLINDNESS

Kevin O'Regan [CNRS]

Change blindness is a phenomenon in which a large change can be made in a visual scene without this change being noticed by an observer.

The phenomenon occurs when pictures of the original and modified scene are separated either by a briefly displayed blank screen (flicker paradigm), by so-called mudsplashes, consisting of random small shapes spattered briefly over the picture like mudsplashes on a car windshield (mudsplash paradigm), or in situations when the original is slowly morphed into the modified picture (continuous change paradigm).

The phenomenon can also be demonstrated during eye blinks, in movie clips, and in real life situations. For a review of the literature see Simons & Levin (1997). A couple of demonstrations are available on the Internet (see related documents).

The phenomenon is taken by proponents of the sensorimotor theory of phenomenal consciousness to be evidence for the claim that the brain holds no detailed, picture-like internal representation of the outside world, and that, in a certain sense, the world serves as an immediately accessible outside memory store (cf. O'Regan, 1992; O'Regan & Noë, 2002). For this reason the phenomenon of change blindness is an important component of the Enactive approach. It suggests that interaction with the world is an important component of perception.

Proponents of the sensorimotor theory explain the phenomenon by supposing that in general, one only "sees" aspects of the visual scene that are currently being attended to. The reason that people nevertheless have

the impression that they continually see everything in the scene, is that if they should so much as faintly wonder whether something is there, they will attend to it, and therefore see it. The illusion of seeing everything is reinforced by the fact that if something should change in the scene, luminance transients will be registered by transient detectors in the low level visual system, automatically orienting attention to the location of change. People thus have the impression of having a continual overview of the scene. In the change blindness paradigm these transients are masked by the blank screen, mudsplashes, blink, eye movements or film cut, or they are faded out by the use of slow morphing, and so there no transients to draw observers' attention to the change location. Under these conditions, the sensorimotor theory predicts that observers will only see the change if they happen to be attending to it, and this is confirmed by empirical observations.

There is however a controversy concerning the interpretation of change blindness, and some consider that alternative interpretations of the result can be envisaged. In particular it is claimed that the brain may actually hold a detailed representation of the environment, it is just not possible to make the comparison with the representation corresponding to the initially presented scene (Simons & Levin, 1997).

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## RELATED ITEMS

CONSCIOUS ACCESS AND COGNITIVE ACCESS  
PERCEPTION, DIRECT APPROACHES: THE  
SENSORIMOTOR APPROACH  
SENSORIMOTOR  
VISUAL PERCEPTION

## RELATED DOCUMENTS

Demos available on :  
<http://nivea.psycho.univ-paris5.fr/demos>.

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## CHANNEL, AFFERENT / EFFERENT

Marco Fontana [PERCRO]  
Annie Luciani [ACROE&INPG]  
Ilaria Polvani [PERCRO]

Literally, an afferent channel is a channel that carries material or impulses to a centre. While an efferent channel conducts outward from a part or organ.

In anatomy, afferent neurons carry nerve impulses from receptors or sense organs toward the central nervous system, and the efferent ones carry the impulses in the opposite direction. These two, impulse fluxes (afferent-efferent) create a "closed loop" system of sensation, decision, and reactions.

Within the field of automation and robotics, the efferent signal is the signal generated by the controller and transmitted to the robot. The afferent signal is the feedback signal from the sensors that allows closing the loop of the control.

This definition may be widened to the context of virtual reality / user interface and, even more generally, to the context of human computer interaction. In this field, the efferent channel is a communication channel that carries the information generated by the user (and measured by the artificial system) and transmits it to the artificial system (computerized environment). The afferent channel carries the information associated with the feedback (force, tactile stimulations etc.) of the artificial system as consequence of the user actions and transmits them to the user.

Such separation intrinsically exists when a mechanical system is represented – modelled, transformed - in input (efferent, resp. afferent) – output (afferent, resp. efferent) model. It exists since the physical equations

[ $\rightarrow$  ALGORITHM] are computed (with or without computer) introducing for example the differentiation between “direct dynamics” in which the inputs of the computational system are forces [ $\rightarrow$  FORCE] and the outputs are displacements (positions, etc.), and “inverse dynamics” in which there is the contrary. It exists when the mechanical system is transformed, by augmentation including sensors and actuators, to an electromechanical system. Consequently, Afferent and Efferent channels can be associated to different outputs/inputs of the Haptic Interface.

In telerobotics, it has been originally conceptually introduced in [Sheridan, 1992]. The creation of two different channels in the system model is a required step for making the interaction control-loop explicit. [Avizzano et al. 1999] proposed to sub-divided the data exchanged by means of the afferent and efferent channel into two levels:

- At the low level, called active information, signals are simply concerned with raw data contents having no relationship with the implicit content of the data itself (no degree of autonomous intelligence is requested to the control).
- At the high level, called reactive information, information on afferent and efferent channels are analyzed.

This distinction into two levels of each efferent – afferent channels allows designing a multilevel control structure which realizes the needed simplified control approach.

In their design of the physically-based modeller-simulator CORDIS-ANIMA [Cadoz et al, 1984], the authors theorised that when external mechanical universe is communicating with a computer by means of sensors and actuators (and their correlated analog-to-digital and digital-to-analog converters), the most general theoretical basis (necessary and sufficient conditions) to describe and implement this communication is through only two dual types of communication ports, called M and L. In each port, both types of physical data (intensive and extensive) are circulating, where the efferent chan-

nel of M conveys the intensive data and its afferent the extensive data (and vice – versa for the port L). All the physical communication between mechanical external world and computer can be supported by a combination of these two duals ports, and only by them.

However, such distinction between afferent and efferent channels is not a natural concept: indeed, no separation between user mechanical actions and user mechanical responses exists in the mechanical nature. It introduces fundamental bias that is a conceptual causality between inputs and outputs (afferent and efferent channels) [Luciani 2004a], which does not exist in the mechanical world. More, when a mechanical system is transformed in an input-output (efferent – afferent) computational model, this bias has a very as the conceptual causality is transformed in a concrete causality that is here a temporal causality between input-output (efferent-afferent) channels that does not exist neither in the mechanical world. This added anti-physical causality creates the major theoretical and technical difficulties in simulating interactive systems including haptics, such as the critical role of the simulation frame rate, the limit in the simulation of the rigidity, etc [→ STABILITY].

Conversely, it leads to possible comparison of the human perceptual system, in which afferent and efferent channels exist de facto, to a computational system [Luciani 2004b], leading to confrontations between theoretical schools: mainly the enactive school and the computation theory of mind school [→ COMPUTATIONAL PARADIGM].

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## RELATED ITEMS

ALGORITHM  
COMPUTATIONAL PARADIGM  
FORCE  
FORCE FEEDBACK  
STABILITY

## RELATED DOCUMENTS

El\_InputOutputParadigm\_Luciani.pdf

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## CLASSIFICATION OF PERCEPTUAL MODALITIES

Elena Pasquinelli [INSTNICOD]  
Nicolas Bullof [NICOD]  
John Stewart [COSTECH]

Classification of perceptual modalities is an important question for psychophysics of multimodal-motor interaction. The specification and classification of the senses, or sensory modalities or perceptual system (Gibson, 1966), is also a long-term philosophical and psychological puzzle that can be traced back to Aristotle.

The senses are associated with a common sense classification (5 senses). The familiar and naive enumeration of the ‘five’ senses is however dubious because there is no uncontroversial single criterion of what counts as one sensory modality. Philosophers (see Casati & Dokic, 1994) following namely (Grice, 1962) and psychologists (Gibson, 1966; Stoffregen & Bardy, 2001) have attempted to make explicit and assess the criteria underlying the familiar taxonomy. Particular taxonomic theories are usually



refinement, combination of rejection of subsets of these criteria:

(1) the quality which is represented. The criterion of the distinguishing accessed properties suggests that sensory modalities are to be differentiated by specific represented properties that can be directly accessed by means of them (i.e., vision is the modality of the access to colours, shades, size or shapes; hearing is the modality of the access to sounds, or timbre, pitch and loudness).

(2) the qualitative characteristics of the subjective experience. The criterion of the distinguishing qualitative properties states that sensory modalities are to be differentiated by the special introspective characteristics or by the special sensations related to the nerve stimulation. It can relate to analyses based on phenomenology, but it fits also the view held by empiricists that each modality gives rise to specific sensations.

(3) the medium that allows the perceptual experience, in the sense of the physical energy involved (i.e., light for vision). The criterion of the distinguishing stimuli states that each sensory modality is connected with specific stimuli and particular media. The criterion depends on the theory of the nature of the considered stimuli (distal versus proximal, effective or virtual and ambient, specific versus global array etc.).

(4) the sensory organs (seeing – eyes -, hearing – ears -, taste – tongue -, smell – nose - and touch – skin – and the non-mystical “sixth sense” of proprioception). The criterion of the distinguishing organ states that each sensory modality depends on the characteristics of a sensory organ (or perceptual system) mainly from the anatomical or functional viewpoints.

(5) the type of representation which is generated (it is possible to see an object which is in front of us but not behind). The criterion of distinguishing belief or knowledge states that each sensory modality is connected to a particular set of beliefs that can be epistemically justified only by means of the use of this modality (Nelkin, 1990).

It is possible to combine two or more criteria, or to abandon the 5 senses in favour of a different choice of the individuating criteria, which do not necessarily coincide with the classification of the senses into five kinds, as:

- behavioural functions (as the sense of movement);
- sensorimotor dynamics or sensorimotor contingencies (the laws that connect possible actions with consequent perceptual experiences, following O'Regan & Noë, 2001).

In the perspective of Enaction, this criterion is promising. In ecological contexts, this means that each modality is multi-sensory and multi-energy form. The integration of multiple sensory channels is not a problem, because the brain extracts integrated sensory-motor regularities, without conscious effort. There are nevertheless two drawbacks:

- this definition runs counter to the more familiar, common-sense partition;
- this definition runs the risk of inflation, since there can be an almost infinite number of modalities.

Producing a unique classification of perceptual modalities is not a trivial task: each of the classifications presented here highlights one aspect of the complex functioning of perception. This complexity is amplified by the fact that, in natural conditions, perceptual modalities work together and in close relation with the motor systems. It is then imperative to be aware of the advantages and disadvantages of each form of classification, and of the artificial, functional nature of any of them.

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## RELATED ITEMS

CLASSIFICATION OF PERCEPTUAL MODALITIES:  
THE ECOLOGICAL APPROACH  
MULTIMODAL (MULTISENSORY) INTEGRATION,  
IN COGNITIVE SCIENCES  
MULTIMODAL (MULTISENSORY) INTEGRATION,  
IN TECHNOLOGY  
MULTIMODAL (MULTISENSORY) INTEGRATION:  
THE BINDING PROBLEM  
MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION  
PERCEPTION, DIRECT AND INDIRECT APPROACHES  
SENSORY SUBSTITUTION

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## CLASSIFICATION OF PERCEPTUAL MODALITIES: THE ECOLOGICAL APPROACH

Thomas A. Stoffregen [HFRL]

Perceptual modalities need to be classified only if there are, in fact, distinct modalities [→ MULTIMODALITY, IN COGNITIVE SCIENCES].

Classically, it is assumed that perception operates through a set of distinct systems, variously known as sensory systems, perceptual systems, perceptual modalities, and so on. While the existence of distinct modalities has great intuitive power, detailed classifications have proved difficult.

Sensory receptors have different anatomy, and different anatomical locations (e.g., eyes, ears, tongue, nasal cavity, skin, muscles, joints). However, classification on the basis of anatomy depends upon the prior acceptance of the assumption that the senses exist and operate either exclusively or primarily as independent units. The anatomical differences do not, by themselves, mandate this assumption. Anatomically distinct receptor struc-

tures often work together to achieve unitary perception (e.g., the two ears in sound localization, and the two eyes in stereopsis). Thus, the anatomical differences between the two ears, the two eyes, and so on, are not a sufficient reason for parsing perception into distinct senses.

An alternative classification is based on the form of physical energy involved: light, sound, chemical, mechanical, heat, etc. However, this is problematic, also. One cannot generate a list of stimulus energies without prior knowledge of perceptual systems. For example, defining vision as the pickup of information from light requires a definition of light. The electromagnetic spectrum is a continuum that has no inherent partitions. Only a narrow band of the spectrum is associated with vision and, thus, called light. Thus, defining vision in terms of electromagnetic energy requires an appeal to visible light, at which point the definition becomes circular.

It might be argued that there is a neurophysiology basis for the existence of distinct perceptual systems. However, the nervous system does not appear to be organized in a sense-specific fashion (e.g., [Stein & Meredith, 1993]). Thus, our current knowledge of neurophysiology cannot be used as an a priori justification for the assumption of separate senses. In addition to being problematic, all of these classification schemes beg the question of whether there actually are separate perceptual modalities.

Does perception really consist of a group of interacting modalities? If perception consists of the detection of patterns in the global array [→ ARRAY, GLOBAL] [Stoffregen & Bardy, 2001], then there may not be distinct perceptual modalities. If this is true, then there is nothing to classify.

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## RELATED ITEMS

ARRAY, GLOBAL  
CLASSIFICATION OF PERCEPTUAL MODALITIES  
MULTIMODAL (MULTISENSORY) INTEGRATION,  
IN COGNITIVE SCIENCES  
MULTIMODALITY, IN COGNITIVE SCIENCES  
PERCEPTION, DIRECT AND INDIRECT APPROACHES

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## CO-LOCATION

Gunnar Jansson [UPPSALA]

In order to act properly, people need correct perception of the location of objects in the environment. In the real world the information about their location is usually the same whatever sense is utilized. In virtual environments this may not be the case. Visual and haptic displays often present the same virtual object in different locations, the visual version on a screen, with or without stereo information, and the haptic version within the working area of a haptic display. This may not be considered to be very important, as perception is highly adaptable and, at least after some training, may function well also under such artificial conditions. On the other hand, it can be expected that virtual conditions similar to the real conditions may be advantageous, as people then can act under conditions more natural for them [→ HAPTIC DEPTH PERCEPTION].

There are efforts to increase the similarity between real and virtual worlds by rendering visual and haptic information that is calibrated to provide co-location. For the ReachIn device (<http://www.reachin.se>), for instance, co-location in this way is a basic idea. However, the expected advantage of co-location for perception and performance has been tested only in a few experimental studies [→ HAPTIC DEPTH PERCEPTION].

Wall et al. (2002) investigated the effects of co-location and stereoscopic information on

performance in a targeting task. The results were significant effects on accuracy for both factors, as well as a significant interaction such that, when stereo information is available, the benefit from haptic information was significantly less. Concerning time to reach target there was an advantage to have stereoscopic information, but haptic information had no effect. There were large individual differences in both dependent variables. As the participants in this experiment were beginners in using a haptic device, Wall et al. recommend caution in generalizing the results to other levels of expertise.

Jansson & Öström (2004) studied the effects of co-locating visual and haptic information, as well as of stereoscopic information, on the precision in the perception of object form. The experimental problem was the following. Is there any difference in precision of judging the distortion of a spherical object, when the information is presented in the form of exploratory motion paths, if (1) the visual information is presented stereoscopically or non-stereoscopically and (2) the visual and the haptic information is co-located or not? In other words, is there any benefit of presenting the visual information stereoscopically and co-locating visual and haptic information? The result was that co-location had a significant effect on the depth dimension under Stereo conditions. This demonstrates that co-location has positive effects on the perception of object form in depth. The studies mentioned were performed within relatively small environments (with a Phantom display in a Reachin co-locating device).

Bouguila, Ishii and Sato (2001) used a larger SCALABLE SPIDER device. They had noted the instability of depth perception in stereoscopic presentations of virtual environments and studied the contribution of haptics to the precision of locating virtual objects with random-dot stereoscopic information. They found that the precision of the location of objects in depth, as well as the time of performance, was improved when

haptic information was added to stereoscopic information.

A still larger virtual environment was studied at University College London (PURE-FORM, 2004). In a CAVE-like environment (ReaCToR) co-location of visual stereo information and haptic information via the Exoskeleton PURE-FORM display was arranged. Informal observations indicated that co-location was very important to enhance the experience, but it was also found that some participants had problems to visualize a 3D stereo object and focused on the front wall instead of the 3D position of the stereo model. This led to a discrepancy between visual and haptic information and loss of the stereo effect. A planned solution was to place the haptic interaction as close as possible to the projection wall.

A detailed analysis of the problems to get stereoscopic information to function well for depth perception in virtual environments was made by Wann, Rushton & Mon-Williams (1995). Such problems are common for all systems intending to present large spatial intervals from a dual 2D source. In contrast to natural conditions, accommodation and vergence eye movements are not coordinated when viewing these virtual displays, and the blur information available in natural contexts are missing in computer generated optical information, the conditions being more similar to 2D pictorial information. This problem increases when the range of stereoscopic depths is wider.

Wann et al.(1995) also stated that the dissociation of accommodation and convergence are not easily solved by increased display quality and concluded that several problems remain to accurately simulate 3D space from 2D images information. These problems motivated the author of a recent study of distance perception in virtual environments (Messing, 2004) to refrain from using stereoscopic information, with additional reference to the lack of difference between monocular and binocular informa-

tion at distances larger than two meters (Philbeck & Loomis, 1997).

In sum, it has been shown that co-location between visual (stereoscopic) and haptic information has positive effects on perception and action in small environments, but that several problems remain with applications in larger environments. It seems to be recommendable, especially in virtual environments with large depth intervals, to consider in each case if the visual information should be stereoscopic or not.

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## RELATED ITEMS

COMPUTER GRAPHICS  
DEPTH, PROBLEMS OF RENDERING  
HAPTIC DEPTH PERCEPTION  
IMMERSION VS. VIS-À-VIS

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## COBOT

Damien Couroussé [ACROE&INPG]  
Jean-Loup Florens [ACROE&INPG]

Cobot stands for collaborative robot. Edward Colgate, Witaya Wannasuphprasit and Michael Peshkin first proposed this term in 1996: they defined a cobot as “*a robotic device, which manipulates objects in collaboration with a human operator*” [Colgate et al., 1996]. Cobots were first designed in order to constrain human operator movements, in particular man-machine environments, but maintaining the human-object mechanical interaction: human movements are constrained by the definition of what is called virtual surfaces.

The simpler example of cobot principle is the “unicycle PCM” [Colgate, 1996]. In a common unicycle, the wheel can freely rotate, but its steering orientation is controlled by the human. In the unicycle PCM, the steering orientation is controlled by a control law depending on the position of the device on the ground; the rotation of the wheel is still free. This means that one degree-of-freedom is still controlled by the human (the motion of the device), but the device controls the other degree-of-freedom (movement direction). One compelling application of cobot use is shown in [Peshkin et al., 2001], where in a car factory the cobot is used as a chariot to transport doors of built cars. The cobot helps the operator carrying the door like a usual chariot would do, and displacements are controlled by the operator as it would be possible with a common chariot. The role of the cobot is to define virtual surfaces where penetration of the manipulated door is forbidden, or to provide safe escape paths from dangerous positions of the

manipulated door. This is done by modifying the chariot trajectories in function of its position, thus preventing contacts between the manipulated door and the car, avoiding hazardous movements that would damage the car’s painting.

Haptic devices are considered by part of the haptic researchers originated from the field of robotics as “*robots essentially designed for direct, physical interaction with human operators*” [Colgate, 1996]. Haptic devices can be considered as a mean to create a mechanical relation between a human and an artificial object, which does not really exist in the human’s physical world, but exists only under the form of an algorithm into the memory of the computer.

Conversely, cobots have been designed to help humans manipulating real objects (see definition above), and we have seen that the mechanical interaction that exists between the human and the object in the natural manipulation situation still exists in the case of cobots. The role of the cobot is to modify the available degrees of freedom, for example by introducing movement constraints. In other words, a cobot modifies an already existing human-object mechanical interaction whereas a haptic device artificially creates a new one.

Cobots are thus defined as a mechanical interface designed to interact with a human without masking the mechanical interaction between the human (manipulating-person) and the manipulated object. The philosophy of such systems remains indeed in a shared control of motion between the user and the cobot, and in the fact that a cobot mechanically interacts both with the human and the manipulated object. To perform that, cobots interact with people only by producing software-defined virtual surfaces, which constrain and guide the motion of the shared payload, but no mechanical energy to the human-object interaction. In cobots, the source of mechanical energy remains the user, and a cobot is only able to modify the energetic link between the user and the ma-

nipulated object: from that point of view, the cobot is a passive device because it does not bring supplementary energy to the human or to the manipulated object. In other words, if the user does not move the manipulated object, the cobot is not able to generate motion on its own.

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## RELATED ITEMS

AGENT, AUTONOMOUS  
 AUTOPOIESIS  
 COGNITION, DYNAMIC SYSTEMS APPROACH  
 FORCE FEEDBACK DEVICE / FORCE PROPERTIES  
 STABILITY

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## COGNITION, DISTRIBUTED

Elena Pasquinelli [INSTNICOD]

Distributed cognition concerns cognitive tasks that are not entirely determined by the internal information processing capacities of single individuals.

The claim that cognition is distributed means that cognition is not entirely determined by the processing information capacities internal to one agent.

Examples of distributed cognitive systems are provided in which cognitive properties, such as representations, are distributed between multiple agents and some special technological device [Hutchins, 1995].

Other examples of distributed processes regard the involvement of material actions that operate changes in the world in order to simplify the internal processing [Kirsh, 1995].

Cognition is thus extended beyond the limits of the single agent and of its internal processes to include social and material conditions of the world and the agent's bodily actions.

In this sense, distributed cognition approaches are connected to the approach called active externalism [Clark, 1998], which asserts that the present external world plays an active role in driving cognitive processes and has a strong impact in the behaviour of the organism.

More generally, the claim that cognition is distributed is related to the situated, to the enactive and to the embodied approach to cognition because of the role assigned to the conditions of the external world and to bodily actions.

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## RELATED ITEMS

COGNITION, SITUATED  
 COGNITIVE SCIENCES  
 ENACTIVE COGNITIVE SCIENCES\_ 1&2  
 PERCEPTION, MOTOR THEORIES OF

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## COGNITION, DYNAMIC SYSTEMS APPROACH

Elena Pasquinelli [INSTNICOD]

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The dynamic systems approach to cognition aims at capturing by dynamical laws the macroscopic organisation of goal directed behaviours of man and animals through the application of the mathematical concepts and laws of dynamics [Thelen & Smith, 1994].

These laws relate quantities describing the states of the system and their evolution in time. The aim consists in finding a meaningful description of the behaviour, in relation to the task goal, and focus on the stability of this behaviour.

These laws are non linear, which accounts for the multistability of behaviours, and the sudden changes between stable patterns of behaviours. The use of dynamical systems [→DYNAMIC SYSTEMS] for the description of self-organization of behaviours originated in the discovery of a phase transition in brain and behaviour by [Kelso, 1984] [Kelso, 1995], modelled by a bifurcation in a dynamical system by [Haken, et al., 1985], using the tools forged in the field of synergetics [Haken, 1977].

At the core of the approach lies the concept of change in real time, concerning the total state of the system with all its components co-evolving simultaneously. This evolution is represented geometrically [Van Gelder, 1999].

The focus of the attention is hence directed upon persistence. Persistence exists because there are changes that reveal them (the concept of transformational invariants), and changes exist because there are states that reveal them (the qualitative bifurcation between states under the influence of a quantitative control parameter).

A large set of co-evolving factors, including bodily factors and environmental factors is taken into account. The dynamic systems approach is in fact characterized by a strong accent on the connections between the body, the brain and the behavioural processes: *“This situates cognition within the same continuous, time-based, and non-linear processes as those involved in bodily movement, and in large-scale processes in the nervous system [...] Finding a common language for behaviour, body, and brain is a first step for banishing the spectre of dualism once for all [...] This changes the information-processing flow from the traditional input-transduction-output stream to one of time-based and often shifting patterns of cooperative and competitive interactions. The advantage is the ability to capture the subtle contextual and temporal influences that are the hallmarks of real life behaviour in the world.”* [Thelen et al., 2000, p. 5].

The dynamic approach is thus related to the view of cognition which is expressed by enactive, embodied and situated approaches [→COGNITION, SITUATED] [→ENACTIVE COGNITIVE SCIENCES\_1&2] in contrast with some of the tenets of the representationalist/computationalist view [→COMPUTATIONAL PARADIGM].

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## RELATED ITEMS

COGNITION, SITUATED  
COMPUTATIONAL PARADIGM  
DYNAMIC SYSTEMS  
ENACTIVE COGNITIVE SCIENCES\_1  
PERCEPTION, MOTOR THEORIES OF

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## COGNITION, SITUATED

Elena Pasquinelli [INSTNICOD]

The claim of the situated character of cognition is a characteristic of a group of approaches to perception, action and cognition that in some way relate to each other and converge in the new wave of approaches to cognitive studies that can be indicated as enactive cognitive sciences.

This new wave is characterized by a strong accent upon the role of action in contest, for consequence upon the situated and embodied character of cognitive processes. Nevertheless, the enactive, situated, embodied view is not a homogeneous theoretical system.

Some of the representative figures of this new wave (such as [Brooks, 1991] [Kirsh, 1991] [Pylyshyn, 2000]) put a strong accent on the fact that action, perception and cognition are anchored in some state of the world external even to the body. External states can be constituted by other people symbolic processes [Vygotskij, 1962] [Hutchins, 1995] and by technological devices and other objects [Hutchins, 1995] [Clancey, 1995]. This kind of situated cognition is also indicated as distributed cognition. As [Brooks, 1991] does, distributed cognition approaches affirm the role of the world and of the actions of collaborating agents in the shaping of high-level cognitive processes.

The situated and distributed character of cognition leads to an externalist view of the mind, as it is explicated by [Clark & Chalm-

ers, 1998]: the external reality is responsible for the beliefs of the individual by driving cognitive processes and behaviours of the organism.

In Brooks' view, it is the embeddedness, the fact that the system interacts with the world through its own body, and not the internal structure, that is held to be responsible for what can be considered the intelligent behaviour of the system. Because the state of the world guides their behaviour, creatures need no explicit representation of the world or of the intentions of the system in order to generate intelligent behaviour.

Another possible attitude toward representations is to accept the existence and the role played by symbolic representations but to advance the necessity of integrating symbolic representations with other kinds of representations which are not based upon symbolic encoding.

[Pylyshyn, 2000] argues for the necessity of including demonstrative reference or visual indexes in order to integrate purely conceptual representations so as to make action in context possible. Symbolic representations are not given away, but they are recognized as insufficient for explaining action on objects based upon visual inputs. A representation that there is a stone in a box is not sufficient to prompt action (emptying the box) if it is not anchored to the situation in which action should take place; there must be a representation that there is a stone in *this* box. The representations [ $\rightarrow$  REPRESENTATION] that there is a stone in *this* box is a demonstrative index or demonstrative reference which is situated in the egocentric perception of the agent. In absence of demonstrative reference, an exhaustive representation should be prompted of the entire scene, including all its properties encoded in absolute terms. Demonstratives are normally required by the visual system and can be used in robotics in order to connect perception to action.

[Clancey, 1995] proposes a view of situated learning and cognition which considers situ-



atedness in a larger sense, such as in the case of the situated and embodied Creatures proposed by Brooks. Contrarily to Brooks, representations are not necessarily discarded within this approach, but the necessity of understanding how representations are created and given meaning is affirmed. In the process of learning, for instance, representations are not means for gaining new knowledge: a learner also participates in the creation of what constitutes a representation, that is in its meaning. The attribution of meaning to representations typically involves two levels of interaction with the external environment: the interpersonal level (social setting) and the gestural-material level (interaction with physical materials, perceptual activities).

In many senses, then, cognition is situated: in a body, in a physical world and also in a social one.

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## RELATED ITEMS

COGNITION, DISTRIBUTED  
COGNITIVE SCIENCES  
COMPUTATIONAL PARADIGM  
ENACTIVE COGNITIVE SCIENCES\_ 1&2  
PERCEPTION, MOTOR THEORIES OF  
REPRESENTATION

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## COGNITIVE DISSONANCE

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Conflicts can be experienced at different levels that influence the believability and performances of mediated experiences. Perceptual conflicts are especially relevant for multimodal and enactive interfaces, but cognitive issues and conflicts are not excluded by these forms of experiences. It is important that, as in the case of perceptual conflicts, spontaneous solutions to cognitive conflicts go in the direction of re-establishing coherence and of preserving expectations. This general indication is especially significant for the proposition of believable experiences because the frustration of expectations, at the cognitive or perceptual level, and the violation of coherence negatively affect the believability of new experiences.

A specific theory has been advanced by [Festinger, 1957] for explaining the fact that the existence of a dissonance or inconsistency between beliefs or other mental states is resented as negative by the subject. [Festinger, 1957] proposes that cognitive dissonance is a psychological tension similar to hunger and thirst and that for this reason people will seek to resolve this tension. The solution consists in changing the beliefs and other mental states in order to reduce the dissonance and re-establish the balance between the cognitions.

According to the theory of cognitive dissonance, the human mind thus tends to adopt thoughts or beliefs so as to minimise the amount of dissonance (conflict) between cognitions. In other words, subjects are assumed to seek consistency among their beliefs and other mental states.

Two factors in particular are described that affect the strength of the dissonance: the number of dissonant beliefs, and the importance attached to each belief. Dissonance occurs when the subject must choose be-

tween incompatible beliefs and when the alternatives are all attractive.

The reduction of cognitive dissonance is operated through different strategies: the reduction of the importance of the dissonant beliefs, the addition of more consonant beliefs that outweigh the dissonant beliefs and, finally, the operation of changes in the dissonant beliefs so that they are no longer inconsistent.

A comparison between cognitive and perceptual conflicts should ascertain whether analogous mechanisms are activated in presence of conflicts and whether analogous solutions are put in action.

The psychological effect of the reduction of cognitive dissonance is the reduction of the tension. But the modification of dissonant beliefs might involve a distortion of the truth and cause wrong decisions. This is true for perceptual conflicts too, where mid-way solutions can be described that do not correspond to the features of none of the involved partial stimuli, with consequent errors and non-adaptive responses [Stein & Meredith, 1993].

However, both in the case of perceptual and cognitive conflicts, the fact of finding a unitary, coherent solution seems to be more important than respecting the truth of the source of information, and producing a response seems to be more important than producing the right one (the behavioural effect of a non-solved state of conflict being a paralysis of action [Stein & Meredith, 1993]).

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## RELATED ITEMS

BELIEVABILITY\_1&2  
COHERENCE OF PERCEPTUAL EXPERIENCE  
MULTIMODAL (MULTISENSORY) INTEGRATION,  
IN COGNITIVE SCIENCES  
PERCEPTUAL CONFLICTS

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## COGNITIVE SCIENCES

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The characteristics of the mind-world connection have a special appeal for philosophers.

In parallel to discoveries in neurophysiology, the development of artificial intelligent and of new interfaces based on action and perception, solicites the redefinition of relevant questions for the philosophy of mind and give contents to the special group of studies dedicated to cognition and grown up under the name of “cognitive sciences”.

The cognitive sciences constitute a gerrymandered group of approaches to the problems connected with cognition. They include approaches directed to different objects that can be quite general or very specific: cognition in general (human and animal cognitive processes as well as machine cognition and the simulation of human cognitive abilities), symbolic processes, memory, attention, consciousness, action planning and execution, learning, knowledge, reasoning, speech and language understanding and reading, perception, including vision, hearing, touch and kinesthesia, the mind-body problem.

The cognitive sciences are not necessarily committed to a particular vision of mind and its functioning. However, there has been a consensus for a working paradigm for many years, although of late cognitive scientists have been divided in their opinion, which has led to a paradigmatic shift in the domain during the last few years.

This paradigm broadly presumes that the mind is an information processor that receives, stores, retrieves, transforms, and transmits information. The information and the corresponding information processes can then be studied as forms, patterns, and functions.

The evolution in the approach to cognition and in particular to perception and action has created the label of cognitivism for the classic cognitive science; cognitivism or classic cognitive science can be identified with an interdisciplinary school of thought, a view of the mind which constitutes the orthodoxy or the mainstream in the sciences of the mind.

The adoption of the computer metaphor for describing the mind and the account of cognitive processes as inferential procedures upon internal, symbolic representations can be indicated a minimal common denominator of cognitivism.

The classicist view can thus also be described as computationalism and representationalism (see for instance Fodor, 1975; Marr, 1982; Putnam, 1961 as representative of computationalism and representationalism and Lucas, 1961; Rumelhart, 1986; Searle, 1980; Dreyfus, 1972 as classic opponents to this view).

Nonetheless, the approaches that are included within the frame of the classicist view of the mind are not homogeneous, and the same is true of the growing research program that is characterized by a critical attitude towards the mainstream.

Some claims can be individuated that are characteristic of the opposition to the mainstream:

- Cognition is not (limited to) being the mirror of reality and perception does not (only) consists of the representation of the world. This claim leads to the criticism of internal representations
- Cognitive processes are not (necessarily) centralized, i.e.: there is no gap between cognitive processes and their surrounds
- Perception and cognition cannot be considered outside the frame of action

However, these claims are differently interpreted by their supporters and under the banner of the criticism to representations alternative positions can be proposed.

Cognitive science is also an interdisciplinary field of research that draws upon many fields including psychology, philosophy,

computer science, artificial intelligence, neuroscience, and linguistics.

One frequently addressed question asks why cognitive science involves so many disciplines or how each of them contributes to the subject. One answer lies in the origin of this research field: in the late 1950s, scientists from different disciplines realized that they were trying to solve the same problems concerning the mind and the brain. They agreed that they would be better off pooling their resources and knowledge and start to work together. This effort is still valid.

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## RELATED ITEMS

ACTIVE PERCEPTION / TOUCH  
 COMPUTATIONAL PARADIGM  
 ENACTIVE COGNITIVE SCIENCES\_ 1&2  
 INTERFACE, ENACTIVE  
 PERCEPTION, DIRECT AND INDIRECT APPROACHES  
 PSYCHOPHYSICS  
 SENSORIMOTOR

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## COHERENCE OF PERCEPTUAL EXPERIENCE

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Not only perceptual experience is usually multimodal, but the integration of information from different sensory modalities allows subject to get a consistent, reinforced knowledge about the surrounding world, thus giving rise to behaviourally relevant information.

This added value of multisensoriality for the production of behaviourally efficient actions has been understood in the framework of new interfaces, such as enactive interfaces.

However, multimodal interfaces put perceivers in the condition of experiencing perceptual conflicts that put believability at risk. The existence of spontaneous solutions to perceptual and cognitive conflicts put in evidence the adaptive value of coherence for adaptive and epistemic behaviours.

The conflict or disaccord between experiences is a form of inconsistency, thus of violation of the coherence of experience.

Coherence is defined as a consistent relation of members of a set. A set is coherent if and only if each member of the set is consistent with the other members and each member is implied by the others. Consistency is defined as an attribute of a logical system that is so constituted that none of the propositions deducible from the axioms contradict one another. Coherence is then an internal characteristic, which does not imply the confrontation with conditions external to the set.

Violations of the coherence of experience can be both synchronic and diachronic:

- violations of diachronic coherence arise when previously acquired knowledge or previous experiences are inconsistent with actually gathered information, thus when actual experience is in disaccord with some expectation
- violations of synchronic coherence depend on the contradiction between two or more synchronic experiences; examples are represented by intersensory conflicts and illusions provoked by ambiguous experiences, such as paradoxes.

In both cases the awareness that coherence is violated alerts the perceiver to the presence of some error and a reaction of surprise arises. This reaction has an epistemic value for the perceiver.

However, different mechanisms exist for maintaining coherence in presence of discrepant perceptual stimuli and even in presence of cognitive dissonances [Stein & Meredith, 1993] [Bruner & Postman, 1949] [Festinger, 1957]. It is hence proposed that coherence has a positive adaptive value and that violations of coherence present a disruptive effect on adaptive behaviours [Stein & Meredith, 1993] [Bruner & Postman, 1949].

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### RELATED ITEMS

COGNITIVE DISSONANCE  
ILLUSION  
MULTIMODAL (MULTISENSORY) INTEGRATION,  
IN COGNITIVE SCIENCES  
MULTIMODAL (MULTISENSORY) INTEGRATION,  
IN TECHNOLOGY  
MULTIMODAL (MULTISENSORY) INTEGRATION:  
THE BINDING PROBLEM  
MULTIMODALITY AND ENACTION  
PERCEPTUAL CONFLICTS

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## COLLISION DETECTION ALGORITHM

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For many years, collision detection has been of major interest in robotics and computer graphics [ $\rightarrow$  COMPUTER GRAPHICS]. Numerous approaches have been investigated to detect interfering objects in applications such as robot task planning, computational biology, games, surgery simulation, and cloth simulation. The central physical concept is spatial exclusion, i.e. the fact that two physical objects cannot occupy the same spatial location.

In the context of virtual computer-simulated objects, the spatial exclusion principle must be implemented through specific algorithms. Consequently, collision detection algorithms (CDA) are developed to avoid the interpenetration of two or more virtual objects.

The CDA depend on the type of objects and the type of their computer representation. They have been first developed in the context of perfectly rigid objects of which the computer models are based on geometry for the shape and direct cinematic for the motion. Consequently the central processes of the CDA are the computation of impact points and impact times, from the geometry and the cinematic of the objects. From these extracted data, movements after collision are programmed, through the computation of the velocity and acceleration vectors after the collision. When the computer representations of motion shifted from cinematic representations to physically based representations, the movement after collision is based on the computation of force applied to objects at

the contact point and at the contact instant [Lin et al. 1997] [Redon et al. 2002].

From the rigid bodies framework, techniques evolved progressively by introducing deformable objects as soft objects are frequent in surgery simulation [Teschner et al. 2005].

Many methods for collision detection of the contact points are based on bounding volume hierarchies. The main idea is to partition the set of object primitives recursively until some leaf criterion is met. Some other widely used algorithms are based on spatial subdivision, stochastic methods, and distance field or image-space technique. While a large number of methods are developed for general or semi-general cases, some other methods are also designed for fast collision detection in special cases with some pre-known geometrical limitations.

The detection of the instant point in cinematic based approaches is mainly based on sample rate adaptation and time forward. So saying, they are not on-line oriented. Conversely explicit physically-based approaches [ $\rightarrow$  PHYSICALLY-BASED MODELLING], are based on the on-line computation of the collision forces at each time sample.

In the context of the haptic rendering [ $\rightarrow$  HAPTIC RENDERING OF VIRTUAL OBJECTS], the purpose of collision detection is not only to check collisions between objects, but more frequently to check collisions between the probe(s) of the haptic device and the virtual objects to compute the interaction forces. It is the elementary basic core of the human-computer enactive interaction. It consists in considering the haptic device as an external non-virtual object. In the hard real time context imposed by haptic interaction between human and virtual objects, collision detection algorithms become a hard bottleneck to overcome, the processes to detect contact and time points being highly demanding in term of computer load.

In the typology of exemplary enactive tasks as presented in [Luciani et al. 2006], the collision detection problem appears as a

critical bottleneck. The complexity and computer load of CDA increases drastically, when the expected interaction between users and physical objects is more and more tangible such as in case of strong enactive interaction. It increases also drastically in spatially-oriented manipulation tasks such as those in CAD (computer aided design) mechanical design, in mechanical maintainability as necessary in industrial applications (mechanics, aeronautics), or in surgery, in which the density of number objects and the density of variable objects are greater than in exploration and navigation tasks in large virtual environments. Such types of interactive tasks are characterized by:

- a high density of objects: very small free space ; highly confined scenes or dense maze.
- a high variety of objects with various mechanical functions, behaviours and shape: rigid well shaped components, deformable parts, wires, tubes, etc.

Real time optimization CDA techniques are then a main component of virtual reality systems and for the future are identified as a major bottleneck of enactive interfaces, linked to object scene local complexity and to the morphological complexity of the probe of the haptic device in tactile and in force rendering.

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## RELATED ITEMS

ALGORITHM  
 COMPUTER GRAPHICS  
 CONTACT INTERACTION  
 FORCE  
 HAPTIC RENDERING OF VIRTUAL OBJECTS  
 HAPTICS, IN COGNITIVE SCIENCES  
 PHYSICALLY-BASED MODELLING

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## COMPLEXITY IN HUMAN MOTOR BEHAVIOUR

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The boundary between simple and complex behaviour remains difficult to define. Classically, the term of simple behaviour has been reserved to mono-articular motion, involving the control of a low number of degrees of freedom. In contrast, gross motor skills were conceived as complex, requiring the mastery of a high-dimensional system. The dynamical approach to motor coordination, nevertheless, had shown that “simple” tasks such as the coordination of the oscillations of the two index fingers gave raise to a very complex dynamics.

An operational definition was recently proposed [Wulf & Shea, 2002]. A behaviour can be characterized as complex when:

- it requires the mastery of a number of degrees of freedom (in contrast with uni-dimensional behaviours);
- its learning cannot be conceived within a single session of practice;
- and this behaviour presents a certain ecological relevancy.

The authors analyzed a number of studies, concerning the effects of various factors, such as feedback, modeling, instructions, or contextual interference, on skill acquisition, and showed that results obtained in simple

tasks cannot be generalized to complex behaviours.

Note that the experimental approach to motor control and motor learning often used very simple laboratory tasks.

Task could be defined as a goal to reach in a specified environment. Task decomposition suggests that a complex task could be decomposed in several sub-tasks, defined by sub-goals which have to be reached, sequentially or simultaneously. Task decomposition has been proposed, notably, for learning purpose, in the aim to facilitate the acquisition of skills.

This approach is underlain by an analytic view of learning that should be questioned. Obviously, the computational models of cognition played an important role in the emergence of such points of view about learning [Schmidt, 1982]. Can we really conceive a task as the summation of elementary components? Is learning only the mastery of all sub-tasks or, rather, the coordination of components? Could task decomposition lead to an essential loss in complexity? The results obtained in such experimental paradigms were supposed to be generalizable to a wide range of situations. This approach was central in the traditional computational conceptions of cognitive sciences.

From the enactive point of view, complexity possesses specific properties that cannot be reduced to the summation of elementary components. A complex behaviour could be defined as the coordination of several sub-components, but in this case the most important is not the sub-components, but the coordination by itself. An efficient learning task should be able to confront the learner to sufficient complexity but also to avoid insurmountable difficulties.

To sum up, in the domain of enactive sciences, complexity is often conceived as a resource for perception and action, that should be analysed per se and not a priori discarded.

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## RELATED ITEMS

COGNITION, DYNAMIC SYSTEMS APPROACH  
DEGREES OF FREEDOM IN HUMAN MOVEMENT  
DYNAMIC SYSTEMS  
LEARNING AND TRAINING METHODS  
SENSORIMOTOR

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## COMPUTATIONAL PARADIGM

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The computational paradigm, also known as the computational theory of mind (CTM) [Horst 2005] is, historically, at the origin of cognitive science. The fundamental postulate is that cognition can be defined as syntactically - regulated operations on formal symbols. It views the human mind is best as an information processing system very similar to or identical with a digital computer. In other words, thought is a kind of computation and the mind is to the brain as software is to hardware. This paradigm assumes that human cognitive abilities are explicable by computational models.

This claim has been objected by arguing for example that some human cognitive processes are not algorithmic considering as Fetzer that “*even if some thought processes are computational, most of them are not*” [Fetzer 1998].

The computational paradigm goes back the pioneers of computing, Turing and von Neumann. As he was wondering whether

computers can think, Turing formulated the famous Turing test: a computer could be said intelligent when, if placed in a room by itself next to another room which contained a human being and with the same questions being asked to both the computer and the human being by a third party human being, the computer's responses turned out to be indistinguishable from those of the human [Wikipedia 2007]. Searle argued about the Turing test with the Chinese room argument [Cole 2004] and concluded that implementing a program is not a sufficient condition to obtain intelligence; it also requires semantics.

During the 1970s and 1980s, the CTM was successfully deployed in psychology [Fodor 75] [Marr 1977], in linguistics [Minsky 85], in neuroscience [McCulloch et al. 1943] and more recently the “connexionist networks”. In computer science, the computational paradigm is closely related to artificial intelligence. Adepts of “strong artificial intelligence” estimate that, correctly programmed, a computer is able to understand and think, whereas adepts of “weak artificial intelligence” only state that computers can simulate mental abilities.

Despite the controversies about this paradigm in its strong or weak acceptance, it has motivated the development of new fields in computer sciences such as artificial life [Emmeche 1992], close to artificial intelligence, and to some extent virtual reality. If one assumes that at least some human cognitive abilities can be explained by computational models, he/she may also assume that it is possible to define computational models that can describe and simulate these abilities, and therefore that one should be able to some extent to create artificial life. Likewise artificial intelligence, it is possible to make the distinction between “strong artificial life”, claiming that it is possible to realize life with computers, and “weak artificial life” that only states that it is possible to replicate aspects of living behaviour by computer simulation [Emmeche 1992].

It is possible to consider a shift from this classical computational paradigm and to question the role of computer with regard to the human cognition: “*computers are not only symbol processors, they are reality generators. Virtual reality is the body of techniques that apply computation to the generation of cognitively valid realities*” [Bricken 1990]. Close to the immersion of the body inside artificial reality, [Mingers 2001] is also advocating for embodying information systems. He points out the embodied and enactive nature of thought and language and argues that “*the disciplines of information systems and artificial intelligence need to become embodied — that is, they must move beyond the dualism of mind and body to recognize that human cognition and social action are inherently embodied.*” Among other proposals, he suggests to consider the importance of interactive embodiment, which particularly involves interfaces, virtual reality, and multimedia.

Hence, during the 1990s, the CTM came up against a number of serious problems (notably the symbol grounding problem, and the frame problem). Although it still has a strong hold on the cognitive science community (notably in terms of presuppositions that are not always made explicit), at the present time there are relatively few cognitive scientists who openly espouse the classical form of the theory. Thus, the time is ripe for a change: the emergent paradigm of enaction is a major contender to replace the CTM. It should be emphasized that this goes beyond mere reform; it is a genuine paradigm shift, in the sense of Kuhn, so that work in one or other paradigm is seriously incommensurable.

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## RELATED ITEMS

AGENT, AUTONOMOUS  
 COGNITIVE SCIENCES  
 ENACTIVE COGNITIVE SCIENCES\_ 1&2  
 FORMAL SYMBOL SYSTEMS  
 INTELLIGENT CHARACTERS INTELLIGENT  
 PERCEPTION, DIRECT AND INDIRECT APPROACHES  
 REPRESENTATION  
 TURING MACHINE

## RELATED DOCUMENTS

EI\_Enaction&CognitiveSciences\_Stewart.pdf

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## COMPUTER GRAPHICS

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The expression computer graphics (CG) describes the usage of a computer to process mathematical algorithms, descriptions, or models to alter or integrate visual and spatial information in order to create a (realistic) image. As today hardware- and software-systems are at a level that allows creating highly realistic virtual images or environments, their use and enhancement in interfaces and applications is still growing. For enactive interfaces, a reasonable amount of work concentrates on improving and developing, as well as using CG.

Classically, CG can be done in different numbers of dimensions (traditionally done in 2D and 3D). Two-dimensional graphic programs are generally based on vector or raster graphics and 3D graphics tend to use vectors through lines between points in 3D coordinates. With these 3D models it is possible to create whole 3D scenes, which can then be defined with different properties, e.g. filled with different light sources or textures on the 3D objects.

Most CG procedures contain a final step in which 3D images are converted into 2D images for displaying. In a rendering process, for example, the 3D scene is viewed from a particular viewpoint and is transformed into a 2D image. This process can be done in real time, which means that a user can interactively move through this 3D scene and the simulated images are created immediately. This is used for virtual reality and computer games. The system speed necessary for real time CG, however, puts constraints on the image quality that can be achieved. For

higher quality images, off-line, non-interactive processes are needed.

There are several techniques, which mix the virtual and real using CG methods: augmented reality [→ REALITY, AUGMENTED AND MIXED] focuses on a mixture of CG and real images – here, synthetic, rendered CG images are added to images gathered from the real world, as if they were in the same space. Augmented virtuality adds real world pictorial data to synthetic images. And mixed reality in which information is simply added to real images without checking for consistency. Techniques based on non-photorealistic rendering are also explored as they can offer new approaches for rendering meaningful information in complex settings (e.g. CAD-CAM, scientific visualization, medical data interpretation, etc).

Recently, there has been a growing interest in interdisciplinary studies of CG and phenomena of perception. The CG community has realized the importance of taking human perception into account in order to increase the perceived realism and believability of images, animations and virtual environments. On the other side, researchers in the field of psychology have discovered the potential of using computer graphics for devising scenes and tasks with stimuli providing full control over all scene parameters and which are able to truly reflect the situations being simulated [O'Sullivan et al., 2004]. These approaches are also taken into account and some projects investigate the perceptual issues of the enactive interfaces. These studies provide a baseline for developing believable enactive applications.

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## RELATED ITEMS

AVATAR  
BELIEVABILITY\_1&2  
DISPLAY, VISUAL  
HAPTIC RENDERING OF VIRTUAL OBJECTS  
PHYSICALLY-BASED MODELLING TECHNIQUES FOR  
MOVEMENT SYNTHESIS AND ANIMATION  
REALITY, AUGMENTED AND MIXED  
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT  
VISUAL PERCEPTION

## RELATED DOCUMENTS

El\_Action-Vision\_Cornerstones\_Luciani\_040915.pdf  
El\_Action-Vision\_Novel issues\_Luciani\_040915.pdf  
El\_ComputerAnimation\_Luciani\_040930.doc  
El\_ComputerGeometry&Light\_Carrozzino\_041001.pdf  
El\_Enaction&ComputerTechnologies\_Luciani.pdf

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## COMPUTER GRAPHICS, FIRST PERSON POINT OF VIEW

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In the literature on computer graphics [→ COMPUTER GRAPHICS], the first person point of view is used by the author to present a story from the narrator's perspective. In computer graphics, the point of view is used to describe the position of the camera inside the 3D scene in order to compute the point of view (POV) of the scene. The first person point of view is a representation of the three-dimensional scene according to the user's position inside the scene. So the first person view shows what the user would see if they were really present in the virtual world.

### Camera definition of First person POV

This POV includes different kind of parameters like position, orientation and frustum angle. The camera (i.e., point of view of

3D scene rendering) is placed in the scene in place of the user's point of view, providing the user the feeling of being "inside" the scene. The user's motion (trajectory or point of interest) is directly retransmitted to the camera, i.e., when the user turn their head, the camera turn as well, identically for the pitch and roll of the head motion. Also, the motion inside the scene is retransmitted to the camera like left or right, up or down motions. When the user move in the scene the camera follows the user motion. This kind of POV is used also with head-mounted display systems.

The main difference with a classical viewing system is that this kind of system includes not only the camera's point of view, but the user also has the sensation of being inside the scene. For example, in a first person POV, the user motion can be limited by the user body constraints and not only by the point of view (the user is not a simple point but also has a volume). Depending on the kind of application, the user is also able to see a virtual representation off their body or some part of themselves (like hands or arms). Many current day games [McCabe & Kneafsey, 2006] use this representation where the user plays the game from the point of view of the protagonist. Some examples of such games are: Quake, Call of Duty and the Need for Speed series.

### **Motion control**

Most of first person POV applications use a combination of keyboard and mouse actions to control the user's motion. One hand uses the mouse, which is used for changing the look-at direction freely, aiming and turning the player's view horizontally and vertically. Mouse button are used to do simple actions like fire function for game applications or to speed up/stop motion. On the keyboard, the arrow keys provide movement forwards, backwards and side-stepping left and right. Another combination of keys could be used to provide simple access to action like taking an object or opening a door. Other devices commonly used to

provide motion control to the user are gamepads and joysticks. More complex applications could also use motion capture systems in order to reproduce the user posture and detect the view direction of the user

The main advantage of this representation is that it provides the most immersive [Rouse, 1999] experience to the user [→ IMMERSION VS. VIS-À-VIS]. Since the user's motion is translated directly to affect the visual result (camera position and point of view), the user has a better sensation of control in the virtual environment [Christie & Olivier, 2006]. This is most often used in virtual and mixed reality environments to give a better sense of immersion. So it is a very important consideration in the design of immersive enactive interfaces where visual feedback is used to guide the user. Users can better appreciate their place (or have an enhanced sense of presence) in the virtual world if they can see the world from their own point of view.

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### **RELATED ITEMS**

COMPUTER GRAPHICS  
IMMERSION VS. VIS-À-VIS  
MOTION CONTROL, HIGH-LEVEL  
MOTION CONTROL, HIGH-LEVEL  
REALITY, AUGMENTED AND MIXED  
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT  
ZOOMABLE EXPERIENCE

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## COMPUTER GRAPHICS, SEMANTICS IN

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Semantic usually refers to the aspects of meaning and to possible meta-data associated to an item to describe a particular content with high level information. It is differentiated from syntax, which is the construction of complex signs from simpler signs. In computer science, semantic is most often considered as an application of logic, where it reflects the meaning of programs [Reynolds 1998].

In the context of computer graphics [ $\rightarrow$  COMPUTER GRAPHICS], the term refers to meta-data information and high level meanings of visual objects, such as for instance what they represent and how they are linked with other objects. Based on their level of abstraction from the underlying hardware the semantics of computer graphics representation can be categorized into three levels. Low-level graphics directly deals with the pixel and vertex level representation through the use of device drivers and shaders [Fernando 2004]. Mid-level representations consist of graphics application programming interfaces [ $\rightarrow$  INTERFACE] like OpenGL [OpenGL, 2005] and DirectX. High-level representations like scene graphs provided by libraries like OpenSceneGraph [OSG, 2007] encapsulate spatial relations between different objects that constitute a scene. As we move towards higher-level representations we become more independent of the hardware and the description of the scene becomes easier while finer control over vertex level data decreases.

In computer animation semantics can be used to abstract specific data such as animation parameters, animation sequences or

virtual human behaviours, into higher-level information for use in complex artificial intelligence based systems or complex management architectures of data.

In the framework of enactive interfaces, as research deal with many aspects of virtual reality, the use of high-level semantics becomes essential to describe virtual environments and behaviours of virtual characters when they interact with real humans.

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### RELATED ITEMS

COMPUTER GRAPHICS  
INTERFACE  
MOTION CONTROL, HIGH-LEVEL  
AVATAR

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## CONSCIOUS ACCESS AND COGNITIVE ACCESS

Kevin O'Regan [CNRS]

In the study of enactive interfaces it is useful to evaluate the degree to which users are conscious of their perceptual and motor activity. The notion of consciousness however is a difficult and much debated notion. A well-known distinction between "access" and "phenomenal" consciousness made by the philosopher Ned Block helps in making the notion more precise [Block, 1995].

Ned Block considers that having conscious access to  $X$  means: being poised to make use of  $X$  in reasoning, planning or speech. Con-

conscious access of  $X$  is something like "being aware of" or "noticing"  $X$ . The notion of conscious access seems to presuppose the existence of a "self" which "knows" that it is making use of  $X$ . For this reason it may be useful to define a more basic notion than conscious access, namely "cognitive access", and then to suppose that what is meant by conscious access to  $X$  is: the self having cognitive access to the fact that it, as an individual, has cognitive access to  $X$ . This approach to conscious access may be related to what have been called "higher order thought" theories of consciousness.

Coming then to define cognitive access, we can use the same definition that Ned Block used for conscious access, but without the notion of self: having cognitive access to  $X$  is: being poised to make use of  $X$  in reasoning, rational action, planning or communication. Note that this notion is applicable not only to humans, but also to animals and artificial agents. Thus the reasoning, rational action, planning and communication involved must be of quite limited kind. On the other hand the peculiar term "poised" is used in order to stress that it is not simply meant that the agent is now using  $X$  in its cognitive processing. The agent must be in a state where it can but need not use it. For this to be possible, the agent must have sufficient complexity for it to make sense to say that it has some choice in the matter. On the other hand, note that it is not necessary that the agent know that it itself exists as an entity or that it know that it has the choice or the cognitive access or the purpose in question.

As an example consider a tic tac toe playing machine. The machine is built to attain a purpose, to win the game, and at each juncture there is a choice about what move to make. The machine registers your move, evaluates the possibilities and prepares an appropriate response. Seen from the outside, it makes sense to say that the machine chooses which move to make and that it has rational cognitive activities since it can reason, plan moves in advance, judge, and communicate to a limited degree: all this even

though the machine itself does not know that it has these capacities. The machine is poised to make use of your move in its further rational behaviour. We must say the machine has cognitive access to your move.

But whereas the tic tac toe playing system has cognitive access to your move, it does not have cognitive access to the fact that right now it is in a sticky situation, or that in general it plays a mediocre game, because these are things that the system is simply not programmed to "think" about: it does not make use of them in its reasoning, planning, judgment or communication.

Another point concerns the notion of point of view. Suppose we take the tic tac toe playing machine and connect its inputs and outputs to colourful buttons and lights which have no resemblance whatsoever to playing tic tac toe. We install the machine in an art gallery and allow people to press on the buttons and observe the resulting light display. The machine may go through exactly the same "mental states" as before, yet it would be inappropriate, seen from the outside, to ascribe the faculty of thought to the machine, or to say it has mental states, makes decisions and choices. It therefore makes no sense to say that the machine has cognitive access.

These examples show that the point of view that one takes determines whether we can apply the term "cognitive access" to a system. Cognitive access is not something that a system possesses inside itself, it is a convenient way of describing the currently potential behaviour of the system as seen from the outside, in a particular context and from a particular point of view.

The importance of point of view is also shown by the following example. Suppose there is a second generation machine of the tic tac toe, which has exactly the same capacities as the first generation, except that the electronics has been simplified: to save power and increase speed, the second generation machine uses a pre-calculated lookup table to determine how to counter each possible

move. For the second generation, it seems no longer to make sense to say the machine has cognitive access to your move because there is no more evaluation, deliberation or choosing of possibilities! The trouble is the two machines behave exactly the same as seen from the outside. Does the new machine have cognitive access or not?

It would seem that there is no fact of the matter. The notion of cognitive access is intrinsically a relative notion: relative to the point of view one takes about the cognitive powers of the system under consideration. The outside observer observing the system must consider that it makes sense to suppose that the machine is deliberating, evaluating possibilities and coming to a decision. But ultimately we know this is just a stance we take, a matter of preference in talking about the behaviour of the system under consideration, irrespective of the actual goings-on inside the machine.

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## RELATED ITEMS

COMPUTATIONAL PARADIGM  
 ENACTIVE COGNITIVE SCIENCES\_ 1&2  
 LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL APPROACH  
 PERCEPTION, DIRECT APPROACHES:  
 THE SENSORIMOTOR APPROACH  
 PHENOMENAL CONSCIOUSNESS AND FEEL REPRESENTATION

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## CONSTRUCTIVISM

John Stewart [COSTECH]

Constructivism is the ontological thesis that reality in general, and the objects of knowledge in particular, are not pre-given and do not exist independently of the cognitive organism which is the subject of knowledge. In other words, reality itself is observer-dependent. Constructivism is di-

rectly opposed to objectivism. It is important because of the strong links between constructivism and enaction [ $\rightarrow$  ENACTIVE COGNITIVE SCIENCES\_1].

Although constructivism has certain affinities with both idealism and relativism, it is very important not to conflate them. Idealism is ontologically subjectivist and unilateral: it is the knower who gives rise to the known. Constructivism, by contrast, is reciprocal: it agrees with idealism that the objects of knowledge cannot exist without a knower; but it immediately redresses the balance, because a cognitive subject equally cannot exist without a "world". The basic principle of enaction is that knower and known, living organism and the corresponding lived world, are brought forth together.

As for relativism, it is essential not to confuse constructivism with the straw-man of "rank relativism". When a constructivist points out that a certain entity (for example, a scientific object, see below) is constructed, this in no way disqualifies it as not real; on the contrary, constructivism insists that every construction is strongly constrained by a reality principle. To someone who thinks that constructivism means "anything goes", the reply is: "well, I certainly wouldn't get into an aeroplane (or even a car) that *you* built". On the other hand, constructivism certainly has strong affinities with the sort of (reflexive, self-critical) relativism that is actually held seriously by certain authors.

Classical examples of constructivist entities that do not exist independently of knowledge concerning them are the so-called secondary qualities, such as colour, sound, taste... Electro-magnetic radiations of varying wavelength may exist independently of the knower (even this is actually debatable, see below), but colour, as such, clearly depends on the perceiving organism (colours are not the same for a colour-blind person, let alone for other species). An objectivist will thus have to declare that colours are not "really real". Objectivists [ $\rightarrow$  OBJECTIVITY] [ $\rightarrow$  OBJECTS' PROPERTIES, PERCEIVED] generally take current

scientific knowledge (with a privilege accorded to physics) as our best (asymptotic) approach to knowledge of a “reality independent of the observer”. Thus, on their own showing, the observer-independent reality objectivists are so keen on is a colourless, soundless, tasteless... affair, quite at odds with our everyday common-sense notion of reality. Constructivists, on the other hand, have no difficulty considering that everyday reality is perfectly real – without, for all that, disqualifying physical reality when the observer is a professional physicist in his laboratory communicating with his colleagues.

The question of the objects of scientific knowledge is therefore particularly important. Constructivism holds that these objects are just as observer-dependent as any others; with the particularity that in this case, the observer is not an individual but a community of scientists, with social rules of functioning (elaborating refutable hypotheses and accepting the verdict of experiment if it does refute the hypothesis; no-holds-barred inter-critical discussion, etc) that construct “objectivity”. Reality is that which resists (Latour, 1979). A “scientific fact” (for example, the existence of black holes) starts out its life in a clearly observer-dependent way in the form of a theoretically-based hypothesis. If the hypothesis gives rise to sufficient refutable predictions which turn out not to be refuted by empirical observations, at a certain point it gains a consensus in the scientific community. At that point, two events occur. The first is splitting: the hypothesis projects a twin copy of itself into the world, thus giving rise to an “object out there”; note, however, that nothing can be said about the “object” that was not already in the hypothesis. The second event is inversion: rhetorically, the relation between hypothesis and object is reversed and scientists start to speak as though the “object out there” is the *cause* of their observations and hypotheses; and the whole history of the “object” is rewritten retrospectively, so that it comes to appear that the “object” was there all along, just waiting to be “discovered”. In other words,

the apparently observer-independent and “objective” nature of scientific objects is itself the result of a structured process of construction (Latour 1979).

Without attempting encyclopaedic exhaustivity, two major authors must be mentioned: von Glasersfeld (1984), and Piaget. Piaget is best known as a psychologist; it is not always realized that his over-reaching aim was a neo-Kantian attempt to account for the genesis of the apparently “pre-given, timeless, universal, observer-independent” *a priori* synthetic categories. The very project is profoundly constructivist.

Finally, we may return to the question of the relation between constructivism and enaction. This is a point of current discussion. For some authors, the two terms are virtually synonymous: enaction is a complementary variant of constructivism (or vice versa, it doesn't matter). Other authors (notably Varela himself) seek to create a distinction. It may be that the wish of these authors to dissociate enaction from constructivism stems from a mistaken apprehension of constructivism – notably the fatal confluences with idealism and rank relativism (see above).

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## RELATED ITEMS

COGNITIVE SCIENCES  
 AUTOPOIESIS  
 ENACTIVE COGNITIVE SCIENCES\_1&2  
 OBJECTIVITY  
 INTERFACE, ENACTIVE  
 LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL APPROACH  
 OBJECTS' PROPERTIES, PERCEIVED  
 PERCEPTION, DIRECT AND INDIRECT APPROACHES

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## CONTACT INTERACTION

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Many research fields are concerned with contacts between objects or between a human and an object. As a first generality, one can say that contact makes the distinction between existence or absence of short distance physical interaction. Furthermore, the notion of contact means a short distance interaction between two physical entities. Short distance means a distance converging to zero between the contours of each bodies. It is not a trivial concept as it implicitly addresses the ranges of spatial scales of the underlying physical phenomena.

When the two interacting bodies are real physical bodies, such interaction corresponds to a trivial one, occurring at every minute of everyday life. In the range of macroscopic physics, interaction contacts are directly correlated to the impossibility for two objects to occupy the same spatial place. Consequently, it is supported by non-penetration interactions such as collisions, more or less instantaneous or sticky.

Another important case is when robots are interacting with real physical objects. In this case, two main categories of issues have to be addressed: (1) the mechanical design of the interface between the robot and the manipulated object, including the choice of actuators and effectors, must lead to a suitable solution for proper interaction contacts; (2) the management of the robot's software for object manipulation, which, by means of control methods and theories, must lead to an efficient manipulation of the manipulated body.

When the two interacting bodies are virtual physical objects, the computer simulation can aim at rendering at the best the interaction contact behaviours, as they will occur in the

real reference situation. Simulations are thus confronted to the main bottleneck of collision detection algorithms [ $\rightarrow$  COLLISION DETECTION ALGORITHM], as developed in real time computer graphics reality [Baraff, 1995], or in virtual reality [Salisbury et al., 2004].

When one of the two interacting bodies is real and the second virtual, the interaction contact between both necessarily requires haptic devices composed at least by sensors, eventually extended by actuators such as in tactile or force feedback devices. Consequently, it can be considered indeed that the haptic device plays the role of a medium between the human and the simulation "world" that is inside or behind the computer [Cadoz, 2004]: this is what has to be called a "mediated contact situation".

Historically, haptic science first focused on collision contacts with rigid simulated objects. One of the major challenges of haptics is still the simulation of very stiff contacts, such as when hitting a metal plate with a rigid object. Due to hardware limitations, both in low-level computer hardware and software and in the design of the haptic device itself, it is very difficult to obtain very stiff contacts in haptics. Another important technical limitation in haptics is the fact that, in most applications, the haptic interaction is only possible through punctual interaction. This means that the hand of the user interacts with simulated objects via a simple point.

From the user's point of view, the hardware and software limitations presented above constitute issues for user perception. It was shown that the discrimination of static stiffness is impossible above 1700 to 3200 N/m for manual perception, but that the discrimination of surface stiffness was still possible for higher values, much above the achievable stiffness values by haptics hardware [Lawrence et al., 1996].

Considering hardware limitations, several works have proposed workarounds as new techniques for improving the perception of hard contacts with current haptic hardware limitations. For examples, Lecuyer et al. have



proposed a technique to improve the perception of contacts when using an under-actuated haptic device in virtual reality [Lécuyer et al., 2005]. The technique was based on modifications of the viewpoint in the visual representation of the virtual scene depending on the orientation of the contact normal. [Kuchenbecker et al., 2005] worked on an evenemential “playing” of force profiles by a haptic device triggered by collision detection.

It would not be until recently that more focus was put on the simulation of surface properties. On the side of human perception, studies about the perception of textures and surfaces properties have begun in the late 90s, and currently more and more hardware designs try to propose new solution for the simulation of complex surface properties.

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## RELATED ITEMS

COLLISION DETECTION ALGORITHM  
FORCE  
FORCE FEEDBACK DEVICE / FORCE PROPERTIES  
HAPTIC RENDERING OF VIRTUAL OBJECTS  
HAPTICS, HAPTIC DEVICES  
PHYSICALLY-BASED MODELLING  
STABILITY

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## CONTROL METAPHORS

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Human interaction is continuous and mainly possible by weighing forces, steering paths and maintaining equilibrium. Each gesture/task constitutes complex control actions, relying on a mixture of visual, kinesthetic and auditory cues. A common way to transfer the knowledge a user has picked up in one domain or situation to another situation, or to transfer intuitive every-day acts to a computer system is by use of metaphors that utilize this mixture of cues. [Lakoff et al., 1999] User interface metaphors [→ METAPHORS IN HUMAN-COMPUTER INTERACTION] are a common and powerful practise in the design of existing computer systems that can be extended for use in control/command metaphors in robotics/virtual reality.

To achieve more natural human-machine communication, systems must support continuous interaction. Tasks such as steering, aiming, or dragging require continuous control and continuous feedback. Aristotle’s definition of metaphor, that “*metaphor consists in giving the thing a name that belongs to something else,*” [Aristotle, 1927] can be extended beyond names to kinaesthetic experiences. In the context of human-computer interaction, Pippen Barr offers the following definition: a user-interface metaphor is “*A device for explaining some system functionality or structure by asserting its similarity to another concept or thing already familiar to the user*” [Barr, 2003]. Extended to the control/command of robotics and virtual reality, the use of metaphor im-

plies physically-based analogies in interface heuristics between that of a natural pattern of manual activity and that of the interface. These metaphors may be based on analogies to gesture, manipulation, or situational experiences which the user may have interacted with in the past, and include the physical effects of gravity, friction, etc. present in such systems.

The most common metaphor for force-feedback robot control/command is the analogy that the user is the robot. For example, if the robot touches something, the user should feel what the robot feels. Similarly, the user should be able see and hear what the robot is seeing and hearing, with this concept extending to virtual avatars as well [→ TRANSPARENCY\_3].

The strength of metaphor in robot or virtual reality control/command is the degree to which the user experience seems familiar to the user. Thus, although powerful from a first-person, embodied point of view, extending a metaphor to a disembodied point-of-view (in which the user's actions control the robot/avatar but he sees the robot/avatar from a different angle, for example) can weaken the familiarity and strength of the interface paradigm. For metaphors to function well, they must be intuitive. And because different users have different past experiences, the best metaphors for common usage should be universal in nature.

In this respect, metaphors for control are metaphors or analogies concerning training derived from real-world, non-professional contexts. These metaphors come from softer, proven-over-time techniques and conceptions concerning learning. They can be used as inspirations and tools for thinking. Metaphors can be presented as a series of questions, to be answered specifically within each application domain regarding the unique attributes of that domain. The conceptual paradigm can be explained by the example of the "Training wheels used for learning bicycling": they only provide complementary feedback to perform the task without altering

the user control of the task itself. The question could be: How can we create training wheels for learning, parsing the training process into separate skills to tackle?

Many high-level concepts in robotic and virtual reality control, such as telepresence or virtual presence [→ PRESENCE, IN COMPUTERIZED ENVIRONMENTS] are fundamentally metaphorical in nature: both imply that the user is present in a place other than where he/she really is. Control/command metaphors imply a further degree of application, in which the experience of presence is further enhanced through the use of additional metaphor, usually relating to manual tasks. Specific skills from the user's past experience, such as pointing, touching, grasping, lifting, cutting, zipping, typing - and the associated force-feedback and audio cues - can be applied to the control/command operation in question.

Wendy Ju et. al point to two useful metaphors in the design of how input devices interact with virtual space: "*The device can act as a tool, or the device can act as the designed object.*" [Ju et al. 2003]. In analyzing the former (tool-metaphor devices such as a pen), the wide range of possible actions that could be taken by such tools are also noted to include hammering, tracing, sculpting, outlining, erasing, etc. This idea is also at the core of the "instrumental paradigm" by [Cadoz et al. 2000] [→ INSTRUMENTAL INTERACTION].

In the field of enactive interface, learning/teaching through interaction metaphors or remote interaction, such as interaction metaphors for understanding non tangible concepts or phenomena, like nano-physics complex dynamic phenomena or interaction forces among molecules, manipulation of graphs or abstract concepts are being investigated.

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## RELATED ITEMS

COMPUTER GRAPHICS, FIRST PERSON POINT OF VIEW  
 CONTROL, DIGITAL  
 INSTRUMENTAL INTERACTION  
 METAPHORS IN HUMAN-COMPUTER INTERACTION  
 PRESENCE, IN COMPUTERIZED ENVIRONMENTS  
 TRANSPARENCY\_3  
 VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

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## CONTROL, DIGITAL

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The advent of computers and computing systems changed several social and industrial functions. Early control systems were designed for using mechanical and electrical circuits and required in deeps design and verification before testing. Watt's centrifugal governor was the first system considered as a mechanical control system, using mechanical feedbacks in systems regulation, and for that it was a precursor of cybernetics and automation [Watt, 1769].

With the development of very reliable computers in the late 1960s, digital computers quickly became popular elements of control systems. Digital control was promoted early in industrial contexts such as automotive and automation industries which found more comfortable the use of programmable digital device to switch on and off specific energy fluxes. In such systems the role of the control was limited in follow-

ing a series of predefined/discrete times rules, while specific electric/electronic circuits still provide to generate continuous time signals and power [Auslander et al., 1981].

The introduction of low cost, all-in-one micro-computing systems, namely microcontroller, drastically changed the conception and the use of digital controllers. Integrated analog-to-digital and digital-to-analog facilities of such devices allowed the digital controller to completely substitute the role of regulating electronic networks [Hintz et al., 1992].

The control laws provided within the design are now coded into programs and converted into electric signals just before actuating a device. Using the digital control theory, a branch of the more general control theory, it is possible to convert continuous time laws into discrete time systems that may be simulated into real-time control software [Astrom et al., 1996] [Leigh, 2006].

Digital controls by means of computers are applied to industrial control problems in three ways: for supervisory or optimizing control; direct digital control; and hierarchy control.

In supervisory or optimizing control the computer operates in an external or secondary capacity, changing the set points in the primary plant-control system either directly or through manual intervention. A chemical process, for example, may take place in a vat the temperature of which is thermostatically regulated. For various reasons, the supervisory control system might intervene to reset the thermostat to a different level. The task of supervisory control is thus to trim the plant operation, thereby lowering costs or increasing production. Though the overall potential for gain from supervisory control is sharply limited, a malfunction of the computer cannot adversely affect the plant.

In direct-digital control a single digital computer replaces a group of single-loop analogue controllers. Its greater computational ability makes the substitution possible

and also permits the application of more complex advanced-control techniques.

Hierarchy control attempts to apply computers to all the plant-control situations simultaneously. As such, it requires the most advanced computers and most sophisticated automatic-control devices to integrate the plant operation at every level from top-management decision to the movement of a valve.

The advantage offered by the digital computer over the conventional control system described earlier, costs being equal, is that the computer can be programmed readily to carry out a wide variety of separate tasks. In addition, it is fairly easy to change the program so as to carry out a new or revised set of tasks should the nature of the process change or the previously proposed system prove to be inadequate for the proposed task. With digital computers, this can usually be done with no change to the physical equipment of the control system. For the conventional control case, some of the physical hardware apparatus of the control system must be replaced in order to achieve new functions or new implementations of them.

Enactive systems make large use of digital controllers. Virtual Environments [→ VIRTUAL REALITY AND VIRTUAL ENVIRONMENT], force rendering [→ HAPTICS, HAPTIC DEVICES], physical based modelling [→ PHYSICALLY-BASED MODELLING], manipulative procedure, only to name a few, are only a part of the complex control laws that can be shown to the users of an enactive interface only exploiting the complexity of control that may be programmed into digital control systems.

In enactive system digital controllers are usually segmented into groups in order to distinguish their role in the whole control systems. Low-level (digital) controllers provide to manage devices and to show at upper levels an easy and stable device to be programmed, while taking into account and compensating all non-linearities existing in the device. Mid-level control algorithms provide to generate on the device simple

stimuli effects in order to show basic interaction modalities (viscous, textures, contact, stiffness, etc). High-level control algorithms introduce in the environment the functionalities of an enactive system by keeping into account the complexity of the interaction and modeling the rules of communication at cognitive level.

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## RELATED ITEMS

FEEDBACK  
DYNAMIC SYSTEMS  
HAPTIC RENDERING OF VIRTUAL OBJECTS  
HAPTICS, HAPTIC DEVICES  
PHYSICALLY-BASED MODELLING

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## CONTROL, LAWS OF

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In cognitive sciences, laws of control are defined as relationships between informational variables (e.g., optical variables, acoustical variables, inertial variables, etc...) and the free parameters of an action system. These relationships are laws because they are based on lawful relationships between energy structure and the movement of an observer

through a stationary environment, according to Gibson's (1966, 1979) theory of ecological optics. They are not, however, deterministic laws because they can be selectively harnessed by the intention, motivation, cognition, etc... of the actor (e.g., Warren, 1988).

Control laws are expressed in the form:

$$fint = g(flow)$$

where *fint* refers to the changes in internal forces applied by the observer, and *flow* to the changes in flow energy (i.e., optical flow) specifying the changes in the relationship between the observer and the environment.

Control laws were first formalized by Gibson (1958) in a not-to-be-forgotten article *Visually controlled locomotion and visual orientation in animals* published in the *British Journal of Psychology*, when Gibson was 54. This article had a major impact in the field, and laid the groundwork for a non-representational, information-based approach to visual control. Warren (1988) defined, formalized, and illustrated control laws in many examples such as visual flight control in insects, stair climbing, running, and walking through apertures in humans.

Control laws are non-representational in the sense that control does not employ an internal model of the environment; control laws are also task-specific, such that different actions may be regulated by different sets of informational variables (see Warren, 1998). The investigation of control laws in various goal-directed movements – such as reaching, standing, walking, driving, somersaulting, hitting, etc.– is a major research area in the field of ecological psychology.

The difference between control laws (Gibson, 1958, Warren, 1988, 1998) and laws of sensory-motor contingencies (O'Regan & Noë, 2001) needs to be clarified. The first clarification was provided by Bill Warren at the third ENACTIVE conference – see Related Documents.

### Intermodal Laws of Control

The intermodal laws of control constitute the intermodal version of single-energy array

control laws. If control laws are lawful relationships between informational quantities and movement parameters, then these parameters may be regulated on the basis on informational quantities that exist, not in single-energy arrays (e.g., the optic array, the acoustic array, etc...), but in the global array, i.e., in the ambient array made of spatio-temporal structures that extend across different forms of energy [ $\rightarrow$  ARRAY, GLOBAL].

The theory of the global array underlying multimodal and cross-modal perception is available (Stoffregen & Bardy, 2001). Experimental evidences that humans regulate their movements on the basis on intermodal laws of control are still lacking. Preliminary evidences have been given in the context of reaching behaviours (Mantel, Bardy, & Stoffregen, 2005).

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### RELATED ITEMS

INVARIANT, PERCEPTUAL  
ARRAY, GLOBAL  
PERCEPTION, DIRECT APPROACHES: THE  
ECOLOGICAL APPROACH

### RELATED DOCUMENTS

Warren's presentation can be found on the website of the third International Conference on Enactive Interfaces ENACTIVE / 06: [www.enactive2006.org](http://www.enactive2006.org)

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## COORDINATION IN HUMAN FUNCTIONING

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The Russian physiologist N. Bernstein (1967) defined coordination for the control of movement as a problem of mastering the very many degrees of freedom involved in a particular movement--of reducing the number of independent variables to be controlled.

Coordination is at work among parts of an organism, and organism and the environment, including social coordination between different organisms (Kelso, 1995; Turvey, 1990). Coordination in human functioning gives rise to synergies, some kind of collective organisation among the parts, which make possible the control of a complex system. The human body in action is indeed a very complex system, which consists of some  $10^2$  joints,  $10^3$  muscles, (Turvey, 1990), which also include the brain, alone is an enormously complex system of approximately  $8 \times 10^9$  neurons,  $7 \times 10^{13}$  connections (Murre & Sturdy, 1995).

The initial theorizing and experimentation on Bernstein's problem was conducted largely in terms of how a device of very many independent variables might be regulated without ascribing excessive responsibility to an executive subsystem. This included in particular questioning the redundancy problem, which means that many ways of organisation of components are available to achieve the task goal. This problem may be solved by organising the necessary interactions among the elements.

The second round is motivated by similarities between coordination and physical processes, in which multiple components become collectively self-organized, coalesce into cooperating groups (Haken, 1977; Kelso, 1995); it is directed at an explanation of

coordination in terms of very general laws and principles. These laws described the behaviour of the system considered at the collective level, using collective variables also called control parameters, which capture the macroscopic pattern of behaviour close to instability - phase transition - bifurcation. The collective level is related to some more microscopic components (e.g., body segments) in a closed way, similarly to a mean field theory in physical or chemical systems, the coupling between the components is made explicit.

These laws of coordination govern the interactions among different parts of a system quite independently of the physical medium over which the interaction is mediated (Kelso, 1995). It reflects functional more than only mechanical constraints. In human behaviours, coordination is defined often defined in spatial frames that are task specific and not merely joints or some preferred combination of muscles. Coordination is more abstract than the language of muscles (Baldissera et al, 1991; Kelso, 1995; Saltzman, 1986). This raises again the very central question of what is effectively controlled in the system's organisation.

Recently it was shown that joints combinations can be decomposed in two broad categories, one that varies the task variable - e.g., the spatial precision of manual pointing), and one that leaves it constant (Scholz & Schönner, 1999). An appropriate change in coordinates reveals the two components, and was coined the uncontrolled manifold theory, as the component which doesn't affect the task variable doesn't need to be controlled. Recently it was proposed that the organisation in controlled and uncontrolled manifold may be realized by minimization solutions (Todorov, 2004).

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## RELATED ITEMS

AUDITORY PERCEPTION  
 DEPTH, PROBLEMS OF RENDERING  
 INTERPERSONAL COORDINATION  
 COGNITION, DYNAMIC SYSTEMS APPROACH  
 DYNAMIC SYSTEMS  
 HAPTICS, IN COGNITIVE SCIENCES  
 VISUAL PERCEPTION

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## CUES, SENSORY

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When studying human perception of objects, information sources and their attributes (such as hue, size, orientation, brightness, etc.) it is essential to understand the basic processes of perception and cognition [Berkeley & Stebbins, 1990]. In this context, the term “cue” refers to a specific piece of information [Howard & Rogers, 2002], which allows the perceptual system to perform a particular task.

The term “cue” is ambiguous, since it can refer to an attribute of a distal or proximal stimulus, or even to the sensory process that codes the proximal stimulus [→ ILLUSION].

One goal of psychophysical research is to find and define perceptual cues. These findings, in turn, can inform the development of enactive applications and interfaces.

## Visual Cues

Visual cues are the basic units of information which define a visual percept. Well-known examples of visual cues are the various cues for depth perception. There are two categories: the monocular cues, which are available using only one eye (motion parallax, atmospheric view, perspective, occlusion, peripheral vision, texture gradient), and the binocular cues, that require input from both eyes (accommodation, convergence, stereopsis).

The monocular cues are purely visual cues whereas the binocular cues also involve proprioceptive feedback from the eyes. Standardized measures of performance have been established for these basic visual cues, and these have provided an essential step towards understanding visual perception and cognition.

## Auditory Cues

Auditory cues [Moore, 2003] define percepts which derive from acoustic information at the ears. Similarly to the visual case, some auditory cues are available using only one ear (monaural perception) and some require both ears (binaural perception). Binaural perception is important for localization of sound sources, where cues are provided by differences in intensity and timing (phase) between the ears.

Speech perception relies on the detection of acoustic cues which provide segmental information (information to identify vowels and consonants, relating to spectral and short-term temporal cues) and suprasegmental information (which indicates stress, inflection and intonation, and relates primarily to cues from changes in voice pitch over the timescale of a word or phrase).

## Haptic Cues

These are information units delivered via the sense of touch or via the kinaesthetic senses (proprioception). In the context of an enactive interface, haptic cues are generated during active exploration of a virtual environment. These cues can give information about the nature of virtual objects, for example, position, orientation, mechanical properties and surface texture.

To make good use of the perceptual abilities of the sense of touch and the kinaesthetic senses, an enactive interface must be provided with appropriate hardware and software. For example, tactile cues are encoded as the intensity or frequency content of the tactile stimulus, or in terms of its spatial distribution (over the skin or over a virtual object) [Rabinowitz et al., 1987]. Some sort of stimulator array is required to deliver these cues within a virtual environment. It is also necessary to implement a scheme for tactile rendering [ $\rightarrow$  TACTILE RENDERING], i.e., a system for generating tactile cues in response to actions of the user [Allerkamp, 2007].

## Cue Interaction

Human sensory systems like vision, hearing or touch are multi-cue systems. Multi-cue systems can be intrasensory or intersensory. How information from different intrasensory or intersensory sources is combined is thus a general question, which is not limited only to multimodal perception. Indeed, much of the treatment on the different types of (cue) interaction has been done in the visual domain, especially in distance perception. A number of classifications for signal interaction are summarized below.

Howard and Rogers [Howard & Rogers, 2004] propose a detailed scheme of different types of cue interaction in depth perception. Their classification can also be applied to any other sort of signal integration/interaction:

- Summation of information (detection or discrimination around threshold can be improved);

- Cue averaging (combination of signals by their weighted mean);
- Cue confirmation (enforces alternative interpretation, which are usually exclusive and discrete);
- Range extensions (cues work together, but one is better suited for a particular physical range);
- Provision of an error signal (if a signal lacks an error signal it can benefit from a second source);
- Cue specialization;
- Cue dominance (suppression of one signal in cases of conflict);
- Cue dissociation (during large conflicts the interpretation of two distal sources can arise);
- Disambiguation;
- Cue recalibration (adaptive shift after prolonged exposure to conflict).

A smaller set of cue interactions with only five categories, has been suggested by Bülthoff and Mallot [Bülthoff & Mallot, 1988]:

- Accumulation;
- Veto;
- Cooperation;
- Disambiguation;
- Hierarchy.

Both classifications are largely similar. Cue dominance resembles the principle of veto. Cue averaging and summation equals in the latter the principle of accumulation. With a supposed hierarchy, the authors emphasize the possibility that information from one cue can be used as raw data by some other. In the past, most empirical studies have investigated the modes of cue averaging and summation.

Possibly the simplest classification of modes of interaction was recently proposed by Ernst and Bülthoff [Ernst & Bülthoff, 2004]. They classify the types of interaction with respect to the redundancy present in the different types of information stemming from different senses or cues.



According to this, they dichotomize the interaction types into:

- sensory combination
- and sensory integration.

The former covers interactions between sensory signals that are not redundant, whereas the later describes interactions between redundant signals. Most of the previously described modes of interaction can be assigned to one of the two categories. Disambiguation and cooperation are examples of sensory combination. On the other hand, the typical examples for sensory combination are accumulation or cue averaging.

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## RELATED ITEMS

COMPLEXITY IN HUMAN MOTOR BEHAVIOUR  
EXTERNALIZATION, PERCEPTUAL  
ILLUSION  
ILLUSIONS, VISUAL  
PSYCHOPHYSICS  
TACTILE RENDERING

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## CYBERNETICS

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Cybernetics was, originally, the study of communication and control processes, regulatory feedback, and principles of (self-) organization in systems. After the Second World War different scientist such as the mathematicians John von Neumann, Norbert Wiener and Claude Shannon, the neuropsychiatrist Warren McCulloch and the anthropologists Gregory Bateson and Margaret Mead made the effort to consolidate single scientific fields to a meta-discipline that should help to understand nature, man and society. In many research fields one discovered and worked with similar structures – cells in biology, atoms in physics, individuals in society. These single elements connect themselves to bigger units (organs, brain, body, social groups).

The aim of cybernetics is to find out general laws in the relation of the whole and its parts. It was looked for patterns and analogies in the transition from e.g. from organs to organism or the nervous system to psychic phenomena. If one could predict the behaviour of the parts then it should be possible to conclude out of this the behaviour of the whole system. This knowledge can be finally used to understand, design, and/or model how systems of any kind (physical, technological, biological, ecological, psychological, social, cognitive, or any combination of those) process information and initiate actions to achieve their goals while counteracting possible sources of interference.

Gregory Bateson once noted that whereas previous sciences dealt with matter and energy, cybernetics focuses on form and pattern and the transmission of information

and/or signals [Heylighen & Joslyn, 2001], so it became possible to compare different domains of science. Most studies in human-machine interaction, even for closed enactive action-perception loops, base their approaches and methods on the theories of cybernetics.

The term cybernetics stems from the Greek word *kybernetes* (“steersman” or “governor”) and was first introduced 1948 by the mathematician Norbert Wiener in his book *Cybernetics, or control and communication in the animal and the machine*. Inspired by Claude Shannon's theories of information, he developed a theory of organization and relations of control in systems. It became an interdisciplinary approach to organization and regulation, concerning the processes of communication within a system and between the system and its environment. Cybernetic systems are continuously influenced by their environment and, as they always tend to maintain a certain state of equilibrium, a so-called control unit counterbalances the disturbances from the environment to ascribe the system to its initial state (self regulation).

Researchers in cybernetics, however, realized that their “science of observed systems” - which can be applied to engineered (trivial) systems such as thermostats or more complex control systems – has to be more or less (also) a “science of observing systems” for natural (non-trivial) systems such as human communication or social systems have to consider the biased description of a specific observer [von Foerster, 1974]. The cybernetic approach is confronted with the unavoidable limitation of the fact that what we can know and perceive is depended on our own subjectivity.

Cybernetics, therefore, developed a constructivistic view of the world where objectivity derives from shared agreement about meaning and where information is an attribute of an interaction between objects or subjects rather than an objective measurable unit [von Glasersfeld, 1987]. By extending theories of self-reference to processes of

observation including cognition, communication, and awareness, cybernetics has been applied to itself and has been developing an epistemology of systems involving their observers (second-order cybernetics), qualitatively unlike the earlier interest in the ontology of systems which are observed from the outside (first-order cybernetics) [Heylighen & Joslyn, 2006].

Cybernetics has influenced various modern sciences such as control theory, computer science, artificial intelligence, information theory, the modelling of artificial life and neural networks, social and cognitive sciences, to name only a few. Engineering examples are the von Neumann computer architecture, game theory, Braitenberg's autonomous robots [Braitenberg, 1986]. In the humanities cybernetic concepts were used e. g. in sociology (Luhmann's concept of autopoiesis), literary science (Wolfgang Iser and Hans Robert Jauss) or in economics (Stafford Beer).

A special sub-field is biological cybernetics, which investigates the processing, modulation, and communication of natural systems such as humans or animals. Biological cybernetics applies the methods and theoretical tools of cybernetics to biological systems. It is concerned with the technical replication or imitation of biological control systems, especially by comparing the processes in biological and artificial systems. Enactive interfaces, however, use this knowledge to improve the believability and naturalism of applications. Therefore, research on enactive interfaces is the optimal place for collaborating between both fields: the perceptual research based on theories of cybernetics and the technical development of interfaces.

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## **RELATED ITEMS**

BELIEVABILITY\_ 1&2

AUTOPOIESIS

CONSTRUCTIVISM

DYNAMIC SYSTEMS

PSYCHOPHYSICS

COGNITIVE SCIENCES

# D

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## DEGREES OF FREEDOM IN HUMAN MOVEMENT

Didier Delignieres [UM1]

Julien Lagarde [UM1]

The concept of degrees of freedom refers to the number of free parameters in a model that should be specified in order to fully characterize the system. The more complex the system, the higher the number of parameters necessary for a complete characterization.

The exact definition of degrees of freedom, nevertheless, remains unclear and differs between authors. In Bernstein's approach [Bernstein, 1967] and a number of subsequent works [e.g., Vereijken, 1991], degrees of freedom are defined at the mechanical level, i.e. the number of joints that are independently involved in the coordination. In that approach, the analysis of cross-correlations between joints allows determining the number of active degrees of freedom in coordination. A more recent approach [Newell & Vaillancourt, 2001] defined degrees of freedom at a dynamical level: degrees of freedom refer to the dimension of behaviour, analyzed through the spatial-temporal relationships of the motions of the body segments. This analysis can be performed through principal component analysis [Haken, 1996].

The human body is characterized by a very highly dimensional state space, with over 100 billions of neurons, the dynamics of each of them being reduced in the more tractable approximation to 2 variables [FitzHugh, 1961], hundreds of muscles, and around 100 joints. This huge complexity however does not prevent coherent, adaptive behaviour. What is observed is the coordination among

the degrees of freedom, and this at different spatial and temporal scales. Neurons are functioning at a millisecond scale within coherent assemblies in a task and context dependent way, body motion in the environment is characterized by patterns of coordination among the joints. Interactions between degrees of freedom lead to this fundamental property of multi-components, multi-scales, high dimensional systems: organization into lower dimensional patterns. Hundreds of trillions of short and long range interactions between neurons allow transient patterns formation in the brain. These dynamic assemblies determine and at the same time are dependent upon functional constraints: behaving adaptively in the environment, which bottom-line rests on relations between perception and action.

The total number of degrees of freedom is reduced to a subset of effective degrees of freedom. In movement science this reduction of dimensionality is sometimes emphasized as simplifying the control, and coordination among the joint degrees of freedom is often coined by the term motor synergy. These synergies allow for immediate perturbation compensation along many directions in the physical 3 dimensional space. One classical question addressed is related to what is controlled and what isn't. Subsets of covariations among the joints lead to a change in the task variables relevant to the goal, other don't and thus don't need to be controlled.

This in turn relates to the redundancy problem made explicit by the Russian physiologist Bernstein, recently stated as an abundance problem: more degrees of freedom are available than needed for the task. Bernstein supposed that the main problem, during learning a new skill, was to master the important number of degrees of freedom of the organism. He suggested a model of learning based on the progressive solving of this problem: in a first stage, beginners try to limit the number of free parameters by freezing most degrees of freedom, performing the task with a few number of residual joints. Then the degrees of freedom are progres-

sively released, and incorporated in functional units, or coordinative structures, allowing the control of the essential redundancy of degrees of freedom.

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## RELATED ITEMS

COORDINATION IN HUMAN FUNCTIONING  
MOTOR CONTROL  
LEARNING AND TRAINING METHODS  
STABILITY

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## DEPTH, PROBLEMS OF RENDERING

Joan De Boeck [UHASSELT]  
Marcello Carozzino [PERCRO]

When visualizing a 3D computer generated environment, very often monitors or projectors are used, resulting on a 2D representation of the 3D world. However, in these bi-dimensional images it is still possible to recover information on the missing dimension (depth) by means of a series of depth cues which our brain relies on. Therefore, in order to provide an accurate simulation of the reality (as often needed in virtual reality systems, or with enactive interfaces) a number of these cues have to be synthesized and reproduced in order to let the observer get an adequate 3D perception.

Depth cues may be monocular (i.e. they can be retrieved in one single image), binocular (if two images, one for each eye, are needed), or non-visual. Parallax, interposition, perspective, shading, depth of field are all monocular cues, and usually they may effectively be generated by high quality computer graphics. Dynamic perspective, following the user's head movements, is an important cue to solve ambiguities related to monocular vision. In this case special devices (trackers) are needed in order to track user's head position and orientation and coherently update its perspective.

Binocular cues, deriving from stereopsis (retinal offset, fusion etc.) are more difficult to simulate and need dedicated devices. A system for stereo visualization basically needs:

- a software module able to generate two monoscopic bi-dimensional images, one for each eye, created and synchronized in order to give back the opportune depth cues
- hardware devices able to let each eye perceive only its correspondent image

The user brain will then merge the received images and will be able to reconstruct depth from them, exploiting the discrepancies between the two slightly different perspective views. So far two different hardware technologies are available for the generation of stereo images.

In active stereo technologies, two images are projected sequentially for each frame, therefore there's a continuous hi-frequency (about 120Hz) switching between images for the right eye and images for the left eye. Users wear special active devices, named shutter glasses, which are synchronized with the image switcher and able to make lenses opaque or transparent. When the image for the right eye is present, the left lens is completely opaque, otherwise it is transparent. The same happens for the right lens. The human brain, actually, receives a sequence of alternate images but they are so quickly pre-

sented that it believes to perceive them at the same time

In passive stereo technology both images are projected at the same time but, thanks to a system of filters (based on light polarization, or on splitting colour spectrum) only the correct images reach each eye. There are advantages and disadvantages for both technologies: active stereo is more expensive and requires dedicated hardware, polarization passive stereo presents the problem of ghosting (or stereo crosstalk), which means that one eye perceives also a small fraction of the image presented for the other eye. Head mounted displays do not suffer from this problem because each eye has a LCD panel directly in front of it. However they are still expensive and offer limited field of view and resolution. Recent new approaches are available to render 3D images, like volumetric displays (able to show information in a volume, rather than on a surfaces) which may be emissive (a volume is filled with a medium able to emit light depending on external solicitations) or based on rotating screens (where a flat screen rotates at a high frequency showing, for each angular position, an image of the object corresponding to the perspective related to that position). Although commercially available, these systems are still quite experimental. Solutions based on auto stereoscopic displays (different technologies exist), which do not need the user to wear devices, are also commercially available and, even if not yet fully mature, look quite promising for the very next future [Carrozzino, 2004].

Non-visual cues are so far almost impossible to simulate. They include oculo-motor cues (cues based on sensations provided by contractions of the muscles around the eye, such as the ‘focusing’ movements of the two eyes), cues coming from the vestibular apparatus, kinaesthetic data from the neck etc. [Bowman, 2005] [Wikipedia, 2007].

The reduced quality of the set depth cues, compared to the real world, results in a diminished depth perception in the 3D world,

which is called the depth problem. This may be confirmed by several experiments. Users tend to have problems accessing objects or menus and dialogs that are placed at a certain depth in the 3D world [De Boeck, 2007]. It may be clear that a reduced depth perception will reduce the enactive experience.

Solutions such as perspective, colour, fog, textures and shadows are already mainstream solutions for a long time, but do not solve the entire problem. Head tracking or stereo vision devices make an additional improvement, but they are still cumbersome and expensive. Moreover, not all users tend to have a stereoscopic view (stereo blindness).

Alternatively, it has been found that force feedback may improve the interaction and reduce the depth problem, as the user has a natural means of feedback when actually touching an object. However, users still have problems finding and accessing the object since the force feedback only returns a virtual contact. In the same context, colocation [Ortega, 2005] [→ CO-LOCATION] and proprioception [De Boeck, 2007] can also be used to reduce the depth problem.

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## RELATED ITEMS

CO-LOCATION  
CUES, SENSORY  
FORCE FEEDBACK

## RELATED DOCUMENTS

El\_ComputerGeometry&Light\_Carrozzino\_041001.pdf

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## DESIGN AND ENACTION

Charlotte Magnusson [ULUND]

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In philosophy, the abstract noun design refers to pattern, or to purpose/purposefulness (or teleology). Design is thus contrasted with purposelessness, randomness, or lack of complexity. More specifically considered in the context of the applied arts, engineering, architecture, and other such creative endeavours, the word design is used as both a noun and a verb. Design, as a verb, refers to the process of originating and developing a plan for a new object (machine, building, product, etc.). As a noun, design is used both for the final plan or proposal (a drawing, model, or other description), or the result of implementing that plan or proposal (the object produced).

Designing normally requires considering aesthetic, functional, and many other aspects of an object, which usually necessitates considerable research, thought, modelling, iterative adjustment, and re-design. Design as a process can take many forms depending on the object being designed and the individual or individuals participating [→ DESIGN PROCESS].

**Enaction and design**

A typical feature of any design process is that much information about the problem (the user, the usage, the context, etc) is missing at the start of the process. And since user, usage and context will change as artefacts change and new artefacts are introduced the designer aims at a moving target. To reach

the goal he or she needs to get going. Or, in the more formal words of Donald Schön [Schön, 1983] [Schön, 1988] [Schön, Bennett, Winograd, 1996], he or she needs to start a reflective conversation with the materials: “*There is no direct path between the designer’s intention and the outcome. As you work a problem, you are continually in the process of developing a path into it, forming new appreciations and understandings as you make new moves*” [Schön, Bennett, Winograd, 1996].

In a sense this can be termed “doing for the sake of knowing”. Actions are not just actions to produce a certain result, but rather acts to inquire into the current design problem. This type of actions can be used to explore or to experiment – to physically test your ideas in the world [Gedenryd, 1998]. An important point in Gedenryd’s thesis is that design is not a purely intramental activity – instead the interaction with materials (in a broad sense) forms an integral part of the cognitive process. The designer is progressively moving along, making judgements about different responses from the medium – and sometimes discovering completely unexpected things. Schön uses the term backtalk for this type of surprising discoveries – the materials talk back at you telling you things you did not know [Schön, Bennett, Winograd, 1996].

Donald Schön introduces the concepts “*reflection in action*” and “*reflection on action*” in his classic book *The Reflective Practitioner* [Schön, 1983]. Reflection in action is different from just knowing how to act, how to do. Reflection in action is closely linked to an element of surprise. A person responds to an unexpected outcome (good or bad) by thinking about what he or she is doing, in a way that influences further doing.

In some situations the person instead responds to the surprise by stopping to think about what happened. In this case it is a matter of reflection on action. A designer may pause to think back over what has been done in a project and exploring the understandings that were brought into the process

and framing new theories [Schön, Bennett, Winograd, 1996]. Of course a designer (or any practitioner) may also reflect on practice. This is a higher level type of reflection which involves patterns of behaviour.

If we go back to the concept of a reflective conversation with materials, it is clear that the conversation setting and the materials (tools, situations, users etc) will change during a design process but the above described reflective and (en)active core will always be present.

In a sense this can be termed “doing for the sake of knowing”. Actions are not just actions to produce a certain result, but rather acts to inquire into the current design problem. This type of actions can be used to explore or to experiment – to physically test your ideas in the world [Gedenryd, 1998]. An important point in Gedenryd’s thesis is that design is not a purely intramental activity – instead the interaction with materials (in a broad sense) forms an integral part of the cognitive process. The designer is progressively moving along, making judgements about different responses from the medium – and sometimes discovering completely unexpected things. Schön uses the term backtalk for this type of surprising discoveries – the materials talk back at you telling you things you did not know [Schön, Bennett, Winograd, 1996]. Donald Schön introduces the concepts “reflection in action” and “reflection on action” in his classic book *The Reflective Practitioner* [Schön, 1983]. Reflection in action is different from just knowing how to act, how to do. Reflection in action is closely linked to an element of surprise. A person responds to an unexpected outcome (good or bad) by thinking about what he or she is doing, in a way that influences further doing. In some situations the person instead responds to the surprise by stopping to think about what happened. In this case it is a matter of reflection on action. A designer may pause to think back over what has been done in a project and exploring the understandings that were brought into the process and framing new theories [Schön, Bennett,

Winograd, 1996]. Of course a designer (or any practitioner) may also reflect on practice. This is a higher level type of reflection which involves patterns of behaviour. If we go back to the concept of a reflective conversation with materials, it is clear that the conversation setting and the materials (tools, situations, users etc) will change during a design process but the above described reflective and (en)active core will always be present.

### **Enactive interfaces in the design process**

That the haptic senses are important in creative processes is underlined by Prytherch and Jerrard [Prytherch & Jerrard, 2003] who state that the haptic senses are of fundamental importance particularly in certain types of creative activities, but that this importance is both unacknowledged and unrecognized by artists and researchers alike. Pen and paper as well as clay modeling which are popular sketching tools today include active exploration and involve real world touch/haptics. Enactive Interfaces, including haptic interaction, can also be of particular aid to support the design process. Indeed, within the idea generation phase computer based haptic/touch interaction adds new possibilities for reflection in and on action [→ DESIGN, VIRTUAL MOCK-UP]. A study of the use of software from SensAble, FreeForm [Bahar, Sener et al 2003], it is concluded that although the studied software has some shortcomings which affects later stages in the design process it can be valuable for idea generation, form exploration, prototyping and early assessment of ergonomic factors.

### **Enactive Interfaces and Special Users**

In many cases a system is designed for a typical user. This often disregards the fact that users within the user group can be very diverse, and also that user abilities may vary over time (the design needs to consider dynamic properties). Enactive interfaces, by featuring a multisensory interaction and allowing a more complete investment of the user, tend to be particularly adequate for any users, including impaired users. Hence, con-



sidering special users in the design of an Enactive interface is important [→ DESIGN FOR ALL (INCLUSIVE DESIGN)].

To conclude: design is an inherently enactive process, and enactive interfaces including haptics offer potentially new and interesting opportunities both for idea generation, evaluation and user involvement.

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## RELATED ITEMS

DESIGN FOR ALL (INCLUSIVE DESIGN)  
DESIGN PROCESS  
DESIGN, VIRTUAL MOCK-UP  
INTERFACE DESIGN  
USABILITY  
USEWORTHY TECHNOLOGY

## RELATED DOCUMENTS

EI\_Design\_Basics\_Magnusson.pdf

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# DESIGN FOR ALL (INCLUSIVE DESIGN)

Teresa Gutiérrez [LBEIN]

Contributors: Charlotte Magnusson [ULUND]

Design for all (DfA) is the intervention in environments, products, services and inter-

faces with the aim that, regardless of age, gender, capabilities or cultural background, everyone can participate in our society on an equal basis. This term is equivalent to inclusive design.

Enactive interfaces play an important role in this field since they open new possibilities in human-computer interaction, both for what regards the subjects of the interaction and the activities they can perform. The use of Enactive interfaces can allow some collectives with special needs to access the full range of the information society technologies.

To apply the design for all concepts in products and services, two simple principles should be taken into consideration:

- Make the use of products and services easier for everyone.
- Ensure that the needs, wishes and expectations of users are taken into consideration in the design and evaluation processes of products or services (“user centred” design). For this is important the “user involvement” at all the stages of the design process. When considering design for all it is important also to consider the notion “design for me” - a discussion of this can be found in the recent thesis [CERTEC, 2006].

At Center for Universal Design from North Carolina State University [Universal Design], seven principles for universal design have been proposed. These principles are:

### Principle One: Equitable Use

The design is useful and marketable to people with diverse abilities:

- Provide the same means of use for all users: identical whenever possible; equivalent when not.
- Avoid segregating or stigmatizing any users.
- Provisions for privacy, security, and safety should be equally available to all users.
- Make the design appealing to all users.

### **Principle Two: Flexibility in Use**

The design accommodates a wide range of individual preferences and abilities:

- Provide choice in methods of use.
- Accommodate right- or left-handed access and use.
- Facilitate the user's accuracy and precision.
- Provide adaptability to the user's pace.

### **Principle Three: simple and intuitive**

Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level:

- Eliminate unnecessary complexity.
- Be consistent with user expectations and intuition.
- Accommodate a wide range of literacy and language skills.
- Arrange information consistent with its importance.
- Provide effective prompting and feedback during and after task completion.

### **Principle Four: Perceptible Information**

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities:

- Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.
- Provide adequate contrast between essential information and its surroundings.
- Maximize "legibility" of essential information.
- Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).
- Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

### **Principle Five: Tolerance for Error**

The design minimizes hazards and the adverse consequences of accidental or unintended actions:

- Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.
- Provide warnings of hazards and errors.
- Provide fail-safe features.
- Discourage unconscious action in tasks that require vigilance.

### **Principle Six: Low Physical Effort**

The design can be used efficiently and comfortably and with a minimum of fatigue:

- Allow user to maintain a neutral body position.
- Use reasonable operating forces.
- Minimize repetitive actions.
- Minimize sustained physical effort

### **Principle Seven: Size and Space for Approach and Use**

Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility:

- Provide a clear line of sight to important elements for any seated or standing user.
- Make reach to all components comfortable for any seated or standing user.
- Accommodate variations in hand and grip size.
- Provide adequate space for the use of assistive devices or personal assistance.

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### **RELATED ITEMS**

DESIGN AND ENACTION  
DESIGN PROCESS  
DESIGN, USER CENTRED

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## DESIGN PROCESS

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Design as a process can take many forms depending on the object being designed and the individual or individuals participating. In any case, the design process is far from linear. It cannot simply be described as a straight road from vision to a final product [Gedenryd,1998]. Instead a typical feature of a design process is the constant shift between different levels and activities. If we look closer at the early parts of the design process different stages may be seen. A design process usually starts with a vision. When the vision begins to take concrete shape we may talk about an operative image. This operative image is usually vague in the beginning, and best shown using sketches and scenarios, and or rough mock-ups/prototypes. During the design process prototypes are to then become more and more well specified. Only when the operative image is sufficiently specified we may talk about a specification [Löwgren, Stolterman, 1998].

Different authors generate different lists of guidelines regarding the design process, but all agree that the design process should be done as an iterative (cyclical) process, including the following basic important points:

- Idea generation and visualization. Ideas should be generated, selected and visualized / articulated.
- Know the user and the usage. You should try to find out user needs, how the user perform the same set of tasks today and how the user will use the proposed artefact.
- Evaluate. Ideas, concepts, models, prototypes needs to be evaluated.

These activities are not strictly separable. To be able to visualize or articulate you need

to know the user and the usage. And information about the user and the usage may result from the evaluation of visualized ideas or concepts.

For an early enactive exploration of the design space, during the idea generation and visualisation phase, prototypes and scenarios etc are crucial. They allow reflection in action and on actions [→ DESIGN AND ENACTION] that involve real users and real usage situations before starting the actual implementation.

A scenario is a description of an imagined future use situation, intended to illustrate the use of a still non-existing device. Scenarios can be used to receive user feedback before the actual development work starts, but they are also useful for the designers/developers, since scenarios encourage thinking about the design problem in a user and task oriented way.

Amongst prototype, an important type is the so-called lo-fi (low fidelity) prototypes. The idea is to make a quick prototype using simple materials such as pen and paper, post-it notes, tape, glue etc etc to be able to test the designs. For this purpose Wizard of Oz techniques can also be employed: a human replaces some of the functionality in the prototype (this technique can be used also at later stages to replace missing functionality). Even if a functional prototype in many cases is necessary, as much work as possible during the early stages should be performed using “lo-fi” prototypes. This is because a designer working with lo-fi prototypes will spend approximately 95% of his or her time thinking about the design and only 5% thinking about the tools used for implementing the prototype while relations are roughly reversed with a computer based prototype [Rettig, 1994].

Another important type are the virtual prototypes or mock-up [→ DESIGN, VIRTUAL MOCK-UP].

When it comes to the testing it is important to note that the degree of situatedness may seriously influence the results. In the rationalistic perspective, the human expert is

seen as a data-processing system having properties similar to computers. As a consequence, the design of man-machine interfaces, workplaces, and organizational procedures has been mainly driven by technological advances, focusing on replacing humans rather than supporting their actual needs. A more appropriate explanation of human cognition is based on the notion of situatedness: human cognition is considered to be emergent from the interaction of the human with the environment, i.e., the current situation the human is involved in. More generally spoken, the system-environment coupling is a prerequisite of cognition and cannot be abstracted away.

More simply put: the way our cognition works and the way we interact with artefacts depend on the situation we are in. To obtain working designs one needs not only to involve users in the design process but also real usage situations as much as possible. A term sometimes used in this context is ecologically valid. Laboratory tests (not ecologically valid) may provide information about how a user can use a device or a system, but one can never be sure about how valid this information is for the real usage situations (ecologically valid).

Situated design assumes an iterative, enactive, approach to design. The design space needs to be explored with actual users and actual usage situations as much as possible to ensure the usability of the product or service being designed. As a design process, it is relevant both as an Enactive process in itself, but also as a means to ensure the usability of Enactive systems.

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## RELATED ITEMS

DESIGN AND ENACTION  
DESIGN, VIRTUAL MOCK-UP  
INTERFACE DESIGN  
USABILITY  
USEWORTHY TECHNOLOGY

## RELATED DOCUMENTS

El\_Design\_Basics\_Magnusson.pdf

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# DESIGN, USER CENTRED

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User-centred design, also called human-centred design is proposed as an ideal approach to guarantee the usability of interactive systems, by actively involving the end-user, in order to understand the user and task requirements.

If a final product is to be usable, then the user and the usage have to be part of the processes of reflection and action described in the design entry (user involvement). Furthermore it is clear that the cost of implementing any changes that may result from this necessary user involvement becomes larger the closer to the finished product we are getting in the design process. This leads to the conclusion that the user has to be involved in the design process as early as possible.

The economic and social benefits are:

- Systems are more understandable and easy to use, while training and support costs are reduced.
- The end-user is more satisfied and experiences the system with less discomfort and stress.

- The productivity of the users and efficiency of organizations increases and the quality of the product is improved.

It is not enough to start a design process by just asking users what they want. Most people will answer “what can I get” to that question. It is also very difficult to know surely exactly what one wants without being able to try it out. Furthermore the situation of use will be changed in the presence of a new artefact. Thus the users have to be involved all along the design process [→ DESIGN PROCESS].

There are many ways to involve users in a design process [Preece, Rogers & Sharp, 2002]. The concept user centered design emerged already in the mid 1980’s. According to Gould and Lewis [Gould & Lewis 1985] the three main principles of user centered design are:

- Early focus on users and tasks, that consists in incorporating various methods to examine characteristics of a user group through e.g. user mapping, task analysis, questionnaires or direct observation as studied in the literature on human factors [e.g. Sanders & McCormick, 1992].
- Empirical measurement, that consists in the practice to let future users use simulations and prototypes and measure their performance through quantitative feedback containing efficiency, number of errors made, time to complete tasks [Rubin, 1994].
- Iterative design, that means that there should be a cycle of design, test and measurements repeated as often as needed, starting with early prototypes [Gedenryd, 1998].

The four most important user-centred design activities that are repeated in each iteration during system development are:

- Understanding and specifying the context of use
- Specifying user and organizational requirements
- Production of design solutions

- Evaluation of the designs against requirements

Usability Engineering [Nielsen, 1993] builds on the user centred approach, but attempts to make the process easier to fit in to an engineering perspective by focusing on the usability goals as a measure of when the iterative design process may be stopped.

All these aforementioned methods can include components of situated observation or design but are not really explicit in this aspect. A more situated method is contextual design [Wixon et al. 1990]. Contextual design emphasize interview methods conducted in the context of the user's work, co-designing with the user, building an understanding of work in its context, and summarizing conclusions through out the research.

Participatory design, finally, is a process of mutual learning where designers and users work close together and learn from each other. If we specify participation of users along the following dimensions:

- Directness of the interaction with the designers
- Length of the involvement in the design process
- Scope of participation in the overall system being designed
- Degree of control over the design decisions

Participatory design can be said to be the high end of all these scales [Winograd, 1999].

User centred design can be said to describe an enactive approach to the design process since it relies on an interactive exploration of a design space. At the same time user centred design is attempting to ensure the usability of the product or service being designed. Thus it is relevant both as an enactive process in itself, but also as a means to ensure the usability of enactive systems.

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## RELATED ITEMS

DESIGN AND ENACTION  
 DESIGN PROCESS  
 DESIGN, VIRTUAL MOCK-UP  
 INTERFACE DESIGN  
 USABILITY  
 USEWORTHY TECHNOLOGY

## RELATED DOCUMENTS

El\_Design\_Basics\_Magnusson.pdf

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## DESIGN, VIRTUAL MOCK - UP

Indira Thouvenin [COSTECH]  
 Ronan Boulic [EPFL]

A virtual mock-up is a 3D representation of a system or an object, and is used in the design process for collaborative reviews. It is also called a “virtual prototype”. This term of virtual mock-up comes from another one, the “digital mock-up” (DMU) which includes technical and specific aspects of the concurrent engineering process. For many years, only the DMU was available because of

rendering difficulties of heavy 3D models. With the recent possibilities of computer graphic, it is now possible to convert the DMU into a virtual mock-up.

### What are the differences between a virtual and a digital mock-up ?

The digital mock-up [Chevaldonne & al,2004] is supposed to collect all the data necessary to manufacture the product, when the virtual mock-up is a collaborative support for review processes, design representation and steps of the mental construction of a new product. It is the design platform in the field of automotive, energy, aeronautics.

The virtual mock-up is not collecting the technical data for manufacturing, but refers to the possibilities of interacting with the product early in the design stages. As a consequence , the description is superficial, usually with unstructured polygons. The representation is rendered in real time to be visualized in large immersive systems. It is the collaborative design visualization platform for the same industries.

### Enaction and the virtual mock-up

The process of design is supported by the virtual mock-up in different ways. Some systems include a virtual human, where the user can regulate the movements with a motion capture system. This process is enactive in the sense that the user constructs an experience while his body is participating completely to the process [Varela & al, 1993]. The interface becomes invisible to the user, the virtual human gesture being part of the reel human and giving him a lived experience in a virtual environment.

The virtual mock-up is often displayed in collaborative virtual environments, where the two solutions are possible: co-located users or distance users. Enaction in the first kind of system [Greenhalgh & al, 1999] emerges from the activity of the full body in the immersive environment [Varela,1979]. The second kind of system gives the opportunity to perceive the others activity through avatars.

Systems which provide users' activity capitalization and representation as a mediation of exchanges are often associated to the virtual mock-up. Design with the virtual mock-up is taking advantage of indexing and knowledge processing systems, and in the future will allow the constitution of an experience with an anticipation of the user's perception with sensorial feedback.

Enactive interfaces aim at allowing a better interaction with this mock-up. For example, it will be possible to use the virtual prototype for usability and/or maintainability studies of complex systems (e.g. plane cockpit). Such studies require the ability to flexibly position the virtual mannequin of the potential user/maintenance worker of the system and simulate various tasks (reach, visibility, force or torque exertion, comfort,...). The paradigm of full body interaction [→ INTERACTION, FULL BODY] is currently being investigated to ease the real-time postural control of a virtual mannequin that has to interact with a virtual prototype. Two critical factors have to be taken into account to evaluate its efficiency:

- the management of collision detection [→ COLLISION DETECTION ALGORITHM] and avoidance that may request a significant processing resource,
- the postural control of a virtual mannequin, that may induce some fatigue and a non-negligible cognitive load.

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## RELATED ITEMS

COLLISION DETECTION ALGORITHM  
DESIGN AND ENACTION  
INTERACTION, FULL BODY

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## DISPLAY, VISUAL

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In context of human-computer interfaces, displays are devices that transform digital data into a human sensorial form. A visual display is a category of displays used for presenting digital information to human through human's visual sensory modality [Lantz, 1997]. In the case of a virtual reality visual display, such information is usually either entirely generated by a computer or a blend of images coming from the real world and synthesized ones.

There are different categories of visual displays, created for different purposes and by using heterogeneous techniques, but they generally conform to display standards. The most used types today are: liquid crystal display (LCD), cathode ray tube (CRT), thin-film transistor (TFT), organic light-emitting diode (OLED), projectors and 3D displays. There are also multi-display frameworks, using several screens either to surround the user (like CAVE installations) or to provide independent images one for each eye thus achieving stereographic rendering (like Head-Mounted Displays). CAVEs (CAVE Automatic Virtual Environment [Cruz-Neira & al, 1992]) are large display based devices in the form of a room-sized cube, with a screen at each side where stereographic images are displayed through projectors. One can note that some displays are sometimes used to support direct interaction with the content

visualized on them by tracking the user's fingers on their surface (touch screen).

Most commonly used devices in computer graphics and virtual reality are computer screens, CAVEs, projectors and head-mounted displays. Head-mounted displays tend to isolate him/her from the real world, thus potentially reducing interactions between the user body and the virtual environment [Sutcliffe & al, 2006]. Conversely, large displays [Czernuszenko & al, 1997] and CAVE systems allow the user and his/her whole body to be physically surrounded by a virtual environment and thus improve the feeling of being immersed [ $\rightarrow$  IMMERSION VS. VIS-À-VIS] in such environment through a 3D perception of the scene [Tyndiuk & al, 2005].

Another variant of large CAVE displays is implemented in the techniques of personal surround display (PSD) [De Boeck & al, 2003] in which the usable user space is reduced to the half top of the body. PSD is an intermediate case between the large CAVE involving the whole body and the usual 2D vis-à-vis screens that cannot provide immersive feeling. Practically, a PSD is a personal desktop setup which consists of three adjoining non-stereo projection screens with a width of 90 cm, and mutual located with an angle of 60°. The screens are synchronized and sharing the same virtual environment, resulting in a wider viewing angle. The PSD offers a low-cost semi-immersive desktop setup for working in 3D environments. Other systems (like the Reachin display) integrate haptic devices with stereo graphics achieved through semi-transparent mirrors, so that haptic actions and graphics rendering are co-located in the same space.

From an historical perspective, we may remark that auditory displays appeared first, before visual displays, in the 50's (thanks to the invention of the digital to analog transducer). The development of Visual Displays required, indeed, a huge quantity of research, starting from CRT technology in which the visual rate depended on the complexity of

the displayed image. CRT technologies were followed, but only in the 70s, by the today's raster display technology, in which the image displaying rate became independent of the complexity of the image. Raster display technology caused a true revolution, triggering standards for both visual displays and visual rendering processes, and funding the today's field of computer graphics. In the history of transducers and displays, finally, we may remark that haptic transducers appeared even more recently, are still in their infancy, and require new huge research and development.

Today's developments in visual displays technology are still very vivid, especially with the aim of covering the full scale of visual space: from large displays to mobile, extra-flat, very small and very low power-consumption visual displays. Other promising developments for new human-computer interfaces are: intelligent and mobile digital sheets, intelligent inks allowing the designing of very large visual walls, etc. The research dealing with augmented reality [ $\rightarrow$  REALITY, AUGMENTED AND MIXED] and tangible user interfaces are also interesting when considered from the point of view of visual displays. Both correspond with new, specific requirements as for the visual display technology; especially, they would require freeing visual displays of the morphology of the display device, allowing displaying digital data visually anywhere. In multimodal interfaces today, the visual modality receives a particular attention. In order to make our human-computer interfaces more "enactive", designers need to better integrate action and vision (i.e.: to design more relevant action-vision loops), and to try to develop further the technology of the displays themselves especially to get rid of the spatial constraints imposed by today's visual displays.

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## RELATED ITEMS

IMMERSION VS. VIS-À-VIS  
 PRESENCE, IN COMPUTERIZED ENVIRONMENTS  
 REALITY, AUGMENTED AND MIXED  
 VIRTUAL REALITY AND VIRTUAL ENVIRONMENT  
 TACTILE DEVICE

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## DUALISM, MIND-MATTER

John Stewart [COSTECH]

How can a material state *be* a mental state? Hoary it may be, yet the problem is anything but solved. As will be explained below, the most common attitude consists of drifting evasively between Cartesian dualism, idealistic monism and materialistic monism; however, none of these positions is tenable when examined fairly and squarely. This is commonly referred to as the mind-body problem; however, without any clear specification of precisely why a (biological?!) body is a privileged substrate for cognitive activity, this is not sufficient to solve the problem. Cognitive science [→ COGNITIVE SCIENCES] requires a solution to this problem.

It is thus a central issue for cognitive science to propose a theory which can account for the relation between matter and mind. Matter has a certain number of fundamental

features, such as spatial extension, spatial location and mass. Mind, as such, does not have these features: it makes no sense, for example, to ask “how much does your mind weigh?” A brain, certainly, has a mass: but a brain, as such, is not a mind – there are strong arguments that the mind is not “in” the brain. For this reason, Descartes proposed an ontological dualism: mind, and matter, are simply two radically different sorts of things that exist. The problem with this is that there is manifestly a relation between mind and matter: material events (a blow on the head, the ingurgitation of alcohol or drugs, etc) clearly have an effect on the mind; and conversely, if mental events such as a decision had no material consequences, mind would become an ineffective, epiphenomenal superfluity – a conclusion which hardly anyone could accept for themselves. However, if matter and mind are indeed ontologically different, it becomes impossible to understand how there could be a relation between them (any possible interface runs into the problem that it must itself be either material or mental, so that it must include another interface within itself; this leads to a vicious infinite regress). A desperate solution is to cut the Gordian knot by truncating one of the two terms: this leads either to monistic idealism according to which only ideas are real, matter being an illusory projection of the mind; or to monistic materialism, according to which only matter is real, and the mind is a illusory epiphenomenon. Whatever their respective merits or demerits, neither of these will do for cognitive science; on the basis of idealism, it may be possible to study the mind (or cognition), but not to do cognitive *science*; on the basis of materialism, it is possible to pursue a scientific study of neurones and brains, but without anything more this is not *cognitive science*.

The two major paradigms in cognitive science do propose real, if very different, resolutions of this conundrum. The computational theory of mind [→ COMPUTATIONAL PARADIGM], by equating cognition with syntactical opera-

tions on formal symbols, can appeal to the theory of Turing machines [ $\rightarrow$  TURING MACHINE]; this theory provides a guarantee that such symbolic operations can always be instantiated by a material mechanism. The alternative paradigm of enaction [ $\rightarrow$  ENACTIVE COGNITIVE SCIENCES\_ 1&2], by equating cognition ultimately with the functioning of living organisms, can appeal to the theory of autopoiesis [ $\rightarrow$  AUTOPOIESIS] which specifies the particular sort of material processes that are living processes.

Enactive interfaces, as artefactual devices built by human engineers, are clearly material entities. However, if they are to be enactive, they must also participate in mental processes. Thus, the very project of enactive interfaces absolutely requires a solution to the problem of mind-matter dualism. Since the two existing solutions in cognitive science are so different, it is important to be clear as to which is being adopted in any particular instance.

## RELATED ITEMS

AUTOPOIESIS  
 COGNITIVE SCIENCES  
 COMPUTATIONAL PARADIGM  
 CONSTRUCTIVISM  
 ENACTIVE COGNITIVE SCIENCES\_ 1&2  
 TURING MACHINE

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## DYNAMIC SYSTEMS

Annie Luciani [INPG]

Dynamic systems relate whether to a real system exhibiting some types of complex temporal behaviours whether a type of models to represent such behaviours.

There are two main types of models to represent behaviours evolving along time: models that describe the evolution of the variables representing a system explicitly along time and models in which time is an implicit variable such as those represented by set of differential equations. A simple example is in mechanics, in which the second type

of model relates to the dynamics although the first one relates to the kinematics. Modelling evolutions along time through a dynamic system shifts the modelling method from an explicit description in time of these evolutions to the design of a system that is able to produce them. So doing, the system plays the role of the “invariant”, able to produce the expected behaviours and revealed by all the temporal changes (possible and actual) in the exhibited behaviours.

All the real physical systems or real mock-ups can be considered as dynamic systems. However, even though that, one does not speak of dynamics systems as long as their behaviours can be represented by sets of linear differential equations, or in other words their evolutions are predictable and reversible in time. There are several types of dynamic systems. One speaks preferably on dynamic systems while at minimum two types of complexity appears in the behaviours:

1) when there are not only temporal evolution within a state (that could be represented by linear dynamics) but also there are state changing – one speak here on non-linear systems;

2) when the evolutions (with in the states and between states) are so non predictable – typical examples are systems of which the behaviour is sensitive to the initial conditions (as the well-known butterfly effect).

Examples of state changing and non-linearities are: the change of phases in critical point such as in solid-fluid-gas phase diagram, limit cycles, hysteresis, etc. Another types of dynamic systems are systems in which a process of regulation or auto-regulation maintains homeostasis against environment and conditions changes. A common feature of all the types of dynamic systems is that the behaviour of a dynamic system cannot be represented by independent (or linearly composed) components as it is possible to do in linear analysis of linear systems. When components are distinguishable, then their behaviours cannot be sepa-

rated and co-evolve mutually. This leads to the apparition of emergent behaviours, i.e. to behaviours that cannot be obtained by any superposition of the behaviours of the components.

When observing complex real phenomena exhibiting such types of evolution, the characterization of the real system that produces these behaviours necessitates to take into account not only (1) the evolutions within each state, but also (2) the state-changing and (3) the types of these state-changing (for example, if it is a triple-point changing phase such as in solid or an hysteresis cycle). This means that all these changes are necessary to reveal the properties of the invariant system behind them. Vice-versa, these complex evolving behaviours cannot be modelled differently than the use of dynamic systems.

In enactive interfaces, dynamic systems and models of dynamic systems are implicated on the human side as a way to see and to model living organisms and/or their cognitive functioning, and on the side of environment in which humans are interacting as a way to model and simulate dynamic objects behaviours on digital and interactive simulations.

In considering or modelling living organisms, René Thom [Thom, 1989] introduced his morphogenesis and catastrophe theories based on dynamic non-linear systems. He developed methodology and models to represent non-linear state changing and he proposes a typology of state changing (fold catastrophe, cusp catastrophe, umbilic catastrophes, pitchfork bifurcation, etc.) that can be used in biology as well in sociology.

In cognitive science, the dynamic systems approaches for cognition assume that cognition may be modelled by – and thus understood as – as a dynamic system. The key example given in [van Gelder, 1998] is that of the “Watt’s centrifugal governor”. The Watt’s centrifugal governor is a mechanical system, designed by James Watt in the late of 18th century to regulate at a constant value the speed of a steam engine. The regulator

controls automatically the aperture of a throttle valve that consequently regulates the amount of the steam flow entering into the boiler. What is interesting is not what the Watt governor does, but how it does it. Instead of implementing such regulation by decomposing the regulation elements into components, the governor achieves the same aim through a mechanism that implements implicitly such a function leading to a complex regulated behaviour. In Watt’s governor, the task is performed without any explicit representation of the evolution of the system and of its states. It is typically a dynamic auto regulated system.

In materialized models of living and human behaviours, as those developed in autonomous robotics or in artificial life (as approach like [Beer, 1995]), the aim is to design autonomous robots able to walk without any explicit description of the walking. Dynamic models are used of several types: physically-inspired models, neural-network inspired models etc. The most famous representatives of that approach are the Brooks’ creatures [Brooks, 1991a] [Brooks, 1991b].

In simulation of physical worlds with which humans interact, as used in virtual reality systems, robotics implementation of haptic control refers to dynamic systems framework. Moreover, the instrumental approach developed by Cadoz, Luciani, Florens and co-workers [Luciani, 2004] [Tache et al., 2006] [Chanclou et al., 1994] necessitates to have at disposal models of the real world and simulation for the virtual objects and worlds that are based on dynamic systems. They assume that it is very fruitful an efficient paradigm to reconstruct genuine multisensory interaction between humans and virtual worlds. They assume that the system human-object and further human-virtual object through multisensory interactions (and mainly through force feedback interaction) has to be considered as a dynamic system and that the dynamics of the coupling is a major element to instantiate enactive interaction and to convey properties such as embodi-

ment and emergent behaviours in a context of digital instruments.

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## RELATED ITEMS

COGNITION, DYNAMIC SYSTEMS APPROACH  
INSTRUMENTAL INTERACTION

# E

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## EFFECTOR

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One can distinguish between three uses (and related definitions) of the term effector:

- In human beings;
- In control systems and robotics, where it is sometimes synonymous of actuator;
- And in robotics, where it may also refers to the tool attached to the last point in a robotic chain

### Human beings effectors

In human beings, effectors are usually muscles, glands, or organs capable of responding to a stimulus, especially a nerve impulse.

### Effector as an actuator element

In control systems and robotics, this term usually refers to a device used to produce a desired change in an object in response to certain inputs. It is also called actuator, which is in fact more appropriate to address its functionality. Then, it relates a fundamental function of artificial systems that involves control and energy flow mastering. In a haptic device [→ HAPTICS, HAPTIC DEVICES], the actuator is an essential and critical component: its properties are determinant for the device quality while its haptic function remains complex and subject of controversial definitions.

In a classical usage (robotics and mechanical controlled systems), the actuator is the device that makes the system able of an artificial action under the control of an artificial informational process (that may be either

an automation data treatment process or a data transmission process).

In haptics, the actuator role differs mainly by the fact that a haptic device does not perform action, but is intended to be a substitute of natural object in human/object interaction situations, these behaviours being either the result of data transmission exchanges with a robot, or synthesized by a computational process. In this context the actuator has to fulfil two requirements:

- Its physical structure and sizing must be able to encompass a certain spectrum of different dynamical behaviours with sufficient precision regarding human sensibility and haptic task requirement. Among these behaviours passive ones are essential since the usual human environment of objects is mostly passive.
- By the means of its control input, the actuator must convey to the user's coupling environment the physical behaviour that is defined by the informational process (simulation or tele-coupling).

Various actuator technologies have been used in haptics. The most usual is the electrical technology which is based on electrical amplification and power electromechanical transducers, mainly electro-magnetic devices liked direct current motors or voice coils. Although the amplifier is the core element of the actuating function, the focus is usually shifted onto the electro-mechanical transducer because it constitutes the main bottleneck of this technology. Indeed energy conversion involves active materials (magnet and conductor) and the power and performance of electrical actuating system is directly linked to the quality and quantity of such material. Several other actuation technologies were used in haptics or are under developments.

Recent developments are focused on the usage of piezoelectric transducers. This technology could constitute an interesting alternate solution in the family of electric amplification based systems since piezoelectric devices offer higher specific force and

power than the classical electro-magnetic transducers.

The piezoelectric transducers can provide interesting alternate solutions to electro-mechanical energy conversion since piezoelectric devices offer higher specific force and power than the usual electro-magnetic transducers. The application of this technology to haptics is still under development.

In a second category there are the circulating fluid actuators that are based on the control of the power of a air or oil flow. The advantage on electrical systems relies on the higher efficiency of the fluid/mechanical converter element that is constituted of a simple piston.

Finally other haptic actuators are based on direct electro-mechanical amplification technologies that need no energy conversion. There are (1) the electrically controlled clutches or brake systems, (2) the direct contact magneto-rheological fluid systems and finally (3) the variable transmission ratio control systems (CVT) that were mainly developed for cobotic applications. The absence of an energy converter is a significant advantage on electric and fluid technologies since the power transducer is always a critical and performance limiting element.

### **Effector as the tool attached to the last point in a robotic chain**

In robots and in haptic devices, the term end-effector refers to a device or tool connected to the end of the robot arm or the mechanical part manipulated by hand in haptic device. Its structure depends on the intended task. In conventional robots, grippers are the most functional end-effectors used to manipulate real objects.

In haptic devices, the user grasps the end-effector of the interface. The shape of the end-effector may correspond to the virtual tool that the user is manipulating in the virtual environment. It can be whether a kind of stylus to simulate pens, pencils, screw drivers, etc. (as in PHANTOM, Mirage F3D-35, Haptic Wand, LHIFAM, etc.), whether a handle or joystick (as in Virtuouse 6D35-45,

EXCALIBUR, DLR-LWR-III, etc.), whether a ball (as in DELTA, OMEGA, HapticMASTER, etc.). It can also consist in a thimble-gimbal or a glove to allow the user to directly feel contact forces without using or simulating any intermediate tools. In some cases, the user can change the end-effector (such as in ERGOS haptic technology [Florens & al, 1990], in which several types of the end-effectors can be plugged on a sensor-actuator basement).

The way the user grasps the end-effector has been deeply studied. Grasping geometry has been classified in two categories, namely power and precision grasps. Power grasp has high stability and force, because the whole hand and palm are used, but they lack dexterity (fingers are locked on the grasped object). Conversely, precision grasps exert less force but have higher dexterity since only the fingertips are used. Typical power and precision grasping configurations can be consulted in [Cutkosky & Howe, 1990].

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### **RELATED ITEMS**

FORCE FEEDBACK  
HAPTICS, HAPTIC DEVICES  
INTERFACE, ERGOTIC  
MECHANICAL IMPEDANCE  
STABILITY

### **RELATED DOCUMENTS**

El\_Actuators\_Florens.pdf

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## EFFORT THEORY, BY LABAN

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[ACROE&INPG]*

The Rudolph Laban's Effort theory [Laban, 1947] is an approach to the analysis of human movement.

The basic concept of this theory is effort, which is a property of movement. The theory describes quality of movement. It considers movement as a communication media [Laban, 1963], and tries to extract parameters related to its expressive power. Moreover, Laban's approach is an attempt to describe, in a formalized way, the characteristics of human movement. It does not focus on a particular kind of movement or dance expression, and is valid also for everyday movements.

Generally there are two way, equally important, to observe a motion:

- The first is related to the cinematic characteristics of the movement.
- The second is related to how the considered motion is performed and to what it communicates.

This distinction is simple to make when referring to an exemplar motion, e.g. to move up an arm. The first type of observation is related, in this example, to the starting point/ending point of the arm, velocity, acceleration. The second type of observation is more related to how the arm is moved (e.g. in a sinuous way or rigid) and to its meaning, e.g. to halt, to greet etc. The Effort theory is an important instrument for evaluate such meaning.

More in details, Laban points out the dynamic nature of movement and the relationship among movement, space and time.

Following the theory of Laban, a vector, called the effort vector, characterizes a movement. Each motion can be mapped in a three/four dimensional space. In his original theory Laban considered a 3-dimensional space, the effort space defined by the space, time, and weight components. A fourth component, flow, was intended as a kind of modifier with respect to the three basic components. Each effort component is measured on a bipolar scale, the extreme values of which represent opposite qualities along each axis.

During a movement, the effort vector describing the motion qualities moves in the effort space. Laban investigates the possible paths followed by the vector and the expressive intentions that may be associated with them.

Following, a short description of the four effort vector components.

### - Space

Space refers to the actual direction of a motion stroke and to the path followed by subsequent strokes (a sequence of directions). If the movement follows these directions smoothly the space component in the effort space is considered to be flexible, while if it follows them along a straight trajectory it will be marked as direct.

### - Time

Time is also considered with respect to two different aspects. An action can be sudden or sustained, which allows the binary description of the time component of the effort space. Moreover, in a sequence of movements, each of the movements has a given duration in time. The ratio of the durations of subsequent movements gives the time-rhythm, as in a music score and performance.

### - Weight

Weight is a measure of how much strength and weight is exerted in a movement. For example, in pushing away a heavy object it is necessary to use a strong weight, while in handling a delicate and light object, the weight component has to be light.

- Flow

Flow is a measure of how bound or free a movement, or a sequence of movements, is. Laban describes flow in these terms: “*In an action capable of being stopped and held without difficulty at any moment during the movement, the flow is bound. In an action in which it is difficult to stop the movement suddenly, the flow is free or fluent*”.

Laban’s core theory considers mainly the first three components of effort (space, time, and weight) to develop a description of human movement. By considering the three-dimensional space built on these three axes, and the opposite qualities for each effort component, it is possible to identify eight combinations of the space, time and weight components (addressed as basic efforts), corresponding to states that the movement can assume in its development.

The power of the effort theory lays in the fact that, even though it is not really expressed in an engineering manner and consequently not simple to follow for measuring purposes, it defines parameters that describe efficiently the quality of the human motion that are independent from the particular motion performed. This means that it potentially allows extracting parameters that are present in any motion.

Also, the Effort theory gives an important starting point also in the study of the enactive interaction. Following the definition of enactive knowledge [ $\rightarrow$  ENACTIVE KNOWLEDGE], the know-how is acquired by doing, and is encoded in the action. It can be found back by searching into the gesture. For an enactive interaction it is important to evaluate and also to represent this knowledge using the same parameters as those processed by humans. In other words, for an enactive interaction with an artificial interface it is important to evaluate both the two subsequent aspect:

- how the human interacts with the system, that is how he uses the motion in order to understand if he is in difficulty, if he is annoyed or stressed in the interaction;

- how the system has to communicate with the human being using the same channels of communication, adapting the interaction to the subject, in particular if it uses virtual agents. This means to add qualities to artificial motion starting from a mathematical representation of them.

In this context the effort space could be considered as an intermediate space where artificial and real motion can be mapped, and the “effort” could be considered as the common language.

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## RELATED ITEMS

- ENACTIVE KNOWLEDGE
  - GESTURE ANALYSIS
  - GESTURE ANALYSIS: LABAN’S KINESPHERE
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## EMOTION

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We, as humans are naturally reactive to emotions in other people and in ourselves. Emotional content is encountered in most human behaviours, such as speech, facial expressions, body gesture and posture. Moreover, many human productions, especially in the arts, exhibit an emotional content, such as such as music, movies, and theatre. Emotions affect all cognitive proc-



esses, perceptions, beliefs, decisions and behaviours.

Emotion is a complex concept and no universally accepted definition or model, exists. The study of emotions straddles many diverse areas of study like neuroscience, psychology, artificial intelligence and virtual reality, and many perspectives such as the Darwinian, Jamesian, cognitive and social constructivist approaches. For an extensive discussion on the context the reader is suggested to refer to [Cornelius, 1996].

The functional aspects of the emotional processes are put in evidence by [LeDoux, 1996] when he describes emotion as “*a way to interact with the environment, to communicate, to evaluate external stimuli, to prepare to act*”. Yet, the relative importance of the physical or the cognitive component is not well separated: in one hand, emotion can be seen as bodily responses that evolved as a part of the struggle to survive or, it can be described on the other hand, as mental states that result when bodily responses are sensed by the brain. Following the work of Klaus Scherer and his theory of the appraisal emotions has to be considered in a dynamic way as a “*constantly changing phenomena integrating more components*”.

Employing virtual characters [→ INTELLIGENT CHARACTERS] considered as enactive interfaces to communicate with the user gives us the unique possibility of letting the user interact naturally with an interface that simulates his interactions with fellow human beings. In such virtual characters, trying to model emotion is very important in terms individualism and realism of the behaviours. Social behaviour of computer characters with emotion and personality increases the believability and quality of the virtual character, such as in games, story-telling systems, interactive dramas, training systems and therapy systems.

The research domain dealing with the processing of emotion is known as affective computing [Picard, 97]. Affective computing is an interdisciplinary field at the convergence of computer sciences, psychology, and cogni-

tive science. It deals with both the question of the detection of emotion (of real people), and of the modeling/simulation of emotion (for virtual character).

Extraction of emotional content from real people’s behaviour employs and develops techniques such as speech recognition, facial expression detection, body posture detection, gaze detection, natural language understanding, as well as measurements of physiological signals on the body, such as skin temperature and galvanic resistance.

For virtual characters, emotions can appear in the virtual character’s way of speaking, facial expressions, body postures and gaze direction. There is a lot of research going on in all these areas [Vinayagamoorthy et al., 2006]. One of the very first models for basic emotions was the one defined by [Ekman et al., 1972]. Ekman categorized the emotions in a set of six basic emotions: happiness, surprise, disgust, fear, sadness and anger. In recent research, among the many approaches to emotion in psychology, cognitive appraisal models [Roseman et al., 1990] has been progressively preferred for computational systems, considering that they better explain the overall process of how emotions occur and affect our decision-making. Here, appraisal means a person’s assessment of the environment, not only including current conditions, but also past events as well as future prospects. Following this model, agent’s concerns in an environment are divided into goals (desired states of the world), standards (ideas about how people should act) and preferences (likes and dislikes). A commonly used and comprehensive appraisal model is the OCC model [Ortony et al., 1988]. This model provides a rule based system for triggering twenty two emotion categories (e.g. hope, fear, pity, love, etc.). However, this has been judged to be too complex for modelling virtual characters [Bartneck, 2002]. Another important model that should be quoted is the activation-evaluation model, which defines emotions according to abstract and continuous dimensions, rather than with discrete labels.

As techniques to model each of the components become better we will be able to develop more emotionally communicative characters, which will serve as better and more believable Enactive Interfaces to the virtual world.

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## RELATED ITEMS

AGENT, AUTONOMOUS  
 GESTURE, EXPRESSIVE  
 INTELLIGENT CHARACTERS  
 VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

# ENACTIVE COGNITIVE SCIENCES\_1

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Cognitive science is an essential reference for giving proper definitions of the key terms

enactive and interface. Cognitive science is certainly not the only relevant theoretical framework; but it cannot reasonably be ignored.

The situation is complicated by the fact that in contemporary cognitive science, there is not just a single paradigm, but two alternative paradigms:

- The classical paradigm (1) based on the computational theory of mind [→ COMPUTATIONAL PARADIGM] this paradigm is allied with analytical philosophy.
- The paradigm of enaction (2). This paradigm is more recent; it is allied with constructivism [→ CONSTRUCTIVISM] and the ecological approach [→ PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH]; philosophically, it is allied with phenomenology [→ LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL APPROACH].

The classical paradigm (1) is based on the concept of the transmission and processing of information, and gives precedence to propositional knowledge. This paradigm mobilizes a relatively linear schema: sensory input from specific modules produces symbolic representations; cognition as such is considered as a process of reasoning on the basis of these symbolic representations which are structured syntactically; a decision for action is considered as an output, and the actual effectuation of the action does not play an essential role.

The alternative paradigm (2) is rooted in bodily sensory-motor dynamics, and higher-level cognition involving language is considered as a subsequent emergence in the course of phylogeny and/or ontogeny. The basic tenet of enaction is this: cognition is to be defined as the process whereby a living organism, interacting with its environment, brings forth, or enacts the world in which it lives. Analytically, the basic scheme for considering enaction is the dynamic sensory-motor coupling between an organism and its environment.

In this second paradigm, by contrast with the first, action is considered as a pre-

requisite for perception: sensory input only has meaning in relation to effectuated actions. The sensory inputs,  $S$ , are used to guide the actions  $A$ ; the actions  $A$  modify the environment and/or the relation of the organism to its environment, and hence modify in return the sensory input. What the world is *for* the organism amounts to neither more nor less than the consequences of its actions for its sensory inputs. Without action, there is no “world” and no perception.

This has important ontological consequences, since it means that reality is not pre-given but co-constructed by the organism. However, although “reality” can be brought forth in an open-ended plurality of ways, this in no way means that there are no constraints; quite the contrary. The sensory inputs  $S$  must be used to guide the actions  $A$  *in a very particular way*; the organism must thereby control its relation with its environment *such that* its own autopoiesis (i.e. the process by which a living organism continually engenders itself) can be maintained. Locally, around any particular viable form of life, the constraints are very tight indeed. “Knowing” exactly *how* to use sensory returns to guide actions is indeed a form of knowledge: not indeed propositional “knowing that” (which comes much later in evolution), but a form of “know-how” expressed directly in action. For the paradigm of enaction, this form of knowledge is indeed much more basic and much more generic than symbolic knowledge.

The idea that cognition and life are aspects of the same basic phenomenon does not mean that cognition never amounts to anything more than the simple sensory-motor dynamics of bacteria and other primitive life-forms. On the contrary: it means that all the changes in forms of life that have occurred during evolution, including their continuation through hominisation and human history, are *ispo facto* changes in what cognition itself is. Characteristically, the paradigm of enaction articulates the various phenomena involved in cognition, by studying their relations in the *genesis* of the phenomena themselves. Thus,

enactive cognitive science is intrinsically reflexive: the act of doing cognitive science is itself a cognitive act, so that cognitive science includes itself as part of its own object.

There are two basic requirements for any paradigm in cognitive science: it must provide a genuine resolution of the mind-matter problem [ $\rightarrow$  DUALISM, MIND-MATTER]; and it must provide for a genuine core articulation between a multiplicity of disciplines, at the very least between psychology, linguistics and neuroscience. Cognitive science owes its very existence to the fact that the computational theory of mind, whatever its defects and limitations, does fulfil these two requirements. The newer paradigm of enaction does the same. Thus, both paradigms are legitimate. However, it is very important to emphasize that these two paradigms are essentially incommensurable. Thus, in any particular discussion, in order to avoid conceptual confusion it is important to specify which theoretical framework is being employed.

Finally, to complete this excessively sketchy outline, the paradigm of Enaction has the ambition to provide a framework which will make it possible to work towards a coherent synthesis of seminal contributions from a number of independent, non-orthodox, non-computational, non-representational lines of thought. To make a rather haphazard, highly idiosyncratic and certainly incomplete list, apart from Maturana and Varela (the Santiago school of autopoiesis and enaction), we may mention: Gestalt psychology and the ecological psychology of Gibson et al; Piaget and the Geneva school of constructivism; Vygotsky and the Soviet school; sensorimotor contingency theory (O’Regan and Noë); dynamic systems theory (van Gelder...); second-generation cybernetics (Bateson, von Foerster); Shanon (the representational and the presentational); clinical neuropsychology (Sacks, Rosenfield; Bach-y-Rita...); consciousness studies (from James to Jaynes...); Pragmatism (Peirce, Dewey...); ethnomethodology (Garfinkel...); cognitive and constructional

grammars (Langacker, Lakoff...) and theories on the origin of language; unorthodox evolutionary and developmental biology (Waddington, Gould, Lewontin, Oyama, Fox-Keller...); radical constructivism (Goodman, Glasersfeld...); situated cognition, cultural anthropology and philosophy of technology (Leroi-Gourhan, Goody, Derrida, Stiegler...); seminal critiques of computationalism (Dreyfus, Searle, Winograd & Flores...); critical epistemology from Kant to Kuhn and social studies of science (Latour...); phenomenology (Husserl, Heidegger, Merleau-Ponty) and diverse kindred philosophical currents (Whitehead; Wittgenstein; Simondon; Jonas...); Artificial Life, swarm intelligence and evolutionary/epigenetic robotics; Ethology (von Uexküll, Gardner, Despret...); neuropsychology; et cetera...

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## RELATED ITEMS

COMPUTATIONAL PARADIGM  
CONSTRUCTIVISM  
DUALISM, MIND-MATTER  
LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL APPROACH  
PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH

## RELATED DOCUMENTS

El\_Enaction&CognitiveSciences\_Stewart.pdf  
<http://liris.cnrs.fr/enaction/index.html>

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## ENACTIVE COGNITIVE SCIENCES\_2

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Enactive cognitive sciences consist of a heterogeneous group of approaches to perception, action and cognition that form a new wave of approaches in cognitive studies. The enactive cognitive sciences have raised in the last two decades in reaction to what has been described as the cognitivist mainstream, characterized by the terms computationalism and representationalism. In opposition to this mainstream, the new wave is characterized by a strong accent upon the role of action in contest, for consequence upon the situated, distributed and embodied character of cognitive processes.

The new wave has expressed three main claims: the criticism aimed at representations, the fundamentally situated and embodied nature of cognition, and the importance of action for the cognitive system. Activity is the common denominator of these three issues, in that the embodied-situated natural organism (and the artificial creature) continuously interacts with its world and this latter entity too cannot be taken for granted, since the interaction with the cognitive agent is relevant for its categorization.

The over-all vision that emerges is that of a cognitive system that is inserted in a context and in an acting body: cognition is more a property of complex systems that include reasons for knowing, ways of acting and perceiving, bodily properties and significant environments, than the function exerted by some kind of abstract entity, whose physical conditions and surroundings can be varied at will.

It follows that the subdivision of cognitive systems into hierarchical levels from the

input to the central elaboration and finally to the output is an oversimplification of the interactions that perception cherishes with action and with more abstract forms of thought. The same distinction between low-level (perception) and high-level (thought, use of symbols) processes can be questioned, even if not (sharply) rejected downright.

The computer is no longer the privileged metaphor of cognition, and artificial intelligence and cognitive psychology surrenders the place of queen of the research on cognition to more embodied disciplines, such as robotics, biology, infant psychology. Even the neurosciences find their explanatory powers reduced when they do not take into account the relationship between the brain, the body and the environment.

At present, a growing number of researches point in the direction of the enactive, embodied, situated view sharing the following key assumptions:

- World is its own best representation: representations can be considered as obsolete for explaining cognition and thus be completely rejected (i.e. [Brooks, 1991] and [O'Regan & Noë, 2001]). The world is thus proposed as to function as its own best representation. In some cases, this strong position is associated with a shift of the explanatory attention from the so-called high-level cognitive processes (such as problem solving, an issue which is typically addressed by classical artificial intelligence) to low-level cognitive processes such as animal motor behaviours (to be reproduced in robotics by artificial creatures, as in [Brooks, 1991], and human perception [O'Regan & Noë, 2001]).
- Strong accent on the role of action in perception and on the situated condition of the cognitive functions. Perception is described as a form of action, an explorative procedure [O'Regan & Noë, 2001] and the functions of representations and memory are externalized in the world and retrieved thank to the perceptual activity of the creature [Brooks, 1991]. The role of

action in perception can be differently interpreted, the reduction of perception to action being an extreme position.

- Low-level, high-level cognitive processes and symbolic representations are described as affected by the presence of the world and by action [Hutchins, 1995; Clark, 1998]. Action, perception and cognition are always anchored in some state of the world external even to the body.
- Different roles can be attributed to actions in perception and cognition. Even if the claim that action plays a role in perception and cognition seems to be shared by the most part of the opponents to the classicist view, this assertion assumes different grades. In particular a difference can be traced between those who attribute to action a role of guidance over perception and those who affirm that action is responsible for the perceptual content [Lederman & Klatzky, 1987] [Noe, 2003].

The described directions of research can be associated to three more organic approaches to perception, action and cognition that share some of the tenets of the group of enactive cognitive studies, and that can hence be considered as part of the new wave in cognitive studies:

- Dynamic Systems approach, claiming that cognition can be seen as dynamic systems able to exhibit implicitly complex behaviours [Thelen & Smith, 1994].
- The enactive vision of cognition, in which cognition is the result of the coupling of the organism and the environment, this coupling being a structural element for their co-evolution [Varela et al., 1991].
- The ecological view that proposes a form of direct perception approach in which not only perception is for action and action directs perception, but what is perceived are the possibilities of action that the objects of the world represent for the organism [Gibson, 1966].