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RELATED ITEMS

COGNITION, DISTRIBUTED
COGNITION, DYNAMIC SYSTEMS APPROACH
COGNITION, SITUATED
COGNITIVE SCIENCES
PERCEPTION, DIRECT AND INDIRECT APPROACHES

ENACTIVE KNOWLEDGE

Elena Pasquinelli [INSTNICOD]

Contributors: John Stewart [COSTECH]

Enactive knowledge is a form of knowledge which is characterized by the fact of not being propositional (knowing that), but rather procedural (knowing how). Thus, enactive knowledge is primarily “knowledge for action”; conversely, action is always necessary in order to acquire enactive knowledge.

The term was first introduced in cognitive psychology by Jerome Bruner [Bruner, 1966] [Bruner, 1968]. Bruner describes three systems or ways of organizing knowledge and three correspondent forms of representation of the interaction with the world: enactive, iconic and symbolic.

- Symbolic knowledge is the kind of abstract knowledge which is proper for cognitive functions as language and mathematics.
- Iconic knowledge is based on visual structures and recognition.
- Enactive knowledge is constructed on motor skills, such as manipulating objects, riding a bicycle, etc. Enactive representations are acquired by doing.

Each mode of organizing knowledge is dominant through a specific developmental phase, but is nevertheless present and accessible throughout. So, all types of representations are present in the adult mind and are part of his cognitive performances.

“Learning by doing” is an important theoretical dimension for enactive theories of cognition, but has also pragmatic consequences for enactive interfaces, where users have to explore the sensory-motor dynamics resulting from a novel interface before they can master it

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RELATED ITEMS

ENACTIVE COGNITIVE SCIENCES_ 1&2
LEARNING AND ENACTIVE INTERFACES

ERGOTIC / EPISTEMIC / SEMIOTIC ACTION- PERCEPTION LOOPS

Annie Luciani [ACROE&INPG]

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The typology of the functions of human-environment interaction proposed by Cadoz [→ ERGOTIC / EPISTEMIC / SEMIOTIC FUNCTIONS] allows drawing out an operational categorization of the implied sensori-motor loops in two complementary categories, according to whether there is or not an energetic structural relation (or energetic consistency) between the actions and the perceived resulting phenomena. Two categories can be distinguished:

- ergotic interaction loops;
- pure epistemic-semiotic loops or non-ergotic interaction loops.

The distinction is operational in the sense that it leads to clearly-cut complementary categories among the technological tools and systems needed to support interaction between human and his/her external universe.

Pure epistemic-semiotic interaction loops

For a human subject, epistemic reception and semiotic emission of information can be linked, constituting an action-perception loop.

In a pure epistemic-semiotic interaction loop, emission of information from the human subject (to the world) and reception of information by the human subject (from the world) are correlated but without structural energy exchanges, in the sense that the energy made to perform the action is not necessarily engraved in the epistemic sensory feedbacks.

Possible epistemic-semiotic loops are:

- Loop from semiotic gesture action to epistemic seeing. That is the case when one speaks about “seen expressive gesture” or “seen non-verbal gesture”.
- Loop from semiotic gesture action to epistemic hearing. That is the case when one speak about “heard expressive gesture” or “heard non-verbal gesture”
- Loop from semiotic gestural action (free gestures, facial movements, etc.) to epistemic gesture perceptions. This is the case of cutaneous touch in which there is any noticeable muscular energetic activity in the result of the action.
- Loop from voice to seeing and hearing.

Examples of epistemic-semiotic loops are: pointing an object, moving to see or to hear, reading, navigating in a data base or in a virtual environments by means of non retroactive sensors as sticks, mouse, triggering a sound signals by acting on a non-retroactive transducer, selecting an object or an icon, conducting an orchestra, etc.

In these action-perception loops, perception depends obviously on action. However, the physical states of the interacting bodies are not modified by the interaction process. These llops are not action-perception loops aiming to act on the world. Mainly they are rather exploratory activities oriented toward acquiring a knowledge of the world, or symbolic activities oriented toward symbolic constructions.

In epistemic-semiotic loops, the muscular energetic activity and the energetic exchanges (if any) can be neglected, or mediated by tools that decrease it, without a noticeable loss in the performance of the task.

Ergotic interaction and its multisensory epistemic feedbacks

Ergotic interaction can be clearly distinguished from pure non-ergotic epistemic/semioyic interaction loops. The cases of the ergotic function, in which the human-environment interaction corresponds with energy exchanges between the interacting bodies during the interaction, cannot be

apprehended by pure epistemic-semiotic loops.

The relevant criteria to distinguished purely epistemic-semiotic loops from Ergotic cases is not the energy spent by the subject during the action, but the energy exchanged between the two interacting bodies, ie, the energy transferred from (resp. to) human to (resp. from) object, which is necessary to physically modify the world, on which the subject is interested in.

As an example, all the handling activities fall in such category, since they imply an energy exchange: grasping, pushing, pulling, cutting, throwing, carrying, moulding, hitting, rubbing, breaking, displacing an infinitely heavy object, writing, digging over the ground, moulding the paste of the bread, crumpling a paper sheet, playing violin, etc.

When one manipulates an object through ergotic interaction, the physical states of both object and subject are modified by the interaction. New mechanical behaviours depending on the interaction (sounds, deformations, fractures, etc...) are exhibited. Thus, the sensory epistemic feedbacks (mainly sight and hearing) inform the subject of the behavioural answers of the object in response to his gestural actions. The sensory stimuli can no more be considered by themselves (as conventionally considered by multimodality). They are due to the physical responses to the interaction, and are not exhibited by the object in the absence of the interaction.

Hence, the sensory stimuli, visual, acoustical or tactile-kinaesthetic, encode the coupled system made of the human body and the physical object. They inform the subject on the physical objects, but also on its physical coupling to the human body. For example, sounds encode the human/object system during the performance, visible motions (displacements and deformations) encode of the human/object system during the manipulation, etc.

In other words, during ergotic interaction, we can state that the physical object transforms the gesture space in auditory (resp.

visual) space. Hence, the physical object transforms – or encodes - the gesture space in auditory (resp. visual) space.

During ergotic interaction, the sensorial space:

- Is intrinsically multisensorial: composed of ergotic interaction (with its action and perception part) and acoustical and/or visual feedbacks.
- Aims at knowing the coupled system object-subject, and not only at acquiring information on the object itself.

This means that:

- The object is known through the sensory feedbacks of the matter in response to the gesture actions.
- All these sensory feedbacks have to be considered a priori as an encoding of the couple human-object. They encode invariants of this coupled system (if they exist) to our cognition.
- All the sensory feedbacks are then physically, energetically coherent in their relation to the actions and in their interrelation.

To conclude

Ergotic situation correspond with two necessary features:

- The interaction correspond with the ergotic function
- The relation between all the sensory feedbacks and the gesture exhibits an energetic consistency.

Such type of interaction is called instrumental interaction [Cadoz, 94] [Wanderley, 00] [→ INSTRUMENTAL INTERACTION].

These two features impact the technology to use when willing to implement instrumental interaction with computers:

- For ergotic loop, there is a structural necessity to introduce force feedbacks and modelling methods based on physics and dynamics, able to correlate all the variables (positions, forces, visual deformations, acoustical deformations) in a spatio-temporal consistent scheme.

- For non-ergotic pure epistemic/semiotic loop, conversely, it is not necessary to introduce force feedbacks nor the correlated methods of modelling based on physics and dynamics. Others types of correlations (symbolic, signal-based, etc..) are most often sufficient to explore the wideness of all the possibilities of these type of interactions.

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RELATED ITEMS

ERGOTIC / EPISTEMIC / SEMIOTIC FUNCTIONS
 GESTURE, EXPRESSIVE
 GESTURE, NON-VERBAL
 INSTRUMENTAL INTERACTION
 INTERFACE, ERGOTIC

ERGOTIC / EPISTEMIC / SEMIOTIC FUNCTIONS

Annie Luciani [ACROE&INPG]

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Claude Cadoz [Cadoz, 1994] has introduced a typology of human-environment relation, identifying three functions. This typology allows characterizing univocally, i.e. in a non-redundant manner, the computer devices and interfaces that allow human to interact with environment through and by computers.

These three functions are: the epistemic function, the semiotic function, the ergotic function. Conversely to the terms epistemic and semiotic that are usual, the term ergotic has been specifically introduced, by Claude

Cadoz [in Boissy, 1992] [Cadoz, 1994] [Cadoz 2000] to identify a function of man/environment relations that cannot be implemented by any association of the epistemic and semiotic functions.

Epistemic function

The epistemic function of man/environment relations is the function supported by the human perceptual apparatus: vision and audition apparatus, and proprio - tactilo - kinaesthetic apparatus (kinaesthetic and tactile receptors). One can speak of the epistemic function of vision, audition, and of the haptic sensory modality, as stated by in the book *Touching for knowing* [Hatwell et al., 2003].

Semiotic function

The semiotic function is the function conveyed by the human channels that are able to emit information toward the world. Humans are equipped only by two such emitting channels: the mechanical body producing gestures (body, arm, hand, face, etc...) and the vocal apparatus producing aero-acoustical motions. Some types of human gesture aim fundamentally at transmitting information to the environment (and not energy, though energy exchanges may be involved secondarily). That is the case of the gestures that accompany the speech, of the sign language of the deaf-mute, of the gestures of musical conductors, of the gesture that consist in pointing a target with the finger, of the action consisting in moving around an object (walking, etc), of the cutaneous touch without movements of muscles and joints, of pulling a infinitely light object.

Ergotic function

The ergotic function intervenes when physical energy is exchanged as a structural functionality of the man/environment relation, i.e. when this energetic exchange is strictly necessary in the performed task, which could not be achieved by other means. A specific ability of the gesture channel is to handle directly the matter: to mould it, to

transport it, to break it, to cut, to rub, to hit, etc. The hand (or the whole physical body) is in such cases in contact with the matter, and exchanges physical energy with it. It applies forces, displacements, deformations to the object, and the object reacts on the human body, resisting to the energetic transfer, and retroacting a part of it [Luciani, 2004]. The fact that energy is exchanged is, in these cases, essential. Ergotic interaction aims not only at informing the external world and at being informed by it, but, more fundamentally, at transforming physically the world. That is made possible thanks to the fact that the gesture channel is intrinsically bi-lateral: it allows acting-on and perceiving in an inseparable way. Hence, during an ergotic interaction, simultaneously with the energetic exchange, the subject both knows (epistemic function) and inform (semiotic function).

The term Haptic is often used to state this function. Unfortunately, as stated by E. Pasquinelli [\rightarrow HAPTICS, IN COGNITIVE SCIENCES], this term covers several meanings underlying several different points of view. In addition, when it is used alone, haptics refers mainly to a part of the human sensori-motor apparatus with no consideration on the relation with the type of information exchanged with the environment. Conversely, the term ergotic, rooted on *ergos* (physical work, energy), represents clearly the principal property of such function. But above all, the current use of haptics, for example in VR, does not cover the idea that this energetic exchange is not only an intuitive help for the user, i.e. an improvement of the performance of the manipulation, but also plays a relevant and structural role in the results themselves. In Musical performance for example, the ergotic property of the interaction with a bow is not only a necessity for the playability of the instrument. More important, it is responsible of the subsequent dynamics and, intimately, of the nature of the sounds. We can say that sound embodies the performed ergotic gestures.

Ergotic and Epistemic-Semiotic functions and technology

The Cadoz' category is efficient to categorize in a non-redundant manner the devices and systems developed to allow the human to interact with the environment through electrified (and further computerized) non-opto mechanical devices. Hence:

- The epistemic and semiotic functions do not require necessarily force feedback devices, nor computer models that simulate the physical consistency between their action inputs and their sensory outputs. A typical example is the control of an electrified fire alarm by an electrified button.
- The ergotic function conversely requires necessarily the use of force feedback devices and of models that simulate the physical consistency between action inputs and sensory outputs. A typical example is the playing of a virtual violin with a force feedback device representing the bow. In this case, force feedback is necessary for the player to perform the gesture, and the sound produced (acoustical energy, dynamics, timbre) is intrinsically the expression of the physical, ergotic interaction.

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RELATED ITEMS

HAPTICS, IN COGNITIVE SCIENCES
 INSTRUMENTAL INTERACTION
 INTERFACE, ERGOTIC

EXPECTATIONS

Elena Pasquinelli [INSTNICOD]

When we consider a certain experience as believable, we do not necessarily consider the experience as being true, in the sense of being an experience with real, existing objects. Neither we consider that experience as being susceptible of becoming true, for instance in the future.

Since the subject cannot compare his experience with reality, then he might compare his experience with his expectations.

Expectations are in fact always present when we have an experience at the cognitive, perceptual or motor level, in mediated and non-mediated conditions. The fact that in normal conditions (non-mediated) we normally hold a certain number of expectations is testified by the fact that we react with surprise when faced with certain, unexpected events. Surprise is in fact an effect of unfulfilled expectations [Dennett, 2001] [Davidson, 1984] [Davidson, 2004]. Dennett writes: “*Surprise ... is a telling betrayal of the subject's having expected something else. [...] Surprise is only possible when it upsets belief. But there are examples of non-linguistic expectancies*” [Dennett, 2001, p. 982].

Expectations consist in the anticipation of events or experiences on the basis of some belief, past or present experience or knowledge. Expectations can be confirmed or disconfirmed by experience. The violation of expectations can be considered as a form of violation of coherence. According to [Bruner & Postman, 1949] even if the organism can perceive the incongruity (be aware of the contradiction), as long as possible, it will ward off the perception of the unexpected.

In virtue of the role played by expectations in believability, it is important for virtual reality designers to identify the expectations held by the users a certain virtual reality application is directed to and to be ac-

quainted with the types of expectations virtual reality users can hold.

One type of knowledge which certainly seems to be involved is the so-called commonsense knowledge. Commonsense knowledge, naïve, qualitative or folk physics make reference to the aspect of the world as most of the people think about it, rather than to the world as physicists think about it [Hayes, 1978].

Other expectations, based on laws of perception and action, do not make reference to some form of belief or theory but are based on the existence of rules of perception, for instance on the existence of established connections between perceptual experiences or between motor actions and perceptual experiences. For example: normal experience is both multisensory and coherent. The surprise caused by the perceived conflicts between sensory modalities testifies the existence of general expectations about the coherence of the perceptual appearance of objects and of specific expectations (activated by specific contexts) about the tactile aspect of an object which is perceived as round by the visual modality.

Expectations that users hold during the interaction with the virtual world can be inherited from past experience with the real world or acquired in virtue of the acquaintance with the virtual world contexts and contents themselves. These expectations are totally internal to the context of the experience. The coherence internal to the virtual world seems hence to be another important parameter for the believability of the experience.

The situation in virtual reality is different from the situation in reality. As a matter of fact only certain expectations are in cause in these kinds of mediated experiences. Some expectations inherited from the real world are deactivated, and substituted by other expectations. These new expectations can be introduced by narrative information at the beginning of the interaction, by perceptual information contained into the interaction

itself, and by training. In the same way, expectations can be deactivated by the awareness of the virtual nature of the world. In this sense, the activation and deactivation of expectations depends both on the contents and on the context of the experience.

A pragmatic indication for the design of virtual worlds hence consists in paying attention to the expectations that are held by users and to the capacity of the system of deactivating the expectations that cannot be fulfilled and of activating relevant expectations through narration, perceptual hints and training. The awareness of the virtual context of the experience can play a positive role in this process because it lowers the expectations of the users and limits the risk of frustration.

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RELATED ITEMS

BELIEVABILITY_1&2
COHERENCE OF PERCEPTUAL EXPERIENCE
INTUITIVE PHYSICS

EXPLORATORY PROCEDURES

Gunnar Jansson [UPPSALA]

Haptics is a very efficient perceptual system making possible recognition of real objects very accurately in a few seconds. Information via the hands is obtained in an active process [→ ACTIVE PERCEPTION / TOUCH] [→ TOUCH, ACTIVE / PASSIVE]. Not only sensors in the skin, but also sensors in the muscles, tendons and joints are involved. The movements performed are typically not random, but differ with what object property the observers want to be informed about. The movements are different when they want to know how hard or heavy an object is, for instance. There are specific movements to get specific kinds of information. Lederman and Klatzky (1987) suggested a number of basic movements during exploration of objects, called exploratory procedures: among others, lateral motion for perceiving texture, pressure for perceiving hardness, static contact for perceiving temperature, unsupported holding for perceiving weight, enclosure (enclosing the object in a hand or both hands) for perceiving global shape and volume, and contour following for perceiving global shape and exact shape. It was demonstrated in an experiment with exploration constrained to specific procedures that each of the exploratory procedures was usually optimal to obtain information about the property, for which it was specifically aimed. For example, lateral movement is optimal for perception of texture, and pressure for the perception of hardness. What exploratory procedure observers choose depends on what object property they want to know about.

Even if exploratory procedures are the main kinds of activity to obtain haptic information, a short contact with an object, "a haptic glance", can be informative (Klatzky &

Lederman, 1999). It may provide at least coarse information that initiates an exploratory procedure to get more exact information.

Haptic identification of real 3D objects is superior to identification of their 2D depictions, which is related to the information available by exploration in the two cases, greater integration across the fingers with real objects, better use of material information, and contribution of 3D shape and size (Klatzky et al., 1993).

Another exploratory procedure suggested is wielding to get information about several properties of an object (Turvey and Carello, 1995). If observers hold a rod with one hand at the end and wield it, they can perceive its length quite accurately on the basis of the haptic information only. It is also the case that objects of different shapes can be identified by wielding.

The exploratory procedure of shaking, for example, a container with liquid, can inform about the amount of liquid it contains. Especially, horizontal shaking is efficient (Jansson et al., 2006).

One of the problems with present-days haptic displays is that they sometimes require non-natural exploratory procedures, for instance, exploring objects, one point at a time, with rigid links such as a probe or a sheath, exploratory procedures seldom used in real life. These conditions constrain the exploration process considerably, by limiting the rich cutaneous information, as well as the number of contact points (Lederman & Klatzky, 2004). The factor that would have most importance for the development of haptic displays would be to increase the extension of the cutaneous information (Jansson & Monaci, 2006).

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RELATED ITEMS

ACTIVE PERCEPTION / TOUCH
TOUCH, ACTIVE / PASSIVE

EXTERNALIZATION, PERCEPTUAL

Charles Lenay [COSTECH]

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In the context of Enactive Interfaces, externalization is the process by which perceptive activity brings forth objects as being situated at a distance, in front of a viewpoint which is distinct from the objects. Noticeably, sensory stimulations are always proximal (see below for the distinction between distal and proximal), since they correspond to the activation of sensory cells and organs of the organism. Nevertheless, it is on this basis that, by means of establishing relations with the actions that are performed, the subjects can construct the perception of an object situated at a distance from them, in a space

which surrounds them. Externalization is thus the simultaneous construction of distinct relational positions of a point of view (the point of perception in general, which corresponds to the position of the subject) and the perceived object [Lenay et al, 2003].

The two terms proximal and distal are particularly useful for describing enactive interfaces, since they allow a distinction between two sorts of space depending on the focal attention of the user of the technical artefact.

Originally, in the context of physiology, the terms distal and proximal are used to describe the relative positions of different parts of the body. The distal parts are those that are further from the abdomen: for example, the foot is distal relative to the knee.

It is worth noting that this distinction can be extended to the use of tools. If one grasps a stick to touch the ground, the point of contact between the stick and the ground is distal with respect to the hand. The distal touch of the stick on the ground is then opposed to the proximal touch of the stick with the hand [Merleau-Ponty, 1945].

Distal and proximal are mutually exclusive: one no longer clearly perceives the stick as soon as one perceives *with* the stick [→ TECHNICAL ARTEFACTS, MODES OF]. Similarly, in the case of a graphic interface, the distal contact of the cursor with an icon on the screen is opposed to the proximal grasping of the mouse with the hand. In this case, as in the case of virtual reality environments and telepresence, this leads to a distinction between a proximal space and a distal space. The proximal space of actions and perceptions is the bodily space in which control commands are manipulated (a mouse, a joystick, or any other sensor of bodily movements or forces). The distal space is the immersive digital space in which the movements of an avatar, of a viewpoint, or of any other means of action, occur. Here again, the proximal space is destined to disappear from consciousness at the very moment when the user's attention becomes focussed on what is happening in the distal space. Since a distal

space of action and perception can only be constructed on the basis of proximal actions and sensory stimulations, the terms distal and proximal are necessary to describe and to analyse the process of perceptual externalization and the construction of distal objects.

This usage of the notion of perceptual externalization must be distinguished from the concept of externalization proposed by the French anthropologist Leroi-Gourhan [Leroi-Gourhan, 1993], to designate the process whereby, over the course of evolution, what were originally biological organs attached to the body (for example, the fist of the hand used as a hammer, or teeth used as a knife) are externalised in the form of tools (hammer, knife...) detached from the body. Externalisation in this sense goes together with internalization, the process by which the tool is (re)integrated with the lived body. In this process of internalization a technical artefact which mediates the interaction between a human organism and the environment disappears from focal consciousness (becoming part of the lived body). Concomitantly, focal consciousness switches to the "lived world", which is enacted, and in which the subject finds affordances (i.e. things to do) [→ AFFORDANCES].

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RELATED ITEMS

AFFORDANCES
LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL
APPROACH
TECHNICAL ARTEFACTS, MODES OF
OBJECTIVITY
ZOOMABLE EXPERIENCE

F

FEEDBACK

Emilio Sánchez [CEIT]

In control theory and control systems, feedback is the signal or variable that is looped back into a so-called controller.

The controller forces the output variable of the system to track a reference signal. It can compute the actuation in the system taking into account only the reference (this strategy is called open loop), or taking into account both the reference and the output variable to be controlled (this strategy is called close loop). In the later case case, there is a feedback loop containing the elements in charge of measuring the output signal and feeding it back to the controller.

Only systems whose behaviour or dynamics are well known can be controlled using open loop strategies. However, even those systems can involve certain uncertainties (i.e. the mass of the vehicle depends on the number of passengers), and these open loop controllers cannot keep on tracking the reference in presence of this kind of disturbances. This is why the feedback loop (the close loop strategy) is so important in control theory: by seeing (monitoring) on-line the output signals the controller can correct the behaviour of the system.

Human beings also use this kind of close loop strategies in their daily tasks. Information collected by our senses plays a crucial role in performing most tasks. We can develop certain skills by means of training, but even in these cases we usually need information provided by our senses to complete tasks. Certain types of feedback (meaning information channels allowing responses to our manipulations) are required in order to

permit enactive knowledge of objects and environments.

RELATED ITEMS

AUDITORY FEEDBACK IN VR AND HCI
CYBERNETICS
DYNAMIC SYSTEMS
FORCE FEEDBACK
CHANNEL, AFFERENT / EFFERENT

FORCE

Annie Luciani [ACROE&INPG]

Physical modelling and interactive physically-based computer models and simulation rise the new important question of the increase of the presence and believability of virtual worlds. The notion of force is then at the core of the modelling process and interaction, since it intervenes in the computation processes and algorithms [\rightarrow ALGORITHM] and in the interaction process by means of force feedback devices [\rightarrow HAPTICS, HAPTIC DEVICES]. It is consequently useful to remind fundamental properties of the concept of force and to have in mind the non-trivial transformations caused by their computer implementation.

In 1687, an idea was born which changed people's approach towards the world and nature: *Principia Mathematica* was published by Isaac Newton and influenced humanity. The core idea was the importance of interaction: action to / action from, formally expressed by the action-reaction principle. Previously, another representation system of the world had been proposed by Maupertuis, based on the minimum-action principle. Maupertuis' concept of action had a different meaning than in Newton's action-reaction principle. Maupertuis' work, though, has had less influence than Newton's. However, one can note that later on, Lagrange and Hamilton revisited Newton's representation, which led back to a Maupertuis-like minimum action principle.

These two representation systems are totally equivalent as for the representation of the dynamics of systems – at least as long as these systems do not evolve at speeds close to the speed of light (relativity theory) and are not at the atomic scale (quantum theory). Nevertheless they differ completely with regards to the concept of representation on which they are based.

The Newtonian's approach is based on, and only on, the idea of interaction. It expresses, step by step in time and space, the correlations of the evolutions of observable phenomena. This means that it considers:

- at least two phenomena, and not only one
- and the phenomenological correlation – i.e. the phenomenological co-evolution of both, and not the evolution of each one.

The basic and non-trivial notions used are (i) the distinction between extensive variables and intensive variables and (ii) the action-reaction principle (sometimes called mutual influences).

These two axioms (the duality of the variables and the symmetry of the influences) are the two inseparable fundamentals of this model of nature. We may say that it represents an algebra of interaction between the two observed evolving phenomena. This means that the abstract – or representational - process starts from two evolving phenomena exhibiting an observable correlation (and after, may continue *ad libitum* with any number of correlated phenomena). This concept is a differential concept, differential in time and differential in space.

The Maupertuis' approach is based on the analysis of the space of movements, where a movement is a point on a 4D space (spatial variables and time). It considers all possible movements, and it determines the rules that regulate the realized ones, via integrated variables such as energy, or quantity of motion. The process consists in minimising such integrated variables. The integrated variables are well summarized under the heading of the general term "Maupertuis' Action". This vision is indeed more a geometry of the 4D

motion space, aiming at describing the topological and geometrical organization of this space, as it is elicited in the term analytic mechanics.

Although the two visions are completely equivalent to explain and formulate the dynamic behaviour of nature, in the Maupertuis' vision, the action/reaction principle is implicit and masked in an integral vision of time and space.

In the Newtonian representation of mechanical phenomena, extensive variables can be positions, displacements, and their derivative (velocity and acceleration). The most representative intensive variable is precisely what is called a force. Due to the action-reaction principle, intensive and extensive variables cannot be separated. Intensive variables (e.g. force) do not represent "things" but mutual influences, i.e. observed correlations, or the so-called interactions. The interaction is symmetrical and formulated by a non-oriented equating rule:

$$\text{Influence (or force) } 1 \rightarrow 2 = - \text{Influence } 2 \rightarrow 1$$

Moreover, the physical rules that represent the dynamic behaviour of two interacting physical objects are equating relations, that correlate intensive variables and extensive variables describing the two observable phenomena. In other words, there is no causality between extensive variables and intensive variables. The force (intensive variable) does not produce the displacement (extensive variable), nor the reciprocal.

Conclusion 1: Newton's formalism as an algebra for dynamics systems

Newton's action-reaction based formalism, by implementing the interaction concept as action to / action from, i.e. actions exchanged, can be, in fact, considered as an algebra for dynamics systems. More than being strictly reduced to representing natural phenomena (Physics for *Physics*), the involved mathematics can be indeed used with benefit to represent a wide variety of dynamic phenomena, that can be physical or not.

Conclusion 2: Force feedback as a non-trivial concept

As long as we aim at studying directly the coupling between the human machine and the physical world, it is, strictly speaking, not valid to talk about force feedback, the two physical interacting bodies being non separable. Moreover, dynamics, and besides it, the principle of action-reaction, which the concept of force is a formal descriptor, is an abstract representation of the system composed of the two bodies. Dynamics is an abstraction, a “beautiful intellectual intuition, able to mentally re-generate for us the phenomenon”.

Conclusion 3: Force computation and physics

In order to be able to talk validly of force feedback, a non-trivial transformation must be done, from an indivisible interacting entity system, to an input-output representational system. This is a necessary transformation to allow defining force feedback and force feedback devices.

The transformation of a non-oriented interaction between two physical bodies, into an oriented bidirectional input-output electrically-based situation, and further into a digitally-based situation, has important non-trivial consequences. It leads to introduce causality between computed variables (from extensive to intensive, and vice-versa), which contradicts the non-causality principles that ground physics. In addition, when supported through exchanges between sensors and actuators [\rightarrow EFFECTOR] by means of a computational process, this causality is aggravated by the introduction of a temporal causality [\rightarrow STABILITY].

Finally, in the context of interactive computational physics, such as needed when introducing force feedback devices, one must note that the Newton’s differential formulation is well adapted. First, it enables potentially a step-by-step computation of the dual intensive/extensive variables. Second, by being based on the action/reaction principle,

it allows an objective modelling and analysis of inter-influence between bodies or phenomena. However, a special attention has to be put on the translation of the notion of force, and in the process of their digital implementations. Most works and methods in the sciences of simulation and in real-time interactive simulations, tackle these very critical questions. When observing macroscopically the behaviours of a virtual reality system, layman has to be aware of the discrepancies between the simulated world and the real world, which are derived from this important transformation and that are not always obviously apparent.

RELATED ITEMS

ALGORITHM
CHANNEL, AFFERENT / EFFERENT
EFFECTOR
FORCE FEEDBACK DEVICE / FORCE PROPERTIES
HAPTICS, HAPTIC DEVICES
SIMULATION
STABILITY

RELATED DOCUMENTS

El_InputOutputParadigm_Luciani.pdf

FORCE FEEDBACK

Jean Loup Florens [ACROE&INPG]

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The term force feedback has a relatively long history in various fields, which led to various meanings that are sometimes unclear.

Teleoperation

The term force feedback originates in the field of teleoperation. It has been introduced at a time when it was important to denote the difference between single-direction tele-actuating systems and fully interacting active systems.

The most widely spread design for single-direction tele-actuating systems consists in a

forward motion control of a slave, associated to a visual feedback. In order to complete such systems so as to obtain a full mechanical coupling, the most natural mean was adding a slave-to-master “force feedback” to the motion control. However, one must note that though this denomination, real implementations usually did not feature strictly a force feedback. In fact, early telemanipulators were mostly designed as differential servo-positioners (hence, as bidirectional motion control), instead of exhibiting truly a force feedback system [Goertz, 1953].

Also in the context of teleoperation, a slightly different meaning of force feedback (or effort feedback) referred to the transmission to the user of the effort sensed by the remote robot. This second meaning, consequently, does not refer to the category of data managed in the systems, but to the sensation finally felt by the user.

Both the meanings (complete coupling and sensation felt by the user) are often confused with each other’s, though they actually differ. The ambivalence of the term originates in the definition of the force considered. Indeed, the term feedback implies that some signal is fed back. Since a signal is by essence directional, as soon as a signal (that, here, represents a force) is considered, one should precise its two extremities. In the term force feedback, what are the origin and destination? That remains unclear. Depending on the author, the paper, the situation, the considered origin may be a force sensor, the output of a computation, the force output by a force actuator, something else, or a vague mix of all of them. And, conversely, the considered destination can be either a force actuator input, a computation, the human being himself, etc.

Amplified Handles

A third usage of force feedback appeared later in the domain of amplified handles (motion followers, assisted command, etc.), when trying to improve such handles by inserting an active generator in it. Indeed, letting the handle become active (letting it

generate for example vibrations, etc) proved to be of interest to overcome the softness of the lever, to re-enable the amplified handles with some important features of the corresponding non-amplified handles, and finally to help the user achieving its task better. The feedback provided to the user by such an active handle is also called force feedback. A classical example is the aircraft pitch control, where artificial vibrations are generated to mimic the behaviour of non-amplified handle in case of a dangerous state in the aircraft, which the pilot should be as intuitively as possible warned of. This type of force feedback is also used in training simulators, in some today’s interactive games, etc.

In this case, the force feedback is not correlated directly to the forward signal, nor sensed on the distant controlled process, like in teleoperation. Also, it is not a mean to implement a physical full coupling. Various studies show however that the effect on the user can be efficient, in terms of believability, even though the coupling of the generated feedback with the distant controlled process is not physically valid. However, since the resulting effect for the user is necessarily active (some energy is introduced in the interaction), obtaining a believable effect when using this type of feedback necessitates that the process controlled through the handle is itself an active system (able to generate energy).

Force-feedback device

Finally, a more recent usage of the term, which is particularly important in the domain of Enactive Interfaces, concerns the so-called force feedback devices, that are a major subclass of the Haptic devices. However, in the case of these devices also, the term force feedback is somewhat unclear. It can refer to the stimulation of human kinaesthetic perceptive system [Burdea, 96] [Ellis, 95] - which is somewhat doubtful since human haptic interaction cannot be reduced to a simple forward / backward model. But it can also refer to the control structure of the device itself, in the case when the actuator is de-

signed as a force actuator [→ EFFECTOR] — which is, indeed, not always the case in this type of devices that are often actually designed as force sensors/position actuators. Following this introduction, a more detailed discussion on the concept of force feedback device is presented in [→ HAPTICS, HAPTIC DEVICES].

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RELATED ITEMS

ALGORITHM
CHANNEL, AFFERENT / EFFERENT
EFFECTOR
FORCE FEEDBACK DEVICE / FORCE PROPERTIES
HAPTICS, HAPTIC DEVICES
SIMULATION
STABILITY

FORCE FEEDBACK DEVICE / FORCE PROPERTIES

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Force feedback devices are, at first sight, a category of haptic devices that are able to exert a controlled force by the means of actuators in their mechanical (or gesture) interaction with a user. This definition, provided for the sake of simplicity, should be considered carefully [→ HAPTICS, HAPTIC DEVICES] [→ FORCE FEEDBACK]. Anyhow, the expression force feedback device clearly relates with the idea of a controlled force.

Hence, an important mean to evaluate these devices consists in considering their force properties.

Force properties of force feedback devices can be decomposed in three categories:

- The sizing properties of the force produced in the real world by the haptic device. These consist mainly in continuous force and peak force.
- The properties of the image of the real force in the virtual world, i.e. the “virtual” force.
- The relation between the real force and the virtual force. This can be analyzed for non-temporal properties through force resolution, force accuracy and for temporal properties through force response.

Sizing criteria: Continuous force and Peak force

The electromagnetic actuators implemented by force feedback devices necessarily present intrinsic limitations. Generally speaking, the force sizing criteria refers to the specific properties of the electromagnetic actuators. This leads to define two different maximum forces: a continuous force (the maximum force that can be applied for an unlimited period of time without taking damage) and a peak force (the maximum feasible force).

The continuous force of a device is always smaller than its peak force. Often, avoiding a possible overheating of the actuators limits the continuous force: the device driver has to reduce the force when temperature reaches a critical value. Typical values for the continuous force of haptic devices lay between 1.5 Newton for the PHANTOM [Massie et al, 1994], more than 100 Newton for the lightweight robot, or 80 Newton for each axis of the ERGOS [Florens et al 04] system.

The peak force is the maximum force that a device can generate during a short period of time. In general, devices operate far below their peak force. Its value is determined by the physical limits of the device or by the power control.

Finally, one can note that for serial-linked devices, the joint torques depend on the device configuration and on changes inside the workspace, even when the load remains constant. Instead of continuous and peak force, one should consider continuous torque and peak torque.

Real/virtual force relation: Non-temporal properties

Firstly, force resolution is related to the quantization step of the force: the smallest change in the actual force that can be exerted or detected.

Force quantization is caused most often by the use of digital technology (e.g. analog-to-digital converters). Designers of haptic devices should take into account the just noticeable difference (JND) for force – i.e. the limit of humans regarding the perception of a change in a force. To allow the device to display smooth changes in the force, the actuator resolution should be higher than the JND. Noticeably, the JND in forces follows the Weber-Fechner law: it decreases with the total force - it is about, indeed, 5-10% of the total force [Allins et al, 2002]. This is an important practical problem for force feedback devices, because in most of them, due to a fundamental limit in the technology, the force resolution is constant over the possible force range.

As for it, force accuracy is defined as the maximum error that exists between the command (or represented) force value to be applied, and the actually displayed force. Hence, force accuracy is a rough description of the force error. The nature and signal characteristics of the various components in the error must be considered to evaluate their relative importance. A particularly important aspect of force error signal is, indeed, its correlation with the corresponding axis motion. Force errors that consist in additional energy source like resolution errors are much more perceptible than passive forces, like the biases in the cinematic model. In a lesser importance, the passive force errors that are correlated to motion by hard non-linearity

like the actuator saturation error may be also perceptible.

Real/virtual force relation: temporal properties of force response

Depending on the type of control mode of the device at hand, the part of the device to consider here is either its force sensing chain (in admittance mode), or its force actuation chain (in impedance mode).

In the case of sensing (admittance mode), in practice, the temporal response is not really limited by the sensor itself, since it is generally based on resistive or piezzo-electric gages. It is mostly limited by the sensor's localization inside the mechanical chain. Indeed, the inertia and elasticities that are situated between the users' contact point and the sensor create a low pass filtering effect in the transfer of the sensed force.

In the impedance mode, the force actuation chain is generally based on a local force control loop, because no actuating device is able to provide a satisfactory force actuation in a complete open loop mode. As a consequence, the transfer properties of the global actuation chain depend mainly on the force sensing properties of the local force control loop involved.

However, in some cases, the effective force sensing is replaced by a motor current sensing. This configuration is generally referred as open loop force actuation, or as open loop impedance mode. In this case, the power of the electro-magnetic motor plays the role of force sensor. This results in several limitations concerning the force transfer: (1) the force transfer gain depends on the parameters of the power device, which may vary in time; and (2) the response is affected by the position of the force sensing point in the mechanical chain. In particular, the response is biased by the inertial and friction forces generated by such a mechanical chain.

Properties of the virtual forces

The properties of the virtual force computed depend mainly on the category of modelling employed.

In the context of spatio-geometrical modelling, the haptic interface is introduced as an additional “display” of a pre-existing geometric model. The dominant methodology consists in completing the existing model by an additional algorithm dedicated to the computation of the force and to the control of the haptic interface [→ HAPTIC RENDERING OF VIRTUAL OBJECTS].

Another approach consists in using a natively physical model [→ PHYSICALLY-BASED MODELLING TECHNIQUES FOR MULTISENSORY SIMULATION]. In this case, the forces computations are inherently taken into account by the model. No specific force response algorithms have to be considered.

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RELATED ITEMS

EFFECTOR
FORCE FEEDBACK
HAPTIC RENDERING OF VIRTUAL OBJECTS
MECHANICAL IMPEDANCE
PHYSICALLY-BASED MODELLING TECHNIQUES
FOR MULTISENSORY SIMULATION
STABILITY

FORMAL SYMBOL SYSTEMS

John Stewart [COSTECH]

Formal symbol systems are important because they are the basis both for modern digital computers, and for the computational theory of mind [→ COMPUTATIONAL PARADIGM] which is one of the two major paradigms in cognitive science [→ ENACTIVE COGNITIVE SCIENCES_1].

The reader can refer to the related document to get details and explanations on the concepts, especially mathematical (e.g. Cantor diagonal, Gödel’s theorem, etc.) that are used in this item.

A formal symbol system consists of two parts: a syntactical part, and a semantic part. A formal language is a pre-requisite common to both parts. The syntactical part consists of the formal syntax with its attendant axioms and theory of demonstration. The semantic part consists of a formal semantics, and quite generally introduces the notions of “true” and “false” which, strictly speaking, do not apply to the syntactical part. The key question now concerns the relation between the syntax and the semantics.

There are four major qualities that a formal symbol system should, ideally, possess:

- 1) A system is said to be adequate if every (syntactical) theorem is a (semantic) tautology.
- 2) A system is complete if, conversely, every semantic tautology is a syntactical theorem.

If both these conditions are satisfied, there is a one-to-one relation between syntax and semantics. Intuitively, this is the situation where the motto “take care of the syntax, and the semantics will take care of itself” actually applies. There are, however, two additional qualities that are also important:

- 3) A system is said to be consistent if it can be proven that there will never be a formula

KK such that both *KK* and *not-KK* are theorems. Intuitively, this would seem to be elementary, but it turns out that it is not trivial to prove that this is the case.

4) Finally, a system is decidable if but only if every syntactical formula is either definitely a theorem, or definitely not a theorem. In the history of formal mathematics, providing a rigorous syntactical definition of decidability turned out to be a difficult task – perhaps because the very notion of decidability, while intuitively meaningful, remained somewhat obscure (we may recall that the whole aim of formalizing mathematics by the “Hilbert programme” was to eliminate this sort of fuzziness typically attendant on intuitive semantics from mathematical reasoning). The invention of the Turing machine [\rightarrow TURING MACHINE] was aimed at providing an operational answer to this question. It turned out that two other proposals with the same aim – Gödel’s recursive functions and Church’s lambda calculus – were formally equivalent to Universal Turing machines, and hence to each other. Furthermore, it has since been proved that a different syntactical definition of decidability could not incorporate Turing machines; and in the event, after 70 years, no alternative proposition has been forthcoming. Pragmatically, then (although there is no formal proof of this meta-theorem) it seems that “calculable by a Universal Turing machine” can indeed be taken as the definition of decidable.

It has been shown that the propositional calculus does indeed possess all four of these desirable properties, so that the high aim of the Hilbert programme was not totally ridiculous. However, Gödel’s theorem showed that for all formal symbol systems sufficiently rich to bear arithmetic (let alone algebra, geometry etc) as an interpretation cannot possess all these qualities. Gödel’s own demonstration of his theorem is extremely difficult to grasp. Interestingly, a much simpler and intuitively understandable proof can be given employing the notion of Turing machines. Firstly, it is possible to assign a positive whole number to any Turing machine (the matrix which

defines its “head” can quite easily be encoded into a whole number). Thus, the number of possible Turing machines, while infinite, is countable. However, the theorem known as Cantor diagonal (see related document) shows that the number of arithmetical functions which have a whole number N as an argument, and which return a number in N as a result, are “more than countable”. Intuitively, it follows immediately that there must be some arithmetical functions which cannot be calculated by a Turing machine. It is not excessively difficult to elaborate on this to construct a formal proof; and in particular, the question as to whether a Turing machine will come to the end of its operations (or not) is in general itself non-decidable. Thus, in a way, the whole theory of formal symbol systems ends up in grandiose self-destruction. In mitigation, it should be noted that this self-destruction is actually a major mathematical discovery in itself; and along the way, a lot of re-usable mathematical understanding (not to mention the theoretical foundation of digital computers) has been gained.

Finally, it is interesting to come back to the question of the relation between (formal) syntax and semantics. A characteristic feature of the whole formal symbol systems approach, that which endows it with a peculiar flavour, consists of giving a primary role to syntax, which can function in a completely autonomous manner, independently of its semantic interpretation (if any). The appeal of purely syntactical operations lies in the fact that they can be carried out in a completely mechanical way (literally, by any material device which is a formal equivalent of a Turing machine). This makes sense if semantics could indeed be completely resorbed into an appropriate syntax; because then the paradoxes which threatened the very foundations of mathematics (which resided essentially in the semantic domain) could be truly solved. Even though Gödel’s theorem shows that this resorbion of semantics into syntax does not and *cannot* work, when the approach of formal symbol systems is taken over into

cognitive science as the basis for the computational theory of mind, something of the primacy accorded to meaningless syntactical operations remains. It is therefore pertinent to point out that in spite of this principled primacy accorded to syntax, when human mathematicians are actually setting up a formal syntax, firstly they must use a meta-language distinct from the formal language in question, and therefore they must use a meta-language *which they already have*, and secondly, they are actually *designing* the formal syntax *so that* it can bear as interpretation a semantics that they *already have in mind*. Thus, as soon as we start to enquire into the genesis of a formal symbol system (and in the context of cognitive science, this genesis has to be a natural process), the absolute primacy of syntax over semantics is called into question.

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RELATED ITEMS

COMPUTATIONAL PARADIGM
ENACTIVE COGNITIVE SCIENCES_1
CYBERNETICS
REPRESENTATION
TURING MACHINE

RELATED DOCUMENTS

EI_Enaction&CognitiveSciences_Stewart.pdf
<http://liris.cnrs.fr/enaction/index.html>

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GESTURAL CHANNEL

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While gestures and actions are getting more and more important in theories – such as the theory of enaction – and in technology – such as the technologies of multimodal interfaces, or the technologies of gesture devices – the definition of a terminology adapted to the different functions involved in the relation between the actuations and the perceptual modalities is of a critical importance. One is forced to observe that the today's term of haptic is unable neither to cover the needs, nor to sufficiently simply and clearly support detailed discussions and developments [→HAPTICS, HAPTIC DEVICES] [→HAPTICS, IN COGNITIVE SCIENCES].

Facing this problem, Cadoz has introduced the expression “gestural channel”, as a compact mean to name elegantly all the human biomechanical sensors-actuators involved in physical motor performance, and its declinations in “gestural action” and “gestural perception” [Cadoz, 1994] [Cadoz 2000].

- The gestural channel is defined as the sensori-motor channel composed of all the physical means, through which the human physical body interacts with the physical external universe: hand, body equipped with all its mechanoreceptors and all its actuators. Gestures are then the result of the use of the sensors-actuators of the human gestural channel apparatus during the performance.
- The gestural action is the motor part of the gestural channel involved in the gesture performance. It involves all the physical

components (articulated skeleton and muscles) of the body.

- The gestural perception is the sensory part of the gestural channel.

The gestural channel is hence the sum of gestural action and gestural perception.

These terms (gestural channel, gestural perception, gestural action) are used to avoid the unneeded detailed description of each sub-means (subset of sensors, subset of motor capabilities), and of the human perceptual and/or cognitive results of the use of these means. Several reasons justify the need of this specific new terminology.

A first motivation is that the word gesture embeds the idea of a task, of a goal. Conversely, haptics” does not. Indeed, in daily life, we talk usually more of gesture than of haptics: the gesture of the craftsman, the gesture of the violonist, learning the gesture of writing...

A second, and more important, motivation is that the term haptics focuses principally on the perception side. If the expression haptic perception is valid, one never talks of haptic action. Indeed, in the use of the term haptics, action remains implicit, so as the grouping of action and perception, which is inherent in human gesture.

A third motivation, which is crucial, is that a major function of a terminology is to support technological clarification, according to the observation that the language of a civilization is also the language of its *techné* and that a language disappears when it is no longer able to define its own technological terms involved in the daily professional life.

This leads to have at disposal a terminology from the needs of the technology, and of the task performed, beside the point of view of the human system.

The needs of technology

From the points of view of the technology, the term haptics is very fuzzy. It does not allow distinguishing between technologies as different as a mouse, a tactile actuator, a motion capture system, a force feedback

device, etc. because some of these technology address action only (ex: mouse, motion capture), some of them address perception only (ex: tactile actuator), and others address the grouping of both action and perception (ex: force feedback device) – whereas, as said before, haptics does not allow referring explicitly to action.

More generally, it is really necessary to have 3 terms available in the case of gesture.

One can consider that, whereas the visual channel and auditory channel are only perceptive channels, human's gesture embeds deeply action and perception. Both are always associated in human gesture performances. In the case of gesture, the sensory channel is intimately linked with the associated actuator channel. The term haptics carries correctly this very important idea.

However, when electrical technology gets into the way, this unity of human body as for action/perception with gesture is necessarily broken. Gesture devices feature necessarily separated actuators and sensors, and we need words to take this irreducible property of the technology when talking, in the context of technology, of the whole human gesture system. In other words, we need to be able to talk separately of the gestural action, which is to be perceived by sensors, and of the gestural perception, which is addressed by effectors. However, we need also to be able to talk of their grouping - that is, of the gestural channel. Haptics, as a matter of fact, does not allow covering these three needs. The three proposed terms are, here, efficient and practical.

But even with non-electrical mechanical technologies, humans developed a large panoply of systems in order to adapt the gestures performed to the tasks and in which the respective weight of action and of perception differs. Some of them necessitate a huge energetic involvement, some of them not. Instruments have been designed to be adapted to the necessary actions. For example, taking the example of a clarinet, there are two types of gestures:

- those (the breath) by which the sound is produced, in which the energy in the sound originates, and that necessitates a strong physical involvement of the player that plays an important role in the quality and the type of the sound produced;
- and those that consist in modifying the properties of the sound such as the pitch (by the keys). For the latest category of gesture, specific mechanical means were invented that makes minimal and optimize the energetic involvement of the player.

The needs of the tasks

Regarding the needs of the tasks, three categories of gesture can be distinguished, leading to the development of specific technologies, technologies for action, technologies for perception, technologies for the link between actions and perceptions.

There are gestures in which the gestural perception does not play an important role, in the sense that it can be performed in various perceptual situations. De facto, a technical mediation is developed to allow achieving the desired result no matter how the gesture is performed. We can call this situation “gestural action with low role of gestural perception”. In the tripartite typology of interaction functions proposed by Cadoz [→ ERGOTIC/ EPISTEMIC/ SEMIOTIC FUNCTIONS] [Cadoz 1994] [Cadoz, 2000], this type of gestural action corresponds to the semiotic function of the gestural channel. Keyboard writing is of that type.

On the contrary, there are gesture that involve a lot gestural perception, but with a small role of gestural action. These correspond to what Hatwell [Hatwell & al., 2003] called *Touching for knowing*, i.e., in the Cadoz' typology, to an epistemic function of the gestural channel. As a matter of fact, and unfortunately, most of the knowledge today on haptic modality corresponds to this case.

And finally, there are tasks in which the correlation between the gestural action and the gestural perception plays a critical role, not only in the performance (for example to

improve its efficiency, its acceptability, or its intuitiveness), but also in the result of the gesture. Best examples are in craftsmanship, high-level professional gestures, sports or artistic performances. In such tasks, gestural action and gestural perception constitute a kind of closed-loop system that cannot be realized by only superimposing a semiotic gestural action and an epistemic gestural perception. Something new is added, which is the energetic or physical coupling between them that cannot be modelled without calling the help of the concepts and theory of dynamic systems. A new term, *ergotic*, was specifically dedicated to that ergotic function of the gestural channel [→ INTERFACE, ERGOTIC] [Cadoz, 1994] [Cadoz, 2000].

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RELATED ITEMS

ERGOTIC/EPISTEMIC/SEMIOTIC FUNCTIONS
 GESTURE / MOVEMENT / ACTION
 HAPTICS, HAPTIC DEVICES
 HAPTICS, IN COGNITIVE SCIENCES
 INSTRUMENTAL INTERACTION
 INTERFACE, ERGOTIC

GESTURE ANALYSIS

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Since gesture and expressive gesture are important channels of communication, new interfaces technologies aims at using this natural paradigm of communication to create

products more human-oriented. The possibilities of the human body to use this channel of communication are quite infinite. In fact, the possibility of humans to communicate using just gestures is well-known, such as in sign language where gestures "tell" a sentence and, at the same time, express an emotion by stressing movements to a greater or lesser extent.

The research on gesture analysis is totally interdisciplinary, trying to understand the mechanism of human communication and to integrate affects into human-computer interaction, in applications such as education and training, virtual environments for diagnosis and rehabilitation, and many typical applications of human-computer interfaces. As for it, work on enactive interfaces as frontier in the human computer interaction, includes necessarily the study of gesture, and gesture analysis, from both the point of view analysis and synthesis.

Gesture analysis can be generally defined as the process of extracting/measuring information from gesture. Obtaining a common agreement of the scientific community on the definition of "gesture", and on all the related problematic, still remain one of the major problem. In [Cadoz & Wanderley, 2000], it is possible to find a survey discussion on this aspect, included a broad definition useful for gesture analysis purposes by [Kurtenbach & Hulteen, 1990]: the gesture is "*a movement of the body that contains information*". That means that in gesture analysis the human body is the subject to be studied.

When gesture analysis aims at extracting high-level motion features, e.g., recognized emotions expressed by other subjects, predicted engagement of other subjects, etc, it is often referred to as expressive gesture analysis, EGA [Camurri et al., 2001]. One of the aims of such analysis is to understand which are the mechanisms involved in expressive gesture communication.

In the work [Camurri et al, 2001], the authors defined a multilayered framework for the analysis of expressive gesture, starting

from sensors signal, up to high-level expressive information, e.g. emotions. In particular, expressive gesture analysis is grounded on classical theories on emotion in human (full-body) movement from psychologists (e.g., [Wallbot, 1980] [Argyle, 1980]), where human full-body movement is considered as a first-class conveyor of expressive content in non-verbal interaction based on expressive gesture. In this perspective, gesture analysis aims at defining a methodology, and algorithms, for individuating the relevant features and their role in communication of expressive content. Conversely, the same framework, and algorithms, can be used for the synthesis of high-level expressive information for example to impress an emotion to virtual agents and so on.

In this perspective, particular relevance is assumed by the qualities of movement that refers to how a movement is performed. That is, these qualities are at a higher level with respect to kinematical measures (e.g., degrees of rotation of a certain joint or the moment that has to be applied) and, rather, they point out qualitative aspects of movement (e.g., whether a movement is impulsive or smooth, contracted or expanded, hesitant or fluent).

Boone and Cunningham distinguish [Boone & Cunningham, 1998] between propositional and non-propositional aspects of movement. Propositional movements are intended as established signs transmitting a given meaning (e.g., a raised hand to indicate stop). Specific movements corresponding to emotion stereotypes can also be considered as propositional (e.g., a clenched fist to show anger or raised arms to demonstrate joy). Non-propositional movements are, instead, embodied in the direct and natural emotional expression of body movement based on fundamental elements such as tempo and force that can be combined in a wide range of movement possibilities. Therefore, non-propositional movements do not rely on specific movements, but build on the quality of movements i.e., how movements are carried through, for instance whether it is

with lightness or heaviness [Camurri et al., 2003].

The notion of quality of movement has also been referred to by Laban in his Effort theory [Laban, 1947]. This theory is relevant in gesture analysis; a dedicated item presents it in details [→ EFFORT THEORY, BY LABAN]. Another important point to consider in the context of gesture analysis, which has also been highlighted by Laban, is the space under analysis. The item [→ GESTURE ANALYSIS: LABAN'S KINESPHERE] provides further hints on this question.

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RELATED ITEMS

EFFORT THEORY, BY LABAN
 EMOTION
 GESTURE ANALYSIS: LABAN'S KINESPHERE
 GESTURE, EXPRESSIVE
 MOTION CAPTURE

GESTURE ANALYSIS: LABAN'S KINESPHERE

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In the context of gesture analysis [→ GESTURE ANALYSIS], defining precisely the space that should be analysed is an important step. In particular, the human gesture/motion can be approached by focusing the attention on the motion of the body itself or on the motion of the body in the space.

This idea is well emphasized by the concepts of Kinesphere and of whole space (the whole space surrounding the Kinesphere), introduced by Laban in his *Modern Educational Dance* [Laban, 1963]. This item provides a short overview of them, and of their use in gesture analysis.

To best introduce these concepts, let's use a few words by Laban himself: "*Whenever the body moves or stands, it is surrounded by space. Around the body is the sphere of movement, or Kinesphere, the circumference of which can be reached by normally extended limbs without changing one's stance, that is, the place of support. The imaginary inner wall of this sphere can be touched by hands and feet, and all points of it can be reached. Outside this immediate sphere lies the wider or "general" space which man can enter only by moving away from their original stance. He has to step outside the borders of his immediate sphere and create a new one from the new stance, or, in other words, he transfers what might be called his "personal" sphere to another place in the general space. Thus, in actual fact, he never goes outside his personal sphere of movement, but carries it around with him like a shell*" [Laban, 1963, p. 85].

The Kinesphere is also referred to as personal space. The whole space surrounding the Kinesphere (i.e., the environment in which the act of movement is taking place) is

referred to as general space. When the body moves in space, the Kinesphere follows it.

A first distinction can thus be done between analysis in the Kinesphere and analysis in the general space. This distinction does not only determine the spatial extent on which analysis has to be carried out (e.g., in case of dance performances, the space occupied by the body of a dancer for the personal space, and the whole stage for the general space), but it also affects the kind of techniques employed for analysis.

In fact, even if analogies can be found among features in the personal space and in the general space, different techniques are most often needed to perform the gesture analysis and extract these features. Further subdivisions can be done depending on the envisaged level of detail in both the personal and the general spaces. For example, it is possible to consider the motion of only one person within the general space or the motion of a group of persons in order to analyse the behaviour of the group as a whole.

In the personal space it is possible to consider global features, such as for example the global amount of detected motion or the contraction/expansion of the whole body or local features like those describing the motion of a given joint or of a given part of the body (e.g., head, hands, feet).

In a perspective from wide to narrow these different spatial points of view can be summarized as follows:

- Global properties in the general space, i.e., behaviour of a group considered as a whole in the General Space;
- Local properties in the general space, i.e., behaviour of single individuals, separately analysed, in the general space;
- Global properties in the personal space, i.e., behaviour of the body considered as a whole in the personal space;
- Local properties in the personal space, i.e., behaviour of given parts of the body, separately analysed, in the personal space

This subdivision should not be considered as a rigid and static one, but rather as a continuum of possibilities through which the focus of attention of a virtual or mixed observer moves, depending on the current needs. Many analyses at each of the four levels of detail can be carried out in parallel and their results integrated toward a global interpretation of the performed movement.

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RELATED ITEMS

EFFORT THEORY, BY LABAN
GESTURE ANALYSIS
GESTURE, EXPRESSIVE

GESTURE AND MOTION (ENCODING OF)

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In the context of virtual reality systems, with the development of haptic systems and motion capture systems, and with the need of inter-communication of virtual reality systems through control data, the questions of gesture and motion data, and of their encoding, becomes more and more important.

There is an evident proximity between movement (or motion) and gestures [→GESTURE / MOVEMENT / ACTION]. The frontier between both is very fuzzy. Both correspond to the moving in space of a part or of the totality of a system. Both refer to the evolution produced by a physical system, whatever it is: human body, real mechanical objects equipped with sensors, virtual objects, motion of a leaf, of a sounding source etc. Differently than actions and symbolic gestures, both motion/gesture data needs to

be represented as temporal signals, i.e. a data (position, velocity, etc..) evolving along time.

The only noticeable differences are indeed:

- The fact that movement/motion can be used for any type of system, whereas gesture is usually more reserved to humans.
- The fact that motion is connoted as the result of the performance, i.e. in mediated computer interaction, as an output of an evolving system, whereas gestures correspond more to motions that cause a performance, i.e. the signals used as an input of a system.

Despite these differences, motion/output and gesture/input are two representatives of similar temporal signals, corresponding with an evolving physical system. Thus, the expressions gesture data and motion data could be used indifferently to refer to this sort of gesture-like data, no matter if it is considered as an input or as an output of an evolving systems, possibly a human body.

Focusing on the similarities between gesture and motion rather than on their differences, we are led to identify them as a new and unique type of data. Gesture/motion signals, whatever the way they are produced (objects or human motion, virtual object...), and whatever the way they are considered (as outputs or inputs of evolving systems), do present specific properties that allow distinguishing them among other temporal signals (especially aero-acoustical signals or visual signals). Gesture/motion signals can be distinguished from visual and audio signals by 3 specific features.

Morphological versatility of gesture/motion signal

The morphological versatility of gestures is a first evidence. While images and sounds can be displayed in predefined environments (displays or 3D Caves, with fixed sizes and resolution, stereo or quadraphonic rendering for sounds, etc.), the structure and the morphology of gesture signals are more versatile, depending on the tasks and the manipulated tools. This morphological versatility can be

split in two complementary variable characteristics: the geometrical and the structural dimensionalities.

Geometrical dimensionality refers to the dimensionality of the space in which the gesture is evolving. It can be 3D (ex: motion capture situations), 2D (ex: cartoon animation), 1D (ex: when we push a piano or a clarinet key) or a pure scalar space, i.e. 1D non-oriented space. And, for a given geometrical dimensionality, like for instance 1D for the key of a gesture device, the structural dimensionality can vary (from 1 to one hundred key(s), or points, or ..., for instance).

Quantitative ranges of gesture/motion signal

In addition to the geometrical and structural dimensionalities, gesture/motion signals present specific quantitative spatial and temporal features.

The frequency bandwidth of gesture/motion signals are positioned specifically on the middle range in the frequency scales of all sensory signals. The visual signal frequency rate is around some Hz, and the acoustical signals frequency rate is some tens KHz. In the middle, gesture/motion signals frequency stands from some Hz to some tens KHz.

Gesture/motion signals also exhibit some specific spatial properties. Whereas acoustical signals are zero-centred deformations of about some millimeters, gesture/motion signals correspond with deformations and displacements that are non-necessarily centred on 0, and that are situated along a spatial range from some millimeters to some meters.

Type of encoded variables of gesture/motion signal

Gesture/motion signal may carry two types of dual variables: extensive variables, such as those derived from spatial information (position, velocity, angle, deformation), and their dual intensive variables (force, torque).

When gestures are used for manipulating object, the correlation between extensive and

intensive variables exchanged between the two interacting bodies must be considered, either explicitly as in Newtonian formalism, or implicitly as in the energy formalisms. Hence, differently than in the case of visual or acoustical data, that needs only to encode one type of variables (usually extensive), both extensive and intensive variables are needed for a complete encoding of a gesture interaction.

Formats for the encoding of gesture/motion data

Many formats have been developed to encode motion signals [Menache, 1999] [Maddock, 2000]. Generally those format come from the motion capture community or the video games community, and aims at animating characters. Exemples of such formats are BVA and BVH (Biovision), HTR (Motion Analysis), AOA (Adaptive Optics), ASD (Acclaim and Oxford Metrics), CSM (Character Studio & 3D Studio Max), and C3D (National Institute of Health & Vicon systems). Those formats - especially C3D - are widely used and proved their usability. However, none of them takes into account all the three specific features of gesture/motion signals.

Within the Enactive Interfaces project, a new format called the GMS (for Gesture and Motion Signal) has been proposed as a first attempt for a low-level, minimal and generic format able to encode any motions and gestures [Luciani et al., 2006] [GMS].

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RELATED ITEMS

GESTURE / MOVEMENT / ACTION
HAPTICS, HAPTIC DEVICES
INTERFACE, ERGOTIC

GESTURE RECOGNITION: SYSTEMS AND TECHNIQUES

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In gesture recognition, a camera reads the movements of the human body and communicates the data to a computer that uses the gestures as input to control devices or applications. This makes gesture recognition a perfect example of an enactive interface because the user actually has to do the appropriate gestures to communicate. Also, gesture recognition is the specially suited to help special users in interacting with computers with the help of sign language.

Static gesture, or pose, recognition can be done using template matching, geometric feature classification, neural networks, or other standard pattern recognition techniques to classify pose. Dynamic gesture recognition, however, requires consideration of temporal events. This is typically accomplished through the use of techniques such as time-compressing templates, dynamic time warping, hidden Markov models (HMMs), expectation maximization and Bayesian networks [Turk, 2002].

The various types of gesture recognition systems are as follows.

Pen-based Gesture Recognition.

Recognizing gestures from two-dimensional input devices such as a pen or

mouse has been considered for some time. The early Sketchpad system in 1963 used light-pen gestures, for example. Some commercial systems have used pen gestures since the 1970s. There are examples of gesture recognition for document editing, for air traffic control, and for design tasks such as editing splines.

Tracker-based Gesture Recognition.

Data gloves: Many projects have used hand input from data gloves for “point, reach, and grab” operations or more sophisticated gestural interfaces. Despite the fact that many, if not most, gestures involve two hands, most of the research efforts in glove-based gesture recognition use only one glove for input. The features that are used for recognition and the degree to which dynamic gestures are considered vary quite a bit.

Body suits: It is well known that by viewing only a small number of strategically placed dots on the human body, people can easily perceive complex movement patterns such as the activities, gestures, identities, and other aspects of bodies in motion. One way to approach the recognition of human movements and postures is to optically measure the 3D positions of several such markers attached to the body and then recover the time-varying articulated structure of the body.

Vision-based Gesture Recognition

Vision-based interfaces use one or more cameras to capture images, at a frame rate of 30 Hz or more, and interpret those images to produce visual features that can be used to interpret human activity and recognize gestures. Typically the camera locations are fixed in the environment, although they may also be mounted on moving platforms or on other people. For the past decade, there has been a significant amount of research in the computer vision community on detecting and recognizing faces, analyzing facial expression, extracting lip and facial motion to aid speech recognition, interpreting human activity, and

recognizing particular gestures [Vance and Jerney, 2005].

Gesture recognition in that case does not only mean tracking of human movement but also the interpretation of that movement semantically. In order to develop computational models of gestures, some form of parameterization is required for the description of qualitative aspects of gestures. An example of parameterization of gestures that is most often used in computational systems of gestures is given by McNeill's study on gestures [McNeill, 1992]. McNeill classifies gestures into several categories such as iconics, metaphors, deictics, beats and emblems based on psychological and empirical studies. Some types of gestures are easier to interpret such as emblems since they have pre-defined meaning but interpreting the gestures that occur spontaneously during communication still remains an open research area as well as the analysis of synchronization between gestures and speech.

Gestures are a very natural form of communication and hence are very apt as an Enactive Interface. They embody the understanding-by-doing concept because they involve the user directly in the interaction.

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RELATED ITEMS

GESTURAL CHANNEL
GESTURE SEGMENTATION
GESTURE, EXPRESSIVE
GESTURE / MOVEMENT / ACTION

GESTURE SEGMENTATION

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The segmentation of gesture performed by a human being aims first at extracting sub motions with particular focus on the identification on the single gestures boundary.

A further goal of segmentation is the individuation of the sub-phases within a motion phase. For example, in [Laban & Lawrence, 1947] explains that *“almost any work-operation or expressive gesture shows the following pattern: preparation – one or several main efforts – termination”*.

Movement segmentation can be considered as a first step toward the analysis of the rhythmic aspects of dance. Analysis of the sequence of pause and motion phases, and of their relative time durations, can lead to a first evaluation of dance tempo and its evolution in time, i.e., tempo changes, articulation (in analogy with music legato/staccato). Parameters from pause phases can also be extracted to individuate real still-standing positions from active pauses involving low-motion (hesitating or oscillation movements).

Furthermore, motion fluency and impulsiveness, that are related to Laban's Flow and Time axes [\rightarrow EFFORT THEORY, BY LABAN], can be evaluated.

A straightforward technique to individuate movement strokes and therefore to perform a segmentation of movement in motion and pause phases is to apply a threshold on the detected energy or amount of movement.

However, segmentation is a not trivial issue because the definition of sub-motion and, in particular, of general gesture does not help in finding precise boundaries.

In the exemplary context of sound segmentation, morphological qualities based on perceptual features enable segmentation of

continuous streams of a (concrete) sound signal: segmentation and identification of music objects are based on perceptual cues such as grain, texture, allure, etc. Analogies can be investigated when we deal with human movement segmentation, where similar problems can be envisaged (e.g., segmentation of a continuous stream of movement data, identification of motion primitives, extraction of a collection of perceptual cues). From such a comparative and cross-modal analysis it may be possible to individuate a collection of features having a similar role in both music and movement domains (in terms of concept). Data from several different physical and virtual sensors are likely to be integrated in order to perform such a step. Each gesture is characterized by the measures of the different cues extracted (e.g., speed, impulsiveness, directness, etc. for movement, loudness, roughness, tempo, etc. for music).

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RELATED ITEMS

EFFORT THEORY, BY LABAN
GESTURE ANALYSIS

GESTURE, EXPRESSIVE

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When non-verbal communication mechanisms are mainly involved in an interaction, related to the emotional, affective sphere plays a particularly relevant role. In this framework, expressive gesture can be considered as a main conveyor of emotional, affective content.

While the relevance of movement and gesture as a main channel of non-verbal communication is becoming evident, and while increasing research efforts are devoted to them (see the *gesture workshop* series of conferences started in 1996 and collecting a continuously growing interest), the focus is here centered on the qualities that make a gesture expressive.

For the same reasons the concept of expressive gesture is directly related to the concept of enactive interfaces, because this channel of communication intervenes from the enactive learning process to the enactive knowledge expression [→ ENACTIVE KNOWLEDGE] [→ LEARNING AND ENACTIVE INTERFACES].

An attempt of defining the concept of expressive gesture can be found in [Camurri et al., 2004]. The definition finds its basis on [Kurtenbach & Hulteen's, 1990] definition of gesture, which states that gesture is "*a movement of the body that contains information*".

Especially in performing arts, gesture is not only intended to denote things or to support speech as in the traditional framework of natural gesture, but the information it contains and conveys is often related to the affective, emotional domain. From this point of view, gesture can be considered expressive since it carries what [Cowie et al., 2001] call "implicit messages", and what Hashimoto [Hashimoto, 1997] calls KANSEI. That is: expressive gesture is the basis of the communication of information that we call expressive content.

Expressive content is different and in most cases independent from possible denotative meaning, even if it is often superimposed to it. Expressive content concerns aspects related to feelings, moods, affect, intensity of emotional experience. For example, the same action can be performed in a number of ways, by stressing different qualities of movement: it is possible to recognize a person from the way he/she walks, but it is also possible to get information about the emotional state of a person by looking at his/her gait, e.g., if he/she is angry, sad, happy.

In the case of gait analysis, we can therefore distinguish among two objectives and layers of analysis: a first one aiming at describing the physical features of the movement, for example in order to classify it; a second one aiming at extracting the expressive content gait conveys, e.g., in terms of information about the emotional state that the walker communicates through his/her way of walking.

From this point of view, walking can be considered as an expressive gesture: even if no denotative meaning is associated with it, it still communicates information about the emotional state of the walker, i.e., it conveys a specific expressive content. In fact, in this perspective the walking action fully satisfies the conditions stated in the definition of gesture by [Kurtenbach & Hulteen, 1990]: walking is “*a movement of the body that contains information*”. Some studies can be found aiming at analyzing the expressive intentions conveyed through everyday actions: for example, Pollick investigated the expressive content of actions like knocking or drinking.

Studies on expressive gesture are grounded on several different sources coming from both science and technology, and art and humanities. Such sources include humanistic theories of non-verbal communication developed for dance and choreography such as Rudolf Laban's Effort theory [Laban, 1963] [→ EFFORT THEORY, BY LABAN], theories from music and composition e.g. [Schaeffer, 1977], theories from psychology e.g. [Argyle, 1980].

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RELATED ITEMS

EFFORT THEORY, BY LABAN
EMOTION
ENACTIVE KNOWLEDGE
GESTURE AND MOTION (ENCODING OF)
GESTURE / MOVEMENT / ACTION
GESTURE SEGMENTATION
LEARNING AND ENACTIVE INTERFACES

GESTURE / MOVEMENT / ACTION

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In the context of virtual reality systems, and, further, in the context of enactive interfaces, the terms action, movement, end gesture, progressively occupy a more and more important place. Their interrelations benefit from being clarified.

Action...

Commonly speaking, the term action refers to different meanings. It can state both a physical task performed by the human body, or the way through which this task is performed. Smyth and Wing distinguish three levels in performing an action: action refers to what is done (e.g. drink a glass, pick a pencil...), movement refers to how it is done (the movement with which the glass is

drunk...) and skill refers to the quality of the movement (how the movement is) [Smyth & Wing 1984].

A given action can hence be acted by several movements, and a movement can be coloured by several skills. These definitions do not correspond easily to the daily uses of such terms. As a matter of fact, the uses of these terms are nothing else than unclear. Action is often used to name both the task performed and the movement to perform the tasks. Movement, as for it, is actually more general than the movement-in-the-action, and skill refers also to the ability to do something.

Action and Movement...

A first distinction between action and movement is that actions can be described at a high symbolic level, whereas movements cannot. In computer representations, for example, actions can be described by language, or by means of event-based representations. A classical example of event-based representation of actions is the MIDI standard. Types of actions that can be so represented are the so-called symbolic gestures, such as for example leaf-and-dumb sign language.

Conversely, movement (or motion) requires to be represented as temporal signals, i.e. a data (position, velocity, etc.) evolving along time. Indeed, movement (or motion), as the moving in space of a part or of the totality of a system, is an explicit spatio-temporal phenomenon. Movement (or motion) refers to the evolution along time of a physical system: human body, mechanical objects, virtual objects, etc. One can speak as well of the motion of a human body, of a leaf, of a sounding source, etc.

Movement and Gestures ...

Similarly with the differentiation between action / movement, and although all the types of gestures convey always information, nevertheless, there exist two types of gestures:

- Gestures that can be represented by language or symbolic representations, often called “symbolic gestures”, or high-level gestures [→ MOTION CONTROL, HIGH-LEVEL] in computer representations. Examples are leaf-and-dumb sign language, keyboard writing, etc;
- And gestures that cannot, such as instrumental musical playing, gestures of craftsmen, etc., that can be called non-symbolic gestures. There is evidence of proximity between movement (motion) and non-symbolic gestures (or performance gesture), when the body that is moving is the human body. The frontier between movement and gestures is then very fuzzy. The only difference we can state is that movement is general and can be used for any type of system, whereas gesture is usually reserved to humans’.

Artificial electrical and digital machines introduce necessarily an input-output paradigm [→ CHANNEL, AFFERENT / EFFERENT]. In such context, objects, either real or virtual, are equipped by sensors and/or actuators, to be observed or to act on each other.

This shift leads to a new operational differentiation between motions and gestures based more on the differentiation between input and output functionalities, than on the nature of the evolving system that produces the signals. This technological basis allows making a clearly-cut distinction between two aspects of gestures, that are mixed, integrated and non separable when performed by human body:

- When one points to all the motions that can be applied as an input signal, i.e. as a “cause of a performance”, whatever the producing system is (human beings or other objects). In that case, the motion of the body serves to produce something – for example when playing violin – and then the term gesture is more appropriate.
- When one points to all the motions that is the output of an evolving system, whatever this producing system is (human beings or other objects). In that case, the attention is

put on the result of the performance and the term motion is then more appropriate, such as when this result is the motion of an object (like when an object is pushed by a human gesture) or the motion of the body itself (such as in dance performance).

... Gestures

In the continuity of these discussions and in conformity with the Gibson's analysis of the development on human haptic apparatus, Cadoz [Cadoz, 2000] proposes to name gesture all what the human physical body can physically perform, whatever the performed objective is, rather than action or movement. Declining the different terms necessary to speak about the components of the gesture and gesture activity, he defines:

- gestural channel [\rightarrow GESTURAL CHANNEL]: all the sensory-motor apparatus composed of all the physical means, through which the human physical body interacts with the physical external universe: hand, body equipped with all its mechanoreceptors and all its actuators. The gestural channel is then a compact word to name all the human biomechanical sensors-actuators involved in physical motor performances.
- gestural action: the motor part of the gestural channel involved in the gestural performance. It involves all the physical components (articulated skeleton and muscles) of body.
- gestural perception: is the part of the sensory system involved with the gestural channel.

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RELATED ITEMS

CHANNEL, AFFERENT / EFFERENT
 ERGOTIC/EPISTEMIC/SEMIOTIC FUNCTIONS
 FORCE

GESTURAL CHANNEL
 GESTURE AND MOTION (ENCODING OF)
 MOTION CONTROL, HIGH-LEVEL

GESTURE, NON-VERBAL

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The expression non-verbal gesture originates in the distinction between two types of gestures in speech:

- The gesture that produces voice, i.e. the movements of the vocal channel, that produces auditory speech events;
- And the gesture that accompany the speech (face expression, hands movements, postural dynamics, etc...), that does not produce auditory speech event and that is considered as a part of the speech (speech is hence viewed as being composed of a gesture body part and of a gesture vocal part).

Speech has been generally thought of as conveying information in discrete linguistic-symbolic units, such as words and sentences representing linguistic meanings. Features as prosody, intonation, and more generally continuous evolutions, were not considered as an important way to convey information. Recently (since about the end of 80s, if we except the visionary introduction by Pierce [Pierce, 1932]), the role of "non-symbolic analog signs" has been re-introduced as a basic component of speech communication.

In [Hadas and al., 2006], analog signs are defined as follows: "*In contrast to symbolic signs, analog signs consist of non-digital continuous signals in which the pattern properties of the signal correspond in some way to the information conveyed by the signal. Examples for the use of this kind of analogical mapping between the intended message and pattern properties of the signal can be found in animal communication [...] as well as in the gestures that accompany speech*".

The expression non-verbal gestures has then been introduced to name this type of analogous information when carried by gesture. At the same time, similar developments could be observed in the domain of human-computer interfaces [Kurtenbach, 1990]. This co-evolution led to use the expression non-verbal gestures to regroup all the analogous information produced by humans gesture for human communication.

Hence, from its origin in speech communication, the expression non-verbal gestures has been extended to refer to all the free movements of the body (of the face, of the hand, of the whole body, etc...), except those that produce speech.

The expression, however, leads to some confusions.

A first limitation is that it presents all the gestures as being able to be classified in verbal and non-verbal gestures. So doing, first, it hides the fact that these two categories are actually sub-categories of the larger domain of symbolic communication [Goldin-Meadon, 1999], including digital and analogous signs. Examples of gestures that do not produce verbal events, but that are not symbolic signs, exist. An exemplary case is music. In Music and musical communication, the importance of the non-discrete analogous properties of the sounds have been usually widely considered, for ages, without calling it non-verbal communication.

More important, the main limitation of the expression is to pre-suppose that gestures only aims at communicating symbolic information, whereas there are other important categories of gesture that do not fall into the domain of symbolic communication, although they communicate information.

Other gestures, such as instrumental gestures in musical performance or interactive gestures in VR, are less considered by such dichotomy between verbal and non-verbal gestures. These types of gestures are useful means to produce sound expression, musical expression, instrumental communication,

expression in movements and animation, and more generally to act on the world and to consequently produce analogous significant transformations regarding the world. In fact, such gestures are similar to the vocal gestures, i.e. the phsyical gesture that produces auditory speech.

In conclusion, in terms of typology of gestures, and given the richness of gestures, especially in the lightening of Enaction that positions action at the centre of the interaction and communication activities, it is useful to clarify all the function of gestures. To that aim, Consequently, rather than classifying gestures into verbal and non-verbal, another more complete classification could be a classification that:

- First, distinguishes between the several macro-functions of gestures, for example between semiotic, epistemic and ergotic functions [→ ERGOTIC/EPISTEMIC/SEMIOTIC FUNCTIONS] as proposed by Cadoz [Cadoz, 1994] [Wanderley & Cadoz, 2000]. In the category of ergotic gestures, there are all the gestures energetically involved in the production process. The vocal gesture may belong to this category.
- And second, in the category of non-ergotic gestures, distinguishes between several sub-categories, amongst which there are the gestures that accompany the speech, but also all the recently-called non verbal gestures.

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RELATED ITEMS

CHANNEL, AFFERENT / EFFERENT

ERGOTIC/EPISTEMIC/SEMIOTIC FUNCTIONS

FORCE

SIMULATION

VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

H

HAPTIC BOARD

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A multi-sensory simulator features a real-time simulation system and several peripherals, each being specialized to address one of the human sensory modalities [→MULTI-MODALITY, IN COGNITIVE SCIENCES]. For sound and graphics, these peripherals are composed of:

- A device (e.g. a screen, loudspeakers, etc.) that transduces signals into/from the corresponding phenomenon
- A board (graphics or sound boards) that adapt signals or commands coming from the computer CPU into a signal usable by the devices.

The board embeds not only particular data input and output capabilities, but also various computation means dedicated to the device/modality they are designed for: a graphics board offers 3D processing, a sound board features filtering, spatialization, sometimes synthesis, etc. These computations are embedded to reduce the computer CPU load (indeed, some of these boards are not far from being as powerful as a computer), but also because they call for specific hardware architectures to be processed efficiently. Also, one can remark that graphics and audio boards features are now globally standardised (at least, their driver is: when the board actually does not implement a feature, the driver usually does, and runs the feature on the CPU). For example, all graphics boards feature OpenGL and DirectX, etc.

We define the haptic board as the component of a real time system for multi-sensory

interaction that plays the role of a communication interface between the computer (e.g. in the case of simulation, the machine computing the simulated model) and the haptic device at hand [→HAPTICS, HAPTIC DEVICES]. We summarize its main functionalities as follows:

- Transforming data from the haptic device to the computer CPU.
- Transforming data processed by the CPU back to the haptic device.
- Ensuring a matching between the two different signal structures and formats that are meaningful on the haptic device side on the one hand, and on the CPU side on the other hand.
- Realizing various computations specific to the above matching, and more generally specific to the needs of gesture interaction.

Today's haptic peripherals necessarily feature some of the above, sometimes reduced to standard analog-to-digital/digital-to-analog converters. Also, most of them embed the signal processing into the electronics of the haptic device. This means that the haptic peripheral embeds in the same place both the functionalities of the device and those of the haptic board.

We consider that the haptic board deserves more attention: its today's characteristics are not yet satisfying. We assume that several of the main bottlenecks of real time platforms for multi-sensory simulation are related to the haptic board. A draft list of problems include:

- The latency introduced in data transmission, which has a particular impact on the reactivity of the simulation loop [→INSTRUMENTAL INTERACTION]. We define latency as the time elapsed between the instant when the data is available on the gesture device, and the instant when it is available in the central simulator memory, or vice versa. Latency is mostly due to the time required by data transmission and the protocols it employs. Also, in the case of AD/DA conversion, the employed technology has a particular impact on latency.

- The available number communication channels. Gesture interaction may require a many bidirectional channels (think about the piano keyboard with its 64 keys...), which is a technological bottleneck. Increasing the number of communication channels is a usual problem in computer hardware. A common solution consists in using temporal multiplexing, but it has a strong impact on transmission latency.
- The numerical format of the transmitted data. Gesture is a physical phenomenon involving a large range of dynamics [Luciani et al., 2006]. On the side of the device, haptic boards use data lengths of about 16 bits, while computer CPUs usually work with 32 bit or 64 bit data lengths. If the haptic board has to embed A/D conversion, digital precision becomes a bottleneck, since good precision is achieved at the expense of conversion latency.

Another problem is to define the dedicated computations that the haptic board could/should embed. What are the computations means needed inside the haptic board, and what hardware architecture do these call for? At least, we assume that one of the features of the haptic board should be to embed various gesture-related processing (e.g. physical simulation, haptic loop...) as close as possible to the device, in order to ensure the highest quality possible to the haptic interaction.

Finally, another major problem concerning haptic boards is standardisation (of the devices, of the gesture signal [\rightarrow GESTURE AND MOTION (ENCODING OF)], of the computation within the haptic boards...). The field of haptics is still in its infanc, and standardisation is far from being achieved. Among the various reasons:

- Gesture is highly versatile. Depending on the targeted application field, the choices made lead to very different technical solutions and implementations. This involves the case of data formats to exchange gesture information, but also the mechanical

structure of the haptic device, the actuating and sensing technology chosen, etc. All of these factors impact the haptic board.

- Signal inputs and outputs of the haptic device might take very different formats (in a very large meaning) depending on the actuating and sensing technologies. As an example, direct current (DC) brushless motors can receive pulse width modulation (PWM) digital inputs, while voice coils actuators usually don't. This means that a haptic board might or not be equipped with analog-to-digital or digital-to-analog converters.

Despite these difficulties and the bottlenecks to solve, we assume that haptic peripherals calls for the invention and the definition of dedicated haptic boards in a more or less near future, with their (very) specific features, architecture, and computation capabilities. A few research, indeed, are emerging – among which, within the Enactive Interfaces project, the work at ACROE.

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RELATED ITEMS

GESTURAL CHANNEL
 GESTURE AND MOTION (ENCODING OF)
 HAPTICS, HAPTIC DEVICES
 INSTRUMENTAL INTERACTION
 INSTRUMENTAL INTERACTION: TECHNOLOGY
 MULTIMODALITY, IN COGNITIVE SCIENCES
 MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION

HAPTIC DEPTH PERCEPTION

Gunnar Jansson [UPPSALA]

Haptics can inform about depth in the real world both by identifying 3D objects and by informing about their position in the 3D world. This information is typically obtained by exploration within the reach of the hands or the feet [→ EXPLORATORY PROCEDURES]. The exploratory procedure of enclosure is especially suited for getting haptic perception of global shape and volume of an object. Objects are usually correctly and rapidly perceived in all three spatial dimensions in this way (Klatzky et al. 1985).

There are also situations when the observer is not in direct contact with an object but can identify it via something surrounding it. An example is palpation, that is, when a physician explores an internal organ under layers of skin and fat. Katz (1925/1989, p. 53) called such haptic perception for volume touch. The phenomenon functions best with a relatively hard object and a medium degree of thickness of the surrounding layers.

There are also haptic devices that provide information to the skin about objects in 3D space via a video camera. The stimulation is provided by a matrix of points, either vibrators or electrodes. Bach-y-Rita (1972) suggested that stimulation to the skin of the back, for instance, via the Tactile Vision Substitution System (TVSS), can be externalized as an object in 3D space in front of the observer when the object or the observer is moving, but the generality of this statement has been questioned. The same device has been shown to provide haptic stimulation that can guide a player of a game ("batting a ball"), where the player has to hit a ball rolling towards him informed about the location of the ball and the bat by haptic stimulation on his/her back (Jansson, 1983). The same study demonstrated that a related device, the

Electrophthalm, with a matrix of vibrators on the forehead can guide a person's walking in a slalom path. It has to be noted that both of these actions were performed in specially arranged environments, and that they do not function in an ordinary, much more complex world. However, the studies demonstrate a basic potential of haptics to guide movements.

In contrast to vision, haptics does not provide a self-evident perception of depth from a 2D perspective representation, even if it works to some extent. There have been many efforts to produce tactile pictures that provide such perception, but there are problems to get it working properly. Edman (1992, pp. 128-130) suggested therefore that objects such as people and animals should be portrayed only in full-front view or in profile and houses and streets only in vertical or horizontal plane to avoid confusion. If 3D objects are depicted in perspective there "*will be a muddle of lines and textures that will probably confuse the reader*".

A more optimistic view on the possibilities for the blind to use and understand perspective was reported by Kennedy (1993, pp. 180-215). He suggested that haptics as vision can provide information to an exploring observer about direction and location of edges in 3D space making it possible to experience the vantage point, that is, the point towards which the edges in a 2D representation converge. Understanding of this point can also be used by blind people when they draw 2D tactile pictures.

For vision an important useful kind of information about depth in a 2D representation is texture gradients, that is, successive changes of texture appearing in a 2D representation of a 3D scene. An experiment by Holmes et al. (1998) demonstrated that this kind of information can be useful also for haptics. The observers in the study explored texture gradients representing different degrees of slant of a flat surface, and the result was that they could reproduce the slants quite accurately. However, the situations in

these experiments were quite simple, and it remains to find out in how complex situations similar results can be obtained.

It is well known that there are problems with rendering depth for vision on 2D screens [→ DEPTH, PROBLEMS OF RENDERING]. To render haptic scenes that provide 3D perception is still harder. The solution has usually been to simplify the scenes considerably and to add verbal information in reading or speech. Haptics is useful in many contexts, but to what level of complexity in information of depth this sense can reach is an open question in several situations.

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RELATED ITEMS

DEPTH, PROBLEMS OF RENDERING
EXPLORATORY PROCEDURES
ZOOM, HAPTIC

HAPTIC FORM PERCEPTION

Gunnar Jansson [UPPSALA]

The term form, often synonymously alternating with shape, denotes a main identifying property of 3D objects. Katz (1925/1989)

referred to this property as macrostructure to distinguish it from microstructure (texture), thereby suggesting that the two phenomena have similarities but differ in scale. Several kinds of sensors are involved in providing the information necessary for haptically perceiving form, consisting of concavities and convexities of a surface, as well as edges [→ SHAPES AND CONTOURS]. The sensors in the skin inform about the deformations of the skin in contact with the object, sensors in the muscles about the movements performed during exploration of the surface, and sensors in the joints about the successively changing directions of the finger parts. Usually a series of movements are used to get this information, even if it sometimes may be possible to identify the form of a real object via a "haptic glance", that is without any exploration, similarly to immediate perception of form via vision (Klatzky & Lederman, 1995).

However, in contrast to vision, this is not the usual way to perceive form via haptics, but form is usually perceived haptically after a more or less time-consuming activity [→ EXPLORATORY PROCEDURES]. Several fingers are usually used, and they are typically curved around the object in different positions, a procedure called enclosure. One hand or two hands may be used to get global shape in this way. Sometimes only one finger is used, often to explore details and to get more exact shape, an activity called contour following (Lederman & Klatzky, 1987). The efficiency of the exploration increases significantly from the use of one finger to two fingers, but not with adding more fingers (Jansson & Monaci, 2004).

In contrast to vision, identification of real 3D objects from their 2D representations is usually not an easy task for haptics, but it is in many cases possible with a time-consuming contour following activity. Tactile pictures, consisting of embossed points and lines corresponding to visual points and lines are the main possibility for visually impaired people to be acquainted with pictures. Pictures to be perceived haptically may in simple

cases be just copies of visual ones, but the more complex they are, the more necessary it is to simplify them. Unnecessary details should be removed, as a too cluttered picture may be impossible to understand haptically.

Form perception of virtual objects via a haptic display with only one contact point (the most common type) is restricted to the exploratory procedure of Contour following. It is time-consuming, but simple forms can be identified reasonably well, especially when they are not too small (Jansson, 2000). However, the possibilities decrease with the complexity of the objects (Jansson & Larsson, 2002). In agreement with the results from experiments with real objects concerning different number of fingers used for exploration, it has been found that an increase of the number of contact points to more than two points between a haptic display and virtual objects does not improve the efficiency (Frisoli et al., 2005).

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RELATED ITEMS

EXPLORATORY PROCEDURES
SHAPES AND CONTOURS

HAPTIC RENDERING OF VIRTUAL OBJECTS

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Haptic rendering can be defined as the process of displaying computer controlled forces on the user to allow him or her interacting haptically with virtual objects.

Haptic-rendering algorithms enable users to touch, feel, interact and manipulate objects in virtual environments through force-feedback devices. Through haptic rendering, the user has access to object mechanical properties and sensorial feeling of its mechanical behaviours; rigidity or softness, resistance to penetration, resistance to displacement, deformation, vibrations, etc. Different types of forces can be replicated (but are not limited to):

- Contact forces: to feel you are touching a virtual object. This force can also take into account physical properties of the material of the object (such as friction, texture, stiffness,..).
- Collision forces intervene when grasping an object and in feeling the collisions with other objects of the scene.

- Weight forces: to allow feeling the weight of objects when they are in hands.
- Long distance forces, such as attraction forces: to attract the user towards a specific point of the virtual scene.
- Constraint forces: to constrain the User's motion on a specific item (such as a pre-defined trajectory).

The haptic rendering algorithms depend on the type of model of the virtual objects. They can be classified in two main categories.

Haptic rendering added to a geometric model, that can be called geometric haptic rendering

In such approach, a haptic-rendering algorithm to touch and feel a virtual object is usually decomposed in two parts [Ruspini, 1999]: a collision-detection part and a collision-response part. Its input is the current position p and velocity v of the probe, as defined by the force feedback device, and a virtual object o , which has to be rendered. The first part of the algorithm, denoted collision (o, p) , is a collision-detection step, which calculates whether the pointer position is located inside the object. The second step, denoted by $render(o, p, v)$ calculates the surface contact point (SCP) and the force that should be exerted by the force feedback device, in case of a collision. There are different denominations for this SCP point like proxy used by [Zilles et al., 1995]. A spring-damper system is then placed between the real probe position and the calculated SCP resulting in the output of the algorithm: a force, pushing or pulling the real probe towards the SCP.

Haptic rendering included as a part of a physically-based model.

In that case, the haptic device is considered as a part of the whole simulated object constituted by a real part and a virtual part, and all the forces – attractive, repulsive, viscous, dry friction, cohesion, plasticity, etc. - that can be modelled in the virtual part can also circulate between the real and the virtual part. This means that several types of components,

not reduced to the usual spring and damper for collision, can be placed between the real part (the haptic device) and the virtual part of the modelled object. Collision or contact rendering become specific cases of haptic interaction. One of the well-suited formalism to implement such generic haptic interaction is the so-called physically-based particles formalism [Cadoz et al. 1984] [Luciani et al. 1991]. More generally, such approaches consider the whole physical system constituted by human, also considered as a physical dynamic system, the haptic interface and a physically-based computer simulation. It leads to explore major concerns for enactive interfaces, because it symmetrizes the interaction: (1) to consider the system human-object as a whole, (2) to consider the haptic interface as a part of the manipulated object, or (3) consider the haptic interface as a mechanical extension of the human body.

No matter the employed approach, besides the performance requirements on the hardware in terms of inertia, peak force or acceleration [Hayward & Astley, 1996], decent haptic rendering also lays severe constraints on the software. Forces must be recalculated at least at 1Khz, implying that haptic algorithms typically are executed within a dedicated thread (called the haptic loop) which may take less than 0.9ms per time frame. When rendering very stiff objects, an even higher update rate of 5-10kHz is desired [Kabelac, 2000] [Florens 2006]. This is a very demanding requirement if comparing to the 25Hz update visual rate.

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RELATED ITEMS

COLLISION DETECTION ALGORITHM
FORCE FEEDBACK DEVICE / FORCE PROPERTIES
PHYSICALLY-BASED MODELLING
PHYSICALLY-BASED MODELLING TECHNIQUES
FOR MULTISENSORY SIMULATION
STABILITY

HAPTIC TEXTURE PERCEPTION

Gunnar Jansson [UPPSALA]

Texture is a fundamental property for our identification of objects in the real world, and haptics has a basic importance for providing us with the necessary information, especially about material properties. The natural exploratory procedure [→ EXPLORATORY PROCEDURES] for perceiving texture is lateral motion of a finger over the surface. When moving a finger in this way, information about the microstructure of the surface is obtained. Typically a surface perceived to have texture consists of homogenously distributed (small) units, less than 3-4 mm or so apart. If the inter-unit distances are larger, the surface

tends to be considered not as textured, but as smooth with irregularities (Klatzky & Lederman, 2003).

Perceived texture is multi-dimensional, the most important dimensions being smooth-rough, soft-hard, and sticky-slippery. A surface can also be described in terms of material characteristics, such as metallic or rubbery, which is important in applications, but it is difficult to determine the physical dimensions involved. Especially roughness has been much studied, and only a few experiments can be reviewed here. One type of research starts from the physical side and defines the stimuli from real or virtual properties, such as grooves with rectangular waveform in a plane surface. One result was that the perceived roughness strongly increased with the distances between the ridges and less so with the sizes of the peaks. Active vs. passive touch [→ TOUCH, ACTIVE / PASSIVE] gave similar judgements, which suggested that the critical feature is the way the skin is deformed, not kinaesthetic information (Klatzky & Lederman, 2003).

However, also exploring a surface with a rigid link between skin and surface, such as a probe or sheath, can provide efficient information for perception of roughness. The stimulation in this case is not skin deformation, but vibration (Klatzky & Lederman, 1999). That this is the case, is important for the use to haptic displays that typically have a probe or a sheath between the user and the virtual surface, as, for instance, the PHANToM has. Also a less expensive device, such as a force-feedback mouse, can provide perceived roughness. The stimuli in one experiment consisted of alternating regions of high and low resistance to movement, and it was found that the perceived roughness varied systematically with the resistance variation (Klatzky & Lederman, 2006).

From an applied point of view it is often important that virtual textures are perceived similar to corresponding real ones. In an experiment the perceived roughness of real

and virtual sandpapers with different grit size was compared, the virtual ones explored with a PHANToM (Jansson et al., 1999). It was shown that the perceived roughness in the two cases was quite similar. The virtual sandpapers were rendered on the basis of properties obtained with a PHANToM moved over real sandpapers, according to a method developed by Green and Salisbury (1997). A vertical stylus was attached to the PHANToM arm and made to follow a straight line trajectory at a constant speed and exerting a constant force. The lateral forces and the z position of the endpoint were measured and used to calculate properties for the virtual surfaces. The virtual sandpapers were not exact copies of the real ones but sufficiently similar to provide closely similar roughness judgments.

In the real world texture is perceived multimodally. When both vision and haptics are available, the result is a complex interaction between the senses. With both vision and haptics available the integrated perception of texture means sometimes dominance of one of the two senses, sometimes some kind of weighted average (Lederman & Klatzky, 2004). Often sounds are produced during haptic exploration of a surface, not the least when a haptic display is used, which also may affect the perceived texture. This can be used to improve the perceived texture, which may be useful especially in applied contexts, but the task is quite complicated and deserves much consideration. A series of experiments by McGee (2002) demonstrated the potentials of improving the perception of texture by combining haptic and auditory information.

On the other side, when pure haptics is under study, the influence of other senses is a disturbance, and in many experiments observers are therefore blindfolded and provided with earplugs or headphones with masking sound to get a purely haptic effect.

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RELATED ITEMS

EXPLORATORY PROCEDURES
TACTILE RENDERING
TOUCH, ACTIVE / PASSIVE

HAPTICS, HAPTIC DEVICES

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“Haptics is used as an umbrella term covering all aspects of manual exploration and manipulation by humans and machines, as well as interactions between the two, performed in real, virtual or teleoperated

environments. Haptic interfaces allow users to touch, feel and manipulate objects simulated by virtual environments and teleoperator systems." [Biggs, Srinivasan, 2002] – quoted by E. Pasquinelli in [→ HAPTICS, IN COGNITIVE SCIENCES].

Indeed, the term haptic devices (or haptic interfaces) covers very diverse technologies and systems. This term is now commonly used by a wide professional community (including interactive robotics, teleoperation and human-computer interfaces, and... the field of haptics). However, we assume that it is not sufficiently precise to be helpful. This includes all the electromechanical actuating systems able to stimulate any part of the haptic perceptual system, eventually correlated with electromechanical sensing systems to acquire data on human's gestures and movements. Indeed, as a preliminary remark, a haptic device comprehends necessarily an actuator, which role is to stimulate human haptic perceptual system.

A today's usual classification of haptic devices is: tactile devices, force feedback devices and haptic display.

Pragmatically, tactile devices [→ TACTILE DEVICE] stands for the electromechanical actuators able to stimulate the mechanoreceptors situated on and under the skin. And Force feedback devices stands for the devices embedding sensors and actuators. Here, the word feedback is essential: it means that the force produced by the actuator depends on the data sensed by the sensors. As for them, haptic displays (or force displays) are only actuators. In both the cases of haptic display and force feedback devices, the forces produced by the actuators aim at simulating kinaesthetic sensations within the muscles.

However, force actuators (in haptic display as well in force feedback devices) stimulate not only the internal muscular mechanoreceptors, but also obviously all the tactile ones. Similarly, tactile devices have to be resistant to the penetration of the fingers and thus necessarily stimulate also the deep tissues and the muscular mechanoreceptors. More generally, due to the complexity of the

haptic perceptual system, the stimuli received when manipulating the device, whatever it is, integrate always both muscular kinaesthetic and tactile perceptions.

We are confronted here with a first very specific difficulty with the expression haptic devices. Indeed, using a term originally introduced to identify human sensors and/or human sensations in order qualify and categorize devices is not adequate. As evidence, the existing device cannot be efficiently classified according to the various perceptual component of the haptic system: tactile, force or others (pain, etc.).

Another way to overcome the fuzziness of the term haptic device and categorize them that has been proposed is focusing on the scale of the actuating data produced: very small values for tactile devices, and upper scale values for force feedback devices. However, this classification is not more valid. For example, force feedback devices must be able to render accurately very low forces, such as friction forces, with very low residual non-expected forces.

Anyway, there is no bijective relation between the human haptic system and the transducers that aim at acquiring and generating phenomena produced or sensed by the human sensory-motor apparatus. And there is no direct relation between the electromechanical properties of the devices (or further of the system that controls the device and the real or virtual object manipulated through the haptic device) and the subjective properties that can be inferred by the human through his perceptual and cognitive system.

Confronted to the ambiguity between the human senses and the objective data provided by actuators that are always present, Cadoz, Florens and co-workers, accompanied their works on the so-called force feedback devices started in the middle of the 70s, by setting-up a specific terminology [Cadoz et al. 1984a, 1984b].

They propose to call all the haptic apparatus, as defined by Gibson, gestural channel [→ GESTURAL CHANNEL], avoiding the unclear

term Haptic. Here, gestural is an integrated term nominating all the mechanical human body activity. The gestural channel declines into gestural action and gestural perception, two expressions that can be associated to technological actuators and sensors without the need to refer to human sensations, perceptions or subjective associations.

Correlatively, they introduced the generic term TGR (in French “*Transducteurs Gestuels Rétroactifs*”, in English “Retroactive Gesture Transducer”, or also “Responsive Input Devices”) [Cadoz and al., 1984]. This expression puts the emphasis on the response to an input. The acronym TGR allows avoiding the term force feedback device which is too much specific and not sufficiently representative of the concepts and the technologies that are implemented by those devices. The advantage of this terminology is to be objective, independent of the human sensing and motor means, and to focus on the true core functionalities of the system:

- The word Transducer (which incidentally is more precise than the buzzword device) addresses the property of fidelity in the signal coding of the physical data;
- The word Gesture indicates that the system is sufficient to be used by human through gesture
- The word Retroactive (which is more precise than the buzzword feedback), addresses the link between what the systems measures (i.e. the signals sensed in response to the human mechanical action via the system sensors) and what the system returns (i.e. the mechanical effect of the actuators, that will be perceived by human haptic perception). It emphasizes also the fact that both these phenomena are supposed to be tightly tied to each other.

The confusion between human sensory-motor system and technical apparatus subsists also when considering sensing functionalities. As a first preliminary remark, it is not usual to put under the umbrella of haptic devices systems that are only sensing systems, i.e. without actuating components. Symmet-

rically, there is no case in which one speaks only on the motor human apparatus under the term haptics. In experiments that set up directly and only the human motor system, when muscles are directly stimulated to create an illusion of action [Albert et al., 2006], the usual term is *virtual action*.

A third question to discuss is related to the morphology of haptic devices. As a haptic device is built in order to be manipulated by hand or by the body through gesture, and actuators and/or sensors are embedded in their mechanical morphology. Morphologies include two parts: the organisation of the mechanical parts that support sensors and actuators, and the morphologies of the end-effectors themselves. End-effector is a term used in robotics to nominate the part of the robot that manipulates real objects. It is used in haptic device to nominate the part of the device that is manipulated by the user.

Morphologies are as diverse as the actuators or sensors are, and as the part of the body involved in the manipulation is. They vary from exoskeleton carried by part or the whole body, to vis-à-vis manipulated systems of various sizes and mechanical organisation, and from versatile morphologies to fixed morphologies [\rightarrow EFFECTOR], see also [Burdea et al. 2003]). Indeed, the question raised by the morphological components is of the same nature as the previous questions discussed regarding actuators. There is no necessary bijection between the morphological organisation of the human sensori-motor system (hand, arm, etc.), and the morphology of the haptic device. The morphology of haptic device plays an important role in the physical adaptation of the manipulation to the task. Thus, it must be defined by taking into account, on the one hand the human morphology and on the other the morphology of the performed task.

Finally, we cannot forget that haptic devices are necessarily controlled by an external processes that can be also from different nature: control-command processes in teleoperation systems, computer simulation

in virtual reality systems. Problems and questions related to that external processes are discussed in several items: [→ ALGORITHM] [→ CHANNEL, AFFERENT / EFFERENT] [→ FORCE FEEDBACK DEVICE / FORCE PROPERTIES] [→ HAPTIC RENDERING OF VIRTUAL OBJECTS] [→ MECHANICAL IMPEDANCE] [→ SIMULATION] [→ STABILITY].

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RELATED ITEMS

ALGORITHM
CHANNEL, AFFERENT / EFFERENT
EFFECTOR
FORCE FEEDBACK DEVICE / FORCE PROPERTIES
GESTURAL CHANNEL
HAPTIC RENDERING OF VIRTUAL OBJECTS
HAPTICS, IN COGNITIVE SCIENCES
MECHANICAL IMPEDANCE
SIMULATION
STABILITY
TACTILE DEVICE

HAPTICS, IN COGNITIVE SCIENCES

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Haptics is a term still mainly used only in professional contexts. In ordinary speaking the sense referred to is most often called touch or feeling, which are less precise terms.

However, touch is a very comprehensive term and, the classification of the sense of touch well instantiates the difficulty of providing unambiguous definitions of sensory modalities. The development of a new generation of interfaces based on action and perception will profit of a clarification of both terminological uses and psychophysiological bases of the active components of touch perception. These components are in fact related both to the perception of one's own body positions and movement and to the extraction of different properties of external objects.

Neurophysiology literature, for instance, makes use of the expression somatic sensory system [Kandel et al., 2000] for referring to two systems: a system for the detection of mechanic stimuli (light touch, vibration, pressure) and a system for the detection of pain stimuli and temperature [Purves & al., 1997]. This classification is based on the physical energy of the stimuli the receptors are sensitive to.

Mechanoreceptors are then sub-divided into tactile or cutaneous receptors which are distributed at the surface (skin) of the body and proprioceptive receptors which are located within the muscles, tendons and joints of the body (localization of the receptors).

Different perceptual qualities are then associated to the two sub-systems: in a general fashion tactile receptors are described as implicated in the perception of the qualities

of the objects of the external world (such as dimensions, shape, microstructure, movement relative to the skin) and the proprioceptive system as dedicated to the (more or less aware) perception of the position and movement of the body.

Neurophysiology deals then with the ascription to the somesthetic system of 4 main functions: discriminative touch, proprioception, nociception, temperature perception.

There is a difficulty in sharply separating the external and the internal mechanoreceptors and associating them separately with exteroceptive and proprioceptive functions respectively.

Active exploration of the world's objects implies in fact the utilization of internal, proprioceptive mechano-receptors, but it provides information about the properties of the external world.

For this reason, active touch has often been considered as a separate category of touch on the basis of the role that movements (and movement receptors) play into the discrimination of the properties of objects. Much discussion has concerned the role of movement in touch. For Gibson it is basic, as it was for the [Katz, 1989/1925], but the importance has also been questioned. It has been suggested that the important property is relative movement of object and observer; moving an object against the observer's skin may sometimes give the same perception as when the observer is active.

Sometimes the term active touch [→ TOUCH, ACTIVE / PASSIVE] is used synonymously with haptics. This use emphasises the role of movement in haptic touch.

The term haptics was first introduced by Revesz [Revesz, 1958] to incorporate cutaneous and kinaesthetic information). [Loomis & Lederman, 1986] make reference to the haptic sensory modality in terms of kinaesthetic touch: kinaesthetic touch is comprehensive of cutaneous and kinaesthetic receptors, provides information about objects and surfaces that are in contact with the

subject and guides the manipulation of objects.

The modality of touch is then composed of three sub-modalities: “*The modality of touch encompasses distinct cutaneous, kinesthetic and haptic systems that are distinguished on the basis of the underlying neural inputs. The cutaneous receptors are embedded in the skin; the kinesthetic receptors lie in muscles, tendons, and joints; and the haptic system uses combined inputs from both.*” [Klatzky & Lederman, 2002, p. 1] These classifications do not then question the divisions operated by neurophysiology and based on the energy of the stimulus and the localization of the receptors.

On the contrary, Katz's *The world of touch*, a classic in the history of the study of touch [Katz, 1989/1925], refused to adopt an atomistic approach to perception by individuating and separating the activity of different sensory receptors (thus multiplying the number of tactile sensations) and he choose to adopt a system of classification based on the qualities perceived by touch. The world of touch possesses three main modifications or qualities: surface touch (the two-dimensional tactile structure that is identified when touching a continuous palpable area, localized at the surface of the object, and following the curvatures of the object), immersion touch (the tactile phenomenon without definite shape nor structure or spatial orienting, as when moving the hand in a fluid), volume touch (the perception of the shape, the spatial distribution of the object that we can have when the object is, for instance, covered by a textile or the hand is covered by a glove). The skin senses cannot then be separate since “*in the living organism (whose expressions, after all, are what we wish to understand), large coalitions of sensory elements always work together.*” [Katz, 1989/1925, p. 34] The differentiation operated by the physiology of the senses is then an artefact, in that complex phenomena constitute the only real component of conscience. The physiology of the senses is then obliged to recombine the elements it created into complex phenomena, thus suggesting that complex phenomena are

cognitive products of logical operations. On the opposite, Katz invites to consider tactile perception as an immediately complex phenomenon which does not require the intervention of successive cognitive operations. Katz's suggestion does not solve the problem of differentiating touch from other sensory modalities, but is only limited to the internal classification of touch, since common qualities (as the shape of an object) can be appreciated by more than one sensory modality (as vision and touch).

A sort of middle-way position is represented by Gibson's classification of haptic touch or haptic system. In fact, Gibson maintains the distinction between physical energies and types of receptors but points more on the object properties. Candidates for receptors involved in the haptic system are located in the skin on one side and muscles, tendons and joints on the other. Much research has been devoted to isolate the different receptors and corresponding sensations. Gibson noted that in many of these studies the observer was considered as passive, that the stimuli were typically small both in space and time, and that the responses were about the impression, not about the object making it. In contrast to these approaches, Gibson suggested that the observer in experiments about haptics should be actively exploring, that the stimulation should be extended in space and time, and that the reporting should concern objects perceived, their affordances and their use.

Gibson [Gibson, 1962] [Gibson, 1966] suggested that there is a great difference in the resulting percept depending on the active or passive role of the perceiver: when the stimulation is passive, as when being touched by an object, even if the object is moving, the subject obtains sensations of skin modification; it is only when the subject plays an active role by actively touching the object that attention is directed to the properties of the object.

Active touch is then defined as an exploratory rather than a merely receptive sense, by

which the variations in the skin stimulation are produced by variations in the motor activity. Thus the unitary perception of an object with more fingers doesn't require a central integrations since the pressure of the fingers upon an object informs about the qualities (e.g. the hardness) of the object and does not give rise to separate, cutaneous sensations (on the contrary, in the case of passive touch, two separate pressures on the skin give rise to two different sensations). In the same way, in active touch, kinaesthesia is not to be separated nor simply combined with cutaneous sensations, since the patterns of change of the skin contact co-vary with the change in limb position giving rise to one and the same information about the object properties. Touch is exemplary of the connection of perception and movement in perception, since in its case the equipment for feeling is anatomically the same as the equipment for doing.

The non-separation of the skin senses from kinaesthesia is labeled haptic system, and distinguished from haptic touch and dynamic touch [Gibson, 1962]: "*The sensibility of the individual to the world adjacent to his body by the use of his body will here be called the haptic system. The word haptic comes from a Greek term meaning "able to lay hold of." It operates when a man or an animal feels things with his body or its extremities. It is not just the sense of skin pressure. It is not even the sense of pressure plus the sense of kinesthesis. [...] The haptic system, then, is an apparatus by which the individual gets information about both the environment and his body. He feels an object relative to his body and the body relative to an object*" [Gibson, 1966, p. 97]. The body parts involved are especially the extremities, and the information obtained is about both the environment and the body.

The haptic system is then sub-divided into: cutaneous touch (when the skin and deep tissues are stimulated without movement of muscles and joints); haptic touch (when the skin and deep tissues are stimulated by the movement at the joints, as in catching an object, palpating, squeezing, etc. in order to extract information about its geometry and

microstructure); dynamic touch (when skin and joints are stimulated in association with muscular effort, as in the discrimination of weight, which is better when the object is wielded, rigidity, viscosity, etc.); oriented touch (the combination of inputs from vestibular, joint and skin receptors); touch-temperature (the combination of skin stimuli with vasodilatation and vasoconstriction); painful touch; social touch (the affective components of touch, as in the new-born cares).

Dynamic touch is a rich domain of studies (see for instance [Turvey, 1996]. Dynamic touch is active, but it does not regard finger exploration, for instance. The perception of object properties by wielding is a prominent example of dynamic touch. The haptic properties that are thus perceived are those regarding the macro-geometry and volume of the objects, as the extension, shape, orientation and weight; in the same time properties of the limb holding the object are discriminated. [Turvey, 1996] states as follows: “*What sets kinesthetic touch apart from other forms of touch is the prominent contribution of muscular effort and its sensory consequences. As a grasped object is wielded, the receptors that interpenetrate muscular and tendinous tissues are mechanically stimulated. These mechanoreceptors, as they are called, respond to the stretching, twisting, and bending of muscles and tendons. Their collective response to the changing flux of mechanical energy is the primary (although not the exclusive) neural basis of dynamic touch.*”

An interesting suggestion for the internal classification of touch can be extracted from the researches of Lederman and Klatsky (see for instance [Lederman & Klatsky, 1987] [Klatsky et al., 1985]. The hand system is an intelligent instrument in that it makes use of its motor capacities for ameliorating its sensitive abilities. Since the movements are coupled with the properties of the objects that are extracted, it is possible to describe a set of exploratory movements or patterns that correspond to object properties as texture (slight movements on the surface), shape (contour following or wielding), presence of parts, etc. It is then possible to sub-divide the

sense of touch (of active touch) with no reference to the energies, to the type of receptors or their localization, but only to observable properties of the exploratory activity such as the movement employed and the perceptual result obtained.

In the domain of technological applications the terms tactile/touch and haptic/haptics are often used interchangeably, but each of them dominates the terminology in some contexts. Tactile/touch is mainly used concerning patterns embossed on a 2D surface, especially when aids for the visually handicapped are discussed (for instance, [Edman, 1992]). Haptic/haptics is most common in the context of computer-connected displays (for instance, [Burdea & Coiffet, 2003])

Computer haptics includes the technologies and processes for the generation and proposition of force-feedback stimuli to human users in virtual reality environments. The focus is on hand exploration and manipulation: “*Haptics is concerned with information acquisition and object manipulation through touch. Haptics is used as an umbrella term covering all aspects of manual exploration and manipulation by humans and machines, as well as interactions between the two, performed in real, virtual or teleoperated environments. Haptic interfaces allow users to touch, feel and manipulate objects simulated by virtual environments (VEs) and teleoperator systems.*” [Biggs & Srinivasan, 2001, p. 1]

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RELATED ITEMS

ACTIVE PERCEPTION / TOUCH
 CLASSIFICATION OF PERCEPTUAL MODALITIES
 EXPLORATORY PROCEDURES
 HAPTICS, HAPTIC DEVICES
 TOUCH, ACTIVE / PASSIVE

HUMAN COMPUTER INTERACTION

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Human computer interaction (HCI, also called as human computer interface) is defined as “*a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them*” [ACM, 2007]. Since computer hardware and soft-

ware is able to transport a reasonable amount of visual and acoustical information, a huge field of research focuses on communication and interaction between people and computers (or machines in general). The work on believable enactive interfaces investigates how to improve the connection between the user and the application. It encompasses those aspects of computer interfaces that process the input to the computer system and translate the output of the system so that the user can understand and believe it.

A basic goal of HCI research is to improve the interaction between users and computers by making computers more user-friendly and receptive to the user's needs. Specifically, HCI is concerned with

- methodologies and processes for designing interfaces
- methods for implementing interfaces
- techniques for evaluating and comparing interfaces
- developing new interfaces and interaction techniques
- developing descriptive and predictive models and theories of interaction

Historically, application developers neglected the users. Only recently, users have been taken into account, with the advent user-centric design approaches in order to place users at the center of the application. The objective is to make interaction more effective, efficient and satisfactory for the users.

A goal of the research on enactive interfaces is to design HCI systems that minimize the barrier between the human's cognitive model of what they want to accomplish and the computer's understanding of the user's task. The expected outcome is to improve users' acceptance, reduce the learning curve, increase the usability and optimize the user's productivity. Users show various conceptions about their possible interactions, they also have different ways of learning, acquiring and maintaining knowledge and skills. Moreover, cultural differences have also to be taken into consideration [Shen, 2006]. Finally, user's

skills and preferences will vary, as they will master the interfaces and applications.

These interfaces range from a simple low-level HCI, such that a standard desktop application of a personal computer system, in which the output is represented through icons, e.g. for the files or documents and the input is supported via mouse and keyboard, up to a high-level HCI, that possibly works with natural conversational interaction.

The interaction is nowadays not limited to an open action-reaction loop between the computer and the typing and questioning of the user but rather to a self thinking and reacting of the computer without specific commands. Current researches play with the tracking of body parts of the user for a well-directed reaction. This is particularly relevant to immersive interfaces (human factors engineering).

Virtual and mixed realities [→ VIRTUAL REALITY AND VIRTUAL ENVIRONMENT] [Wilson, 2006] [Nijholt, 2004] are often presented as the ultimate user-interface as they aim at completely immersing the user inside the application with interactive multisensory and multimodal user-interfaces. Enactive interfaces are new types of human-computer interface that allow expressing and transmitting the enactive knowledge by integrating different sensory aspects. The driving concept of enactive interfaces is then the fundamental role of motor action for storing and acquiring knowledge (action driven interfaces). Enactive interfaces are then capable of conveying and understanding gestures of the user, in order to provide an adequate response in perceptual term. The actual trend is orienting the future developments and research towards pervasive adaptive enactive interfaces in user-aware ambient environment [Kostakos, 2005].

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RELATED ITEMS

AVATAR

BELIEVABILITY_ 1&2

COGNITIVE SCIENCES

COMPUTER GRAPHICS

INTERFACE

REALITY, AUGMENTED AND MIXED

VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

I

IDENTIFICATION OF OBJECT PROPERTIES

Annie Luciani [ACROE&INPG]

Trivially speaking, identification of the properties of an object is a part of the process of recognition of that object. It is useful to distinguish between recognition tasks that may be considered as spatially and topologically oriented and tasks that are physically-oriented (or dynamically oriented).

In spatially and topologically oriented tasks, we are interested in recognizing or identifying:

- Spatial features: macroscopic shapes, location.
- Topological features: number and structures of objects.

In physically-oriented tasks, conversely, we are interested in recognizing or identifying:

- The matter of the object. Although it seems to be just supplementary information, it requires in the context of multisensory simulation the rendering of completely different properties of the objects, and leads to quite different models, computational algorithms and machines for interaction.

Spatially and topologically oriented tasks have to be separated in two spatial scales: (1) macroscopic scale, and (2) microscopic scale.

A frontier exists today between these three types of implementations, putting a clearly-cut frontier in the tasks consisting in recognition of spatially-oriented macroscopic properties, recognition of physically-oriented properties and recognition of spatially-oriented microscopic properties, the second one being inserted between the two different spatial scales.

Consequently, the identification tasks can be split in three types of processes [Luciani et al., 2006], as explained in the following.

1) Object recognition and identification of *spatial and topological features* by means of exploration through *spatial action* (positioning) and exteroceptive channels.

It consists in a recognition task by means of sensory channels: audition (spatial features) and vision (spatial and topological features), associated to actions such as positioning action in a large meaning (displacing and displacements) i.e. with no possible modification of the dynamic state of the object. Here, 3D vision or 3D sounds may play a predominant role.

2) Object recognition and identification of *physical features* by means of exploration through *ergotic action* (squeezing, stretching, hitting, etc.) and proprioceptive and kinesthetic sensory channels.

Here, the identification process needs to interact with the matter to detect its rigidity, its fluentness, its weight, etc. that are more physical than geometrical properties. Visual, haptic and acoustical matter deformations may here play a predominant role, exhibiting all the scales of the behaviours of the physical object (visual scale, haptic scale, auditory scale) and revealing as well its dynamic properties as its geometrical and topological ones [→ SHAPES AND CONTOURS].

3) Object recognition and identification of *spatial features* by means of exploration by *tactile action* (palpating, brushing, skimming, etc.) and tactile sensory channels.

Continuing the traversing of the scales, for the recognition of the surface state (roughness, micro shapes as sharp edges, etc.), tactile exploration becomes the most important. The above strongly-in-hand situation can be relaxed. We are back to a recognition and exploration process similar to object non-closely-in-hand (case 1), though on a restricted and more precise spatial area.

Conclusion

This proposed three-scale is operational when seeking enabling object identification in the context of virtual reality and multisensory simulation. Indeed, depending on the level on which the designer wants the user to base object identification, or reciprocally on the level on which the user's task should be based, the system would have to render completely different properties of the objects, hence could need fundamentally different models, computational algorithms and machines for interaction.

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RELATED ITEMS

HAPTICS, HAPTIC DEVICES
HAPTICS, IN COGNITIVE SCIENCES
SHAPES AND CONTOURS
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

ILLUSION

Elena Pasquinelli [INSTNICOD]

The notion of illusion is widely used in the domain of mediated interactions and constitutes one of the most addressed phenomena in current studies about perception.

Some perceptual illusions were known to the ancient Greeks (for instance, the so-called Aristotle's illusion), but it is in the XIX century that the first scientific description of illusions were given.

In 1832 L. A. Necker illustrated how a rhomboid reverses in depth, sometimes one face appearing the nearer, sometimes the other (perceptual reversal or alternation); W. Wundt described the Horizontal-Vertical illusion: a vertical line looks longer than the horizontal line of equal length that it encoun-

ters (distortion illusion); interest in illusions grew higher suite to the publication of some figures showing distortions which could affect the use of optical instruments, thus producing errors: the Poggendorff figure of 1860 (a straight line crossing a rectangle appears displaced), the Hering illusion of 1861 and the Wundt of 1896 (straight parallel lines look bowed outwards or inwards), the Mueller-Lyer arrow figure of 1889 (the outward-going arrow heads produce expansion of the shaft, and the inward-going heads contraction). Distortion phenomena were then explained with reference to the stimulus pattern, (for example, in the case of the Mueller-Lyer figure that the acute angles tend to be overestimated and the obtuse angles to be underestimated).

The number of phenomena that are described as illusions has greatly grown during the last two centuries [Gregory, 1968], and the term "illusions" is used in relationship to:

- ambiguities (as the Necker cube, the visual effects provoked by mist or retinal rivalry);
- distortions (as the Size-weight illusion or other classic geometric illusions, such as the Horizontal-Vertical illusion, but also mirages);
- paradoxes (as the impossible triangle of L. S. Penrose and R. Penrose of 1958, which cannot be seen as a sensible three-dimensional figure, the so-called impossible figures and impossible objects in general);
- fictions (as the rainbow, the faces one can 'see' in the fire, galleons in the clouds and so on, the after-images and figures such as the Kanisza triangle).

However, the notion of illusion is not theoretically neutral, but has come to be associated with the indirect, inferential approach to perception: illusions are defined as systematic perceptual errors or systematic discrepancies between what is in the world and what we end up perceiving of it, with the intermediate of inferential, cognitive processes [Gregory, 1997].

Between direct views of perception the ecological approach to perception denies that perception can be untrue, and then discards the concept of illusory perception as error [Turvey et al., 1981].

Sensorimotor and enactive accounts of perception strongly criticize the idea that perception is bounded to the representation or mirroring of the external reality, and then the idea of adequacy-inadequacy between perception and the unperceived world. However, the notion of illusion is not completely discarded [O'Regan & Noë, 2001].

Illusions seem nevertheless to have a great heuristic value for theories of perception (and as a matter of fact, illusory phenomena are largely exploited by ecological theories of perception [Turvey, 1996]) because they permit to distinguish a class of phenomena which presents some structural differential features:

- the awareness that there is something wrong in the actual perceptual experience, associated with a reaction of surprise when this awareness is achieved. This awareness does not depend on a comparison of internal perceptual experiences with external states of the world, but rather on the detection of some violation of coherence (between experiences in different sensory modalities, between past and present experiences, between knowledge or information and present perception); the reaction of surprise alerts the subject to the possibility of error and hence represents an epistemic value and a potentially adaptive behaviour
- the systematic character of the experience, both at the intersubjective and at the intra-subjective level.

In reference to these features, a characterization of the notion of illusion can hence be proposed that is neutral in relation to theoretical assumptions about perception.

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RELATED ITEMS

BELIEVABILITY_1&2
 COHERENCE OF PERCEPTUAL EXPERIENCE
 ILLUSIONS, AUDITORY
 ILLUSIONS, HAPTIC
 ILLUSIONS, VISUAL

RELATED DOCUMENTS

El_hapticillusions_Pasquinelli.doc

ILLUSIONS, AUDITORY

Amalia de Götzen [DEI]
 Federico Avanzini [DEI]

Auditory illusions occurs when the listener hears sounds that are not present in the stimulus and our brain organizes and interprets sensory stimulation producing a distortion of a sensory perception. It is possible to distinguish between classical examples of auditory illusions and the illusions that emerge because of the interplay of audition with multisensory perception.

Auditory illusions can be then taken into account in designing anactive interfaces for their possible creative uses. A good parallel can be drawn with visual illusions, often used by hyper realistic painting (e.g. the image of a mirror without the painter that is painting it, etc.).

Auditory illusions in an immersive, enactive environment can be made to be much

more striking than in a usual one because an immersive environment allows to enhance the cooperation between modalities. The interaction between hearing, vision and haptics can be tightly controlled in such an environment and the cooperation between these modalities can therefore be increased or decreased at will.

Examples of auditory illusions

We summarize in the following classical examples of Illusions (more details available in [Deutsch, 1982]).

- The Shepard tone or scale

“Shepard used complex tones whose partials consist of only octaves of the fundamental. [...] When a set of tones of this type, whose fundamental frequencies cover the range of an octave in semitone steps, are played cyclically, or if the fundamental frequency is swept continuously over an octave range, the impression is one of constantly rising or falling pitch.” [Deutsch, 1982].

- The Deutsch tritone paradox

This illusion is produced by two synthesized tones that are related by a half-octave (a tritone). When one tone of a pair is played, followed by the second, some subjects hear an ascending pattern, while other hear a descending pattern.

- Octave illusion

Two simultaneously played sequences of two notes, spaced by an octave apart in separate stereo channels over headphones, are perceived in a different way by right/left-handed subjects: Right-handed tend to hear the higher pitch as being in their right while left-handed subjects doesn't show a clear behaviour.

- Glissando illusion

This illusion is produced when a sound with a fixed pitch is played together with a sine wave gliding up and down in pitch, and they are both switched back and forth between stereo loudspeakers. The fixed tone is heard as switching between loudspeakers while the sine wave is heard as joined together seamlessly, and as moving around in space in accordance with its pitch motion.

The glissando is perceived by right-handed as traveling from left to right with an ascending glissando, and then back from right to left with a descending glissando. Lefthanders often obtain different illusions.

- Illusory continuity of tones

This illusion is caused by the interruption of a tone for a short time (approximately 50ms or less), during which a narrow band of noise is played. Whether the tone is of constant, rising or decreasing pitch, the ear perceives the tone as continuous.

Interplay of audition with multisensory perception

Interesting studies focus on auditory illusions driven by the interplay of audition with other sensory modalities. In general, the amount of cross-modal integration [→ MULTIMODAL (MULTISENSORY) INTEGRATION, IN COGNITIVE SCIENCES] depends on the features to be evaluated or the tasks to be accomplished. The modality precision hypothesis [Welch & Warren 1986] states that discrepancies are resolved in favor of the more precise or more appropriate modality.

Much literature on multisensory perception has focused on spatial interactions. In spatial tasks, the visual modality usually dominates, because it is the most precise at determining spatial information. An example is the ventriloquist effect, in which the perceived location of a sound shifts towards a visual stimulus presented at a different position. Identity interactions are also studied: an example is the McGurk effect [McGurk & MacDonald 1976], in which what is being heard is influenced by what is being seen (for example, when hearing /ba/ but seeing the speaker say /ga/ the final perception may be /da/).

As for the interplay between touch and audition concerning object properties, the studies that have been carried out focus mainly on contact properties such as hardness, stiffness and texture. For surface roughness and stiffness, [Lederman et al., 2002] showed that touch usually dominates over audition, but both of them can improve

the perception or even create an illusion. Classic studies on the perception of gratings in tactile alone, auditory-alone, tactile-auditory conditions, report also dominance of the tactile modality. The “parchment skin illusion”, in which tactile perception of skin is modified by auditory feedback, was studied in [Jousmaki & Hari, 1988]. [Schurmann et al., 2004] show that audition can affect the perceived number of tactile stimuli in a rapid sequence and that tactile stimulation can affect the perceived intensity of auditory stimuli.

The multi-modal correlates between haptic size and auditory pitch have also been investigated. In [Magnusson & Grahn, 2005] the authors state that appropriate contact sounds and object sounds together with greatly simplified haptic objects will, for one point haptics, create working illusions for moving objects such as cars or bicycles.

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RELATED ITEMS

AUDITORY FEEDBACK IN VR AND HCI
 AUDITORY PERCEPTION
 ILLUSION
 MULTIMODAL (MULTISENSORY) INTEGRATION,
 IN COGNITIVE SCIENCES
 OBJECT PERCEPTION, ARGUMENT FROM ILLUSION

ILLUSIONS, HAPTIC

Otniel Portillo [PERCRO]

According to a narrow definition, illusion is a misperception or misconception of a stimulus object, image, event, experience, or problem, or a stimulus that generates such a misperception or misconception; more generally, any misleading, deceptive, or puzzling stimulus or the experience that it generates [→ ILLUSION].

Perceptual illusions can arise through any sensory modality, but the most prominent are the auditory illusions, tactile illusions and above all visual illusions. A perceptual illusion is a phenomenon where the percept of an object or an event differs from physically measurable properties of the stimulus. There are two contradictory opinions about the importance of perceptual illusions in general for the understanding of perception. On one side, it is suggested that they are basic for understanding the functioning of perception as they indicate perceptual processes not originating in the physical stimulus [Gregory, 1966 - and later editions]. On the other side, it is suggested that illusions are not basic for everyday veridical perception, but that they are interesting as deviations from the normally correct perception [Gibson, 1966]. There is agreement about there being many different kinds of illusions and causes to their appearance, even if the classifications of them differ.

Illusions are often amusing and sometimes used in visual art. They may also be useful for technology. The visual phi-phenomenon, for instance, is the basis for the functioning of films, where static pictures produced in rapid succession are perceived as including motion and other changes. This phenomenon was also important for the early gestalt psychologists. They interpreted it as a key phenomenon for their main thesis "*the whole is more than a sum of its parts*".

Haptic illusions have not been as extensively studied as visual illusions [→ ILLUSTRATIONS, VISUAL], and there are not as many haptic illusions as visual ones. Haptics is to a large extent normally considered as the sense of reality [→ TOUCH, THE SENSE OF REALITY]; we check often with haptics if a visual phenomenon is an illusion or not. However, there are also haptic illusions, even if they sometimes are smaller in magnitude than corresponding visual illusions [Hatwell, 1960].

One haptic illusion that has been much studied is the cutaneous rabbit phenomenon [Geldard & Sherrick, 1972] [Geldard & Sherrick, 1983] [Flach & Haggard, 2006]. It is a phenomenon appearing when five brief taps are presented at each of three locations on a forearm. When the temporal intervals are suitable there are spatial mislocations. The whole event has been described as a rabbit jumping up the arm. This indicates an interdependence of spatial and temporal factors in tactile perception.

Robles-de-la-Torre and Hayward [Robles et al. 2000] [Robles et al. 2001] [Hayward, 2004] discovered an interesting haptic illusion using paradoxical objects in active touch. Haptic perception normally entails an active exploration of object surfaces over time, this is called active touch. When the shape of an object is explored, we experience both geometrical and force cues, for example, when sliding a finger across a surface with a rigid bump on it, the finger moves over the bump while being opposed by a force whose direction and magnitude are related to the slope of

the bump. The steeper the bump, the stronger the resistance. Geometrical and force cues are correlated, but it has been commonly assumed that shape perception relies on object geometry alone. They have shown that regardless of surface geometry, subjects identified and located shape features on the basis of force cues or their correlates. Using paradoxical stimuli, for example combining the force cues of a bump with the geometry of a hole, they found that subjects perceived a bump. Conversely, when combining the force cues of a hole with the geometry of a bump, subjects typically perceived a hole [Flanagan et al. 2001] [Lécuyer et al. 2004].

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RELATED ITEMS

HAPTICS, HAPTIC DEVICES
HAPTICS, IN COGNITIVE SCIENCES
ILLUSION
ILLUSIONS, AUDITORY
ILLUSIONS, VISUAL
STIFFNESS, AUDITORY PERCEPTION OF
TOUCH, DYNAMIC
TOUCH, THE SENSE OF REALITY

ILLUSIONS, VISUAL

Manfred Nüsseck [MPIT]

The visual perception is not a simple 1:1 translation of the retinal input, but rather an information gathering of the eyes that is processed by the brain to create a certain percept [Bruce et al., 2003]. This does not necessarily have to match with the physically measurable source of the stimulus. The theories of the Gestalt psychology demonstrate this phenomenon quite well [Koffka, 1999]. A visual illusion is, therefore, characterized as a visual impression that is deceptive, misleading, or realistically impossible [→ ILLUSION].

The famous artist M.C. Escher made a large set of pictures with physically and realistically impossible objects. Nevertheless, it is still possible to look at these images and get an impression of the objects even if they are not creatable in reality. These pictures contain different perspectives or viewpoints, which melt together in one picture. The individual parts make respectively sense, whereas the whole picture is actually an impossible object. By looking at the images we consider only one part at the time and try to merge these parts into a coherent unit that would fit into a normal and reasonable physical reality.

Generally, there are two major ways of explaining visual illusions. The first is the physiological approach in which the illusion is caused by the physiological operation mode of the eye (e.g., the Hermann grid illusion). The construction of the visual system leads to false information sending for certain kinds of percepts, which are actually not existing in the outside world. In the case of the Hermann grid illusion, little black dots occur at the crossings of the white lines. This happens as there are supposedly certain so called receptive fields with differently reacting cells in the visual cortex.

The second is a cognitive approach where the illusion is created through the perceptual system (e.g., the simultaneous contrast illusion). Here, we have the impression that the two little squares in the bigger ones differ in brightness. Actually they are not. The different contrasts of the larger surrounded squares, abstractly said the different contexts of the squares, lead to a misinterpretation of color.

Both forms of illusion work for static images, as well as for dynamic sequences.

The advantage of visual illusions is that they can be used to investigate how the human perceptual system works [Seckel, 2006]. Nowadays, illusions are also the subject of the neurosciences to find possible correlations between brain activities and the mental representation of an illusion [Bruce et al., 2003].

The appearance of visual illusions and their inferential factors has to be taken into account concerning especially the creation of virtual environments and human computer interfaces to avoid accidental problems. This could be e. g. an illusionary perception of depth [→ DEPTH, PROBLEMS OF RENDERING] in a virtual world or of virtual objects caused by wrong or missing perceptual cues or their interaction [→ VISUAL PERCEPTION]. To create believable enactive interfaces and applications these illusions are important to consider.

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RELATED ITEMS

COGNITIVE SCIENCES
DEPTH, PROBLEMS OF RENDERING
ILLUSION
VISUAL PERCEPTION

RELATED DOCUMENTS

IMMERSION VS. VIS-À-VIS

Annie Luciani [ACROE&INPG]

The axis immersion – vis-à-vis is an efficient mean to qualify virtual reality and virtual environments systems [→ VIRTUAL REALITY AND VIRTUAL ENVIRONMENT]. Further, it addresses the fundamental question of the types of relation between humans and the external world.

Immersive systems, in short, focuses on the seeing (or hearing) sense. The corresponding actions are spatial actions, such as displacements of the full body (ego-motion). This is an observational situation, implemented in the computer by metaphors such as magic carpet, fly-and-see, move-and-see, etc. These are exploratory metaphors [→ METAPHORS IN HUMAN-COMPUTER INTERACTION] used in virtual environments as well as in flight or driving simulators, landscapes or cities' navigation, etc.

The questions raised by immersion are indeed similar in both the real spatial world and in virtual or abstract worlds. Both of them correspond with difficulties such as knowing where we are, keeping a spatial reference, planning the displacements in order to reach

a goal. Nevertheless, some drastic discrepancies appear between immersion in virtual environments and immersion in the real world. The most important of them is that in virtual environment, the human body itself does not displace. Movements are instrumented by means of an intermediate real object (stick, wheels, balls, travelators, etc.) assisted by a virtual one (virtual arrow, virtual camera, etc). Thus, a physical transformation between the localization and displacements in real world and their effect in the virtual world is necessarily introduced. This transformation leads to the design of adapted metaphors and to the study their effects in regards with human's capabilities. One of them is the question of co-location [Jansson et al. 2004] [Messing, 2004] [→ DEPTH, PROBLEMS OF RENDERING]. Furthermore, the immersive situation remains conceptually problematic.

Regarding manipulation, immersion in virtual environment is a sort of teleoperation situation: human manipulates a tool in human space that has an effect in a task's space, i.e. as a kind of vis-à-vis situation. Regarding sight (what the user actually sees), it is an immersive situation in which the space is moving around the human body.

Conversely, the vis-à-vis situation is related to manipulation activities. It refers to objects that are in a local space, i.e. at the scale of the hand or body's attainable objects. Further, the vis-à-vis situation is needed to allow, ultimately, the embodiment process involved in the functional transformation of the object from the status of object to the status of instrument as a usable object to do something - the cognitive transformation of a part of the world considered an external object, into an instrument considered as a true part of the body. This final step allowed by the vis-à-vis situation is further discussed in [→ INSTRUMENTAL INTERACTION].

In the vis-à-vis situation and in the immersive situation, the relation between action and sight and/or hearing deeply differs. During the immersive activity, seeing and hearing are mainly the goal of the current action (move

in order to see, move in order to hear). Conversely, in the vis-à-vis situation, seeing and/or hearing are mainly a way of controlling the current action (put here, hit, write, etc...).

This analysis shows that it is fruitful to consider the two concepts of immersion and of vis-à-vis as being not competitive, but rather as being complementarily operational. Considering their complementarity is in particular helpful in the analysis of the relations between human and the external world in order to obtain guidelines for the design of new interactive tools and instruments. Three progressive different scales can be distinguished in objects:

- *Surrounding objects*: Surrounding objects are far in spatial distance. For such objects, there is a clear predominance of space and of the geometry of the space, and a clear predominance of seeing and hearing for spatial localisation.

- *Ready-to-hand objects*: Objects ready-to-hand are objects one can potentially manipulate. For such object, there is with a balance between space and geometry on the one hand, and between physics and materiality on the other hand.

- *In-hand objects*: Objects in-hand are objects actually manipulated. For such objects, there is a clear predominance of the materiality in the experience. At that point, there may be also a fluent and permanent trade-off between the notion of object (that remains cognitively external) and the notion of instrument (cognitively embodied, playing as a part the body).

In the daily life, the operational role of objects is permanently changing along these three states, stressed between the two extreme cases of environment/immersion and instrument/vis-à-vis. In the middle, the notion of object is somewhat fuzzy that can be considered either as a part of the environment or as a vis-à-vis. Today, the implementation of such versatility in the functions of simulated objects is still a fundamental question. For example, we are still unable to

implement the continuous state changing, and the required correlated algorithms and simulation processes transformations, as when one experiences walking toward a violin or a hammer, then grasping it in hands and transforming it into an instrument to be played or to hit. One of the major challenges the fields of multimodal interfaces, and especially of enactive interfaces, face today is the possibility of co-articulating in a versatile way all these three drastically different states in computer mediated relations between humans and artificial systems.

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RELATED ITEMS

DEPTH, PROBLEMS OF RENDERING
INSTRUMENTAL INTERACTION
METAPHORS IN HUMAN-COMPUTER INTERACTION
REALITY, AUGMENTED AND MIXED
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

INFORMATION TRANSFER

Ian Summers [UNEXE]

In the context of communications engineering, for a message which passes from a transmitter to a receiver, information is a quantity which represents the number of distinct categories of message which can be received. If the number of distinct categories is n , the information is $\log(n)$ [Shannon, 1948].

The logarithm is conventionally taken to the base 2, in which case the unit of information is the bit. This concept is also applicable in the context of enactive interfaces, where the messages are provided by the multimodal input to the user during active exploration of a scenario.

The perceived (received) information may be less than the available (transmitted) information, because of the limitations of the user. In this case it is useful to introduce the concept of information transfer. Information transfer represents the number of distinct categories of stimulus which can be distinguished by an observer. If the number of distinct categories is N , the information transfer is $\log(N)$, where the logarithm is taken to the base 2. Information transfer is measured in (dimensionless) units of bits. A common abbreviation for information transfer is IT.

If M stimuli are presented to the observer, either serially or in parallel (or in a serial/parallel combination) and this composite message is successfully recognised (with N distinguishable categories within each stimulus), the IT is $\log(N^M) = M \cdot \log(N)$.

With a multimodal stimulus, A perceived categories from modality 1 and B perceived categories from modality 2 combine to give an IT for each stimulus of $\log(AB) = \log(A) + \log(B)$.

In most cases, it is necessary to specify the speed at which information can be transmitted to the user. There is often a trade-off between the rate at which messages are received and the number of categories of message which may be distinguished. Information transfer rate is the product of the information transfer (which represents the number of discriminable categories of stimulus) and the rate at which stimuli are presented. If M stimuli are presented within a time T , and the number of distinguishable categories is N , the information transfer is $\log(N)$ and the information transfer rate is $(M/T)\log(N)$, where the logarithm is taken to the base 2. Information transfer rate is meas-

ured in units of bits per second. A common abbreviation for information transfer rate is IT rate.

As mentioned above, information may be presented at a higher rate than the observer (user) can deal with. For example, at a given presentation rate for stimuli, the number of discriminable categories N' may be less than the number of presented categories N . In this case the IT rate $(M/T)\log(N')$ is less than the information presentation rate $(M/T)\log(N)$. The relation between N' and N can be determined by measuring the observer's confusions between the various presented stimuli [Miller, 1955] [Miller and Nicely, 1955].

It is possible to use an enactive interface to interpret data which originate in a different representation (for example, numerical data). This requires an appropriate strategy for data encoding, whose design is constrained by considerations of information transfer.

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RELATED ITEMS

COMPUTATIONAL PARADIGM
ENACTIVE KNOWLEDGE
GESTURE AND MOTION (ENCODING OF)

INSTRUMENTAL COMMUNICATION

Annie Luciani [ACROE&INPG]

Instrumental communication is the type of communication carried out through instrumental interaction.

Instrumental interaction [→ INSTRUMENTAL INTERACTION] is a type of multisensory-motor interaction between humans and physical objects during which the human manipulates a physical object to perform a task that is not only the object manipulation for itself. In such interaction, the object with which the human interacts to perform the task is transformed into an instrument. Instrumental interaction is an integrated activity, merging ergotic, epistemic and semiotic activities.

Although an instrumental interaction is a manual performance, since the manipulated object is an instrument, the output of the performance can differ from the manipulation activity *per se*. The aim of instrument and instrumental interaction – in other words the consequence of the physical, cognitive and cultural transformation of a physical object into an instrument – is to produce a result through which symbolic information is conveyed. This sort of symbolic information is the support of a particular sort of communication between humans, which we call, precisely, instrumental communication.

Importantly, one should note that there exist forms of communication that cannot be imagined, that could not exist, without an instrumental interaction. Hence, instrumental communication is a side, an aspect of human-human communication in general.

Examples of instrumental communication situations are: *this* hole in a wall, with its imperfection, which was produced by human-wall interaction through a tool, and which engraves this interaction, communicates how it was done; music listened by a listener, produced by an instrumentalist playing on his instrument through an instrumental interaction; the way of skiing for anyone, when considered as the main feature to be focused on; the grace of a pirouette in dance, etc... More generally, the features that differentiate things produced by hands and by the body, such as in craftworks, arts, sports, etc., that are produced through an instrumental interaction, carry instrumental communication.

In the notion of instrumental communication interface [Cadoz, 1994] [Cadoz, 2002] [Luciani, 1993], the instrumental interaction occupies a peculiar place within the general aim of multimodal interfaces. Multimodal interfaces usually aim at producing and conveying symbolic information. That is also the objective of instrumental interaction, based on what we called instrumental communication. Consequently, in the context of multimodal interfaces, instrumental and non-instrumental interaction are complementary, conveying two complementary types of information and creating two complementary types of communication between humans.

Hence, as evidence, instrumental communication is a major mean to build enactive knowledge.

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RELATED ITEMS

INSTRUMENTAL INTERACTION
 INSTRUMENTAL INTERACTION
 ERGOTIC/EPISTEMIC/SEMIOTIC
 ACTION-PERCEPTION LOOPS
 ERGOTIC/EPISTEMIC/SEMIOTIC FUNCTIONS

INSTRUMENTAL INTERACTION

Annie Luciani [ACROE&INPG]

The expression instrumental interaction as been introduced by Cadoz [Cadoz et al., 84a,] [Cadoz et al., 84b] to identify a human-object interaction during which a human manipulates a physical object – an instrument – in order to perform a manual task. Classical examples of instrumental interaction are all the professional manual tasks: playing violin, cutting fabrics by hand, moulding a paste, etc....

Instrumental interaction differs from other types of interaction (called symbolic or iconic interaction) in which the media supporting the interaction are rather symbols (such as languages), icons (such as graphics), earcons, etc. It may differ also from a type of manipulation in which the manipulated object is not an instrument. Take the example of a usual object such as a stone: when it is used to sculpt another object, it becomes an instrument; when the stone is manipulated for itself, for example, to observe it, it is no longer an instrument.

A problematic case is object manipulation in 3D computer graphics. As discussed in the item [→IMMERSION VS. VIS-À-VIS], in usual 3D interactive graphic situations, the object is ready-to-hand. So, it is an in-between situation, which alternates from considering the object as a part of environment in the aim to know it, to considering the object as being manipulated and further as an instrument. Indeed, in instrumental situation, the object with which the human interacts to perform the task is transformed in an instrument. Once sufficient learning has been achieved, the instrument is a type of second nature that prolongs the humans, who is transformed in an instrumentalist, - as discussed in the item transparency_1 [→TRANSPARENCY_1].

In instrumental interaction, the instrument is a physical object on which humans applies physical gestures and that is able to return multisensory feedbacks that are consistent between them and with the performed gestures [Luciani, 2004] [Cadoz, 1994]. Differently than in non-instrumental interaction, as for example in symbolic or iconic communication, that could be monosensorial, the instrumental interaction is intrinsically multisensorial, even if all the sensory modalities are not necessary used in the task. Indeed, being manipulated, a physical object “answers” by exhibiting perceptual behaviours. Haptic behaviour is necessary in instrumental interaction. When haptics is not necessary, it means that the task could be performed optimally through a non-instrumental interaction. Since the physical object produces haptic feedback, the object has physical behaviours at the human scale. Then, it produces necessarily visual and/or acoustical behaviours (or both) that are physical deformations in response the gesture activity. In terms of how input devices interact with virtual space [→CONTROL METAPHORS], instrumental interaction is a type of what [Ju et al. 2003] called “*the device can act as a tool*”. This is different than “*the device can act as the designed object*”.

Within the Cadoz’ typology of interactions functions [Cadoz, 94] [→ERGOTIC/ EPISTEMIC/ SEMIOTIC FUNCTIONS], instrumental interaction is a typical case in which all the three ergotic, semiotic, and epistemic functions of man-environment interactions are present.

However, the properties to consider in the case instrumental interaction differ from those involved in the manipulation of an object, for example of the same object considered for itself. These properties are designed – or chosen – to perform a task. For example, the properties of a violin played in a concert hall are obviously not the same as the properties of the same violin when considered as an object, for instance hanged in a museum.

When aiming at designing a virtual instrument:

1) One has first to provide the following basic properties to the model: to be a simulcrum of a physical object, to be physically manipulable by the human physical body (the hands for example), to be able to generate haptic and other correlated sensory behaviours as physical responses to the action. The item "instrumental interaction: technology" [→ INSTRUMENTAL INTERACTION: TECHNOLOGY] goes further in this analysis.

2) One has then to select, among all the properties of the physical objects, those that are necessary for the task. This means that the modelling activity necessary to model a virtual instrument differ from the physicist's modelling activity of the object itself. Physicist's modelling activity aims at knowing the physical object as entirely as possible. Modelling an instrument requires to have another kind of knowledge focusing on what are the necessary properties of the instrument for the task. Such knowledge is not a part of the physicists' knowledge. For example, in the case of musical instrument, a part of the needed knowledge is related to the human action and perception capabilities. It also relates with cognition and cultural judgments capabilities.

Finally, a second aspect by which instrumental interaction is distinguished from object manipulation is that it aims at being a way for communication between humans, which is called instrumental communication [→ INSTRUMENTAL COMMUNICATION].

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RELATED ITEMS

CONTROL METAPHORS
ERGOTIC/EPISTEMIC/SEMIOTIC FUNCTIONS
IMMERSION VS. VIS-À-VIS
INSTRUMENTAL COMMUNICATION
INSTRUMENTAL INTERACTION: TECHNOLOGY
TRANSPARENCY_1

INSTRUMENTAL INTERACTION: TECHNOLOGY

Annie Luciani [ACROE&INPG]

Trying to implement the concepts of instrumental interaction / instrumental communication [→ INSTRUMENTAL COMMUNICATION] [→ INSTRUMENTAL INTERACTION] by using computers requires specific technologies. It leads, indeed, to the new technological paradigm of instrumental computer simulator.

Such an instrumental computer simulator, in order to allow instrumental interaction, must satisfy a number of needs [Uhl et al., 1995]:

- Since the objects to interact with are physical, their computer models have to be physically-based models.
- These models must be able to produce all the physical behaviours of the modelled objects that will be perceptible, whatever their spatial and temporal scales (auditory, visible, haptic) is .
- These models must also be able to provide the ability of being handled (ergotic interaction).
- The computer simulation of these models has to be performed in real-time; the simu-

lation must not present any noticeable difference with the equivalent instrumental situation in the real world (when it exists; for a discussion see the item “simulation” [→ SIMULATION]).

Such an instrumental situation re-built around a computer by using physical simulation and appropriate devices can be called a representation of real instrumental situation.

Some conceptual difference with the usual approach implemented in virtual reality can be noticed:

- There is no need of “reality” nor “immersion”, but it is conversely necessary to have at disposal a genuine simulation of the instrumental universe, i.e. of the objects near or close to the body, and with the relevant properties necessary to achieve the task.
- This simulation of the instrumental universe has to be run with a range of performances comparable to the real instrumental situation, especially in terms of dynamics. This is often not required in reality

These properties are necessary in order to convey the main qualities of the instrumental situation, such as: the possibility of the progressive appropriation of the object as an instrument (that is the embodiment property); the strong feeling to have it in-hand (that is the presence property), the playability (or instrumentability) in order to stimulate not only efficiency but also creativity (for example, new way of manipulation, new strategies of exploration, etc.).

One example of such computer-enabled instrumental interaction is reported in the articles dealing with the notion of ergotic sounds [Florens, 2003] [Luciani et al., 2007]. In the experimental setup discussed, the performer, when bowing a virtual string, has a strong impression of the presence in-hand of the string, thanks to a specific implementation of the string-bow simulation and to the haptic-audio interaction in which the simulated vibrating string itself returns sensitive information to both the hand and the hear. These principles, incidentally, have been also

used in the implementation of a real time instrumental simulator to learn nanophysics [Marlière et al., 2004].

Re-building an instrumental interaction in the context of computerized systems is a non-trivial modelling and implementation process. In this process, the main important features are not the objective realism, nor the subjective realism of the situation, are no more only the performance of the task, but tentative new concepts such as presence, believability, embodiment, intimacy, creativity, etc [→ PRESENCE, IN COMPUTERIZED ENVIRONMENTS] [→ BELIEVABILITY_ 1&2].

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RELATED ITEMS

BELIEVABILITY_ 1&2
 INSTRUMENTAL COMMUNICATION
 INSTRUMENTAL INTERACTION
 INTERFACE, ENACTIVE
 PRESENCE, IN COMPUTERIZED ENVIRONMENTS
 SIMULATION

INTELLIGENT CHARACTERS

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An intelligent character is comprised in the definition of an intelligent agent. In our domain, virtual reality, a character is a virtual representation of a human or an animal. By extrapolation, an intelligent character is a character doted of the same qualities as intelligent agents.

A widely adopted definition of an intelligent agent in the computer science community is the following: an intelligent agent (IA) is a software agent that exhibits some form of artificial intelligence that assists the users and will act on their behalf, in performing repetitive computer-related tasks. While the working of software agents used for operator assistance or data mining (sometimes referred to as bots) is often based on fixed pre-programmed rules, “intelligent” here implies the ability to adapt and learn (see also [Jennings, 2000])

In some literature IAs are also referred to as autonomous intelligent agents. This means they act independently, and will learn and adapt to changing circumstances. According to Nikola Kasabov, IA systems should exhibit the following characteristics:

- learn and improve through interaction with the environment (embodiment);
- adapt online and in real time;
- learn quickly from large amounts of data;
- accommodate new problem solving rules incrementally;
- have memory based exemplar storage and retrieval capacities;
- have parameters to represent short and long term memory, age, forgetting, etc;

- be able to analyze itself in terms of behaviour, error and success.

Finally, in [Ingham, 1997], the following recognized intelligent agent categories are given (agents can have some of them, not necessarily all):

- Autonomous: an agent is able to take initiative and exercise a non-trivial degree of control over its own actions.
- Goal-oriented: an agent accepts high-level requests indicating what a human wants and is responsible for deciding how and where to satisfy the request.
- Collaborative: an intelligent agent does not blindly obey commands, but has the ability to modify requests, ask clarification questions, or even refuse to satisfy certain requests.
- Flexible: its actions are not scripted; it is able to dynamically choose which actions to invoke, and in what sequence, in response to the state of its external environment
- Self-starting: unlike standard programs which are directly invoked by the user, an agent can sense changes to its environment and decide when to act.
- Temporal continuity: They are continuously running processes, not one-shot computations that map a single input to a single output, then terminate.
- Character: an agent has a well-defined believable “personality and emotional state”.
- Communicative: Such intelligent agent is able to engage in complex communication with other agents, including people, in order to obtain information or enlist their help in accomplishing its goals.
- Adaptive: It automatically customizes itself to the preferences of its user based on previous experience. The agent also automatically adapts to changes in its environment.
- Mobile: an agent is able to transport itself from one machine to another and across different system architectures and platforms.

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RELATED ITEMS

AGENT, AUTONOMOUS
AUTOPOIESIS
COMPUTATIONAL PARADIGM
COMPUTER GRAPHICS
ENACTIVE COGNITIVE SCIENCES_1
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

RELATED DOCUMENTS

El_Enaction&ComputerTechnologies_Luciani.pdf

INTERACTION TECHNIQUE

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An interaction technique (IT) may be defined as a "*way to use input devices to enter information into the computer*" [Shneiderman, 1998]. When interacting with computers, a user interface is presented to establish the communication between the human and the machine. Interaction techniques are also defined as primitive building blocks from which a user interface is created. As the interface grows more complex, the interaction is also getting more complicated.

In case of an interactive system, the execution of a task often requires a sequence of actions to be performed by means of a set of input and output devices or technology. For instance, to grab an object in a virtual environment, the user has to move the virtual hand to the object by stretching his arm which is tracked. Subsequently the object can be grabbed by pinching his thumb and index, or by simply clicking a button.

To fully exploit enaction within an interaction technique, the interaction is preferred to be multimodal [De Boeck, 2007]. Undoubtedly, continuous visual and auditory feedbacks are necessary, but also haptic feedback in the form of force feedback, tactile feedback or proprioceptive feedback are strongly recommended.

For an interaction technique, mostly metaphors (analogies with domains the user already knows) are used to make interaction techniques simple, easy to understand and easy to learn. By adopting a metaphor for the interaction, prior (enactive) knowledge acquired from another domain is copied and directly applied into the new situation.

As humans communicate multimodally by nature, interaction with a computer environment is also preferred to be multimodal. Therefore, we can also state that the interaction technique may require one or more modalities, as well as from adopting a metaphor in order to improve the ease of use, respectively the ease of learn (by means of reusing or setting up new enactive knowledge).

Some well-known metaphors:

- The desktop metaphor: bringing the idea of a 'real desktop' to the computer screen
- World in hand metaphor: a navigation technique that allows users to navigate as they have the virtual world in their hand.
- Ray Cast metaphor: objects within a 3D world can be selected by pointing them with a virtual ray, as if they are pointed by a laser pointer.

Interactions in a virtual environment have been classified with two taxonomies. The first one, made by Douglas A. Bowman specifies two categories which are travel interactions on one hand, and selection and manipulation interactions on the other hand [Bowman, 1999]. Bowman describes each interaction for a task to be accomplished and on a technology used for its accomplishment. The second one, made by Poupyrev, defines a user-centered taxonomy [Poupyrev, 1999]. Poupyrev distinguishes two kind of interac-

tion: egocentric and exocentric. In both cases, authors characterize interactions on 3D objects.

The problem with an interaction technique is that it's difficult to predict its acceptance by the end-user. For the standard (2D) desktop setup, using mouse and keyboard, a lot of research already has been performed, resulting in a solid knowledge base in the form of usability rules and heuristics. For 3D interfaces, multimodal or enactive interfaces, a lot of research has been performed over the last decades as well, but the result is still not fully understood. This is especially true when dealing with multiple simultaneous modalities. Although some work such as the CARE properties, by Nigay and Coutaz [Coutaz, 1995] define a framework that enable a designer to make prediction about a solution, a formal user experiment, measuring the user's performance (efficiency, speed, number of errors, ...) is mostly conducted. This experiment can (statistically) prove whether the proposed interaction technique is better or not. This results in a iterative design cycle: *Design of an IT* → *Implementation* → *Formal Test* → *Evaluation* → *Redesign* → *Implementation* → etc.

which is often a lengthy and hence expensive process. High-level notations such as the interactive cooperative objects (ICO) notation [Palanque, 1994] or NiMMiT (Notation for Modeling Multimodal Interaction Techniques) [De Boeck, 2007] may shorten this development cycle as they minimize the amount of code to be written.

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RELATED ITEMS

FEEDBACK
FORCE FEEDBACK
INSTRUMENTAL INTERACTION
INTERFACE
MAPPING, IN HUMAN-COMPUTER SYSTEMS
METAPHORS IN HUMAN-COMPUTER INTERACTION

INTERACTION, FULL BODY

Ronan Boulic [EPFL]

Full body interaction let the user exploit the whole body postural space to achieve a task. Achieving a minimal sampling rate of 20Hz and a sufficient precision in body posture reconstruction still requires a complex (and expensive) acquisition system completed with the processing power to interpret sensors measurements in real-time.

The acquisition stage is often referred to as motion capture when exploiting more or less invasive technologies whereas it is rather called motion tracking when based on non-invasive video input. The body posture reconstruction stage can be achieved by either analytic or numeric Inverse Kinematics [→ INVERSE KINEMATICS].

Both the technological and processing complexity of such type of interaction have hindered its adoption. It is presently mostly used for real-time puppeting of virtual characters for live TV shows [Shin et al., 2001]. Another prior work [Emering et al., 1998] has exploited such full body interaction to control an avatar interacting with intelli-

gent characters [→ INTELLIGENT CHARACTERS]. This latter application requested an additional interpretation of body postures into semantic action units so that intelligent agents could react to them.

From an enactive point of view, the information of a full body posture is very complex and tedious to synthesize with standard desktop interfaces, hence the interest to capture it directly from the user's movements. Such information is especially precious to control the posture of a virtual mannequin in the field of ergonomic studies.

In the framework of enactive interfaces, various investigations are studying metaphors to retain the intuitiveness of performing full body movement while trying to control the posture of a mannequin that may have a very different height than the user. Indeed, one important field of application for full-body gestural input is virtual prototyping [→ DESIGN, VIRTUAL MOCK-UP]. In such context the user is in charge of evaluating key design decisions at the earliest stage possible in the conception process. A full-body input is particularly suited for evaluating ergonomic and maintainability issues. Such an evaluation has to be conducted for a representative sampling of the future users of the real system. Hence the person in charge of the evaluation has to impersonate the action of smaller or taller persons. The risk is high, if such body height difference is poorly handled by the interaction metaphors, that a break of the internalization is produced. Various scaling strategies are presently experimented to overcome this additional issue [Boulic & al., 2006].

The challenges described above are also pertinent for other fields of potential applications such as games based on full-body movements, or rehabilitation [→ VIRTUAL REALITY THERAPY].

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RELATED ITEMS

DESIGN, VIRTUAL MOCK-UP

INTELLIGENT CHARACTERS

INVERSE KINEMATICS

MOTION CAPTURE

VIRTUAL REALITY THERAPY

INTERFACE

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Generally speaking, an interface is the point, area or surface in which converge two or more distinct entities. Therefore, the term interface can be used to denote any mean that realizes the interconnection of two entities. Also, when considering an entity, an interface can be an abstraction that the entity provides of itself to the outside world.

In the technological fields connected to enaction, the word interface may be seen as a buzzword, given the particularly numerous meanings it covers. However, in all these fields, it can acquire much more precise meanings. This item reviews a subset of these many meanings that are often encountered when dealing with enactive systems.

Interface, in software design (computer sciences)

In software design, the interface of a software entity (namely: a class, in object-oriented programming) consists in all the

functionalities (namely: methods or functions) of the entity that are publicly available, hence usable from other parts of the software to modify the state of the entity in a consistent manner. More generally, in the same context, one calls application programming interface (API) all the functionality of a larger piece of code (namely: a software library) that can be used for building a larger program.

In object-oriented programming, interface acquires a more precise definition. It is, either:

- a specific category of class that has no implementation, but only promises the future existence, in subclasses, of a couple of services (namely: methods). The subclass is then said not to inherit, but to implement the interface.
- or, equivalently, a set of methods that the object must respond to.

Finally, in computer sciences, one can call interface (of the computer) the various computer's communication ports. For example, a network interface is the network card of the computer.

User interface, in human computer interaction

In (traditional) human computer interface (HCI) [\rightarrow HUMAN COMPUTER INTERACTION], the term interface stands for user interface. Even though HCI is concerned with the interactive system in its whole, the user interface usually denotes only a specific part of the software that enables the interactions, and implements the interaction of the user with the core features of the software. It excludes, for example, the devices by which the user manipulates the user interface, and also the core features (the know-how) of the software.

Rather old categories of (user) interfaces in HCI include textual interfaces (UNIX Shell...), graphical interfaces (with widgets: windows, buttons... The most common type of user interface in everyday computers), and direct manipulation interfaces (graphical interfaces based on an either "faithful" or

metaphorized interactive representation of the document on which the user works. Examples are the graphical desktop metaphor [\rightarrow METAPHORS IN HUMAN-COMPUTER INTERACTION], most word processors, image editors...).

More recent or specific qualifiers of the user interfaces that are particularly important in the field of enactive systems, and which incidentally may apply not only the user interface but also to the whole interactive system at hand, are intuitive, reactive, proactive, multimodal and ergotic.

- Intuitive interface

As expressed by Barentsen in [Barentsen, 01]: "*An intuitive interface may be defined as an interface, which is immediately understandable to all users, without the need neither for special knowledge by the user nor for the initiation of special educational measures.*" In computer science the term intuitive interface is commonly used in a perverted way, for describing logical metaphors that allow easy understanding of the system interface (usually through direct manipulation). However, by principle, no interface based on a metaphor can be considered as truly intuitive since it requires a prior knowledge of the system to understand the metaphor. Indeed, the closest implementation of a perfect intuitive interface can be perhaps found in virtual reality systems where the user performs natural movement are user to interact, as in reality.

- Proactive interface

A proactive interface is an interface able to predict future events and take appropriate action accordingly, especially by alerting the user or proposing solutions to deal with the forthcoming situation [Bustamante et al., 02]. For example in application controlling objects in movement, a proactive interface could alert about possible future collisions and help the user to take counteractions to avoid them. An example of proactive interface is the companion of an editor; the proactive interface behaviour is implemented in an avatar that proposes tips about logical future actions. [Xiao et al., 03] offers an

evaluation of such proactive user interface assistants.

- Reactive interface

A reactive interface is in general an interface that gives feedback about encountered events by modifying its behaviour. [Pucella, 98] defines reactive systems as “*systems that maintain an ongoing interaction with their environment, activated by receiving input events from the environment and producing output events in response*”. As opposition to proactivity, reactivity of an interface can be seen as the faculty of an interface to give a proper output response after an event as occurred. Reactivity is also used to characterize the manner in which the system will treat its inputs to produce the most appropriate outputs; especially, the shorter the response time is, the more reactive the interface is. Finally, in many cases, to qualify a system as an enactive system, the overall reactivity of the whole system is crucial (for example, see “instrumental interaction” [→ INSTRUMENTAL INTERACTION]).

- Ergotic interface

An ergotic interface is an interface that makes it possible to simulate an energy exchanged between the user and virtual objects he/she manipulates. The adjective ergotic is important in the context of enactive systems; the reader will find more details in the item “Interface, ergotic” [→ INTERFACE, ERGOTIC].

- Multimodal interface

Finally, multimodal is another possible qualifier of the interface or of a whole system that is also important for enactive systems. The term, which actually requires clarifications, is analyzed in the item [→ INTERFACE, MULTIMODAL / MULTISENSORY].

Interface, in robotics and haptics

In these fields, hardware interface can be used to denote some gesture device. In particular, in robotics, when a robot is to be used by a user to interact with a computerized system, it is often called a robotic interface. Not all the computer devices are “robots” (e.g. the screen and the mouse are

not). Conversely, haptic interfaces [→ HAPTICS, HAPTIC DEVICES] are often active robotic interfaces, since kinaesthetic feedback involves movements and efforts. However, for fine tactile feedback, other devices [→ TACTILE DEVICE] are used instead of robotic interfaces.

Enactive Interfaces?

In the expression enactive interface, usually, the term interface stands more for the whole system than for the user interface, as specifically defined in HCI. Very shortly said, the expression is a practical mean, an ellipsis, to denote whether or not, or how much, the system at hand allows the user to enact the lived world [→ LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL APPROACH]. This idea is further analysed for example in [→ INTERFACE, ENACTIVE] and, more generally, in... all the items in the Handbook.

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RELATED ITEMS

HAPTICS, HAPTIC DEVICES
HUMAN COMPUTER INTERACTION
INSTRUMENTAL INTERACTION
INTERFACE, ENACTIVE
INTERFACE, ERGOTIC
LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL APPROACH
METAPHORS IN HUMAN-COMPUTER INTERACTION
TACTILE DEVICE

INTERFACE DESIGN

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Human-computer interface design is concerned with how to design the way the user influences a system and the feedback the user experiences. Good interface design allows an efficient and intuitive interaction with computers, gadgets, appliances, machines, mobile communication devices, software applications, and websites. To achieve this, the design needs to focus on the user's experience and interaction [Norman, 1988]. As is the case for most design there is often a compromise between the esthetical demands and the usability – the challenge for a skilled interface designer is to achieve both. An important concept in this context is usability [→ USABILITY]. There are many definitions of usability, but a simple one contains relevance, attitude, efficiency and learning – the interface should provide relevant feedback, it should be subjectively pleasing (attitude), it should be efficient to use and easy to learn. To construct a useable system is not generally all that easy – although there are checklists / heuristics that can (and should) be used, real life usability also depends on both users and situations. Thus one needs to bring the users into the design process. One general way of doing so is to adopt a user centred design methodology [→ DESIGN, USER CENTRED].

The interface is the user's gateway or front end to a system (or product) [Shneiderman, 1998]. The user already has a mental model that describes the task the system is enabling. This model arises from a combination of real-world experiences, experience with other software, and with computers in general. For example, users have real-world experience writing and mailing letters and most users have used email applications to write and

send email. Based on this, a user has a conceptual model of this task that includes certain expectations, such as the ability to create a new letter, select a recipient, and send the letter. An email application that ignores the user's mental model and does not meet at least some of the user's expectations would be difficult and even unpleasant to use. This is because such an application imposes an unfamiliar conceptual model on its users instead of building on the knowledge and experiences of the users [Norman, 2007] [Wikipedia, 2007].

Good interface design, thus takes advantage of people's knowledge of the world to convey concepts and features of the system.

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RELATED ITEMS

DESIGN AND ENACTION
DESIGN, USER CENTRED
USABILITY
USEWORTHY TECHNOLOGY

INTERFACE, ENACTIVE

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The term interface is clearly of central importance. However, the term itself is the vehicle of an ambiguity that requires clarification: interface between *what* and *what*?

As we understand it, the term interface is properly used as the interface between an organism (human or otherwise) and its environment. Thus, the basic interfaces are the biological sensory and motor organs; for humans, technical artefacts are extensions to these basic interfaces, but they remain interfaces. New technical devices constitute new worlds: think for example of the world of the car-driver, or the world of the skier, or the world of the violinist. But note this: we do not talk about the interface between the man and the ski (or car or violin); the ski is the interface between the man and the snowy mountain, or better still between the skier and the ski-ing world that is brought forth.

Does this change in the case of computers? Our point of view is that computers are basically technical devices, and should be treated in the same way as other technical devices. The computers mediate interactions between humans and their world, or mediate communication between humans and humans. Certainly, they are devices of a special sort, and the worlds that are brought forth when a human being uses them are a special sort of world; but the interaction that occurs (that is mediated by the machine) is between the human being and this world; it is not an interaction between the human being and the machine. Thus, there is something deeply wrong in the very phrase human computer interface (HCI). Of course, HCI has become a hackneyed term, but this engrained (mis)-use does not make it correct. The basic problem lies in the implication that human beings and computers are entities of the same sort, so that they could interact on a basis of equality. This would only be correct if one whole-heartedly embraces the computational theory of mind [→ COMPUTATIONAL PARADIGM] according to which humans function like computers; but as we understand it, the enactive approach rejects this classical paradigm in cognitive science.

Finally, an interesting question that arises is the status of virtual reality. In this case, it does seem as though the computer is playing the role of the world, by providing the sen-

sory consequences of actions on the part of the human being. But even here, note that the experience of a human being immersed in a virtual reality is not that of interacting with a computer; the human interacts with the entities that populate the world that has been brought about. We only become conscious of the computer (the interface) when a malfunction triggers the switch to the put-down mode; in normal functioning (the in-hand mode) the computer-interface disappears from consciousness.

This remark is in no way meant to decry the interest of virtual realities; on the contrary, such experiments are deeply revealing. What they show is that in order to create a virtual reality, it is neither necessary nor sufficient to compute (in all its gory detail) the total physical reality – an impossible task anyway, as shown by flight simulators that have to fall back on analog models; what is required is neither more nor less than to provide the appropriate sensory returns to human actions. This helps, greatly, to understand the point that what human beings experience in natural situations is not the world in itself, but the sensory-motor contingencies of their embodied situation [→ TECHNICAL ARTEFACTS AND PERCEPTUAL EXPERIENCE].

To sum up: the term enactive interfaces is dangerously misleading. It is not the interface that is (or is not) enactive: it is the human subject, using an (appropriate, well-designed) interface who enacts a world. Thus, although an interface in itself never enacts anything, the role of interfaces is absolutely crucial: interfaces can permit (or not) humans to enact the world, and the world we live in depends on their design.

RELATED ITEMS

COMPUTATIONAL PARADIGM
 INTERFACE, ERGOTIC
 LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL
 APPROACH
 SENSORIMOTOR THEORY
 TECHNICAL ARTEFACTS AND PERCEPTUAL
 EXPERIENCE

INTERFACE, ERGOTIC

Claude Cadoz [ACROE&INPG]

This term qualifies an interface that makes it possible to simulate an ergotic interaction between the man and something in the computer.

One can relate it with more usual expressions and terms such as responsive input devices [Cadoz et al., 1988], force-feedback gestural transducer [Luciani et al., 1994], haptic interface, force-feedback device, etc – [→ HAPTICS, HAPTIC DEVICES] – haptic device. All these terms and expressions are easy to use but they don't express scientifically, with a sufficient precision to avoid misunderstanding, the content of the concept and consequently of the underlying technological principles. It is then of an actual relevance to have this specific term in order to avoid some frequent confusions.

Let us first recall the definition of the ergotic [Cadoz, 1994] [Cadoz, 2000] [Luciani et al., 2004] function of the gestural channel [→ GESTURAL CHANNEL] [Cadoz, 1994] [Cadoz, 2000].

We consider that the relations of the human to his human or material environment are, simultaneously or separately, of three possible types:

- Epistemic

When he gets some knowledge from it.

- Semiotic

When he produces, by a means or by another, with or without a material intermediary, something which can potentially or actually emit an information, bear a message, a knowledge, etc. addressed to other human beings.

- Ergotic

When, physically engaged (by his hands, his arms, his legs, his whole body) he enters in a mechanical interaction with a material object or a material part of the environment.

In this case, there is a mechanical work spent not only in the human body, but, globally, in the complete mechanical system constituted of the human and of the manipulated physical object. The consequence is a mechanical modification or transformation of the object or of the material environment or, at least locomotion of the human being. The human being is then the source of energy producing this mechanical work.

It is important to notice several essential points:

- These three functions are not exclusive.
- Only the gestural channel can play the ergotic function (not the acoustical or visual ones).
- The gestural channel can support all the three: epistemic, when, for example, touching and manipulating physical objects, we get knowledge on their surface quality, forms, weight, temperatures, etc., semiotic, when, for example, we do some sign of the hand or play a musical instrument, and ergotic when for example we insert a nail with a hammer.
- Furthermore, the gestural channel can play the three functions at the same time and, in certain cases, the ergotic aspect is necessary so that the epistemic and/or the semiotic functions can be effective. A typical example is the instrumental gesture with a musical instrument, for example a violin where the violinist needs to physically interact, through the bow, with the string, in order to feel everything in his fingers if he wants to succeed in the expressivity of his gesture and of the sound produced.
- But of course, the ergotic function can be played without any semiotic or epistemic role.
- And finally, semiotic and epistemic functions can be supported by other channels than gestural channel.

So, when the human is in relation with the computer or with the human or material environment through the computer, it is of course impossible to speak about ergotic relation with the computer itself, unless we

consider for example the actions to transport or to break it.

However, when we implement and use force-feedback devices within a computer, we actually bring into play the ergotic function of the gestural channel. Indeed we enter in a mechanical interaction with a material object (the stick, the keys, the levers, etc. of the device). Manipulating it and playing with - or opposing to - certain of its movements, we are producing mechanical work, exchanging, and, globally, spending energy.

This is this paradoxical situation that we must clear up.

Two kinds of combined considerations will enable us to do it:

- The first giving a clear characterization of the constitutive functionalities of such interfaces.
- The second trying to answer the question with what are we interacting? in such situations.

Constitutive functionalities of an ergotic interface

From one side, we have a mechanical real part (the material part we are actually manipulating), one the other digital data and digital processing.

We don't interact with digital data or processing, in the previous physical sense. The digital data and processing of course correspond to energy spending and exchanging, but i) at a scale which is not commensurable with the gestural energy, and ii) without any obvious quantitative correspondence like it may exist between the gesture energy of a violinist and the acoustical energy he produces when playing.

Digital data and processing are, from a purely energy point of view, mainly electronic or magnetic phenomena.

So, between the two extremities of the complete device, there are at least transducers, for example, transducers converting mechanical energy into electrical one or conversely.

As we can know, a transducer is generally with single direction: a displacement or a force sensor can convert displacement or force phenomena into electrical phenomena. But the opposite transducers are generally built with another technological principle.

This implies that if we want to assume the inherent symmetry of the ergotic interaction, we need at least two combined kinds of transducers, a first one taking in charge the man to computer direction, and a second one assuming the computer to man direction.

The first category may be displacement sensor, force sensor, etc. The second one is no more no less than what we call a motor, an electro-mechanical motor.

Now, the digital data, whereas they are indeed electric (or electronic, etc.), are binary numerical representations of the direct electrical phenomena received or sent to the transducers. The digital to analog converters and analog to digital converters are well known since the middle of the 50's. In fact, the importance of digital nature of phenomena is, as everyone knows, that it allows the symbolic processing, within the computational technology.

But what is more important is the difference in scale of energies concerned.

If it is possible, from the man to the digital data universe, to consider that the energy in the second one is very little, compared to the previous, and, consequently that (although it is not at all the case) it could be extracted from this one, it is absolutely impossible in the opposite direction. The energy corresponding to what it must be opposed to the human gesture, by a motor, must be provided by a supplementary external source.

This is a first unconditional necessity within an ergotic interface. In a certain way, we can say that the thing with what the human is interacting (of course in a very specific way) is this external energy source transduced with a motor.

A second important point, indissociable of this concept of ergotic interface, is the notion

of amplification or (close concept) of energy relay.

Indeed, when we drive the input current of a motor in order to make the electromotive force provided by it corresponding to a certain value, represented by a certain value of a low energy signal, we use such a relay of energy: There are two different energy sources and two different energy circuits (the primary or control one, and the secondary one) of completely different scales and with a very specific influence between the first and the second: a small variation in the first can, for example, imply a strong (but analog) one in the second.

Although the principle of the energy relay probably gone up with Alexandrians engineers (300 before JC), it is, of course the three-electrodes lamp, then the transistor, from the twentieth century, which are the essential representatives of this principle.

So, as a consequence, we can say that the energy continuum is here broken (which is not the case when, for example, we play a musical instrument).

With what are we interacting?

As said below, rigorously speaking, we are interacting with an electrical energy source transduced by an electro-mechanical motor. But we know also that it is not so simple, since the amplifier, with its input and output phenomena, is playing a strong role.

We know that, in the usual uses, the sensors and analog to digital converters of the enactive interface provide input data to the computer, which processes something and returns digital data to the digital to analog converters.

Very roughly speaking, we can consider two different situations:

- One where the data, as well in input as in output are, and remain symbols or abstraction, like for example when we use a force-feedback device in order to follow the shape of a mathematical curve – in this case, incidentally, it is legitimate to speak

of haptic rendering [\rightarrow HAPTIC RENDERING OF VIRTUAL OBJECTS].

- One where, expressly, the input and output events, as well as the internal data processing are specifically conceived in order to establish a believable correspondence with possible real physical objects. In this case, we will speak of simulation, of course.

Let's just add that in the previous case, even with very formal or abstract data, it is often possible (by an enactive feature) to give a believable physical interpretation of the process (the "thing") inside the computer.

But, to conclude:

Even when the digital process is a very genuine simulation of a physical realistic object, it is not correct to say that we have an ergotic interaction with this object.

The correct attitude is to say that we simulate the ergotic interaction with a simulated object, (while, strictly speaking, we are interacting with an electric energy source).

Having guaranteed the conditions for such a simulation of an interaction with a simulated object, it is possible now, according to the various situations and our various goals, to add or not the simulation of semiotic and/or epistemic relation within the gestural channel, even in a multisensory context, around our ergotic interface which can become the core of any other haptic, force-feedback, multimodal, etc. and, of course... enactive interfaces.

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RELATED ITEMS

GESTURAL CHANNEL
HAPTIC RENDERING OF VIRTUAL OBJECTS
HAPTICS, HAPTIC DEVICES
INSTRUMENTAL INTERACTION
INTERFACE, ENACTIVE

INTERFACE , MULTIMODAL / MULTISENSORY

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When one speaks about a multimodal interface, it refers to the second definition of multimodality [→ MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION]: a multimodal interface is an interface that supports various means for the user to express or interpret information e.g.: keyboard, mouse, spoken language, icons, etc. In general, a multimodal interface is a class of interfaces, designed to make the interaction process between a human and a computer more similar to human-to-human communication (e.g., by means speech, gesture, emotions), by exploiting the human's natural use multimodal interaction. Users can interact with this type of interfaces in a more natural and transparent way by the integration of multiple input and output modes.

What is important in a multimodal interface, is that these kinds of systems strive for meaning [Nigay and Coutaz, 1993], as de-

finied in multimodality from the point of view of HCI. If we consider a system-centered view, a multimodal system has the capacity to communicate with a user along different types of communication channels –and- to extract and convey meaning automatically. A system that allows the user to involve various action-perception, focusing solely on the sensory aspect, as defined in multimodality from the point of view of psychology, would rather be called a multisensory or multimedia system. We may observe that both multimedia and multimodal systems use multiple communication channels. But in addition, a multimodal system is able to automatically model the content of the information at a much higher level of abstraction.

The relationships between the different modalities, as well as the user's preference can be expressed by means of the CARE properties [Coutaz, 1995].

- Complementary:

Modalities are complementary when all the modalities are necessary for completing the task, but each is carrying just a part of the information. A typical example is a spoken command that must be accompanied by a pointing gesture, to indicate the subject of the command.

- Assignment:

A modality is assigned if there is no other modality to execute the task.

- Redundancy

Modalities are redundant if they have the same expressive power for the task (see equivalence) but all of them must be used.

- Equivalence:

Modalities are equivalent for completing a task if it is necessary and sufficient to choose one of them.

All relations can be permanent or transient and are total or partial. A relation is permanent if it is true in any state of the application, otherwise it is transient. A relation is total if it applies to every task of the application, otherwise it is partial.

It may be clear that in a decent multimodal interface, the system CARE [Coutaz, 1995]

properties must meet the user's preference (user CARE properties), while for consistency, the relationship must be permanent and total.

In the scope of the research on enactive interfaces, an important question is how are they positioned with regard to multimodal interfaces, and how both are related to each other.

As a multimodal interface focuses on exchanging meaning by means of multiple sensory channels, and enactive interfaces focus on our human knowledge acquired by (multisensory feedback while) doing, one can state that enactive interfaces are particular and more specific kind of multimodal interface, that besides the striving for meaning, also allows users to learn from their sensory-motor actions.

Another way to distinguish between multimodal and enactive interfaces is the following consideration: As referred in [Oviatt, 2002], user(s) can interact with this type of interfaces in a natural and transparent way by means the integration of multiple active and/or passive input modes. "*Active input modes are ones that are deployed by the user intentionally as an explicit command to a computer system*", whereas "*passive input modes refer to naturally occurring user behaviour or actions that are recognized by a computer. They involve user input that is unobtrusively and passively monitored, without requiring any explicit command to a computer*". Example of the active input modes is speech, examples of passive input modes can be considered facial expression, gaze and manual gestures. The integration of modalities is the central issue to be faced by these interfaces. In multimodal interfaces, both modes (explicit command and recognized passive command) are used to control the system's behaviour in an explicit way (the recognized command is interpreted by the system in a univocal way). In multimodal interfaces, the emphasis is put not on the control, but on the interaction, and there may not be the recognition at all [→ MAPPING AND CONTROL VS. INSTRUMENTAL INTERACTION]

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RELATED ITEMS

CLASSIFICATION OF PERCEPTUAL MODALITIES
INTERFACE
INTERFACE, ENACTIVE
INTERFACE, ERGOTIC
MAPPING AND CONTROL VS. INSTRUMENTAL
INTERACTION
MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION

INTERFACES, SOCIAL DIMENSION

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An important question for enactive interfaces is the question of their social acceptance and of their social dimension.

To approach this question, we first propose to distinguish the modes in which technical artefacts exist. First of all, we can distinguish two modes: in-hand and put-down [Heidegger, 1996]. Put-down corresponds to the mode in which the artefact is the object of the explicit attention as an assembly of the matter with certain proprieties (the specifically scientific mode of relation to the object). One can think on the difference between designing and riding the bicycle. The in-hand mode is the mode in which the user is engaged in the activity, and in which, under normal conditions, the artefact is transparent, one feels it like the extension of the body, not like the object of the physics [→ TECHNICAL ARTEFACTS, MODES OF] [Merleau-Ponty, 1945].

The fact that technical artefacts exist in the mode of being put down has an important consequence: the persons who design and

make technical artefacts are, generally, not the same as those who use them. Thus, technological development goes together with a division of labour and, correlatively, the development of mechanisms of social synthesis (exchange, market economies), which organize the integration of technical systems as functional wholes.

Traditionally, social and political science (with the exception of Marx) has not paid much attention to technology, which is usually considered as a black box, as intrinsically neutral means to pre-defined ends. The approach outlined here leads to a new perspective in which technology occupies a central position. The work of engineers has immense social significance because, in fine, the choices of technological devices and systems fashion the human condition itself, by constructing the world that human beings live in, and particularly by manufacturing interfaces that change the means of action, and influence sensations. Thus, in our society, any really serious political debate necessarily involves debate on technological choices.

Since the technology is not something neutral, it affects the quality of interaction between the human and the world. This introduces the debate about the usage of technology. Is the knowledge of the usage situated in the user? Does the quality of the interaction depend only on this user's knowledge? How to make an artefact responding to the enactive knowledge of the user?

On our point of view, we need to understand how the enaction takes place between the two terms, the user and the artefact. In other words, in the case of human being, it seems impossible to talk about a standalone user on whose knowledge depends the use of the artefact, and the ability to make it enactive. Since the enactive knowledge (if one considers enactive as the sensori-motor knowledge) is not something independent on the practice of artefacts, it seems difficult to say that it is situated in the user. If we agree that the artefact modifies the established

sensory-motor contingencies, then the enactive knowledge depends on the artefacts.

Now, the enactive is a quality that does relate to the individual, and that it is the human who enacts: the experience of enaction (i.e. experience of an enacted world as a world of possibilities) is always for a human (who is always technically equipped, even if he/she doesn't actually use any interface), and the artefact alone does not enact anything. But if the capacity to enact lies in the user, the human's experience is always depending on the artefacts, and the artefact does change the quality of enaction.

So already for a single user the enactive knowledge is something situated between the user and the artefact, but what about the social exposure? The couple artefact / sensory-motor contingencies is something that does evolve on the scale of the society. We think that the problem of usage is something intrinsically social, and that's why it is difficult to report this problem to enactive knowledge of a single user.

What is enactive, it's not the interface itself, neither the usage alone, it's the combination of them. If one designs a very enactive interface, but there is no social acceptance or implication, in the best case the usage will be restricted to a narrow community. But the contrary is also true: if the interface is not appropriated, there'll be no enaction (in the following sense: no good quality of relation between the human and the world) even if there is a wide social exposure. So, we need to distinguish two sorts of enactive interfaces: in a broad sense, every artefact is enactive because it does modify the sensory-motor contingencies, and bring forth a particular lived experience, even if the artefact is really constraining; in a strong sense, the criteria for the interface to be enactive (good quality of interaction, transparency, etc.) are actually still to find.

But this is probably not enough. If we continue to think, - and that was the mainstream of industrial engineers -, that it is sufficient to design an interface that seems good to de-

signers, we would be probably wrong. Many works on the anthropology of usage and on involving the end-users in the process of design seem to go in this direction.

Moreover, what one accepts as a quality of interaction, is not something independent on technology itself, more precisely on the socially accepted aspect of technology or, let's say, its historical aspect (it's not sure that the mobile phones with built-in cameras, in their actual state, are really useful and enactive interfaces, they are however widely socially accepted as something having a quality of interaction). In other words, the artefacts are not only responding to functional criteria, they are also, as Leroi-Gourhan [Leroi-Gourhan, 1993] for example has pointed out, a support of figurative aesthetics, and this may be to the detriment of the pure functionality. This could help us to understand in which way the acceptance of the artefacts is related to sensory-motor knowledge: this knowledge is always socially and technically transmitted and determined (however, it's important to underline that in any case we are not talking about a technological determinism: the question is how the social structures arrange with the technology, and not what technology imposes by itself.) The core question is that it is difficult to know which interfaces will have the social implications.

Would the artefact have or not the social exposure is not something lying in the technology if one considers the technology as the pure functionality of the artefact; but it is something lying in the technology if one considers the technology also as something intrinsically socially constructed, and also if one considers the social structures (for example the exposure of the artefact related to the socially accepted criteria of aesthetics) as something technically transmitted.

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RELATED ITEMS

DESIGN AND ENACTION
DESIGN FOR ALL (INCLUSIVE DESIGN)
ENACTIVE KNOWLEDGE
INSTRUMENTAL COMMUNICATION
TECHNICAL ARTEFACTS, MODES OF

INTERPERSONAL COORDINATION

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Contributors: Johann Issartel [UM1], Julien Lagarde [UM1]

As assumed by the enactive interface network, enactive knowledge is the knowledge stored in the form of motor responses and it is acquired by the act of doing [\rightarrow ENACTIVE KNOWLEDGE]. This kind of knowledge is based on the experience and on the perceptual responses to the motor acts of the actor. This same enactive knowledge can be observed in interpersonal situation (i.e., situations when two or more people are coordinated). In such a situation what both persons learn is based on person 1's perception of person 2 reacting to the movements of person 1.

Interpersonal coordination is much more frequent in everyday life than one might imagine. Growing evidence demonstrates that interpersonal coordination is present all the time and in every situation as soon as two people establish a perceptual exchange, that plays the role of coupling, which may be mediated by single sense (e.g. tactile, visual, sound), or by a combination of senses. For instance, when two people are walking together in the street, while they are holding their hands or even just talking together, they immediately couple (co-ordinate) their gait by walking in-phase [Courtine et al., 2007]. A similar phenomenon can be observed at the end of a performance when applauses of

hundreds of people become synchronized in-phase. Interpersonal coordination may also arise via mutual mechanical coupling, as illustrated when a large crowd walked in unison over the Millennium Bridge in London and dangerously amplified its lateral oscillations.

Recent studies demonstrated interpersonal coordination at work in various types of human interaction, ranging from simple, visually mediated, coupling between two oscillating limbs - the legs of two people sitting across from each other, or the index fingers of two people facing each other, to more sophisticated situations of coordination that include dance - two dancers dancing together, the coupling between posture and conversation, or when listeners mirrors the movements of a storyteller when he ducks while telling a story. The phenomenon of interpersonal coordination is so powerful that two people synchronize together even when they are not aware of it (named unintentional coordination). Experimental evidence of unintentional coordination was first brought to light by [Schmidt et al., 2007]. In this study each participant has to move a pendulum at his/her preferred frequency. But when they saw the other participant's moves, they both immediately coordinate together. The authors concluded that unintended coordination emerges even if the synchronization was not the goal of the situation (or the instructions). In the line with the previous results, [Issartel et al., 2007] conducted an experiment where pairs of participants were instructed to intentionally not coordinate their movements with the other participant. Their findings demonstrated that participants were unable to not coordinate with each other. Unintentionally, they influenced each other's movements. These two experiments show that the emergent phenomenon of coordination is so powerful that humans cannot avoid an unintended dyadic motor co-ordination.

All together, these illustrations demonstrate that the interpersonal coordination phenomenon is perfectly enactive. The three

main characteristics that define what an enactive phenomenon should be, are present in interpersonal coordination situations.

First, each participant influences the other. The dyad's reactions are completely intertwined: person 1 acts based on his/her perception of person 2 reacting to the movements of person 1.

Second, it is in the act of doing that such an interpersonal coordination phenomenon occurs. It is because person 1 acts that person 2 reacts triggering, in return, person 1's actions.

Third, interpersonal coordination emerges from the multimodality (of the senses). The coupling between the two actors is the result of visual, tactile, auditory... information. Interpersonal interaction emerges from the complementarities of each modality (each sense specifies a particular information), but also from the coupling between the actions and the perceptions of the two people.

Interpersonal coordination is mostly observed and measured by quantifying frequency, amplitude and phase relations between the participants, in particular the phase difference for pairs of people, and the mean of the phases for large groups. Several authors like [Amazeen et al., 1995] [Schmidt et al., 2007], highlight the fact that preferential coordinations (phase or anti-phase) and preferential frequencies emerge between two people when they are constrained in amplitude and frequency. But the same authors also showed that despite the individual part of each person (their preferential frequencies or phases), a specific coordination emerges from the interaction between the two persons. In other words, in every interpersonal coordination situation there is a permanent trade-off between the individual part (of each person) and the common interaction between the two persons. Globally, the study of interpersonal co-ordination requires a conjoint analysis of individual and collective properties [→ INTERPERSONAL COORDINATION, ANALYSIS OF].

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RELATED ITEMS

COGNITION, DYNAMIC SYSTEMS APPROACH
DYNAMIC SYSTEMS
ENACTIVE KNOWLEDGE
INTERPERSONAL COORDINATION, ANALYSIS OF
SENSORIMOTOR

INTERPERSONAL COORDINATION, ANALYSIS OF

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Interpersonal coordination [→ INTERPERSONAL COORDINATION] is the coordination between two (or more) people. Several different fields ranging from robotics to neurosciences to social psychology have studied interpersonal coordination. Although each has its own specificities, the same two main characteristics are common to all fields as soon as one wants to investigate interpersonal coordination signals:

- Signals are non-stationary.
- There is a permanent trade-off between the individual parts and their interactions.

These two characteristics require specific methods to analyze interpersonal coordina-

tion signals. This is what we are addressing in this item.

Signals are non-stationary

In a very specific situation, interpersonal coordination signals can be stationary; for instance, when two people are voluntarily synchronized as soldiers do when they march in the army, or when the goal of one person is to synchronize with a rhythmical and regular artificial device or robot. In such particular situation the cross-correlation function is a simple and easy method to estimate the correlation (the interaction) between two signals (time series) by investigating the relationships within events. Cross-correlations give the strength and the direction (sign of the correlation) of the interaction (i.e. presents information on the phase relationship). Except in the situations previously described, in our everyday life, interpersonal coordination is non-stationary. For instance, if we consider the wrist's movements of two tennis players over an entire match, they move in different directions, quickly or slowly, with high or low frequency and high or low amplitude. Classical methods cannot be used to analyze such signals. Consequently, specific methods must be performed to investigate the temporal evolution of two signals. The goal of studying interpersonal coordination is obviously to estimate the degree of interaction between two signals (e.g., between two tennis players' wrists). In such a context two methods are particularly well suited for non-stationary signals: the windowed cross-correlation function and the cross-wavelet transform. The windowed cross-correlation function is based on the calculation of the cross-correlation function. In this method, the cross-correlation is calculated within pre-determined short intervals called windows (by convention it is assumed that the signal within a short window is stationary). Once the size of the window is defined, the window is moved forward gradually, step by step, until both signals have been covered. Another method, called cross-wavelet transform, can also be used to inves-

tigate non-stationary signals. We will see its description in the next section.

Permanent trade-off between the individual parts and their interactions

The second interpersonal coordination's main characteristic is the constant trade-off between individual and collective properties. As we have seen in the interpersonal coordination item, interpersonal co-ordination is defined as the link between (i) each individual's properties and (ii) collective properties coming from the interaction between persons. In such definition, properties of each person are still present throughout the entire coordination. Von Holst [Von Holst, 1939/1973] had already defined this idea in 1939 when he claimed that individual biological components possess intrinsic properties that tend to persist even when these components are coordinating with other biological components. [Issartel et al., 2007] showed in a recent experiment that when two participants are coordinated together, each of them still maintained their individual frequency and amplitude properties throughout the experiment. They all maintained their individual motor signature [Issartel et al., 2007] to coordinate with the other participant. Consequently, to investigate interpersonal coordination, we have to use a method able to analyze both individual and collective properties in non-stationary signals. If the method of the windowed cross-correlation function previously described is interesting to analyze collective properties, it is not well suited to analyze individual properties. Conversely, the method of the wavelet (and the cross-wavelet) transform is the most appropriate to take into account all aspects of the interpersonal coordination phenomenon. The wavelet transform analyzes individual properties (motor signature) and the cross-wavelet transform gives information about interactions (collective properties) between two non-stationary signals. The results of the permanent trade-off between the individual part (of each person) and the common interaction between the two persons can directly

be seen from the analysis of this method. The wavelet transform and cross-wavelet transform methods are based on a time-frequency representation that allows the three main components (amplitude, frequency and phase) of a non-stationary signal to be portrayed.

In conclusion, the study of interpersonal coordination requires a conjoint analysis of motor signature (individual tendencies) and collective properties. The cross-wavelet transform method is the most appropriate to analyze the properties of interpersonal coordination.

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RELATED ITEMS

COGNITION, DYNAMIC SYSTEMS APPROACH
COMPLEXITY IN HUMAN MOTOR BEHAVIOUR
DYNAMIC SYSTEMS
ENACTIVE KNOWLEDGE
INTERPERSONAL COORDINATIONX
INTERPERSONAL COORDINATION, ANALYSIS OF

INTERPERSONAL COORDINATION, IN DANCE IMPROVISATION

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Interpersonal coordination [→ INTERPERSONAL COORDINATION] is the coordination between two (or more) people. Interpersonal situations are perfect illustrations of enactive situations.

Interpersonal coordination situations are almost never stereotyped - except in very

specific situations such as marching in the army. Walking in the street with someone, working with a teammate, or practicing a collective sport are never stereotyped events. There is always an unpredictable and an unintentional coordination in a dyadic situation. By definition, we never know how the other one will react. But his/her reaction can produce in return a change in our own behaviour. In other words there is always an improvisational part in interpersonal situations.

To go further in investigating the unpredictable characteristic of interpersonal coordination, it is interesting to examine how a real improvisational task can help to understand interpersonal coordination. In such a context contemporary dancers (or jazz musicians) are perfect subjects since an important part of their everyday work is to practice improvisational tasks. In dance in general, communication between the performer and the spectator is transmitted via the body, any added speech components (words, songs, mimics etc) and/or any acting components made of movements between dancers. The originality in an improvisational dance task is that dancers' body movements are not based on prediction. There are not any scripts written in advance, nor any expected gestures: dancers act in the very instant. Thus, the signification of the artistic composition emerges within the action from the context. Dancers are in a total open state that plunges them into the character or the theme that they want to be in [Petit, 1992] [Simson, 1999]. Such a state gives them the possibility to capture all components of the context and also to create new ones. Total freedom with respect to the maximum possibilities of any aspect of movement is a *sine qua non* condition of the quality of any improvisation tasks [Simson, 1999]. To some extent, this open possibility state is the basis of the improvisation performance itself. The other *sine qua non* condition of an improvisational dance task is the uncertainty of the situation coupled with the dancers' creativity [Simson, 1999]. Altogether, dancers intend to cre-

ate/built relevant and aesthetic sequences. They wish to create emotion to the spectators.

In an enactive experiment, [Marin et al., 2007] have manipulated expert contemporary dancers in two conditions. In the first condition, participants were alone to move their right forearm however they wanted (improvisational task). In the second condition they were paired and were instructed to take into account the movements of the other participant to perform their own moves (see the video in Related Documents). The preliminary data showed that when dancers were paired, they were able to synchronize their improvisational moves with the other dancer. If the pairs were changed (exchange of partners) a new type of interaction occurred, indicating that frequency and phase relations [→ INTERPERSONAL COORDINATION, ANALYSIS OF] were specific to a given pair. But the results also revealed that each participant maintained his/her own motor signature (individual properties). In literature, [Issartel et al., 2007] showed that non-dancers always keep their individual properties even when they interact with someone. Von Holst had already defined this idea in 1939 when he claimed that individual biological components possess intrinsic properties that tend to persist even when these components are coordinating with other biological components. The preliminary data of the previous study demonstrated that dancers also maintained their individual properties even if they interact and coordinate with another dancer. Dancers keep the same amount of frequencies they used throughout the experiment, and more interesting, they maintain the same frequency distribution between conditions (when alone and paired). In conclusion, even if experts are able to perfectly coordinate their movements with another dancer, they maintain their motor signature as anyone does.

An improvisational dance task is an interesting paradigm to study interpersonal coordination. First, an improvisational task is enactive and second, the same characteristics that are observed in an interpersonal coordi-

nation situation are also observed in an improvisational task (individual and collective properties)

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RELATED ITEMS

COGNITION, DYNAMIC SYSTEMS APPROACH
DYNAMIC SYSTEMS
ENACTIVE KNOWLEDGE
INTERPERSONAL COORDINATION
INTERPERSONAL COORDINATION, ANALYSIS OF

RELATED DOCUMENTS

El_dance_improvisation.avi

INTUITIVE PHYSICS

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This field of research began with the examination of the nature and origin of common misconceptions when humans predicting the behaviour of simple physical events. Literature shows that many people show systematic errors when making judgments about basic physical principles that govern the motions of objects in the world [Bertamini et al., 2004] [McCloskey et al., 1980] [Proffitt, 1999]. For example, when

asked to draw the path that a pendulum takes when the string is cut at various points, many people make systematically incorrect judgments.

These examinations are studied in the fields of intuitive, folk, or naïve physics. They relate more to specific naïve beliefs, rather than to a general inability to reason about mechanical systems [Riener et al., 2005]. These naïve understandings of physical coherences are based on heuristics and intuition. While observing the environment, we construct common-sense conceptions of why the world works the way it does. These constructions often end up in simplifications, misunderstandings, or misconceptions that are at variance with formal physical laws. For example, one heuristic is that an object remains in motion only as long as someone or something keeps it moving (Aristotelian view, instead of Newton's first law of motion: An object in motion continues to travel with constant velocity unless acted on by an external force).

Research findings have shown that these confusions are not related to the observer's age and surprisingly are also not influenced by the knowledge and the educational background of the participants [Proffitt, 1999] [Riener et al., 2005]. The confusions, however, strongly depend on the complexity or difficulty of the task. Furthermore, the confusion is often greater when the observer is not only confronted with a merely static situation description than when he actually performs the task or sees an animation of the situation. Therefore, the misconception of physical laws is not related to a misperception of physically driven events. This can be shown in the excellent perception-action abilities we do naturally and unconsciously while catching a flying ball or the perception of dynamical properties.

In the framework of the enactive research, investigations of these differences in judging an object have been addressed for both a passive and an active situation. The results showed that different strategies and informa-

tion sources were used for passive perception versus actively predicting future behaviour even if the stimulus and its physical properties were the same [Nüsseck et al., 2007]. The used strategy and information depend on the task to fulfil. For enactive interfaces with different user tasks, these strategy differences have to be taken into account to find the optimal relation of presentation and usability. Work in this field helps to improve enactive applications.

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RELATED ITEMS

CONSTRUCTIVISM
EXPECTATIONS
FORCE
PERCEPTION, DIRECT AND INDIRECT APPROACHES

INVARIANT, PERCEPTUAL

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Invariants are patterns of stimulation over time and/or space that are left unchanged by certain transformations. The concept appeared in the work of Helmholtz, Koffka and of course Gibson [Gibson, 1979] (see also [Cutting, 1983], for an overview), but the term is also rooted in mathematics, namely the group theory, since Klein's Erlanger program, which describes a geometry by identifying the group of transformations under which its theorems remain true. Within the field of perception, we can distinguish two kinds of invariants: structural invariants and transformational invariants [Shaw & al, 1977]. The former refer to the shape constancy of objects under change (e.g. whatever the view point, the transformations a rectangle undergoes are specific to its rectangular shape). The latter are the way it changes, that is, the structures of movements (e.g. getting closer to objects will produce particular optical expansion or sound increase).

Some psychologists (e.g., [Cutting, 1983]) have criticized the overgeneralization of the term invariant: for example, its use for the second kind of invariant. Effectively, referring to transformations as being themselves invariants is unusual in mathematics. Nevertheless, transformations can be themselves seen as elements that remain unchanged under certain other (high order) transformations, thus forming a kind of meta group.

Whatever their type, invariants emerge unequivocally only with a flux, that is, as James Gibson ([Gibson, 1979], p.73) wrote: "*the essentials become evident in the context of changing nonessentials*".

Intermodal invariant

Perceptual invariant is often understood as being a pattern within a single ambient energy (e.g., optical invariants). But invariant patterns also exist across energy flows for the simple reason that physical properties of an object of the environment (e.g., its shape or its movement) has simultaneous consequences on the structure of various ambient energies (e.g., photons reflection and absorption in optics and sound waves reflection and absorption in acoustics). Thus, there are invariant relations that extend across multiple ambient energies, that are specific of a given aspect of the real world [Stoffregen et al, 2001], and that (in principle) allow this aspect to be directly perceived by individuals [→ ARRAY, AMBIENT ENERGY].

As an example, for an individual moving in front of a static object, monocular motion parallax and optical expansion provide only angles and their derivatives and thus they don't yield any information about scaled egocentric distance of the object. However, this motion of the observer has simultaneous consequences on inertial and optic flows and egocentric distance can be derived from the resulting intermodal invariant relation [Mantel et al, 2005]: in short the apparent optical motion of the object is scaled by inertial information. Similarly, intermodal invariants provide information about bodily orientation [Fouque et al, 1999].

The concept of intermodal invariants is also useful to the understanding of affordances. Most of our perceptual systems have both proprioceptive and exteroceptive role. As Gibson stated it "*perception of the environment is inseparable from proprioception of one's own body*" ([Gibson, 1977], p.79). This is what allows perceivers to perceive directly affordances, that is, to perceive properties of the environment scaled with reference to properties of the body. These intermodal invariants are behaviourally meaningful for the perceiver [→ AFFORDANCES].

Some experimental studies, assuming that modal information are redundant, or at best

complementary, create artificial conflicts between modal sources in order to investigate which sense will dominate the other or what will be the weight attributed to each sense by the central nervous system. Unfortunately, by breaking the natural congruency between sources, they do not solely create conflicts between sources, but more importantly they suppress the relational information (i.e., invariants) that existed across sources. The former intermodal invariant relation is replaced by a new (arbitrary) relation, which this time carries no meaning for the perceiver. As a consequence, such experimental design involves perceptual processes that would probably not have occurred in everyday life perception.

Intermodal invariants are rooted in the perception-action cycle (perceiving to behave, behaving to perceive) and hence are strongly related to the concept of enaction in two ways. First, because intermodal invariants are the best tools to explain how we can directly perceive what we can do and not do in the world (i.e., affordances). Second, because in many cases, such as the example given above, the intermodal invariant won't even exist if there is no active movement of the perceiver.

Consequently, intermodal invariants have also important consequences for the design of interactive systems such as enactive interfaces. Among these, the interface should permit adequate (task related) exploration to allow the user to generate the perceptual information necessary to perform the task. More specifically, the designers' will to have a realistic simulation should apply not only to the individual content of each device or display but also (and maybe more importantly) to the relation that stimulation provided by each device or display bear to each other. This implies a special emphasis on synchronization and spatial correspondence (including relative scaling) of each device constituting the interface, and possibly exploiting their potential compensatory nature. The reader can refer to the Related Document for a more detailed presentation.

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RELATED ITEMS

AFFORDANCES

ARRAY, AMBIENT ENERGY

ARRAY, GLOBAL

OBJECTS' PROPERTIES, PERCEIVED

PERCEPTION, AS BAYESIAN INFERENCE

PERCEPTION, DIRECT APPROACHES: THE
ECOLOGICAL APPROACH

RELATED DOCUMENTS

EI_DRD212_final.pdf

INVERSE KINEMATICS

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This term was first introduced in Robotics [Craig, 1986] where it defines the operation

of computing the configuration of a robot from the input of the desired location and/or orientation of the tool (called the end-effector). This problem is of great importance to evaluate whether a task is achievable by the robot. Industrial robots are designed to offer an analytic, fast computable, solution to such problem. This explains why they are often limited to six degrees of mobility to be able to achieve the desired 6D location of the end effector (3D position and 3D orientation).

Nevertheless, in the general case, the controlled articulated structure may possess more degrees of mobility than necessary to position and orient the end effector(s); it is said to be redundant. For example the human skeleton possesses at least 40 degrees of mobility excluding the hands (each hand adds around 25 degrees of mobility). On the other hand, more than one body part (i.e. end effector) has to be controlled to achieve a correct postural control: hands, feet, gaze direction, center of mass, etc.

So inverse kinematics is often formulated as a problem of constrained minimization converging towards an optimal solution for achieving simultaneously multiple effectors positioning and/or orienting [Zhao & Badler, 1994]. Such formulation allows to handle the following three scenarios:

- Infinite number of postural solution: the approach converges to one optimal solution that depends on the initial state and on the optimized criteria (e.g. minimal weighted norm of instantaneous variation, minimization of kinetic energy, etc.). In the context of the human postural control, controlling the position of the center of mass is important to ensure that such posture is balanced, hence plausible.
- No solution: the specified goals for the body parts are conflicting, e.g. attraction of each hand in opposite directions, hence none can be fully satisfied. Nevertheless the minimization leads to the posture that minimizes the remaining error. However, due to the local nature of the constrained

minimization such a posture can be a local minima (it ignores potentially better posture solutions).

- Unique solution: such theoretical case is rare in real case studies.

Generally the inverse kinematic control of a complex articulated structure such as the human skeleton evolves in a continuously changing context where goals are successively achievable or not as they move over time. (See for example the item “motion capture” for the typical application [→ MOTION CAPTURE]). Some specialized analytic solutions dedicated to the human case [Tolani et al., 2000] proposed in computer animation have been used in full body interaction contexts [→ INTERACTION, FULL BODY].

Only recently can the constrained optimization formulation be exploited in a real-time context as they request a much heavier computing power.

The enforcement of strict priority levels also helps to produce more effective solutions as the goal of the most important effectors (e.g. center of mass) are ensured as much as possible before searching to achieve lower priority goals [Boulic et al., 2006]. Such ability is crucial for producing believable human postures as the balance has to be totally enforced prior to try to achieve other tasks (e.g. reaching with one hand).

From the point of view of enaction, recent investigations exploit the inverse kinematics technology and extend it to address the following issues:

- Reconstruction of musician movement from a partial set of sensors to uncover whether the partial knowledge of body part movement is sufficient to recover the full body synergy of a musical performance.
- Real-time postural control of a virtual mannequin from the input of sensors carried by the user, or simply from images [Boulic et al., 2006]. One critical aspect explored in this context is whether the user can still be intuitively exploit his/her own body movement to drive a human representation that is performing in an increas-

ingly different context: (a) the human representation may differ in body size, (b) the environment may contain obstacles.

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RELATED ITEMS

INTERACTION, FULL BODY
MOTION CAPTURE

L

LEARNING AND ENACTIVE INTERFACES

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Enactive Learning is a relatively new expression, used in enactive community, to designate the process of learning by doing. In human sciences, several theories/models are confronted concerning the learning process. Usually, three main theories of learning are distinguished:

- Behaviourism, which is mainly based on the model of reinforcement of stimuli – response.
- Cognitivism, related to computational theory of mind [→ COMPUTATIONAL PARADIGM], which is mainly concerned with information processing and the perception – decision - action schema.
- Constructivism [→ CONSTRUCTIVISM], related to enactive cognitive sciences [→ ENACTIVE COGNITIVE SCIENCES_1&2] - which is understood here as an umbrella term (from Vygotsky and Piaget to Varela).

Within the constructivist approach, one can quote for example:

- Bandura's social cognitive theory [Bandura, 1986] and social learning theory which put an emphasis on two types of learning: observational learning, self-regulation and learning through direct experience.
- Bruner's [Bruner, 1966] approach [→ ENACTIVE KNOWLEDGE] of learning progress from sensory (enactive), to concrete (iconic), to abstract (symbolic) knowledge.

Nowadays, many works refer to the use of computer systems in learning activities, such as Technologically Enhanced Learning (TEL) [kaleidoscope 2004-2007].

Especially, lots of research and developments are performed regarding databases, digital libraries, and didactic tools in the context of formal sciences learning (mathematics, geometry, etc.), etc. Conversely, despite their potential interest, only a few new uses are emerging from the development of interactive simulation and virtual reality systems. Among the most important are:

- Case 1: the use of computer to learn manual tasks. It appears that there are difficulties to overcome to implement them in e-learning or Technologically Enhanced Learning TEL systems;
- Case 2: more recently, the use of multi-modal human-computer interfaces to sensorialize (visualize, sonify, haptize) the learning process of domains that are traditionally taught theoretically through formal representation (geometry, nanophysics, chemistry, etc). Such learning process may highly benefit from being supported by sensory representations allowing an active investment of the learner.

Case 1

Regarding manual tasks (driving a car, playing the violin, skiing, handwriting, etc.), considering that they are typical enactive examples, their learning can be called enactive learning. For these tasks, mental or abstract rehearsals based on only symbolic or iconic representations are trivially inefficient; a direct (enactive) training is absolutely necessary. However, to help this direct training, since the instructor's know-how cannot be made objective, learning necessitates instructors to mimic the task, find understandable metaphors, etc. As a consequence, reaching a stable learning requires a large number of trials/error cycles.

For the learning of such tasks, new systems such as real time interactive simulators or virtual reality platforms offer the unique opportunity to objectivise the manual process: replay of the instructor gesture, record and analyse the learner's performance, adapt the situation (the behaviour of the simulator)

to the learning level, etc. A major question is, however, the possibility of a back-transfer from the virtual situation to the real one, on which the learner will really act after the learning process. This requires reaching the appropriate level of similarity between both situations, which leads to question the concept of the action fidelity [\rightarrow ACTION FIDELITY].

The case of the new instruments and systems that are based from the outset on computerized technologies, and of their learning, calls for a few specific remarks. In the continuation of the Leroy-Gourhan anthropological approach [Leroy-Gourhan, 1964], one can note that in this case the same technological instrument serves both the enactive learning of the task, and the task itself after the learning. As an important feature, such instruments inherently offer the possibility discussed above of objectifying the learning process. Action fidelity is, indeed, no more a question.

Case 2

The use of enactive interfaces is today particularly promising regarding the sensorialisation of non-sensory based domains in order to support the learning process. Some examples (the list is not limitative) are: learning geometry through senses [Gouy-Pailler et al., 2007], and learning what nanophysics is through a simulator allowing an enactive interaction with simulated nano objects [Marchi et al., 2005]. However, a lot of work has still to be achieved to circumscribe exactly the gain of such training simulators for symbolic knowledge, and to develop efficient solutions adapted to the task to be learned, as exemplified in [Sreng et al, 2006].

Despite these difficulties, as a conclusion, improving learning of manual tasks, and moreover improving learning of non-manual knowledge, through enactive computer-based systems, such as those sketched by virtual reality systems, robotics, interactive simulation, including haptic devices and multisensory feedbacks, are two major promising

aims with societal, scientific and technological implications.

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RELATED ITEMS

ACTION FIDELITY
 COMPUTATIONAL PARADIGM
 CONSTRUCTIVISM
 ENACTIVE COGNITIVE SCIENCES_1&2
 ENACTIVE KNOWLEDGE
 LEARNING AND TRAINING METHODS
 MANUAL TASKS
 TEACHING TOOLS, FOR ENACTIVE TASKS

LEARNING AND TRAINING METHODS

Didier Delignieres [UM1]

Training methods aim at facilitating learning. A number of methods have been proposed, and a natural tendency is to generalize the obtained results to a wide range of tasks or activities. A first important principle is

that the efficiency of a given training technique depends on the nature of the task to be learned. In other words, training techniques are specific, and generalization in this domain remains problematic. We examine in this definition some classical training methods, with a special focus on their differential efficacy, with regard to the tasks under study.

Active vs. passive learning

A quite appealing solution for skill teaching could be to guide passively learner, by means of direct manipulations or artificial devices (exoskeletons, etc.). Passive guidance, nevertheless, was early showed to be a rather inefficient strategy for teaching. Learning requires an active involvement of the subjects, which have to discover by themselves the invariants and regularities of the task at hand. Learning can be enhanced by channeling behaviour toward the optimal solution (by virtue of task management), or by manipulating the amount of information to be processed. But learners should be able to actively explore the workspace of the task [Newell, 1991].

Practice

Learning requires a large amount of cumulated practice. An effective change in behaviour cannot be expected after a limited set of trials on the task. A number of solutions have been proposed for enhancing and speeding learning. Nevertheless, the main determinants in skill acquisition remain practice and repetition.

Feedback

A generally accepted assumption is that learning cannot occur without feedback. This proposition has to be discussed, nevertheless, as intrinsic feedback, when available, seems able to overcome the absence of extrinsic or augmented feedback. It has been shown in a learning experiment on a ski simulator that participants receiving various feedbacks concerning oscillation amplitude, frequency or fluidity, did not reach better performances than participants that did not receive any

augmented feedback [Vereijken & Whiting, 1990].

Implicit vs explicit learning

The most natural and obvious way for teaching is to verbally instruct the learner about what he/she has to do. This teaching strategy leads to the so-called explicit learning, during which learners try to solve the task using controlled and sophisticated cognitive processes. In contrast, a number of authors have proposed the concept of implicit learning, describing situations where learners try to reach the assigned goal without any conscious processing. Implicit learning is not very well defined in the learning literature: sometimes the concept refers to learning without the intention to learn and sometimes only to a kind of discovery learning, without explicit explanations or instruction [Wulf & Weigelt, 1997]. A number of experiments have shown that explicit learning and implicit learning represent two possible ways for acquiring a new skill. In general, explicit learning provides better results during practice sessions. Nevertheless, during post-tests in stressful conditions, subjects submitted to explicit learning present important decrement in performance, whereas implicit learners seem able to cope with stress and to reach in these conditions acceptable levels of performance. These results have important implications in the domain of skill training especially when skills have to be practiced in difficult and stressful conditions, training should as possible promote implicit forms of learning.

Modelling

Modelling is a widely used method of teaching, especially for morphokinetic skills (e.g. in dance, etc.). The interest of this procedure appears wider, nevertheless. Modelling seems especially efficient in the case of coordination tasks, i.e. when subjects have to build a new coordination, which was not present in the initial dynamics [Magill & Schoenfelder-Zohdi, 1995]. In the case of control tasks, i.e. when the problem is to

adapt a pre-existing coordination, modelling appears less relevant.

Transfer

Transfer is the most important problem for training. The usefulness of training depends on the possibility of transfer between learning task and real environments [Schmidt, 1982], from the point of view of his schema theory. According to this theory, the introduction of variability in the training schedule allows providing the acquired skill of transfer potentialities. These results, nevertheless, remain confined in a theoretical approach of learning, and consider the problem of transfer as the potential influence between learning a laboratory task and practicing another laboratory task. Transfer to real environments is a more complex problem. Real actions are essentially situated in an emotional context, requiring decisions, risk-taking, coping with stress. As such, simulated training should take into account these specific environments in order to optimize transfer.

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RELATED ITEMS

COMPLEXITY IN HUMAN MOTOR BEHAVIOUR
ENACTIVE COGNITIVE SCIENCES_ 1&2

LIVED BODY / LIVED WORLD : PHENOMENOLOGICAL APPROACH

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Lived world is a term of central importance for understanding human action, including the case of (computer) mediated action.

Lived world is a rather clumsy English rendering of the German *Umwelt*. The term is used by Husserl (and in phenomenology in general; see Merleau-Ponty and the French *monde propre*) to designate the world as it exists from the point of view of the perceiving subject, after the exercise of phenomenological reduction. What is enacted or brought forth by a human subject is a world of lived experience, world as a world of possibilities, of things and situations which makes sense for the subject, and not the objective and neutral world as-it-is.

The term was also employed by the German ethologist von Uexküll to designate the world as experienced by this or that species of animal. A famous example is the world of the tick. Even though it is blind, deaf and dumb (and can only crawl slowly), the tick nevertheless succeeds in the remarkable feat of identifying a warm-blooded mammal, catching it and feeding by sucking its blood. To do this, tick uses just 3 bits of information, which von Uexküll identified experimentally in a laboratory setting:

- Butyric acid / or not. If there is, the tick lets itself fall from its perch on the twig of a bush.

- Hairy / smooth surface. If the surface is hairy, the tick crawls until it finds a smooth surface i.e. bare skin; it then pierces the surface with its head.
- Liquid at 37+2°C / or not. If yes, the tick will suck the liquid.

The concatenation of these three perception-action cycles, in ecological context, enables the tick to find a mammal. The lived world of the tick is thus remarkably impoverished, containing just three beacons; but this minimalist simplicity conditions robustness of the actions, and robustness is more important than richness.

It is interesting to note that the Gestalt psychologists (largely inspired by phenomenology) made a similar effort to avoid the error of the stimulus – the error in question consisting of attributing perceptual experience to the perceived objects, to the detriment of describing the actual subjective experience as such.

There is a similar distinction between body and lived body: on the one hand, the biological body as a physical object (*Körper*), on the other hand the lived body as the seat of subjective experience (lived body is a rather clumsy English rendering of the German *Leib*, French *corps propre* or *chair*). The interplay between these two radically inseparable facets of the body leads to the theme of embodiment.

Let us consider the situation called tactile chiasmus, when one explores by touch his left hand with his right hand. In that case, the subject feels his left hand from the inside, as being touched. However, at the same time, for the right hand, the left hand is also an object of the world, that is considered as any other object. The notion of lived body is closely related to the kinaesthesia, understood as the very locus of inhabiting the body and feeling it from the inside.

Finally these notions should be understood, strictly speaking, in the light of the specific phenomenological methodology which is called phenomenological reduction. The basic method is that of phenomenologi-

cal reduction or *Epochè*. Phenomenological reduction consists in putting into parentheses the naïve thesis of the existence of the external world; and in neutralizing belief in the existence (or indeed the non-existence) of objects in the world. This is methodologically necessary in order to focus attention on the mode of appearance of objects, and hence to define the way objects appear to the consciousness (or the modalities of their coming into presence). It is important not to confuse phenomenological reduction with introspection, with a restriction or limitation, nor with reductionism as it is practised in the context of scientific enquiry.

Phenomenological reduction leads to the discovery of the intentional structure of consciousness. While maintaining the Kantian insistence on the transcendental level, Husserl put emphasis on the concept of phenomenon (i.e. what appears to the consciousness, and the way it appears to the consciousness, and this independently from the real existence of the object). He then redefines consciousness in terms of intentionality. Consciousness is no longer a thinking substance (*res cogitans*), but rather a dynamic action whereby (the subject) aims at (something).

Phenomenology thus introduces a double shift from classical approaches to the question of knowledge:

- On the one hand, phenomenology seeks to account not for the object that appears to the consciousness, but for the way in which the object appears. This process of appearing supposes that there is an a priori correlation between consciousness and its objects; experience – and hence knowledge – only exists for (a subject of consciousness); conversely, consciousness is always consciousness of (something).
- On the other hand, contrary to Kant for whom the a priori categories of experience (space and time) are purely formal categories, phenomenology seeks to describe up to the cognitive categories as arising from the flow of the lived experience. These

ideas, though related to the transcendental tradition, renews it radically; the notion of lived experience (*Erlebnis*), which is the centre of gravity of phenomenology, implies that knowledge and consciousness is not possible without a grounding in embodiment.

Through this thematisation of lived body and embodiment, phenomenology leads thus to a reconceptualization of consciousness, which is then understood as an activity of the subject which enacts the lived world. Although the concept of enaction was introduced by Varela and Maturana, it is largely inspired by – and grounded on – phenomenology.

RELATED ITEMS

COMPUTATIONAL PARADIGM

CONSTRUCTIVISM

ENACTIVE COGNITIVE SCIENCES_ 1&2

TECHNICAL ARTEFACTS AND PERCEPTUAL

EXPERIENCE

TOUCH, THE SENSE OF REALITY

M

MANUAL TASKS

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Contributors: Ilaria Polvani [PERCRO]

Manual tasks are carried out in most types of work, meaning any activity requiring a person that uses any part of his or her musculoskeletal system in performing his or her work. They may include the use of force to grasp, manipulate, strike, throw, carry, move, lift, lower, push, pull, hold or restrain an object, load or body part, repetitive actions, sustained postures, exposure to vibration.

Therefore, manual tasks cover a wide range of activities including stacking shelves, using a computer keyboard and mouse, repairing pipes, directing traffic, using an angle-grinder, pipetting, using microscopes and handling library books. Many manual tasks have historic significance dating back to the creative importance of jobs performed by craftsmen in mediaeval Corporations. Today, manual tasks tends to refer to the action and the abilities of the hands when used to perform a job/task.

Manual tasks can be reproduced inside a virtual stage linked to different topics and assisted by experts/animators. In this way, the user's musculoskeletal system can control or be controlled by a robotic/virtual environment interface system.

Performing manual tasks can contribute to cause to workers several musculoskeletal disorders such as sprains and strains of muscles, injuries to muscles, ligaments, intervertebral discs and other structures in the back, injuries to soft tissues such as nerves, ligaments and tendons in the wrists, arms and shoulders. In order to significantly reduce the incidence and severity of musculoskeletal disorders caused by manual tasks using enac-

tive interfaces, a risk assessment should be done and control measures should be taken.

In the state-of-the-art there are no approaches that highlight action with respect to the modelling and rendering of the environment (virtual, audio, physical or geometrical models). According to the enactive vision the concept (and the potentialities) of action are still underestimated when considering human-machine interaction.

The scientific research on enactive interface is the first that considers the capabilities of employing human manual tasks without any mediated form of codification and/or interpretation. Such an approach is especially important when considering new applications such as eLearning, eInclusion or "teaching by showing".

A great effort is being put in order to validate and use systems for the assessment of human performance in the execution of manual tasks using enactive interfaces. In particular potential emblematic scenarios, such as simulation of assembly using haptic platforms in mixed, virtual and augmented reality, manual tasks requiring sensorimotor coordination and multisensorial integration and learning/teaching through interaction metaphors or remote interaction have been set-up and studied.

RELATED ITEMS

ACTIVE PERCEPTION / TOUCH
BIMANUAL INTERACTION
INTERACTION, FULL BODY
REACHING

MAPPING

Doug Van Nort [SPCL]

Contributors: Marcelo Wanderley [SPCL]

Mapping is an important and widely used concept in the many fields related to Enactive Interfaces, including research in human-computer interaction, virtual reality, com-

puter music, etc. It is a term whose meaning may change in these differing research contexts, yet across all of these fields mapping can be seen to derive from a common theoretical basis. The purpose of this item is to establish this basis so that the different areas of research related to enactive may discuss the various roles of mapping within a unified conceptual framework. Other related items exemplify the use of the term in various concrete cases.

In its most general sense, mapping can be considered a function f that associates every element within a *domain* set X to another element in a *codomain* Y , within the set $f(X)$, known as the *range*. The range is generally considered as a subset of the codomain, which endows $f(X)$ with its boundary, relevant properties, etc. We then write $f:X \rightarrow Y$.

In order for the mapping to be *well-defined*, for every $x \in X$, there must exist a *unique* element $f(x) \in Y$. That is, there cannot exist multiple elements $b_1, \dots, b_n \in Y$ such that $f(a) = b_1 = \dots = b_n$. In some cases one control variable x_1 may be mapped to several output variables (y_1, \dots, y_n) . This may seem contrary to the well-definedness of the mapping. However, the domain and codomain can be multi-dimensional with $\dim(X) = n \neq m = \dim(Y)$, so that in this instance the value $f(x_1) = (y_1, \dots, y_n)$ constitutes a single element mapped across dimensions of the range set $f(X)$, and so does not violate the well-definedness of f .

The domain and codomain may be composed of many types of elements. It is most common that in engineering-based applications this will be a subset of the real numbers, the integers or some Cartesian product of these, though this functional description of mapping extends to and includes the more general conceptual framework of a correspondence between objects that are themselves a collection of elements, and that may possess further relations within and across domain and codomain.

In one important example, a mapping may also act on a set of functions itself, in which

case we refer to the mapping as an operator. A linear operator is in practice commonly represented by and referred to as a matrix. The special case of an operator that maps back into the set of real numbers is called a functional.

Properties

A mapping can possess properties outright by virtue of its existence as such (thus, ontological properties). In this sense, a mapping that is well-defined will always be:

- continuous or discrete
- differentiable or not

A mapping is differentiable if one can describe its rate of change for all values of the domain. If this can be described iteratively on the resulting expression of change, the mapping is considered to be higher order differentiable.

- implicit or explicit

A mapping is explicit if it can be represented via an expression that may be used to determine any element of the range given an element of the domain. An implicit mapping lacks this property, and requires additional knowledge of a dependence between input and output elements (with possible restrictions on domain or range sets) in order to find the corresponding range element of a given domain element.

- computable or not
- invertible or not

A mapping f is invertible if and only if there exists a mapping g such that for every x in the domain and y in the range with $f(x) = y$, then $g(y) = x$.

- Injective, surjective (together, bijective) or not

A mapping is injective if every possible element in the range is mapped to by precisely one element of the domain. If every element in the codomain is mapped to by at least one (not necessarily unique) element of the range, then the mapping is surjective. If both of these conditions exist, the mapping is bijective and the domain and codomain are considered to be in one-to-one correspon-

dence. This property is a precursor to other information about a given mapping, for example a bijection exists if and only if a mapping is invertible.

In addition to these inherent qualities, how a mapping acts is contextual in that it depends on the properties that are possessed by the domain and codomain. In addition to dimensionality, these sets can be endowed with properties that provide them with a sense of internal structure, such as binary operations that define a group on the set, or through properties that provide a notion of distance and un/boundedness, through the definition of a metric or topological space. In these cases, mappings between these sets may possess qualities that address these inherited properties of the sets on which they act. These include:

- Smoothness

At what point a mapping is considered smooth enough is contextual, but this property is directly related to the order of differentiability of the mapping. This property may be directly linked to expected or perceived dynamic qualities of a mapping.

- Composition of mappings

A mapping $h: X \rightarrow Z$ may in fact be a composition of mappings f and g wherein $f: X \rightarrow Y$ and $g: f(X) \rightarrow Z$, with range $f(X)$ a subset of Y . If X, Y or Z are distinct, then we can say that the mapping is composed of several *layers*.

- Linearity

Given the existence of a binary operation on the domain/codomain, a mapping is linear if it obeys the principles of superposition and homogeneity. Otherwise the mapping is non-linear.

- Embedding (in its multiple definitions)

- Morphism

This refers to mappings that preserve structure with regards to a specific criteria. The essential sub-types include

- 1) Homomorphism, Isomorphism: If a domain X is endowed with an algebraic structure (i.e. it is closed under some binary operation, satisfying certain axioms), a map-

ping from X is a homomorphism provided that it preserves this given structure. If the mapping is further bijective, then the mapping is an isomorphism.

- 2) Homomorphism, Diffeomorphism: These arise if one endows the domain/codomain sets with spatial structure by virtue of properly defining distance and belongingness (to a given subset). A homeomorphism is a bi-continuous, bijective mapping that exists between topological spaces, and which preserves the relevant spatial structure such as compactness (closed, boundeness), connectedness, etc. A mapping between two smooth manifolds (sets endowed with notion of space which can be considered Euclidean at a local level) which is bijective and bi-differentiable is called a diffeomorphism. This mapping preserves the local Euclidean-ness from domain to codomain.

This latter list of properties might be considered more high-level than the former in that they consider contextual information and they directly relate to and are determined by the underlying objects on which they act. In this way they may consider more directly the purpose for which a given mapping is being constructed.

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RELATED ITEMS

CONTROL, DIGITAL

MAPPING AND CONTROL VS. INSTRUMENTAL INTERACTION

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Marcello Wanderley [SPCL]*

For a human-computer interactive system, implementing the paradigms of control/mapping [→ MAPPING] can correspond, in some cases, to fundamental drawbacks. The current item provides an illustration of this observation by examining the typical case of today's mapping-based digital musical instruments [→ MAPPING, IN DIGITAL MUSICAL INSTRUMENTS].

In traditional musical instruments (i.e. acoustic instruments, such as the violin or the clarinet), energy within the sounds originates in the player himself ([-→ INTERFACE, ERGOTIC]; see also the figure in the related external document). The sound then results from a physical gesture interaction between the instrument and the player, featuring an energetic coupling. The energetic coupling, and the tactilo-proprio-kinesthetic gesture feedback [-→ GESTURAL CHANNEL] are intimately correlated with the sound, influence sound quality and diversity, and readability of gestures within the sound. They ensure a high level of sensitivity and expressivity.

Contemporary digital musical instruments modified fundamentally this situation (see also the figure 2 in the related document). The performer's gestures are encoded by a gesture controller (e.g. keyboard, pad...) through a unidirectional gesture signal. Often, this signal is not sampled, but event-based, for example by using the MIDI protocol [→ GESTURE AND MOTION (ENCODING OF)]. The gesture signal then passes through the mapping stage, and is finally input, often with

a noticeable latency, into the synthesizer. The performer receives a primary gesture feedback due to the passive physics and ergonomics of the gesture controller, and a synthesized sound feedback through sound transducers, also provided to the audience.

The quality / readability of the control depends especially on the chosen mapping strategy. However, in any case, the sound is not originated in the gesture of the performer; it is built by a "distant" computational process which is controlled or triggered by the performer. The energy in the sound, and the microstructure of the sound, can hardly be intimately correlated with gesture. Though one can say that the system is interactive, it does not offer a strong multisensory instrumental interaction.

Indeed, one can note that digital musical instruments conforming to this structure have rarely succeeded in offering as interesting expressive possibilities as those of acoustic instruments, such as the violin, or the electric guitar, for example [Wanderley, 1999]. This is particularly clear when considering the case of sustained sound instruments, such as strings or winds. This is not due to the sound models that are now very accurate. Indeed, now that this mainstream approach has led to a high level of complexity and technological efficiency, there must be some fundamental reasons that explain this still-remaining lack of expressivity.

The framework of enactive interfaces emphasizes the unity of human perception, and as a vis-à-vis the need of a particularly high and thin correlation between the gesture of the user and the various multi-sensory stimuli generated in feedback (sound+gesture feedback in the case of musical instruments). Indeed, the mapping of gesture to control various exogenous parameters of a signal-based synthesis model implies that there is an ontological rupture between the two mapped domains. This ontological rupture risks to reduce, and sometimes to break, the close interaction needed between the various stimuli generated.

Facing this problem, an alternative is using physical simulation along with force feedback transducers, altogether allowing to obtain an ergotic interface. Potentially [Castagne et al, 2004], a physical simulation is able to generate all the sensory stimuli in response to gesture in one shot [\rightarrow PHYSICALLY-BASED MODELLING TECHNIQUES FOR MULTISENSORY SIMULATION]. In that case, there is no more need of a complex mapping strategy introducing an ontological cut. Gesture signals are directly meaningful inside the physical model. As for them, force feedback interfaces potentially make it possible to simulate an energetic interaction, by allowing a coupling of the dual force and position variables – see the Figure 3 in the related document.

A couple of experiments [Nichols, 2002] [Florens, 2002] nowadays foresee the relevance of such a structure. In Florens' work, the string was considered as a fully linear system, and the bow/string interaction implemented a simple non-linear viscosity curve. Conversely to the simplicity of the string model, the installation implemented a high quality ERGOS haptic device [Cadoz et al, 1990], [Florens et al, 2004]. As a result, most of the relevant sound cues could be obtained: full excitation of the string on its first mode, full harmonic, creaking, etc. Hence, the use of a high-quality force feedback system and of physically-based modelling is at least as important (and probably more important) than the accuracy of the computed model.

Hence, ergotic interfaces may correspond with a fundamental evolution in our digital musical instrument, a paradigm shift. As an alternative to the principles of control, mapping and interactivity, they promote the concept of multisensory instrumental interaction interaction [\rightarrow INSTRUMENTAL INTERACTION] with a digital artefact through an energetically coherent bidirectional gesture coupling, allowing to experience again, with digital systems, the situation in which “the hand makes the sound”.

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RELATED ITEMS

GESTURAL CHANNEL
 GESTURE AND MOTION (ENCODING OF)
 HUMAN COMPUTER INTERACTION
 INSTRUMENTAL INTERACTION
 INSTRUMENTAL INTERACTION: TECHNOLOGY
 INTERFACE, ERGOTIC
 MAPPING
 MAPPING, IN DIGITAL MUSICAL INSTRUMENTS
 PHYSICALLY-BASED MODELLING TECHNIQUES
 FOR MULTISENSORY SIMULATION

RELATED DOCUMENTS

El_MappingDigitalMusicalInstrument.pdf

MAPPING, IN DIGITAL MUSICAL INSTRUMENTS

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A digital musical instrument (DMI) can be defined as an instrument that contains a control surface (also referred to as a performance controller, or hardware interface, an input or gesture device, the latest being more used outside the strict field of Computer Music) and a sound generation unit. Both units are independent modules related to each other by mapping strategies [Miranda and Wanderley, 2006]. The sound generation unit most commonly consists of signal-based synthesis algorithms generated by a computer, including additive, subtractive, FM synthesis, physical modelling, sampling synthesis, etc. In this item we focus on mapping strategies and their influence on the design of and performance with DMIs.

This modular structure extends the possibilities for musical interaction above and beyond that which is provided by acoustic musical instruments, thus enabling innovative musical uses. Musicians now have the opportunity to choose the gesture controller from any existing input device or a novel controller designed from scratch, choose a sound synthesis technique, and to relate both through specific mapping techniques. In light of this, the mapping stage is responsible for filling the ontological gap between the gestures performed by the user (or more precisely the gesture signals), and the parameters of the sound processes.

Mapping therefore is a strong determinant of the behaviour of a given DMI: in short, it strongly contributes the essence of the instrument [Hunt et al., 2003]. As such the

choice and building of an appropriate strategy is difficult, in particular because there may be no model on which to base its design (when, for instance, the DMI has no acoustic basis such as an existing instrument). Other difficulties may arise due to the fact that various input parameters often must be varied in correlation in order to approach sufficiently subtle variations in the sounds and obtain a consistent effect on perception [Verfaillie et al., 2006]. This is especially the case when the real time sound process is a signal-based synthesis model (loudness has to be varied along with spectrum, fundamental frequency along with level of harmonicity, etc.).

In DMI design, mapping has been approached from various directions, and as a result different properties become more or less salient. Indeed, depending on the design criteria, mapping can manifest as an interpolation or extrapolation between parameters or states, as a static or dynamic multi-parametric function that may be explicit (described analytically) or implicit (adapted through training), static or dynamic, continuous or discrete, composed of several layers of mapping between intermediate parameter sets, etc. The mapping may possess further properties depending on the chosen controller, sound synthesis and the underlying interaction context.

Indeed, generalizing the mapping concept allows potentially letting *any* parameter in the sound model, and (at least) theoretically any conceivable quality of sound to become playable. Hence, for example, through an appropriate mapping strategy, the performer becomes able to play (with) - to “interpret” - sound spatialisation effects (localisation, room effects), level of harmonicity in the sound, timbre, rhythm of a loop, morphing between sounds, etc. Indeed, as says [Risset, 1999], new DMI “*freed the musician from the mechanical constraints*”.

A second evolution one can observe today is that musicians (both composers and performers) now have the ability to directly

define and adjust the behaviour of the instrument. Hence, not only the mapping concept allows playing dimensions of the sound that were not accessible with traditional instruments, but the mapping itself becomes “playable”, adaptable, etc.

Both because the design of appropriate mapping strategies is known to be difficult, and because (as discussed) the concept of mapping and its generalisation in the case of novel DMIs possesses numerous substantial benefits, the research focused on mapping [VanNort et al., 2007] and the systems that aid in designing mappings [Malloch et al., 2007] is developing rapidly today in the field of computer music.

However, despite its many interests, one should note that the concept of mapping is not the unique, nor definitive, solution toward expressive digital instruments. The item “mapping and control vs. instrumental interaction” provides a possible critique of the mapping concept [→ MAPPING AND CONTROL VS. INSTRUMENTAL INTERACTION].

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RELATED ITEMS

MAPPING
MAPPING AND CONTROL VS. INSTRUMENTAL INTERACTION
SOUND ALGORITHMS
SOUND ALGORITHMS – SOUND SYNTHESIS AND SOUND MODELS

RELATED DOCUMENTS

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MAPPING, IN HUMAN - COMPUTER SYSTEMS

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In the technologic and scientific fields connected to Enactive Interfaces, the term mapping is used in a variety of situations, with various meanings. These cover for example the very technical memory mapped protocol (mmap) for inputs/outputs of a computer CPU from/to its devices, the data mapping between data models or categories of data (for an example, see [→ SONIFICATION]), the mapping between different modalities, etc.

This item deals with another category of mapping particularly important in the context of Enactive Interfaces: the mapping of human gestures onto a computer process. It is provided in the continuity of the theoretical definition in [→ MAPPING]. Here, the mapping’s domain is the human gesture, or more precisely a data stream acquired from a gesture transducer, and the mapping’s codomain is the computer process. Also, one defines a mapping strategy as a set of general guidelines and instructions useful to design the mapping. The choice of an appropriate map-