

ping strategy is particularly important, and difficult.

This being said, the item reviews such human gesture mapping in three more specific cases.

Mapping (of human gesture) in HCI

In classical human computer interaction, and more generally in ergonomics, the mapping concept has long been seen as being of a major importance. Hence, in [Norman, 88], mapping, and associated mapping strategies, are presented as one of the 5 most important things to carefully consider when designing a system usable by a human being (either a graphical computer interface, a telephone, a plane cockpit, etc.), along with mental models, affordances [\rightarrow AFFORDANCES], constraints and visibility/feedback.

Examples of well-designed mapping are the mapping of wheel to power steering in cars (it is easy to learn...), and the logarithmic-based mapping of the potentiometer to the power in audio amplifiers (which is well adapted to loudness, i.e. to the human perception of sound power).

In the case of traditional man-computer interfaces, especially graphical interfaces, the domain is typically made of the mouse trajectories, or further of the motion of a graphical slider (or more generally widget) that accompanies the mouse on screen, and the codomain is the interface at hand, or more precisely various of the state parameters of the core system above which the interface is built. Here, the chosen mapping strategy not only affect the naturalness of the handling of the interface through the relatively poor device available (keyboard and mouse). In some case, it can also dramatically reduce the complexity of the whole interface. For example, implementing a well-chosen mapping can allow replacing numerous sliders, each of which would control a unique parameter in the system, by a unique control which state is mapped onto various parameters in the model (through a one-to-N mapping), allowing obtaining the desired effect much more easily.

Mapping, when using Motion Capture

In this context, mapping comes as an issue when interfaces are used to map the motion of particular points of the body onto an artificial display. Here, the mapping's domain is made of the moving points trajectories captured on the real body in earth frame, and the codomain is the motion in the virtual space in the interface.

To design the mapping, the designer has first to choose specific points on the body, that could be end effectors or limbs, or joints, or any variable calculated from these basic elements. Second a particular mapping strategy has to be defined.

The mapping strategy may, for example, map the captured points in a smaller or a larger dimensional space (e.g., a surface instead of a volume), delayed or not in time, via a possible transformation linear or non linear, keeping or not symmetry, keeping or not redundancy of the original inputs, scaling, etc. One can also imagine mapping onto a different space, for example from physical space to phase space.

In this context, the possibility of an adaptation (of the user) to mapping is an important issue.

The study of adaptation to such mappings is classical in experimental psychology and neurosciences. It originates in the study of adaptation to prismatic goggles that imposed a constant angle rotation of the environment, enabling a new spatial relationship between the "non rotated" tactile or proprioceptive information and the rotated visual layout. However, this area of study still lacks a systematic or theoretical treatment, and the effects of variation in mappings are often underestimated.

Particular mappings of body motion onto visual interfaces quite systematically changed the measured behavioural adaptation (which led to misunderstand divergent results between apparently similar experiments) and sometimes simplified notably the learning and execution of otherwise difficult coordination tasks [Flaugloire et al, 2004]

[Mechsner et al, 2001] [Swinnen, 1996] [Swinnen et al 1997]. This line of research may well pave the way for rehabilitation interfaces.

Mapping, in the context of Synthesis

Mapping is also a very important issue in computer-based (sound and/or visual) synthesis. Here, the domain is the gesture signal sensed on a gesture device (a musical keyboard, a motion capture system, etc.), and to codomain is made of the parameters of the synthesis model at hand.

In this context, the concept of mapping is progressively made more and more objective, as a new area of research toward better (more expressive, more interesting, more diverse, etc.) synthesis systems. The item “mapping, in digital musical instruments” discusses further the various benefits of the mapping concepts in the case of digital musical instruments, but can be generalized from sound synthesis to the general case of synthesis [→ MAPPING, IN DIGITAL MUSICAL INSTRUMENTS].

However, despite the substantial benefits of the generalization of the mapping paradigm, a couple of drawbacks can be discussed. The item “mapping and control vs. instrumental interaction” goes further on this discussion [→ MAPPING AND CONTROL VS. INSTRUMENTAL INTERACTION].

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RELATED ITEMS

AFFORDANCES
 HUMAN COMPUTER INTERACTION
 MAPPING
 MAPPING AND CONTROL VS. INSTRUMENTAL INTERACTION
 MAPPING, IN DIGITAL MUSICAL INSTRUMENTS
 SONIFICATION

MECHANICAL IMPEDANCE

Damien Couroussé [ACROE&INPG]

Contributors: Jean-Loup Florens [ACROE&INPG], Emilio Sánchez [CEIT], Jorge Juan Gil [CEIT]

Mechanical impedance is a transposition to mechanics of the term impedance that is used and defined in circuit theory. The theory of circuit (theory of Kirchhoff networks) is basically applicable to electric networks but can be considered more generally as a unifying simplified theory of physics available in several domains like mechanics, electromagnetism, aero-acoustics and fluids mechanics.

Similarly to Maxwell or Newton physics, the theory of Kirchhoff networks involves local properties and dual variables (current & voltage, magnetic & electric field, force & motion, flow & pressure, etc.), and furthermore constitutes a discrete and modular description of physical systems. Within this formalism, physical systems are described as networks made of inter-connected dipolar entities whose constitutive property is to present two poles constituting input and output of a circulating flow. These abstract dipoles are not necessarily elementary physical elements; they may be sub-networks or a pair of poles belonging to a multi-pole element [Boite and Neiryneck, 1983].

The electric impedance is defined as the voltage to current ratio that is related to a dipole. This definition is meaningful if this ratio represents an invariant property of the dipole (i.e. independent on the current and voltages temporal variations) and then appears as a characteristic property of a physical object or system. More generally, the concept of impedance could be extended to an abstract operator that would link the physical dual variable and would stand for the invariant property of a system at its dipolar link point.

In the domain of mechanics, the concept of impedance is mainly used in vibro-acoustics, aero-acoustics and fluid mechanics where small or non-geometrical motions are considered. Indeed like Kirchhoff theory the concept of impedance is only limited to non-geometrical dynamical systems (i.e. a system in which no distance related properties are considered in its motion space).

In the field of haptics, some works present the mechanical impedance as a static representation ($F=Z \times V$) [Colgate and Brown, 1994]. A more general approach considers that the mechanical impedance of a given mechanical system also depends on the frequency of the mechanical perturbation [Lawrence and Chapel, 1994], [Lawrence et al., 1996].

Hence, the mechanical impedance (Z) can be defined as an operator providing a force (F) given a displacement (V):

$$F = Z(V)$$

When one wants to evaluate a haptic device in situ, one of the most basic tests used is the model of the virtual wall. It allows testing two very important properties of a haptic device:

- The quality of hard contacts. By colliding the simulated wall, it is possible to evaluate how powerful are the actuators, how fast and how stable is the control loop, how precise are the sensors, etc.
- The quality of motion at free movement. Inherent friction, proper mass of the moving parts, and other physical characteristics

limit performances of haptic devices at free movement. If they become perceptible from the user's point of view, the presence of the haptic device becomes perceptible between the user and what is simulated.

This means that a perfect haptic device should be able to simulate

- very hard contacts, like when hitting a strong wall or a big plate made of metal;
- pure free movement, that is, movement that wouldn't make the user lose more energy than the energy he/she would lose if he/she wasn't grasping the haptic device.

From the mechanical engineer's point of view, an infinitively hard contact corresponds to infinite mechanical impedance, whereas a purely free movement corresponds to mechanical impedance that is null.

When designing a haptic device, the difficulty is to achieve at the same time these two properties (quality of free movement and quality of hard contact). It is not possible to obtain such a haptic device, because the two requirements of free movement and hard contacts require opposite technological design solutions. This maximum range of mechanical impedance is defined as the Z-Width of a haptic device in [Colgate and Brown, 1994], which is in this paper assumed to be comparably as broader as the dynamic range of the device.

A very rough example can illustrate this problem: when one wants to increase the hardness of contacts, one may want to increase the power of the actuators. However, due to the fact that actuators provide a ratio of power over mass that is limited by the technology chosen, increasing the power of the actuators will lead to increase their mass. This will lead to increase the whole inertia of the kinematic chain, thus decreasing the quality of free movement.

In the domain of haptics and teleoperation robotics, the concept of impedance has mainly been used because it allowed dealing with system composition and system separation. In these disciplines basic compositions between three types of systems have to be

considered: device-object, device-human, human-object where the device is an artificial haptic device or a robot. In these conditions it may be helpful to characterize intrinsic properties of each of these three entities at their coupling points where there are linked with the others. This leads to apply the usage of the impedance concept to physical objects, to robots at the point of their end effectors, to haptic device at their manipulating point, and to the human hand.

Several classical haptic issues are defined and treated with the help of impedance concept, including: transparency of a teleoperation system; specification of a haptic simulators human behaviour characterization; compliance of a robot device.

Finally, various specialized usages of impedance term are also available in haptics device domain and haptic simulation, such as: impedance matching; impedance range (Z-Width); characteristic impedance; critical impedance; gyration impedance.

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RELATED ITEMS

FORCE FEEDBACK DEVICE / FORCE PROPERTIES
STABILITY
TRANSPARENCY_2
TRANSPARENCY_3

RELATED DOCUMENTS

El_WP3_DLVI_050210_v2.pdf

MENTAL CONTENT, TELEOLOGICAL THEORIES OF

Elena Pasquinelli [INSTNICOD]

Teleological theories of mental content are motivated by the desire, which is common to contemporary philosophers of mind and cognitive scientists, of naturalizing the contents and the functioning of the mind.

One of the main problems addressed by teleological theories of mental content is the naturalization of intentionality, that is, the fact that mental states are about something or have meaning. A naturalistic treatment of intentionality must not make use of intentional concepts. As a first alternative, intentional descriptions can be excised from scientific or natural accounts of mind functioning, as the phlogiston has been excised from chemistry [Churchland, 1989]. As a second alternative, it is proposed that natural ontology and intentional account of the mind are compatible, but cannot be reduced one to the other: the result is an anomalous monism where no nomological law bridges between the two descriptions of mental functioning [Davidson, 1984]. A third alternative is represented by those who propose an informational treatment of mental content. Within this approach, intentional content is equivalent to the information which is carried by a system under certain conditions [Dretske, 1981].

The teleological interpretation of representations is thought to address an additional problem, which subsists for informational accounts of intentionality, which is the problem of misrepresentation [Millikan, 1984] [Dretske, 1995]. The proper of teleological approaches is the introduction of the notion

of function in the definition of representational content.

According to [Dretske, 1995], for instance, a system S represents F if and only if S has the function of indicating F , that is, of providing information about the F of some domain of objects. Two notions are thus employed to characterize representations: the notion of information and the notion of function; a system which carries some information without having the function of carrying it is not a representational system; any other system which associates information carrying and teleology is a representational system. Any representational system is open to misrepresentation, when it does not perform the function it is designed for.

[Dretske, 1995], in particular, proposes a representational account of perceptual experiences. The representations that are characteristic of perceptual experiences are natural, as all the others mental states, in opposition to conventional representations (conventional representations characterize for instance the functioning of artefacts as the thermometer which are designed by human beings and in which the fact that the level of the mercury indicates the temperature of the environments depends on a convention).

Natural selection and other types of selection are invoked in order to account for the content of natural representations in the absence of conventions. Selection operates on functions and functions constrain the content of perceptual representations. When a system is not carrying the information it has been selected for the system malfunctions and then it misrepresents the world. Perceptual systems are described by the [Dretske, 1995] as having the general function of representing the world, each perceptual system having specific functions selected.

Perceptual representations are also non-conceptual, as opposed to the conceptual representations that are typical of thought and judgment. Two types of awareness of the mental states are distinguished by [Dretske, 1995]: phenomenal awareness, or the aware-

ness of something as having some phenomenal quality, and conceptual awareness, which is possible only when the corresponding concept is possessed. This distinction corresponds to the distinction between simple seeing and epistemic seeing [Dretske, 1969]. Hence, one can have phenomenal awareness of something as blue or heavy (see it as blue or feel it as heavy) without being conceptually aware of something that is blue or heavy (see that it is blue or feel that it is heavy). A thermometer can have representations and in a certain sense it perceives the temperature, even if in a conventional and not natural way. Children and animals perceive and represent the world at least phenomenally. Also, since in Dretske's approach the property of having representations only requires a function and the carrying of information, sub-personal systems of adult human beings (the perceptual systems) can have representations.

Also within the teleological approach proposed by Millikan, the content of the representations is determined by the function of the system which consumes the information. For this reason, even organs such as the stomach of the frog are described as having the function of representing [Millikan, 1984][Millikan, 1993].

Within this account of perception, thus, errors can be assigned not only to non-conceptual creatures but also to the perceptual system and other components of the organism.

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RELATED ITEMS

COMPUTATIONAL PARADIGM
DUALISM, MIND-MATTER
OBJECTIVITY
PERCEPTION, DIRECT AND INDIRECT APPROACHES
REPRESENTATION

MENTAL LOADS

Walter Aprile [PERCRO]

Mental load as a concept [Bainbridge, 1974] can be broken down into several sub-concepts that perhaps can be used to reach a better understanding. Considering an operator at work (a computer user that is retouching an image, for example), we have to distinguish between what the task requires of the user, something that we can call mental stress and the amount of effort that the user makes, something that we can call mental strain.

At the same time, the level of strain depends on individual user factors (that we could call capacity) and also on specific and temporary user conditions: the performance of people in a condition of flow [Csikszentmihalyi, 1990] is usually better.

Load, as a word, is borrowed from machines engineering - the amount of load that a structure can carry, the load lifted by a crane - and as such it misleads into assuming the existence of a unique instant load placed on a user: this load must be carried by a unique force or capacity. In fact, early theories of mental load were based on this one load-one effort vision. The picture is made more complex in [Wickens, 1984], that introduces the presence of multiple resources (such as auditory and visual) that are consumed as different demands are placed on the subject. This accounts for the fact that a subject fully engaged in a visual discrimination task can, at the same time, execute a

secondary auditory task without a marked decrease in the performance of the first task. Another example argument for a more complex picture is typing and reading at the same time.

Yet another angle on mental load tries to relate it with actual, measurable brain activity. In particular a computation pipeline view of information processing [Sanders, 1983] identifies four stages that the load passes through, viz. stimulus preprocessing, feature extraction, response choice and response adjustment. Each stage is related to a mental/brain module, and it has a limited capacity. The stage's activity can be measured through electrical and magnetical techniques. Energetical views [Pribram and McGuiness, 1975] use concepts such as activation, arousal and effort. In their view, activation is the physical readiness to act, arousal is the "*energy mobilization of the organism*" [Sanders, 1983] and effort is a limited capacity pool that allows the activation and arousal pools (also limited) to adapt to task demands. Effort is, of course, voluntary.

Another useful division of the concept of mental load is among intrinsic load, germane load and extraneous load [Paas et al., 2003]. Intrinsic load is that effort which results from the individual. Germane load is that load created in construction of schemas and mental models - it is the load that produces learning. Extraneous load is further cognitive load outside of what the experimenter is interested in, generated for example by the interface, by experimenter's errors, or by adverse environmental conditions.

Mental load can be measured by instruments like the Nasa Task Load Index (NASA TLX) [Hart and Staveland 1988], the Subjective Workload Assessment Technique (SWAT), and the Workload Profile (WP).

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RELATED ITEMS

DESIGN, USER CENTRED
USABILITY
USEWORTHY TECHNOLOGY
TRANSPARENCY_ 1&2&3

METAPHORS IN HUMAN - COMPUTER INTERACTION

Joan De Boeck [UHASSELT]

Contributors: Chris Raymaekers [UHASSELT]

General Metaphors

A common way to transfer the knowledge a user has picked up in one domain or situation to another situation, or to transfer intuitive every-day acts to a computer system is by use of metaphors. Undoubtedly the most-well known metaphor is the desktop metaphor, which projects the knowledge of the

every-day office-desktop to the computer. The same is true in other applications for other tasks that are to be executed by the user.

Navigation Metaphors

When navigating in a virtual world, or even when navigating in any other desktop application four questions arise: "Where am I now?", "What is my current attitude and orientation?", "Where do I want to go?", "How do I travel there?". Answers to those questions, which imply the more psychological questions about navigation and way finding are answered in [Satalich, 1995]. To accomplish the task of navigation, several metaphors have been developed already. Although no metaphor exists that fits in every application, each metaphor has its specific benefits. When navigating in a 3D environment, the problem often is to find an intuitive paradigm to use a 2D input device for a 6DOF task. The best solutions however are found using 6DOF input devices. In [Ware and Osborne, 1990], three basic metaphors are presented, as there are: Flying Vehicle, Scene in Hand and Eyeball in hand. Other metaphors, for special applications, or using special hardware can be found in literature: [Tan et al., 2001] describes a metaphor that increases the camera's elevation when increasing the speed. [Koller et al., 1996] shows a method that allows orbital viewing by rotating the head in an immersive environment. [Camera-In-Hand] and [Ext Camera in Hand] test a metaphor that uses the PHANToM Device and makes usage of force feedback in order to navigate through a 3D world. Finally, WIM (world in miniature) [Mine, 1995] provides the user with a miniature representation of the world that allows him to interact on a general overview of the world.

Another category of navigation metaphors can be found with body based techniques: tracking the user's body or torso can activate a flying vehicle metaphor: by leaning or by extending ones arm, a virtual vehicle can start its movements.

Selection Metaphors

Selection of objects in 3D environment can be completed in several ways. The most intuitive metaphor is by direct manipulation, by directly touching the object with the virtual hand or the pointer, the object becomes selected, as we know from our everyday life. The problem with this technique is that selection is limited to the objects that are within the proximity of the user, (or better) within the bounds of the used device. To solve this problem, ray casting (or cone casting) is proposed by [Mine, 1995].

Manipulation Metaphors

Objects that are selected can be manipulated or queried. In general both selection metaphors can be used for manipulation. Although direct manipulation is limited to the user's close environment, while ray casting go without some degrees of freedom such as rotating around another axis than the axis of the ray itself [Bowman and Hodges, 1997]. A complete taxonomy of the most frequent manipulation techniques can be found in [Poupyrev et al., 1998]. A distinction can be made between exocentric and egocentric metaphors. The former defines metaphors in which the user is outside the world and is looking at it from a kind of a god-eye's view. The latter class defines metaphors in which the user is standing in the world itself: virtual pointer metaphors, such as ray casting [Bolt, 1980], flashlight [Halliday and Green, 1996], aperture or image plane, virtual hand metaphors such as classical virtual hand, "gogo" [Poupyrev et al., 1996] or "indirect gogo".

Relevance with Enactive interfaces

For all metaphors (navigation, selection and manipulation) an adequate feedback is essential for acceptance by the user. As metaphors are used to explicitly copy previously learned knowledge (iconic, symbolic or enactive) to the new situation, it is necessary to provide sufficient feedback corresponding to the feedback expected from the former knowledge. Imagine for instance a metaphor

for exploring an object that mimics the rotation of ball or a miniature globe on a stand. In the real world, the user can rotate the ball, receiving direct visual feedback, but also receives even more direct haptic feedback of the ball and its rotation, and of the proprioceptive feeling of the movement. If we want to transfer this (enactive) knowledge (of looking at different sides of a ball), we have to provide similar feedback in the metaphor.

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RELATED ITEMS

COMPUTER GRAPHICS
INTERACTION TECHNIQUE
MULTIMODAL (MULTISENSORY) INTEGRATION,
IN TECHNOLOGY
MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION

RELATED DOCUMENTS

El_HCI_Metaphors_DeBoeck.pdf

MIND, MODULAR THEORIES

Elena Pasquinelli [INSTNICOD]

The correct development of enactive interfaces is highly correlated with the correct understanding of mental processes, in particular of processes related to perceptual and motor behaviours.

One influent theory of mind functioning – the modular theory of mind - presents the cognitive architecture as structured into vertical systems: the modules that are deputed to the computational transformation of the incoming inputs into representations; the representations are thus offered to the central part of the cognitive system, which is not modular, and then transferred to the modules that are deputed to the output, such as linguistic and motor modules [Fodor, 1983].

The input or perceptual modules are domain specific, their action is mandatory, the central processes have access only to their final issue and they are encapsulated.

All these characteristics define the independence of the input systems from the action of the central cognitive processes; in particular, the encapsulatedness indicates that the action of perceptual systems cannot be influenced by the action of the central processes.

Perceptual illusions such as the Mueller-Lyer are cited in order to illustrate the fact

that some of the general information at disposal is inaccessible at least for some of the perceptual mechanisms

However, other illusions, such as the golf-ball illusion, provide evidence that certain perceptual phenomena can interest only subjects that are in possess of specific knowledge or skills. Hence that knowledge and skills can influence the perceptual outcome. There is also evidence that perception depends on motor-related capacities (as shown by illusions produced by the projection of laws of biological movement into the perception of dynamic events, or Viviani illusions).

The encapsulatedness of perceptual processes cannot hence be generalized. This fact has pragmatic consequences upon the design of enactive mediated experiences because it shows that the perceptual contents of the experience vary not only in relationship with the stimuli, but also in reason of the user's past experiences, knowledge, skills and motor competences.

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RELATED ITEMS

COGNITIVE SCIENCES
COMPUTATIONAL PARADIGM
ILLUSION
REPRESENTATION

MOTION CAPTURE

Damien Couroussé [ACROE&INPG]

Contributors: Ronan Boulic [EPFL]

Motion capture systems have mostly been developed to record the movements performed by human beings. The main use of these systems is in computer animation, for the creation of animated characters in video games or in movies, but these systems are

used too for therapeutic purposes or for professional sportsmen/women.

The measure of the movement is generally performed thanks to sensors that are fixed on the body of the performer, or thanks to markers, which position in space is easily discriminated from environment by the sensing system. Position and orientation of each of the sensors is sampled over time, and can be obtained in a three-dimensional space immediately after the measure, or after post-processing.

The measures obtained can feed computer models for the generation of the movement of a synthesized character. However motion capture data are seldom used directly. Most of the time they are processed to recover the postural state of the underlying skeleton. Errors can be introduced due to the deformation of soft tissues between the markers and the skeleton bones [Menache, 1999].

Various technologies are used for motion capture.

Optical systems.

Optical systems are largely used in motion capture applications. They exploit infrared camera with either passive reflective markers, or active LED markers. Nowadays most professional systems for the analysis of human movement are optical systems with passive markers. Systems with active markers are more recent and tend to be more and more adopted.

Magnetic systems.

This solution is similar to optical systems, but the sensors are sensitive to magnetic information instead of light information. The main advantage of this solution compared to optical systems is that the capture of movements is still possible even if one marker is visually occulted from the sensor by a part of the actor's body or by another actor. However, this solution is not as widely used in motion capture as the two first ones.

Exoskeletons.

The actor is equipped with a light exoskeleton attached to its body and that will follow its movements. Most of the time, sensors fixed on the exoskeleton directly record the angles of the articulations. Data processing allows for the reconstruction of the position of the limbs of the actor from the angles measured.

Video-based systems.

The movement of the actor is extracted from the analysis of the image and is performed by a computer either after performance, or in real-time during performance. This solution is costly in terms of computational resources especially for real-time applications, but allows avoiding the use of markers on the actor, and can lead to several other uses (for example shape recognition). This technology is also widely used by people working especially on the animation or motion of human faces. The expression motion tracking is mostly used in the field of computer vision, where the video stream from one or more video cameras is the input data. In this context many alternate input data types are exploited to obtain a higher precision and/or performance [Moeslund and Granum, 2001].

Other systems have been developed for very specific uses (thus very limited), but which cost is limited as compared as the technologies cited above. During some time, it had been possible to buy puppets representing faces of the character to animate, equipped with a small control panel connected to a computer, which is providing control on the face's motion. The user can directly manipulate the puppet, which, combined with pre-programmed reactions of the puppet, will create a realistic animation. For example, if the user moves the mouth of the puppet, the computer will make moving the eyes and the cheeks of the puppet, thus providing a realistic facial movements and expressions. This kind of motion capture

system seems no longer to be commercially available currently.

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RELATED ITEMS

DEGREES OF FREEDOM IN HUMAN MOVEMENT
GESTURE AND MOTION (ENCODING OF)
GESTURE, EXPRESSIVE
HAPTICS, HAPTIC DEVICES
INTERACTION, FULL BODY

MOTION CONTROL, HIGH-LEVEL

Schubert Carvalho [EPFL]
Ronan Boulic [EPFL]

In virtual reality, high-level motion control is understood as the cognitive process that manages how high-level abstract information (e.g., walking fast to take the bus) will be transformed in complex coordinated movements (gaze, movement). Hence, high-level motion control relates very much to computational theory of motion control [\rightarrow MOTOR CONTROL], which supposes that a “motor program” is responsible for an ordered sequence of movements. According to this theory, the mental signals originate in the cortex of the brain and pass through deeper cerebral centers and the spinal cord before they reach muscle. Specialized sensor cells continuously feed information about joint and muscle position and movement back to the brain and spinal cord, where the motor signal can be modified to produce smooth, coordinated muscle contractions necessary for complex movement [Jessica & James 1994].

In the framework of virtual reality interactions where real-time interaction with intelligent virtual characters is important, a simpler abstraction level is necessary because simulating the high level motion control in detail is too time consuming. Such an approach allows the system to be responsive to the user's actions, a key requirement for interactions where information through motion is the main channel of communication.

The high-level control paradigm used in virtual reality systems focuses mainly on a small set of behavioural variables. These intuitive parameters (e.g., height of a jump can be easily exploited to provide new motions derived from the same class of jump motions). This space of behavioural variables is called the latent space in which independent variables can be controlled, resulting in the production of synergistic solutions in the motor-level space. The latent space has an important property: it encloses the key aspects of a specific class of motions. Variables from the latent space may be [Boulic & al 2004, Grochow & al 2004, Glardon & al 2006]:

- explicit when built in a procedural model (e.g. walking speed, angular speed of a walking motion model);
- implicit when built through recent machine learning approaches (i.e. they cannot be qualified by an intuitive property of the associated model but their small number eases the control process).

One can note that the main stream as for character animation, including high level motion control, relates to the motor theory of human motion. The seeding of computer graphics/virtual reality models by more recent theories of motion control that are closer to the enaction way of thinking (e.g.: self-organisation theory), is still in its infancy today (example: [Luciani&al, 2006]).

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RELATED ITEMS

COMPUTATIONAL PARADIGM
INTELLIGENT CHARACTERS
MOTOR CONTROL

MOTOR CONTROL

Julien Lagarde [UM1]

Motor control is a field of research on human and animal movement that integrates insights from biomechanics, physiology, neurophysiology, neuroimaging, and experimental psychology. Broadly speaking motor control is a part of neuroscience, with research directions focusing mainly on behavioural data, and others directions integrating also physiological (e.g., EMG: muscle electrical activity) and brain measures (e.g., EEG, FMRI, MEG, local field potential, single cells recordings). Issues dealt with in the motor control field cover movement trajectory formation, regulation of movement, and coordination, the three being related. Motor control involves perception of the body, of the environment, in interaction with generation and control of movement.

There are two main theories about motor control: a computational theory (Wolpert et al, 1995), and a self-organization theory. The

former focused on explanations calling for an important role of memory in the generation and control of movement, while the later emphasizes that the stability of the behaviour has to be studied first. One key concept of the former is the motor program, a set of commands sent by the cortex to the muscles to generate an ordered sequence of movements. The motor programs are stored in memory. The self-organization approach, using tools from (non linear) dynamical systems and synergetics (Haken, 1977), emphasizes generic dynamical properties of behaviours that relate to the underlying architecture (networks of non linear couplings between components) and symmetries of the system and can be readily addressed with observable quantities representing a functional level. A paradigm shift as been visible in that field when the self-organization approach found solid experimental ground (see Kelso, 1995) in dialog with modelling (Haken et al, 1985) that led to totally original predictions later verified. Other approaches exists that seek for a middle ground, making few assumptions overlapping with the computational approach but taking care of material elements, whether biomechanical or physiological, like the mass-spring model, the equilibrium controls models like the alpha model (Polit & Bizzi, 1978) or the lambda model (Feldman, 1980).

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RELATED ITEMS

COGNITION, DYNAMIC SYSTEMS APPROACH
COMPUTATIONAL PARADIGM
COMPLEXITY IN HUMAN MOTOR BEHAVIOUR
DYNAMIC SYSTEMS
INTERACTION, FULL BODY
MOTION CONTROL, HIGH-LEVEL
PERCEPTION, MOTOR THEORIES OF

MOVEMENT, CONCRETE AND ABSTRACT

Elena Pasquinelli [INSTNICOD]

It is possible to make a distinction between two types of movement, depending on their characteristics and on the intention by which they are sustained [Merleau-Ponty, 1945]:

- Concrete movements are bound to the real, actual situation. In this sense they are reactive, or perceptually guided.
- Abstract movements allow the performer to act freely and in a creative manner. The action is not elicited by the present stimuli but by a projective function, and they have a productive character.

This distinction is significant for the design of interfaces based upon action and perception because it permits to identify different ways in which perception and action can interact.

First, following this distinction it seems possible that proposing a certain perceptual experience will allow to predict the performance, on the side of the perceiver, of a certain number of concrete movements that are strictly related to perception. Not only in the sense that perception serves as a guide for movement and appropriate action, but also in the sense that perceptual contents can work as a sort of constrain upon subsequent action.

Evidence from the study of haptic perception, confirms the existence of couplings between action and perception. On one side, the execution of certain specific actions (exploratory procedures) will produce better

results on the extraction of certain specific haptic properties (texture, shape or other), rather than on others. On the other side, the intention to perceive a certain haptic quality will drive the execution of specific movements [Lederman & Klatsky, 1993].

Second, the distinction of concrete and abstract movements seems also to correspond to the existence of two distinguishable motor intentions: on one side the actions that are guided by the intention of knowing and on the other side the actions that are guided by the intention of reaching [Merleau-Ponty, 1945].

The dichotomy between the intention of knowing and the intention of reaching has been developed by [Milner & Goodale, 1995] in the case of visual perception.

It is asserted by [Milner & Goodale, 1995] that the function of vision is not bound to the perception of the world; vision also provides control over movement. The authors argue that two types of visual behaviour can be distinguished both on functional and on anatomophysiological basis. Hence it is possible to speak of two systems for vision: vision for action and vision for perception, as associated to different pathways in the brain. The two visual systems are anatomically associated with two broad groups of projections that have been identified in the macaque monkey brain by Ungerleider and Mishkin in 1982 as the ventral and dorsal streams.

The two groups of projections both originate in the primary visual area: the ventral stream eventually projects to the inferior temporal cortex, and the dorsal stream projecting to the posterior parietal cortex. It seems likely that the human brain may involve a separation into ventral and dorsal streams similar to that seen in the monkey.

Ungerleider and Mishkin argued that the two streams of visual processing play different but complementary roles in the perception of incoming visual information: the ventral stream plays a critical role in the identification and recognition of objects

(what); the dorsal stream has a role in the localization of those same objects (where). Lesions of inferior temporal cortex of monkeys' brain produce in fact deficits in the ability to discriminate between objects on the basis of their visual features but did not affect their performance on a spatial localization task; lesions of the posterior parietal cortex produce on the contrary deficits in the spatial task but do not affect object discrimination.

According to [Milner & Goodale, 1998] the distinction stands between perception on the one hand and the guidance of action rather than between sub-domains of perception.

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RELATED ITEMS

ERGOTIC/EPISTEMIC/SEMIOTIC FUNCTIONS
 GESTURE, EXPRESSIVE
 LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL
 APPROACH
 PERCEPTION, MOTOR THEORIES OF

MULTIMODAL (MULTISENSORY) INTEGRATION, IN COGNITIVE SCIENCES

Julien Lagarde [UM1]

Does information need to be integrated?
 How can it be done? What elementary in-

formation are integrated to give rise to what higher order "information", which must be functionally, and behaviourally relevant?

Here we emphasize the relational nature of multimodal functioning. In multimodal environments, the functionally relevant information is provided by relations among sensory modalities. The information, specific to the task, is considered a function of different quantities (candidate could be time remaining before an event, position, angle, distance, mass, velocity, direction, depth, elasticity etc) each provided by so called specific modalities. The behaviourally relevant information is thus not specified by only one sensory modality. Sensory integration can be acquired by learning, and later extremely well optimized, by exploration of the consequences of perceptual movements in the environment the coupling between environment variables and movement variables (control laws).

One way of studying multisensory integration is to assume a "sensory weighting model". Several versions exist and each of them addresses the question of how weights are determined. Some of these models view multisensory fusion as a constant-weight, linear (or approximately linear) process; that is, the weighting of sensory inputs is constant (or approximately constant) within a given sensory condition. (e.g. Borah et al., 1988; Gusev and Semenov, 1992; Kuo, 1995; van der Kooij et al., 1999, 2001; Kiemel et al., 2002). A number of these (e.g., Gusev and Semenov, 1992, Kuo, 1995, van der Kooij et al., 1999) have proposed a Kalman filter (or an extended Kalman filter) to model multisensory fusion. Linear weighting rules have been showed to subservise many phenomena in the domain of perception and action, notably because all sensory systems normally provide congruent information about a specific physical variable (e.g. self-motion, posture or the shape of an object). However, various studies have reported evidence that the nervous system processes multisensory information in a non-linear fashion (e.g. Crowell et al., 1998; Mergner et al., 2000; Jeka et al., 2000; Oie et al., 2001; Lambrey et al.,

2002; Oie et al., 2002; Hillis et al., 2002) and that it was non specific to situations of large changes in sensory stimulus amplitude (Peterka and Benolken, 1995, Oie et al., 2001). For example, some authors, investigating the combination of touch and vision for postural control in humans, have suggested that multiple sensory inputs are dynamically re-weighted to maintain upright stance as sensory conditions change (Oie et al., 2002). The re-weighting hypothesis makes the prediction that changes in postural response in different sensory conditions should be due to changes in sensory weights (i.e., increasing the weight to certain sensory inputs while simultaneously decreasing the weight to others). Simultaneous re-weighting of more than one sensory input has been rigorously demonstrated in the Oie et al.'s (2002) experiment. Their results support the hypothesis that it is sensory weighting and not the control strategy (i.e., changes in stability parameters), which changes across sensory condition. Indication of simultaneous re-weighting had been already mentioned in previous reports (Peterka and Benolken, 1995) as well as in recent experiment on body turns reproduction (Lambrey and Berthoz, 2003).

Sensory integration can be looked for in the human brain, and can be related to particular brain rhythms and phase synchronization between distant segregated areas, as shown by EEG data (Hummel & Gerloff, 2004). From the recording of cells in the cat superior colliculus (SC), Stein and Meredith (1993) proposed a model of multisensory integration at the level of a single neuron. The SC plays a major role in transforming sensory signals into attentive and orienting behaviours (eye, head, and gaze saccades). This structure is impressive in the multiplicity of sensory modalities represented within it and the widespread areas of the nervous system that it affects directly through the activity of its output neurons. Many SC neurons have multiple sensory and motor properties and are involved in a variety of different circuits and functions. Sensory (essentially visual, auditory and somatosen-

sory) and motor representations are distributed in maplike forms. One could think that these maps function in parallel, with no interaction, even if many neurons are involved in different maps as they respond to different modalities. However, since the different sensory maps in the SC are composed of many of the same neurons, it may be more appropriate to think of them as components of a supramodal, or integrated multisensory map, rather than three parallel independent maps.

Stimuli occur at various positions in space and time and the brain must create perceptual order to produce an integrated, comprehensive assessment of the external world. In large part, this is accomplished by attending to some complexes of stimuli and ignoring others. At the neuronal level, Stein and Meredith have found that some stimulus combinations produce significant increase in neuron activities over unimodal responses: this is called response enhancement. Therefore these combinations become more salient. On the other hand, some combinations produce the opposite effect: neuronal depression. This enhancement or depression in activity is based on factors that generally signal the presence or absence of a meaningful relationship among the stimuli. For example, stimuli that occur at the same time and place are likely to be interrelated by common causality and to produce enhancement, while those that occur at different times and/or in different places are unlikely to be related and will produce depression (or no interaction).

The notion of integration of inputs from different modalities thus implies that the result of this integration process is more than the simple co-existence of linear sum of their individual product. How the notion of integration relates to intermodal perception and intermodal control of action remains an open question. Stoffregen & Bardy (2001) have suggested that inputs from *different modalities may not have to be "integrated" at all* (at least in the traditional cognitive sense) because cross-modal, between-energy, stimulation convey

information about the animal-environment system that are directly accessible [\rightarrow ARRAY, AMBIENT ENERGY]. Along the same line the notion of crossmodal integration is a hypothetical integration of multiple sensory modalities into a coherent cognitive experience. Such integration is required if and *only if* we accept the classical assumption that multisensory perception consists of a set of distinct processes (e.g., vision, hearing) whose outputs are compared within the nervous system. If perception consists of the pick up of patterns in the global Array (Stoffregen & Bardy, 2001), then crossmodal integration is not needed; the stimulus itself is integrated across forms of ambient energy.

A complementary view states that understanding multisensory integration for adaptive behaviour has to be related to the dynamics of behaviour, i.e. its stability properties (Lagarde, Kelso, 2006). Following that line integration means embedding into a stable coordinative structure or coordination pattern, which is characterized by qualitative dynamics, which can be multistable, monostable, coherent, or disordered (but stable), and generically include phase transitions (bifurcations) with instability when key parameters are changed. In such framework it is clear that the organization that characterizes the so-called multisensory integration can change and also can break.

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RELATED ITEMS

ARRAY, AMBIENT ENERGY
 INTERFACE, MULTIMODAL / MULTISENSORY
 MULTIMODAL (MULTISENSORY) INTEGRATION,
 IN TECHNOLOGY
 PERCEPTION, DIRECT APPROACHES: THE
 ECOLOGICAL APPROACH
 PERCEPTION, DIRECT APPROACHES: THE
 SENSORIMOTOR APPROACH

MULTIMODAL (MULTISENSORY) INTEGRATION, IN TECHNOLOGY

Giovanna Varni [DIST]
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As explained in the two items multimodality [→MULTIMODALITY, IN COGNITIVE SCIENCES] and [→MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION], the concept of modality has (at least) two sides, depending on the domain in which it is defined (typically cognitive sciences and human computer interaction). The current item, though written in the framework of technology and system design, uses mainly the meaning of cognitive sciences: a modality is understood as a perceptual modality, and multimodality is understood as multisensory.

In cognitive sciences, the idea that the human brain realizes an integration of the various independent perceptual modalities was very developed in the framework of the computational theory of mind [→COMPUTATIONAL PARADIGM]. Since recently, however, in the field of enactive cognitive sciences [→ENACTIVE COGNITIVE SCIENCES_ 1&2], and especially under the light of the ecological approach to perception this idea has been criticized [→MULTIMODAL (MULTISENSORY) INTEGRATION, IN COGNITIVE SCIENCES].

In technology, for the designers of systems that use at the same time images, sound, and gestures, ensuring a coherent perceptual experience for the user is a major aim. One can note that only a couple of technological works, for example within the Enactive Interfaces NoE, aims at approaching this question by using the recent concepts offered by Enaction. Hence, for engineers, the idea of a multimodal integration in the human brain is still very vivid. It is also, at least partially, operational. Indeed, in front of the

unity of human perception, the machine offers only multiple transducers, each of which addresses a unique human sensorimotor modality. Naturally, the idea that these modalities are “integrated” by the human brain in a coherent perceptual experience appears to be helpful.

This being said, given the importance of this approach today, this item reviews shortly how the idea of multimodal integration is used in the framework of traditional human-computer interfaces (HCI), especially to help in the design of multisensory systems and interfaces [→INTERFACE, MULTIMODAL / MULTISENSORY] (although such an approach does not match well the Enactive approach in cognitive sciences).

In HCI and computer modeling, multimodal integration refers to two technological research areas according to whether the focus is on designing a system to be used by humans, or on designing a system able to mimic human sensory aptitudes – especially as for the “integration” of streams of various sensory signals.

How to let a user realize multimodal integration

Sarter [Sarter, 2006] reports a set of design guidelines regarding the presentation of multisensory information. More specifically, this study focuses on the following four issues.

- selection of modalities.

This first step is very crucial because the use of multiple modalities is not always needed, but its employment is strictly correlated to a large number of factors such, for example, environmental constraints and types of tasks. Furthermore, as referred also in [Spence, 2003] “*the decision to stimulate more senses actually reflects a trade-off between the benefits of utilizing additional senses and the costs associated with dividing attention between different sensory modalities*”.

- mapping of modalities to tasks and types of information.

Once those modalities have been chosen, one needs to find natural relations between them, the tasks at hand, and the informative content. By exploiting different modalities, it is possible to convey the same information, creating redundancy or different modalities for different information.

- combination, synchronization and integration of modalities.

The previous step implies considerations about spatial and temporal combination and synchronization of the sensory channels involved in the interaction.

One needs to take into account that even if signals for various modalities are presented simultaneously, this synchrony does not imply necessarily simultaneity in perception. For instance, in cases of auditory-visual interactions, it can be observed that there is a maximum effectiveness when auditory event happens before the visual event (the dimension of the time window of stimulus presentation is variable). As referred in [Oviatt, 2002] *"the empirical evidence reveals that multimodal signals often do not co-occur temporally at all during human computer or natural human communication. Therefore, multimodal system designers cannot necessarily count on conveniently overlapped signals in order to achieve successful processing in the multimodal architectures they build"*.

- adaptation of multi-sensory presentation to accommodate changing task context and circumstances.

Flexibility to environmental changes and user skills is a basic requirement for any system using multiple modalities. Several methodologies and strategies can be adopted to switch between modalities.

How to model the multimodal integration process?

The other approach that uses, in Technology, the concept of multimodal integration is research on novel methodologies for building biologically inspired systems able to integrate streams of various sensory signals (coming

from a camera, a microphone, etc.). In this case, the interest on the concept is shifted directly from user to machine. The main goal is to design systems reflecting as much as possible the (supposed) skill of brain in processing and merging together perceptual cues afferent by different sensory modalities. Such a goal, in fact, is not only interesting for the systems it leads to, but also because the designed models of multimodal integration are, in returns, interesting in the framework of psychology.

As cited in [Boda, 2004], there are currently two architectural metaphors helping to build such systems and interfaces performing integration, according as the instant of fusion process: early fusion and late fusion. In both cases integration is performed in one step only. Another interesting reference is [Coen, 2001]. The paper of Coen presents a possible methodology to design and build systems supporting cross-modal influence, that is "systems in which sensory information is shared across all levels of perceptual processing and not just in a final integrative stage". Classes of algorithms generally used to implement the integration step exploit, for example, neuronal networks and HMM (Hidden Markov Model).

To conclude, multimodal integration is still a very open issue, not only in neurophysiology, but also in technology, and the implementation of mechanisms of sensory fusion based on the mimesis of human and animal perceptual systems are useful to better understanding natural multisensory interactions.

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RELATED ITEMS

COMPUTATIONAL PARADIGM
ENACTIVE COGNITIVE SCIENCES_ 1&2
INTERFACE, MULTIMODAL / MULTISENSORY
MULTIMODAL (MULTISENSORY) INTEGRATION,
IN COGNITIVE SCIENCES
MULTIMODALITY, IN COGNITIVE SCIENCES
MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION

MULTIMODAL (MULTISENSORY) INTEGRATION: THE BINDING PROBLEM

Elena Pasquinelli [INSTNICOD]

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The fact that natural perception is usually multimodal (events of the world activate multiple sensory modalities) and the consequent development of multimodal interfaces [→ INTERFACE, MULTIMODAL / MULTISENSORY] raises the problem of how complex multimodal perceptual units are formed. The possibility is described of intersensory conflicts [Welch & Warren, 1981] and of illusory conjunctions where wrong associations of features are realized depending on the perceptual context [Treisman, 1996]. The problem arises then of how information about separate features of objects is combined, thus giving rise to correct or incorrect combinations. The problem has received the name of binding problem.

As a matter of fact, the binding problem arises only when certain theoretical assumptions are made about perception. Specifically, the binding problem is an inevitable consequence of the assumption that perception is composed of different, parallel sub-systems for the detection of different properties (for example, the concept of distinct sensory modalities). In this case, independently sensed "properties" have no coherent relation to one another; coherence must be generated internally, that is, through processing. How this internal processing might operate is the crux of the binding problem.

Within this framework, solutions for the binding problem have been identified by different authors in the existence of neural spatial and temporal mechanisms [Crick & Koch, 1990] [Stein & Meredith, 1993] or of attentional mechanisms [Treisman, 1996].

However, under theoretical assumptions that do not consider sensory modalities as separate systems (as in the ecological approach to perception), properties do not need to be bound together following to their extraction, hence, there is no binding problem. The assumption is made that perception is based on sensitivity to the global array [Stoffregen & Bardy, 2001] [→ ARRAY, GLOBAL]. The necessity of internal mechanisms can also be undermined by the recourse to external connections between action and perceptual consequences in different sensory modalities conceived as different types of sensorimotor contingencies [O'Regan & Noe, 2001] [→ PERCEPTION, DIRECT APPROACHES: THE SENSORIMOTOR APPROACH].

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RELATED ITEMS

ARRAY, GLOBAL
 CLASSIFICATION OF PERCEPTUAL MODALITIES
 COHERENCE OF PERCEPTUAL EXPERIENCE
 INTERFACE, MULTIMODAL / MULTISENSORY
 MULTIMODAL (MULTISENSORY) INTEGRATION, IN
 COGNITIVE SCIENCES
 MULTIMODALITY AND ENACTION
 PERCEPTION, DIRECT APPROACHES: THE
 SENSORIMOTOR APPROACH

MULTIMODALITY, IN COGNITIVE SCIENCES

Julien Lagarde [UM1]

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Dependent on the discipline, slightly different definitions can be found of multimodality.

Literally, “multi” refers to more than one and the term “modal” may cover the notion of modality as well as that of mode:

- Modality refers to the type of communication channel used to convey or acquire information. It also covers the way an idea is expressed or perceived, or the manner an action is performed.
- Mode refers to a state that determines the way information is interpreted to extract or convey meaning.

Apart from this, each scientific branch can distinguish its proper work describing the meaning of multimodality.

In this definition we will elaborate the cognitive sciences point of view on multimodality; see also [→ MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION].

In the context of the human sciences, a modality is often defined as a sensory modality: a (sensory) modality is a perception via one of the three perception-channels (visual, auditive, tactile) [Charwat, 1994]. However, as this definition lacks generalization considering just three perception channels, it can be more precise considering more senses, such as vestibular, besides the three cited. [Silber-nagel, 1979]

In a multimodal system, there are multiple senses, but at the same time there is coordination because of interactions between these multiple senses. Each sense possesses particular properties relevant when considering their collective merging, required for the efficient accomplishment of goal directed behaviour.

Some senses are faster than others, for instance they may allow faster simple reaction times, and some senses provide, better than others, control of behaviour when spatial accuracy is required. Despite these differences, adaptive behaviour rests on the coordination between the senses and with movement. This coordination is reflected by a higher order organization, which can be described by relational quantities that capture the pattern formed by the interactions. This is analogy to more general approach of coordination dynamics. The actual relevant information is at the level of the coordination; this information is created by the interactions in a specific, goal directed behaviour, context, and is not separately “contained” in individual components. In some case it is defended that some degree of redundancy exists between the information made available by each modality, the coordination may then be considered as probabilistic, to make the behavioural outcome (be it a judgment, a movement) more robust, meaning more resistant to perturbation, intrinsic or environmental fluctuations (variability) and noise; in other cases the focus on the relation is made directly explicit by the task at hand: for instance a judgment of simultaneity between a visual flash and an auditory beep calls for information about a relation. One can specu-

late that the coordination may be located at different levels, between brain areas if the relation is restricted to redundancy, or at two levels both between brain areas and between more macroscopic and behaviour related quantities for non redundant relations. Anyway one could argue that the high order level has to be rooted in some components, or lower order levels. Then the coupling has to come from somewhere.

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RELATED ITEMS

COGNITIVE SCIENCES
 INTERFACE, MULTIMODAL / MULTISENSORY
 MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION
 MULTIMODALITY AND ENACTION

MULTIMODALITY, IN HUMAN-COMPUTER INTERACTION

Joan De Boeck [UHASSELT]

Contributors: Barbara Mazzarino [DIST]

In literature on Multimodal Systems, it is notable that nearly all authors have their own usage of the basic terms in this domain. Dependent on the discipline, slightly different definitions can be found.

Literally, “multi” refers to more than one and the term modal may cover the notion of modality as well as that of mode.

- Modality refers to the type of communication channel used to convey or acquire information. It also covers the way an idea is expressed or perceived, or the manner an action is performed.

- Mode refers to a state that determines the way information is interpreted to extract or convey meaning.

Apart from this, each scientific branch can distinguish its proper work describing the meaning of multimodality.

In this definition we will elaborate the HCI point of view on multimodality; see also [→ MULTIMODALITY, IN COGNITIVE SCIENCES].

In the context of enactive interfaces, multimodality plays an important role, because all enactive knowledge that we acquire throughout our live, learned by doing, is stored in our brain as motor-responses to multimodal stimuli: visual, aural and haptic feedback of our actions. For instance, imagine a pianist who should play piano without the feedback when actually pressing a note.

From the HCI point of view, a modality is considered as a representational modality, as defined by [Arens and Hovy, 1990]: “*a (representational) modality is a single mechanism by which to express information. e.g. spoken and written natural language, Tables, forms, maps, [...]*”.

Hovy also defines other important terms such as channel, medium (having similarities with a sensory modality) and exhibit.

From this point of view we can say that a multimodal system strives for meaning [Nigay & Coutaz, 1993] supporting communication with the user through different modalities such as voice, gesture, and typing [→ INTERFACE, MULTIMODAL / MULTISENSORY].

To achieve this meaning, it is also important to know the context in which the received data is interpreted. This refers to the mode as defined above. This makes that in a communication act, whether it is between humans or between a computer system and a user, both the modality and the mode come into play. The modality defines the type of data exchanged whereas the mode determines the context in which the data is interpreted.

Several attempts to develop taxonomies of input and output modalities can be found in literature; however none of them appears to be fully complete. In [Coomans & Timmer-

mans, 1997] a first version of an input-output taxonomy has been presented. One of the more elaborated and theoretically founded taxonomies are described in [Bernsen, 1994a] and [Bernsen, 1995b] for output modalities. In essence multimodal output is seen as a combination of several uni-modal outputs, where a modality is defined as a vector of five orthogonal properties referring to the definition of a (representational modality): a modality both can be linguistic or non-linguistic, analogue or non-analogue, arbitrary or non-arbitrary, static or dynamic and communicates via a certain medium such as the visual, haptic or auditory channel.

- Linguistic representations are based upon the systems of meaning we know from natural human language. A written text is an example of a linguistic representation.
- Analogue representations are called those pieces of information, from which the representation shares an analogy with reality. For instance, a picture is analogue, but the roman script is not.
- Arbitrary are those representations that are arbitrarily chosen. This is in contrast to the representations that cannot be chosen arbitrarily because they are widely known. Beeps can be arbitrarily, while spoken language is clearly not.
- A static representation can be decoded by the user in any order desired and as long as desired. A picture for instance is static, while a spoken phrase is an example of a dynamic representation.
- The media which are considered in this output taxonomy are visual, auditory and haptic, referring to a 'sensory modality'.

Based on this definition, all output modalities can be classified in a hierarchical structure. In [Bernsen, 1995a] the extension of the taxonomy to input modalities is proposed. This results in a similar structure in which in general the haptic channel has been replaced by a kinaesthetic channel. In his subsequent work [Bernsen and Verjans, 1998], the authors use this taxonomy to support multimodal interface design and make transitions

from the task domain to a human computer interface and make a well-considered choice between the available possibilities.

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RELATED ITEMS

HUMAN COMPUTER INTERACTION
INTERFACE, MULTIMODAL / MULTISENSORY
MULTIMODALITY, IN COGNITIVE SCIENCES
MULTIMODALITY AND ENACTION

MULTIMODALITY AND ENACTION

Annie Luciani [ACROE&INPG]

There exist several understanding and practices of multimodality that depend on the context. From these, how can we revisit the

notion of multimodality in the context of “Enactive systems”, “Enactive Interfaces”, “Enactive Interaction” “Enactive Knowledge” mediated by contemporary technological instruments and tools to analyze or to produce multimodal events?

Before the arrival of electricity, sensory phenomena were only produced directly by physical mechanical and optical objects. These phenomena – acoustical, optical, mechanical – were directly sensed by the human sensory channels.

Along with the arrival of electricity – and its more recent use in computers -, the notion of signal, derived from the design of electrical sensors and actuators, appears. Electrical signals, acquired by sensors (microphones, video cameras, sensors of mechanical phenomena such as forces, positions, velocity, etc...) or returned by actuators (loudspeakers, video displays, mechanical motors, etc...) aim at transducing sensory phenomena (acoustical pressures, optical flow, etc...) into electrical representations.

Such technological shifts produced an epistemological breakthrough.

Sensory events acquired by sensors or returned by actuators can be artificially superimposed before being sensed by the human sensory apparatus. Such dissociation / re-association was not possible before the arrival of the notions of signal, i.e. of the electrical representation (or transduction). It allows to create novel sensible associations such as in cinema and video arts. From a research point of view, it allows to explore experimentally, in a larger domain, what are the properties of the human sensory apparatus, extending widely human knowledge.

In such contexts, multimodality is used and understood as a post-superposition of sensory signals that can be objectively produced separately, i.e. by objective different objects or means. Most psychological experiments on multimodality, most Human-Computer multimodal interfaces, and most tools that create new signals (as for example, through

sound and image synthesis), are related to this type of methodology.

One of the main consequences is that such reconstructed situations are a priori not ecological, nor enactive. From an ecological point of view, having in mind that the sensory phenomena perceived by humans are necessarily produced by a physical object, the multisensory events produced by an object are not independent. They are correlated by the physical properties of the object that produces all of them: sound, images, visual motions, mechanical effects (forces, deformations, etc...). Subsequent fundamental questions could be: How and why the artificial reconstruction of multisensory events can address validly the human perception and cognition, and consequently the cognitive categorization process, built throughout all the experiences of the interaction between humans and the physical world?

The perceivable phenomena produced by a real object are not separable in the absence of specific sensing technologies. They are also holistic means to identify objects and are holistically linked to human actions. From an enactive point of view, if we want to be able to recover the genuine correlation between sensory phenomena produced by a real object in the context of electrical and digital technologies, then it is necessary to re-built this correlation artificially by implementing specific computer models, specific algorithms and specific inputs-outputs (sensors-actuators) relationships. In this direction, [Luciani, 1993] [Cadoz et al., 1984] developed the concept of integral or complete representation of instrumental situations with the computer.

In the context of Enactive Interfaces, the search for the recovery of interaction through a genuine sensory modalities, likely as in the real world, corresponds to a truly fundamental paradigm shift from “*multimodality to multisensoriality*” [Luciani, 2002]:

- from the sensory signals synthesis and recombination – in other words according

to a signal-based approach as mainly developed since the 50's until now.

- to the simulation of the underlying cause - in other words according to an object-based approach as started in virtual reality approach [Krueger, 1983] and continued with the instrumental paradigm approach.

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RELATED ITEMS

INSTRUMENTAL INTERACTION
INTERFACE, MULTIMODAL / MULTISENSORY
MULTIMODAL (MULTISENSORY) INTEGRATION, IN
TECHNOLOGY
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

N

NAVIGATION IN VIRTUAL ENVIRONMENT

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Contributors: Annie Luciani [ACROE&INPG]

Navigation is one of the most commonly applied tasks when interacting with immersive virtual environments [→ VIRTUAL REALITY AND VIRTUAL ENVIRONMENT]. Mostly, immersion focuses basically on the seeing (or hearing) sense. The related actions are thus spatial actions such as displacements of the own body itself: that 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 used in virtual environment navigation as well as in flight or driving simulators, landscapes or cities' navigation, etc. In such cases, the immersive situation seems to be natural and common.

Indeed, a good navigation metaphor is important for the immersive feeling in the virtual world, as it is one of the most commonly used tasks in any 3D environment [Satalich, 1995], as well as it is in our real existence. From our daily experience, we have built an intuitive understanding of navigating in a complex or large environment, such as a city. This makes that navigation consists of two main components: wayfinding and travel; the first preceding but overlapping the second in time. It may be clear that computer interfaces that want to exploit this enactive knowledge must fit to this mental model.

The two navigational components are [Bowman, 2005] wayfinding and travel.

1) Wayfinding is the cognitive process of defining a path through the environment to the desired location. It consists of four steps:

- Orientation: determining ones current position in respect to the target location
- Route Planning: choosing the route that leads to the destination, based upon ones mental models and route knowledge of the environment
- Route Monitoring: while traveling, constantly monitoring if the correct route is followed.
- Destination Recognition: recognizing when the destination has been reached.

2) Travel is the purely motor component of navigation. It is the task of moving from the current location to the destination location. Normally traveling should occupy as less mental overhead as possible, which is true for natural movements (walking, running) in the physical environment.

Basic correlated questions are similar when navigating in the real spatial world and in virtual or abstract worlds. Both of them raise the two following difficulties:

- to plan step by step the displacements to reach the goals;
- to memorize a spatial reference to locate at each time where we are and how we reach.

Nevertheless, some drastic discrepancies exist between navigation in real and virtual world. The most important of them is that in virtual environment, the human body does not move. 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 introduced. This transformation leads to the design of adapted metaphors and to study their effects on human's capabilities. One of them is related to the question of co-location [→ CO-LOCATION], widely discussed in research on perception [Jansson et al., 2004] [Wann et al, 1995] [Messing, 2004]. Furthermore, the immersive situation remains conceptually

problematic, because of the discrepancies between actions and perceptions when exploring and navigating large immersive virtual environments. From the point of view of action, it is a kind of teleoperation, and not a kind of navigation with egomotion: 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. From the point of view of seeing, it is an immersive situation in which the space is moving around the human body, as in egocentered perceived motion.

Such type of discrepancies between action and perception when navigating in large immersive virtual environments, leads to specific bottlenecks when designing enactive interfaces, one of them is how force feedback interaction can be introduced, as well as the metaphoric level as at the technical level?

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RELATED ITEMS

CO-LOCATION

IMMERSION VS. VIS-À-VIS

METAPHORS IN HUMAN-COMPUTER INTERACTION

VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

O

OBJECT PERCEPTION, ARGUMENT FROM ILLUSION

Elena Pasquinelli [INSTNICOD]

The development of enactive interfaces based on action and perception has the effect of bringing the attention on the functioning of perception. Since enactive interfaces have the aim of producing perceptual objects and meaningful perceptual interactions, a relevant problem is constituted by the problem of what counts as an object of perception.

An overview of different possible answers to this problem is presented here in relationship to the so-called argument of illusion, where the experience of reality is compared to the experience of illusions.

The argument from illusion (see [Ayer, 1955] for its classical formulation) can be schematized as follows [Dokic, 2004]: all experiences have an object, but the experience of illusions lacks a material object. The objects of experiences are all the same, both for illusory and veridical experience; therefore the objects of experience are not material objects.

The immaterial objects that are supposed to be directly perceived in illusory and non-illusory experiences are the sense-data. In the case of the stick that looks bent, for instance, the experience of the pretended illusion is assimilated to the experience of a delusion, which lacks of any reality. Thus, since no real object is perceived, but some kind of object must be, the existence of immaterial objects or sense-data is postulated.

[Austin, 1962] opposes two main criticisms to the argument from illusion. First, the argument from illusion is based on a wrong definition of illusion. Illusions are different

from delusions and from familiar mistakes and unusual perceptual phenomena. The class of illusions only includes public, reproducible and surprising phenomena such as the geometric illusions or the tricks of the magician. Second, it is not strange or surprising that an object that is in a certain way, looks in another, in special conditions. Thus there is no need for postulating special objects that are directly perceived: what we perceive are the ordinary things.

Different positions can be traced in respect to the argument from illusion that belong to different views of perception and illusions [Dokic, 2004]. The argument from illusion is defended by phenomenists and the indirect realists and it is rejected by three theories of perception: the disjunctive theory, the bipolar theory and the adverbial theory.

Phenomenism sustains that all we can perceive are sense-data and that perception does not regard objects that are external and independent from the perceiver.

According to indirect realism perception can only give access to sense-data, but reality is not limited to sense-data: the physical world exists and can be known because of the structural, causal relations between physical reality and sense-data.

The adverbial theory considers that the so-called objects of perception are in reality modifications of the verbs of perception, as adverbs are. Hence the distinction between veridical experiences and illusions depends on the fact that veridical experiences are appropriately caused by elements of the physical reality.

The bipolar theory considers that perception does not consist of the experience and of the intentional object only, but also of propositional contents of perception. Illusions and veridical experience can thus have the same content but not the same object (only veridical experiences have an object).

In the disjunctive theory of perception illusions and veridical perception are considered as two different phenomena. When one is fooled by the world one is not perceiving a

fact of the world, but he is just having a perceptual experience. Perceptual experiences, or the mental states that are described by the verb “having the perceptual experience that *p*”, can both be veridical or illusory; but the two states, are different in their essence, because only the first one has for object a state of the world.

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RELATED ITEMS

COMPUTATIONAL PARADIGM
EXTERNALIZATION, PERCEPTUAL
ILLUSION
OBJECTIVITY
PERCEPTION, DIRECT AND INDIRECT APPROACHES

OBJECTIVITY

Elena Pasquinelli [INSTNICOD]

Traditionally, objectivity is associated with independence of the (perceived) object relatively to the mental activity of the subject and with the justified distinction between the experience of the subject and the object of the experience.

[Proust, 1999] suggests to redefine the traditional approach to objectivity in terms of distality /proximality. An animal possesses an objective world when it is able of making reference not only to the proximal sensations provoked by a stimulus, but to the stimulus as distal, or to contrast an inner representing state and an external represented condition.

This capacity depends on a pre-condition: that the animal is able to evaluate its own representations and to correct them when faced with contrasting evidence in order to achieve veridicality. This structural pre-requisite seems to be related to the presence

of multiple sensory modalities. In fact, animals with different sensory modalities seem to possess specific mechanisms dedicated to the calibration-recalibration of the inputs: the inputs of one sensory modality are corrected when they are not spatially coherent with the stimuli of another sensory modality [Stein & Meredith, 1993]. Veridicality is hence equated an internal condition to the organism: the coherence between experiences of different sensory modalities.

Objectivity as externalization also resents of the active vs. passive character of the experience. Experiences with sensory substitution devices [Bach-y-Rita, 1982], show that external projection is the effect of active exploration of the environment, while in passive conditions the tactile pattern is perceived as a simple stimulation of the skin and recognition is impaired. Hence, it is asserted that successful experiences with sensory substitution devices are characterized by the projection of the experience in the external world.

However, an experience which is projected in the exterior is not necessarily true of the external world: illusions are perceptual experiences that are systematically projected distally and not experiences of proximal stimulations, but they are nonetheless considered as errors.

Other criteria must then be added and tests performed for ascertaining the truth and objectivity of an experience in mediated and non-mediated conditions. Two approaches to this issue have been proposed that have the advantage of not requiring the perceiver to step out from his own experience in order to ascertain its truth. Within these approaches objectivity depends on the structure of the experience itself or on the comparison between experiences of different subjects, but not on comparisons with the unexperienced world.

The first approach proposed by [Strawson, 1959] consists in equation of objectivity and unperceived existence. The main criterion indicated by [Strawson, 1959] for recognizing

objectivity (for establishing that an entity exists even when unperceived) is the possibility of *re-identification*: the possibility of re-identifying the object as the same object that has been perceived before the interruption of the perceptual experience. An event that exists even when it is not experienced by a perceiver can in fact be re-identified after an interruption in the experience. A special condition must be present for re-identification to be possible: the experience must be spatially organized, since it is the reference to spatial concepts (the fact of occupying a certain parcel of space) that allows the identification of an object as the same object.

The second criterion for objectivity is *intersubjectivity*, that is, the independence from the subject's judgement, validity for all subjects [Carnap, 1928]. [Davidson, 1982, 1984] proposes that assigning objectivity and truth is the necessary condition for interpreting and understanding other speakers in radical interpretation. In analogy with radical translation (translation of languages which meanings are not known at all to the translator), radical interpretation assumes the charitable position that the beliefs of the interpreted are globally true and consistent with his own beliefs (charity principle), in reason of the fact speaker and interpreter share the same world. Successful communication can hence be taken as evidence for an intersubjective, objectively valid world, and the verbal exchange about common experience can be considered to enhance the objectivity of the experience for the subjects.

In addition to externalization, re-identification and intersubjective communication should hence be considered as effective tests for objectivity in different mediated and non-mediated conditions.

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RELATED ITEMS

BELIEVABILITY_1&2
 COMPUTATIONAL PARADIGM
 EXTERNALIZATION, PERCEPTUAL ILLUSION
 MULTIMODALITY, IN COGNITIVE SCIENCES
 OBJECT PERCEPTION, ARGUMENT FROM ILLUSION
 PERCEPTION, DIRECT AND INDIRECT APPROACHES
 SENSORY SUBSTITUTION

OBJECTS' PROPERTIES, PERCEIVED

Bruno Mantel [UM1]

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Certain philosophical approaches consider that physical or mental objects possess properties, sometimes also called qualities. When perceiving an object a perceiver gets access to perceived properties [→ IDENTIFICATION OF OBJECT PROPERTIES], which are frequently divided into two classes: primary and secondary properties (the distinction traces back at least to Locke, see [Bullot, 2005]). In analytical philosophy, primary properties, also called intrinsic or categorical properties, refer to properties (such as shape or size) that can sometimes be perceived but whose existence does not depend on the mental states of the perceiver. Secondary properties, also called relational properties, refer to properties that can be perceived but whose existence is assumed by scientific knowledge to depend on the nature of the mental states of the perceiver.

The ecological approach to perception and action proposes a shift from the approaches discussed above. It hypothesizes that the properties of objects that we perceive in every day life are neither primary properties nor secondary properties, but are what we could call action properties or functional properties of objects [Gibson, 1977] [Gibson, 1979] [→ PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH]. In fact these properties, called affordances, are not only related and specific to the object but are object properties that are relevant for a given action, taken in reference to the individual properties that are relevant for the same action [Warren, 1984] [Michaels et al., 1981]. They are relational properties of the animal / environment system [Stoffregen, 2003], and as such, are as real as objects properties or as objects themselves. They are facts about the world and do not depend on the mental state of the perceiver for their existence. They provide individuals information about what actions are possible, effective and so on... [→ AFFORDANCES]. Whether that available information will be detected and picked up by individuals is another question which depends, among other things, on mental states.

This does not mean that we cannot perceive primary properties of objects (such as shape, etc.) if it is required by the task. This only means that these primary properties are not the basis for our everyday motor behaviour. As a consequence, this alternative view is particularly relevant when addressing human-human interactions or human-environment interactions, may these interactions be direct or mediated by an interface. This approach is even more relevant in the context of enaction and enactive interfaces which emphasize the necessary role of action in perception and its counterpart: the action-oriented grounding of perceptual activity (refer to external document for recommendations to designers).

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RELATED ITEMS

AFFORDANCES
 COMPUTATIONAL PARADIGM
 IDENTIFICATION OF OBJECT PROPERTIES
 PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH
 EXTERNALIZATION, PERCEPTUAL
 MULTIMODALITY, IN COGNITIVE SCIENCES
 OBJECT PERCEPTION, ARGUMENT FROM ILLUSION
 PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH

RELATED DOCUMENTS

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PERCEPTION AND VICARIOUS PROCESSES

Brice Isableu [UM1]

The theory of vicarious processes, applied to the framework of perception and control of spatial orientation, aims at investigating and modelling the conditions of emergence and disappearance of the between subjects variability observed at the multisensory integration or the reference frames selection levels [Reuchlin, 1978] [Ohlmann & Marendaz, 1991].

This theory first considers that inter-individual differences better reflect spatial referencing or sensory integration habits rather than being biological noise. The differential model of vicarious processes postulates that each subject:

- can gain access to the totality of the processes or physical reference frames useful to solve a given task,
- but that the probability of evocability of these processes or referents would be higher for some of them, leading each subject to build its own referents hierarchy (i.e., from the more frequently used or economic or generic...to the less).

The conditions of emergence and disappearance of the between subjects variability mainly depends about the importance of the constraints (either internal or external), which would orient the actor toward the selection of the most suitable processes [Reuchlin, 1978] or referents [Ohlmann & Marendaz, 1991] for perceiving and acting efficiently in the current situation. More precisely, in weakly demanding tasks several competing processes or reference frames of comparable efficiency could be selected, each of them producing equiefficient behaviour. In these

cases, redundancy of spatial referencing modes would be maximal and would generate the wide expression of the between subject behavioural variability. Conversely, it is likely that all the processes or spatial referencing modes do not have the same efficiency in order to solve very demanding tasks. Thus, in such cases the theory predicts that the wide expression of different modes of spatial referencing should disappear in order to engage the more reliable, the more suited spatial referencing mode to solve the task.

This theory seems to be rather reliable for explaining the evolution of the between subject differences, in some perceptual tasks (viz., embedded figure test, kopfermann figures...), which were reorganised by postural equilibrium difficulties.

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RELATED ITEMS

COMPLEXITY IN HUMAN MOTOR BEHAVIOUR
MOTOR CONTROL
PSYCHOPHYSICS

PERCEPTION, AMODAL

Gunnar Jansson [UPPSALA]

Perception has often in the past been contrasted with sensation and considered as some kind of combination of several sensations, an idea that is alive also today. It means that there should be some sensory correspondence to every aspect of perception. This thesis has been questioned by several authors in the Gestalt tradition. Koffka

(1935) referred to the perception of a table top extending behind a book on it but perceived as a full table top. He also discussed in this context the blind spot in the eye. If a cross is presented to an eye in such a way that the projection partially covers the blind spot, it is perceived as a full cross in spite of the partially missing sensation. Koffka thought these examples are cases of perception that has no direct correspondence in any specific sensation but is based on the whole stimulation.

Michotte, Thiès and Crabbé, (1964) described an amodal screen effect. It can appear in both static and dynamic contexts. An example of the former kind is an object partially covered by another. The covered object is seen as a complete object in spite of part of it being covered. A dynamic example is the continuous transformation when a circular object moves over an empty space and the leading contour stops while the trailing contour continues to move. This is perceived as the circular object being occluded by an edge in spite of lack of any sensation of part of the object. Another dynamic example is the tunnel effect (Burke, 1962), which is the perception of a continuously moving object when the motion sensations consists of two successive distinct motions with an empty space between the end of the first and the beginning of the second. The object is seen to move in a tunnel but there is no sensations corresponding to the object when it is in the tunnel. Michotte and Burke (1962) thought that these phenomena are a kind of perceptual completion related to the Gestalt phenomena

Gibson (1966) preferred to call these phenomena sensationless perception and suggested that there is information, especially at edges, that can be detected by observers and form a basis for perception without any sensations. Among his examples is the perception of a 3D object in spite of only the 2D front of it being in view. When persons are moving in the environment an enormous amount of such events are happening. Surfaces are being covered and uncovered for

the moving persons and their perception consists of a world with objects from many surfaces that are often partially represented by sensations and sometimes totally covered by other objects. In the real world the surfaces are typically textured, which enhances the effect, especially together with motions of them on the retina.

A corollary for the rendering of virtual objects is that the design of the edges and textures are important for getting the wanted 3D perception.

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RELATED ITEMS

DEPTH, PROBLEMS OF RENDERING
 HAPTIC RENDERING OF VIRTUAL OBJECTS
 STABILITY

PERCEPTION, AS BAYESIAN INFERENCE

Elena Pasquinelli [INSTNICOD]

The Bayesian frame-work is a general formalism for specifying the information available to perceivers and for modelling perceptual inference [Knill & Richards, 1996].

The information about the world contained in a percept (for instance in an image) is characterized as a probability distribution.

This approach is based on the Bayes formula for calculating the posterior probability:

$$p(S|I) = p(I|S) * p(S) / p(I)$$

In the domain of visual perception, for instance,

- S represents the visual scene, such as the shape and location of the viewed objects;
- I represents the retinal image;
- $p(I|S)$ represents the likelihood function for the scene: it specifies the probability of obtaining the image I given a scene S . The likelihood function incorporates a model of image formation and also of noise;
- $p(S)$ is the prior distribution: it specifies the probability of different scenes occurring in the world, thus it formally expresses the prior assumptions about the scene structure;
- $p(I)$ is a normalization constant derived from $p(S)$ and $p(I|S)$ and represents the probability of occurrence of an image.

The posterior distribution $p(S|I)$ is thus the probability of the scene to be perceived as S , given the retinal image I , and taking into account: the probability of obtaining a retinal image I whether it is given a scene like S , the a priori probability $p(S)$ that a scene like S occurs in the considered parcel of world, the probability that a certain image I occurs in those world conditions and given the characteristics of human visual perception.

The Bayesian framework thus suggests that the probability of obtaining a certain percept is determined in part by the image formation processes, which include the noise added to the image coding process, and in part by the statistical structure of the world.

Noise has the effect of making the information provided by an image more unreliable, and spreads the likelihood function over a wide range of possible scenes.

This unreliability is partly corrected by previous knowledge of the environment, which has the effect of constraining the perceptual estimate of scene properties.

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RELATED ITEMS

COGNITIVE SCIENCES

PERCEPTION, AS BAYESIAN INFERENCE: MLE
METHOD

PERCEPTION, INDIRECT APPROACHES: THE
INFERENCE APPROACH

PERCEPTION, AS BAYESIAN INFERENCE: MLE METHOD

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Perception, the act of retrieving information about one's relation to the environment, is achieved by the mean of several modalities [→ MULTIMODAL (MULTISENSORY) INTEGRATION, IN COGNITIVE SCIENCES]. Assuming that these modalities operate as independent sensors leads to the necessity for explaining how modal information is integrated to yield a unique percept.

Some of the existing cognitive approaches of sensory integration claim that the nervous system employs probabilistic models based on

Bayes' rule [\rightarrow PERCEPTION, AS BAYESIAN INFERENCE] for processing sensory information during perceptual tasks and sensorimotor activities [Ernst et al., 2004]. This approach is based on the view that our sensors possess variability or noise, which consequently provides imperfect information about physical properties of an event (e.g., target location, hand displacements and direction, ball velocity and so on...), so we can only have an estimate of them. Combining information from multiple modalities could be a well-suited strategy to reduce the error of the estimate, thereby providing a much more reliable percept. Thus, a strategy based on Baye's law (Maximum-Likelihood Method - MLE), would allow reducing uncertainty by combining the statistical distributions of the individual channel estimates (e.g., visual and proprioceptive) while taking into account their degree of certainty. Moreover, measurements are combined together with prior knowledge to arrive at an estimate. This process would lead to the production of an estimate having a greater reliability than that based on individual inputs. To use a Bayesian strategy, the nervous system would need to represent the statistical distribution of the prior and the level of uncertainty in the sensory feedback. For example, Körding and Wolpert [Körding et al., 2004] showed that subjects both internally represent the statistical distribution of the task and their sensory uncertainty, combining them in a manner consistent with a performance-optimizing bayesian process. The nervous system also employs probabilistic models during sensorimotor learning even when the priors are multimodal. Interestingly, Ernst and Banks [Ernst et al., 2002] showed that weighting changes with the reliability of the signals. The weight can be changed from visual dominance when there was no noise added to the visual information (high reliability) to haptic dominance when there was a lot of added noise. However, limits of the MLE were also pointed, for instance, when multisensory stimuli are spatially or temporally incongruent. In these cases behavioural responses can

be significantly degraded [Frens et al., 1995] [Stein et al., 1988] and neural activity can be significantly depressed [Calvert et al., 2000] [Jiang et al., 2001].

Bayesian integration models provide nice predictions of the behavioural responses that occur when the relation between modal sources is changed, and could therefore be an inspiring source for multisensor computer perception. However, one can stress that by changing artificially the relation between modal sources, we lose the higher order relational information that existed between modal patterns, which possibly constituted the basis for behaviour in natural situations [\rightarrow INVARIANT, PERCEPTUAL].

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RELATED ITEMS

COGNITIVE SCIENCES
 INVARIANT, PERCEPTUAL
 MULTIMODAL (MULTISENSORY) INTEGRATION, IN
 COGNITIVE SCIENCES
 PERCEPTION, AS BAYESIAN INFERENCE

PERCEPTION, DIRECT AND INDIRECT APPROACHES

Elena Pasquinelli [INSTNICOD]

The claim that perception is direct consists in the argument that perception is a form of non-inferential awareness of the things we normally take ourselves to be aware of when we perceive.

Mental intermediaries such as sense data, impressions, appearances are thus refused to be the things we are directly aware of in perception.

The perceiver is instead directly aware of the world itself, and the world is accordingly very similar to what it seems like in perception (naïve or direct realism is connected to the direct approach to perception).

There exist a certain number of direct approaches to perception, including psychologists and philosophers.

Between the philosophers, the direct approach refuses the notion of sense data and of a general object of perception that would be common to illusory and non-illusory experiences. In particular [Snowdon, 1980-81] and [McDowell, 1982] adopt an externalist view of perception according to which perceptual experiences are constituted by the relation between the perceiver and an external object.

[Sellars, 1956] and [Strawson, 1979] too refuse the idea that perception might regard our sensory impressions: perception consists in the intentional experience of the world as being in this way or that.

In the domain of psychology, two main approaches to perception represent the direct view: the ecological approach introduced by [Gibson, 1966] and the sensorimotor approach of [O'Regan & Noë, 2001].

One of the arguments against the direct approach to perception is the so-called argument from illusion. Following the argument, the experience of seeing a really existing object and the experience of seeing an object that does not exist but is merely hallucinated are indistinguishable. Thus, a common entity must exist which is the object of perception in both cases: a sense datum. The real object enters the perceptual experience only as a more or less far cause of the perceptual process.

In the same vein, indirect perception approaches assert that when a round form is perceived from a generic viewpoint, an elliptical scheme is directly accessed by the visual system, so that the round shape of the object must be inferred as a result of conjecture and speculation.

In general, the problem of perceptual science committed with the indirect view is to explain how do we perceive what we do (i.e. a three-dimensional world) given the patterns of stimulation of the sensory organs. The main idea is that the brain actively constructs the perceptual experience through the intervention of inferential processes, thus affirming the paradigm proposed by Helmholtz of perception as unconscious inference [Fodor, 1981].

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RELATED ITEMS

COGNITIVE SCIENCES

ENACTIVE COGNITIVE SCIENCES_ 1&2

PERCEPTION, DIRECT APPROACHES: THE ECOLOGICAL APPROACH

Elena Pasquinelli [INSTNICOD]

The ecological approach to perception and action originated in the work of J. J. Gibson (see [Gibson, 1966]), who claimed that the perceiving organism and its environment form a system, and that perception is an achievement of the system; thus, the input is defined by the overall system, notably including the motor activities through which the organism enters in contact with the surrounds. No intermediary steps or representations are necessary in order to achieve perception.

To this effect the theory introduces the notion of ambient array. Ambient arrays are structured by specific animal-environment settings and constitute what is directly perceived. Ambient arrays are higher order properties, as the changing patterns of light that are typical of an animal approaching to an object or, vice-versa, of an object approaching to the animal: for instance, a global change in the pattern of light is specific of self-motion, local change against a stationary background is specific to object motion. The specific patterns of optic flow (the patterns of light structured by particular animal-environment settings, available to a point of observation) that are identified as relevant in guiding activity are called invariants. Invariants are what organisms directly perceive.

There is no space for knowledge in the direct picking-up of invariants.

The invariants an organism is sensitive to are not necessarily the ones the experimenter is expecting, the ones that are named in the linguistic description of the task (as the measurable weight and length of an object). As such, they must be discovered empirically. The muscular system for instance is sensitive to variations in the resistance an object opposes to being moved, and the invariant quantities (the inertia tensor) that can be individuated for describing this resistance appear to be well suited to explain all the phenomena of the dynamic perception of object, included the so-called illusions.

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RELATED ITEMS

AFFORDANCES

ARRAY, GLOBAL

COGNITIVE SCIENCES

ENACTIVE COGNITIVE SCIENCES_ 1&2

TOUCH, DYNAMIC

PERCEPTION, DIRECT APPROACHES: THE SENSORIMOTOR APPROACH

Elena Pasquinelli [INSTNICOD]

The direct approach to perception proposed by [O'Regan & Noë, 2001] and [Noë et al., 2001] [Noë, 2003] [Noë, Forthcoming]

[Noë, Commissioned] raises the problem of the recourse to internal mechanisms and representations as the problem of the consciousness of the perceptual object as a whole. As a matter of fact, the authors explain, when grasping an object or looking at it only a part of the object enters in direct contact with our sensors. Despite this limitation of the stimulus condition, we normally perceive (haptically or visually) the entire object and not an object with only its frontal part or its grasped part.

The problem of the presence or wholeness of the perceptual content also arises from the observation that the content of the perceptual experience is not given all at once. This is well shown by change blindness phenomena [O'Regan & Noë, 2001]: an observer is presented with a very detailed scene, say, a picture of Notre Dame de Paris; the vision is interrupted by a slight flicker and immediately reappears; even if a major change is made in the picture, the observer typically misses it, even if he can be looking directly to the change area. Thus, not all the components of a picture are directly and synchronously perceived. Nonetheless, the perceiver has a complete experience.

The authors refuse two main strategies for solving the problem of the consciousness of the perceptual experience as complete: on one side the suggestion that filling-in mechanisms are active in completing the partial experience with details that are added from the brain; on the other side, the suggestion that internal representations of the objects constitute the relevant knowledge which is recalled in order to complete partial impressions of the object and to experience the object as a whole. The second suggestion is strictly connected with the image of the perceptual system as based on inferential processes based on representational knowledge, that is, with the indirect inferential approach.

As an ability of exploration, perception does not happen instantaneously, but develops in time. This is the reason why, accord-

ing to the authors, even if the perceiver does not see all the details of a scene simultaneously, they can be present for him (be part of his perceptual experience) as details that one has the possibility of discovering during the scan of the image. Touching a part of the object is making the experience of the object as a whole because a simple shift of the hand allows the perceiver to enter in contact with the other parts of the object. The other parts are thus present to the perceiver as the necessary consequences of possible exploratory actions, given a certain group of sensorimotor contingencies.

The perceptual sense of presence of an object as a whole arises because the parts that are presently unsensed are nevertheless within reach, in ways that are known by the perceiver [Noë, Forthcoming].

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RELATED ITEMS

COGNITIVE SCIENCES
 ENACTIVE COGNITIVE SCIENCES_ 1&2
 SENSORIMOTOR
 SENSORIMOTOR CONTINGENCY OR DEPENDENCY
 SENSORIMOTOR THEORY

PERCEPTION, INDIRECT APPROACHES: THE INFERENCE APPROACH

Elena Pasquinelli [INSTNICOD]

The inferential approach to perception can be traced back to H. von Helmholtz's notion of perception as a process involving unconscious inferences: perception is only indirectly related to objects in the world; data signalled by the senses are fragmentary and often hardly relevant, so that perception requires inferences from knowledge to make sense of the sensory data. Indirect approaches to perception affirm that it is not directly the objects that we perceive, but intermediates. The inferential approach is a variation of the indirect approach: "*Following von Helmholtz's lead we may say that knowledge is necessary for vision because retinal images are inherently ambiguous (for example for size, shape and distance of objects), and because many properties that are vital for behaviour cannot be signalled by the eyes, such as hardness and weight, hot or cold, edible or poisonous. For von Helmholtz, ambiguities are usually resolved, and non-visual object properties inferred, from knowledge by unconscious inductive inference from what is signalled and from knowledge of the object world.*" [Gregory, 1997, p. 1121]

One of the most important applications of knowledge to perception regards the vision of scenes and object in a three-dimensional way. In the indirect perspective, in fact, three-dimensional vision is not straightforward, even if we normally perceive a three-dimensional world because the bottom-up information the visual system disposes of is just "*flat ghostly images in the eyes*" [Gregory, 1997, p. 1122]

To read reality from images is to solve a problem. And when the problem is quite difficult errors are to happen. Marr's researches about vision go into this same direction [Marr, 1982]

We can reconstruct the main argument for this position as follows:

- Stimuli are ambiguous (such as visual size) or insufficient for specifying object properties (such as for weight by sight).
- Nevertheless, the final percept is unambiguous and specified.
- Some process must have taken place which has solved the ambiguity and allowed specification of object properties.
- In addition to present information, the subject disposes of previously acquired knowledge about objects of the world.
- Knowledge can be used to disambiguate present stimuli and to specify incomplete information through a process of inference.
- Inference is a mechanism that allows the use of past knowledge for producing new knowledge, thus the final percept is the result of an inference based on the content of actual experience and the content of past knowledge.

As a consequence, errors might arise at different moments in the course of the inferential process.

The argument of the inferential approach has been contested at different levels.

As we will better see in what follows, the type of direct perception approach represented by Gibson [Gibson, 1966] and others (ecological approach) contests the first point, that is, the assumption that information is ambiguous or insufficient. As a consequence there is no need for additional, cognitive processes as stated at point three in order to obtain a coherent, informative final percept.

Points two and three are discarded by [O'Regan & Noë, 2001], who endorses another type of direct approach to perception and sustains that there is no need for internal mechanisms because the final percept is not complete and the coherence of the final percept is simply warranted by the unity of the motor-perceptual experience.

Finally, point five of the argument can be contested because inference is not considered

as the proper process at stake (as in the case of the application of Bayesian inference).

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RELATED ITEMS

COGNITIVE SCIENCES
ENACTIVE COGNITIVE SCIENCES_ 1&2
PERCEPTION, AS BAYESIAN INFERENCE
PERCEPTION, AS BAYESIAN INFERENCE:
MLE METHOD

PERCEPTION, MOTOR THEORIES OF

Elena Pasquinelli [INSTNICOD]

Theories of perception that assign to the motor experience a significant position in the explanation of perceptual phenomena are called motor theories of perception (for an historical review of motor theories of perception, see [Viviani, 1990]).

Motor theories of perception are compatible with the existence of internal representations, i.e. of movement; in particular they are not necessarily committed to the denial of the role of representations or computations in the case of higher order cognitive processes. Anyway, action and perception are conceived as directly linked as in the case of a sensory-motor loop, with no mediation of cognitive processes (the central processor positioned between the input and the output signals).

An example of neurophysiological model for this closed relationship is represented by the functioning of mirror neurons. Mirror neurons is the name given to a particular group of neurons which are activated both by the execution and by the observation of some specific motor actions, as reaching and manipulating [Rizzolatti, 1996]. It is suggested by [Rizzolatti, 2001] that mirror neurons have a role in the imitation and understanding of perceived actions. The connection between performed actions and perceived actions is then direct, with no form of interpolated cognitive mediation.

Motor theories of perception assign different roles to movement.

It is possible to distinguish two different claims within the assertion of a key role played by action in perception.

The first claim is that action directs perception through the exploration of the environment: it is impossible to separate perception from action, since there is no perceptual activity without the movement of sensors and the active exploration of the environment. The second claim is that motor competences and motor acts shape the perceptual content.

As an example of the first claim of motor theories of perception, Berthoz proposes a theory of perception as simulated action: perceptual activity is not confined to the interpretation of sensory messages but anticipates the consequences of action, so it is internal simulation of action. Each time it is engaged in an action, the brain constructs hypotheses about the state of a variegated group of sensory receptors throughout the movement; the brain of the skilled skier for example does not control the state of all the body receptors in a continuous and permanent way, instead it internally simulates the trajectory and controls the state of a specified group of receptors only intermittently. The ensemble of the receptors that are implicated in the analysis of movement and space (movement of the body and of the environment) are particularly important for this task;

they circumscribe what Berthoz calls the sense of movement or kinaesthesia (with a broader extension than the classic term kin-aesthesia which included only the receptors located within the muscles, tendons and joints). When the product of the integration of the different kinds of receptors that participate in the sense of movement is not coherent, the brain suffers from perceptual and motor troubles, this eventually leading to perceptual illusions. In general, within the theory of the sense of movement, illusions can be considered as solutions that the brain creates when faced with discrepancies between sensory information and the internal pre-representations or anticipations.

In the sensorimotor vision of perception [Noë, 2003] [O'Regan & Noë, 2001], perceptual experiences depend upon sensorimotor activity: movement is necessary in order to perceive objects as unitary, coherent and present entities. Thus, action shapes the formal aspects of the perceptual content.

In the frame of the ecological approach the aspect of perceptual content depends upon action. [Turvey, 1981] [Gibson, 1979, 1966] [Stoffregen & Bardy, 2001] emphasize the relevance of activity in defining the stimulus to be perceived and the structure of the animal-environment coupling. In fact, according to the ecological approach what we directly perceive is affordances, that is, possibilities for action [Turvey, 1981] [Gibson, 1979]: the “walkability” of a surface, the “sittability” of a chair, etc.

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RELATED ITEMS

COGNITIVE SCIENCES
 ENACTIVE COGNITIVE SCIENCES_ 1&2
 HAPTICS, IN COGNITIVE SCIENCES
 ILLUSION
 SENSORIMOTOR THEORY

PERCEPTUAL CONFLICTS

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Can there be conflict in perception? What are the necessary and sufficient conditions for speaking of a perceptual conflict?

A conflict can be identified with an incoherent set where contradictory elements coexist.

The necessary conditions for a perceptual conflict to exist are then: the presence of multiple, separate perceptual elements, that are combined into a common unit or set, and which (individually) can indicate or suggest states of the world that are not compatible with states indicated by other perceptual systems.

An example of perceptual conflict is represented by so-called intersensory-conflicts, when discrepant information is presented to

different sensory modalities [Welch & Warne, 1981].

The concept of intersensory conflict implies that information from two (or more) perceptual systems is compared (e.g., by a scientist, or within an animal's nervous system). When the comparison reveals non-redundancy, this is interpreted as discrepancy between the information available to different perceptual systems, or conflict between systems. Sensory conflict must be resolved to yield a single estimate of reality. This resolution is assumed to be an internal process taking the form of an antagonistic weighting of inputs from different senses (with the weights being assigned on the basis of stored expectations [Ernst & Banks, 2002]).

However, the existence of discrepancies in intersensory stimulation does not require the interpretation of those discrepancies in terms of intersensory conflict. The fact that stimuli can be compared does not necessarily imply that they are compared. There is no conflict, for instance, in perceiving something red and something blue until red and blue qualities are attributed to different objects or to the same object at different moments.

As a matter of fact, different responses are described for perceptual systems presented with discrepant stimuli: combination of the stimuli in one and the same percept, with or without awareness or experiencing a conflict, and constitution of two distinct percepts [Bruner & Postman, 1949] [Stein & Meredith, 1993]. One example is binocular stereopsis. The images on the two retinæ are different, but these differences do not constitute conflict. Rather, they constitute information about the three-dimensional layout of the animal-environment system.

Additionally, elements that appear to be in conflict at one level of analysis may, if considered at another level of analysis, not be in conflict. Thus, the interpretation of perceptual elements in terms of perceptual conflict depends upon the level of analysis, that is, on the level at which we define units or elements of perception. In binocular stereopsis, infor-

mation about the third dimension is an emergent property of relations (discrepancies) between the images on the two retinæ. If the single, binocular visual system is the level of analysis, then there is emergent binocular information, not conflict.

The interpretation of non-redundancies in terms of conflict arises out of the tendency to approach perceptual stimuli at low levels of analysis. Consider optic flow, which is a pattern of optical change made up of many individual velocity vectors. If the level of analysis is the individual velocity vectors, then perceptual conflict arises because in optic flow (in most cases) different vectors have widely different velocities (i.e., speed and direction of optical change).

At this level of analysis different vectors would seem to indicate different (and incompatible) motions of the observer. However, at a higher level of analysis the velocity vector reveal a higher order pattern. At the level of the overall pattern of vectors, there is no conflict: taken together, all of the vectors correspond to one coherent motion of the observer.

The visual systems of humans and many other species are known to be sensitive to relations between velocity vectors, that is, to optic flow, *per se*. Thus, in perceiving optic flow, there are no perceptual conflicts that need to be resolved. Similarly, in optic flow no binding is required (relations between flow vectors are part of the stimulus and can be perceived, as such), and so there is no binding problem. Thus, the existence of perceptual conflict, and the consequent need to postulate internal processes that resolve conflict (e.g., binding) depend upon the level of analysis chosen by the scientist [Stoffregen & Bardy, 2001].

Given this, the question about the conditions for giving perceptual conflicts then becomes: What is the appropriate level of analysis?

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RELATED ITEMS

COHERENCE OF PERCEPTUAL EXPERIENCE
PERCEPTION, AS BAYESIAN INFERENCE
PERCEPTION, DIRECT AND INDIRECT APPROACHES

PERCEPTUAL LEARNING

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That people usually improve their performance when a task is repeated is a well established fact that is applicable also to perception. However, there has been a lively debate about what kind of phenomenon this is. Gibson, J. J. and Gibson, E. J. (1955) suggested that the theories can be divided into two groups, enrichment theories and differentiation theories. Even if this division has been questioned (Postman, 1955) it will be used here in a short overview. The basis for each is a general theory of perception.

The enrichment theories go back to Berkeley (1709), who stated that perception is formed by associations between elementary sense impressions and images of past impressions. Motor actions have later been added as elements to be associated. In this tradition perceptual learning has been described as an increase of such associations. Helmholtz (1925) put forward the theory that the mechanism providing the associations was

unconscious inferences, which is still an established idea, especially in many cognitive theories of perception. These theories state that "*something is thought to be added to preliminary registration of the environmentally produced stimulation*" (Gibson, E. J., 1969, p. 37). A leading theorist with this approach was Bruner (1957), who saw perception as a sequence of cognitive operations and perceptual learning as including increasingly specific categorizations of stimulus inputs.

The differentiation theories have their background in an ecological theory of perception that considers perception to be direct extraction of information from the stimulation in the environment, not something similar to cognitive inferences from sensations and images (Gibson, J. J., 1966). Perceptual learning is then an increase in the organism's ability to do such extraction (Gibson, E. J. 1969, p. 3). A common case of this is the increased ability of discrimination between different object properties, for example, the well-trained wine tester's ability to discriminate different kinds of wine, an expert's ability to identify the sex of newly hatched chickens, and a medical expert's ability to get information from X-ray plates. Perceptual learning according to the discrimination theories means an increased ability to differentiate between variables of stimulation that the observer could not distinguish before. The observer has detected that two objects, for instance, that he had perceived before to have the same properties, had different properties. This means that the perception is increasingly precise to differences in the environmental stimulation.

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RELATED ITEMS

ENACTIVE KNOWLEDGE
 EXTERNALIZATION, PERCEPTUAL
 LEARNING AND ENACTIVE INTERFACES
 LEARNING AND TRAINING METHODS
 SENSORY SUBSTITUTION

PHENOMENAL CONSCIOUSNESS AND FEEL

Kevin O'Regan [CNRS]

The term phenomenal consciousness was used by the philosopher Ned Block in an influential article which distinguished it from access consciousness (Block, 1995). Phenomenal Consciousness is the feel, or what-it-is-like or phenomenality associated with sensory stimulation or with mental or bodily states. Contrary to other forms of consciousness which seem amenable to analysis in functional, scientific, terms, it poses a problem for science because we cannot see how biological systems obeying known laws of physics could generate feel: feel seems to be something outside the realm of science.

The importance of phenomenal consciousness for enactive interfaces lies in the fact that, in general, when creating new tools for exploring real or virtual worlds or when interacting with machines, it is advantageous to ensure that the operator will have some kind of feel when using the device. What the conditions are that will ensure that this will

happen have been laid out by the sensorimotor approach to phenomenal consciousness, developed by O'Regan and collaborators (O'Regan et al., 2001, 2006).

This approach is, among enactive approaches, the one that attempts to most precisely understand the origin of feel. The theory tries to find a way of defining phenomenal consciousness which at the same time satisfies normal intuitions about what it is like to experience a sensation, and also avoids the explanatory gap problem of how to link phenomenal experience of feel and physical processes in the brain. For this, the approach distinguishes different kinds of feel.

The most basic feels are those which are not associated with any additional component: no automatic bodily reaction, no drive or motivation to undertake certain forms of behaviour, no mental associations that positively, negatively or otherwise color the feel. An example of a raw sensory feel might be that sub-part of the sensation of looking at a red surface which corresponds solely to the redness itself, and that is devoid of the knowledge that the surface is a rose petal, devoid of the knowledge that roses signify love, etc.

Jealousy, love, hate, are feels, which involve certain, often ill-defined, urges to do things or to modify the present situation. Emotions like fear, anger, and shame, and states like hunger and thirst, would appear to involve both specific bodily manifestations (for anger for example: changes in heartbeat, flushing), or reactions of the autonomic nervous system, and also they are accompanied by drives to engage in certain particular activities.

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RELATED ITEMS

CONSCIOUS ACCESS AND COGNITIVE ACCESS
LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL
APPROACH
PHENOMENAL QUALITY: THE SENSORIMOTOR
APPROACH
SENSORIMOTOR THEORY

PHENOMENAL QUALITY: THE SENSORIMOTOR APPROACH

Kevin O'Regan [CNRS]

Phenomenal quality is what distinguishes different sensory experiences from each other: so for example, auditory sensations have a different phenomenal quality from visual ones, and within auditory sensations, a high-pitched sound has a different quality from sounds of other pitches.

Explaining the origin of phenomenal quality is generally considered by philosophers to be the hard problem of consciousness (Chalmers, 1995). The importance, in enactive systems, of phenomenal quality is of course the question of how to obtain phenomenal qualities from enactive interfaces, and how to determine what those qualities will be.

Help for addressing these issues comes from the sensorimotor approach to phenomenal consciousness. Under this approach, phenomenal quality is assumed to be constituted precisely by the laws of sensorimotor contingency (or dependency) that govern a user's interaction with a device. Thus sensory substitution devices can for example provide visual-like experiences by ensuring that the sensorimotor contingencies that are generated follow visual-type laws.

What distinguishes the sensorimotor approach from classical approaches, and in particular from approaches where some neural mechanism is assumed to cause sensory experience or feel, is the idea in the sensorimotor approach that feels are not the

kind of things that can be caused, but that they are on the contrary constituted by a certain state of affairs concerning the observer's interaction with the world. The example of the softness of a sponge illustrates this clearly: the feeling of softness is not an essence that is generated anywhere in the brain or caused to be exuded by any mechanism. Feeling softness is: having cognitive access to the fact that we are doing the kind of thing we do when we press on the sponge.

A point to note is that the sensorimotor approach claims that it is not the feel itself, but the quality of the feel that is constituted by the sensorimotor contingency. This is important, because it is not sufficient for a system to be engaged in exercising a sensorimotor skill for there to be a feel. There must additionally be cognitive access to this fact.

Another point is that because the experienced quality of a feel is taken to be constituted by the accompanying sensorimotor contingency, there is a basis for explaining the similarities and differences between feels. This provides an advantage over other theories which invoke some causal mechanism: such theories must then explain why and how the particular mechanism produces the particular pattern of similarities and differences in feels that exist.

It is this last point which provides the sensorimotor approach with strong leverage to overcome the mystery of feel and explain the special characteristics of phenomenal experience. It is precisely the nature of sensorimotor skills that accounts for these unique properties.

When constructing new devices which extend the human's modes of interaction with the world, the role of understanding the source of the accompanying phenomenal quality is obviously extremely important.

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RELATED ITEMS

CONSCIOUS ACCESS AND COGNITIVE ACCESS
LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL
APPROACH

PHENOMENAL QUALITY: THE SENSORIMOTOR
APPROACH

SENSORIMOTOR CONTINGENCY OR DEPENDENCY

SENSORIMOTOR THEORY

SENSORY SUBSTITUTION

PHYSICALLY - BASED MODELLING

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Physically-based modelling originates in the 70's. Since the 90's most of the research regarding modelling in virtual realities, animation, sound synthesis, movement synthesis, haptics, etc, in which models are employed to produce sensible phenomena, deal with physically-based modelling.

Physically-based modelling as opposed to signal based modelling

A model can be said to be physically-based when the modelling and the synthesis of sensible phenomena one want to produce (a sound, a movement, etc) by using signal-based models, is replaced with the modelling and the simulation of its physical origin or cause (the sound structure that produces the sound, the objects that moves, some prominent properties of a real-world object, etc.) [Borin et al., 94] [Cadoz 94]. Hence, physically-based modelling corresponds with an historical evolution of the categories of models. According to the literature, the evolution from signal-based to physically-based models is guided:

- By the interest of the physically-based parameters as compared to the signal based parameters (e.g. modifying an inertia in a string-like model produces a more consistent effect on perception than modifying, for example, the frequency of an oscillator in an additive synthesis patch).
- By the aim of obtaining more believable synthesized phenomena and interactive virtual scenes. Modelling and simulating the cause (instead of the phenomena themselves) allows obtaining a wider range of validity for the model.

Physically-based modelling as opposed to physical modelling

As a common property, physically-based models implement some laws of physics more or less freely. However, one should distinguish upon physically-based modelling (as practiced in virtual reality, etc.) and physical modelling (as practiced in physics, acoustics, etc.). The two differ in their goals, problematic and tools [Castagne et al., 04].

Physical modelling is rooted on the search of a better understanding of real world objects. Models tend to become more and more complex (in the sense that more and more behaviours are considered for a given object) and precise (in the sense that the bias between the generated behaviours and the behaviours of the real object is made the smallest possible). The research also aims at obtaining accurate models for prediction, i.e. models that can be used to foresee the behaviour of a hypothetical object one have in mind. In this context, traditional physics (with continuous time and space) is a key tool. A computable algorithm is eventually obtained by implementing a numerical analysis process on the model. Simulation (generally non-interactive) is used in order to study the validity of a model, by comparing the model's outputs with measurements on the real object.

As an example, acoustics produces more and more complex models of the bow-string interaction, enabling a better understanding

of the laws at hand, and cosmology produces more and more accurate models of the universe. Also, one would build a physical model of a bridge while designing it to study its resistance to constraints like weights, air, etc.

The goals pursued with physically-based modelling (as practiced in virtual realities, etc.) differ. One aim at finding the appropriate physical rules, and reusable, generic and modular algorithms that could improve the quality of the generated sensible phenomena, and of the interaction of the user with the model when it is computed, through gesture transducers, force feedback transducers, etc. Physically-based algorithms are implemented within the model with the aim of guarantying that the model is lively and believable, even when the model do not refer to a real object [→ BELIEVABILITY_ 1&2].

The study of a real object is never an aim *per-se* in physically-based modelling but, when needed, a tool for further research. A physically-based model may have no real counterpart (eg. be non-realistic) but still be considered as perfectly valid. Models are evaluated mainly through subjective judgments. Rather than the quality of the model as compared to a real object, one will seek the quality of the model's behaviour as for the user, when heard, seen and manipulated. Precision in modelling is not the goal, and the implementations of physical laws are made freely, as long as the model behaviour keeps being satisfying. Research necessarily deals at the same time with technical aspects (physically based frameworks, devices for interacting with the models, appropriate user interfaces, etc.) and psychological or at least psychophysical concerns.

Finally, as evidence, the frontier that separates physical modelling and physically-based modelling is not that clear. Mutual empowerment is possible, and needed (eg: physical models often led to convincing models to be used in virtual realities, computer graphics and computer music). But researchers on physical modelling and on physically-based modelling respectively point

goals, needs, and results that are different. See also [→ PHYSICALLY-BASED MODELLING TECHNIQUES].

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RELATED ITEMS

BELIEVABILITY_ 1&2
 HAPTIC RENDERING OF VIRTUAL OBJECTS
 INSTRUMENTAL INTERACTION
 PHYSICALLY-BASED MODELLING TECHNIQUES
 SIMULATION
 VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

RELATED DOCUMENTS

[El_Enaction&ComputerTechnologies_Luciani.pdf](#)

PHYSICALLY - BASED MODELLING TECHNIQUES

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Overview

Physically-based modelling have developed considerably for the past 20 years in computer graphics, computer music, haptics and virtual realities [→ PHYSICALLY-BASED MODELLING].

For many, the practice of computer physically-based modelling is necessarily based on a numerical analysis process. Such a traditional methodology consists in first con-

structuring a continuous-time series of equations using the laws of physics, and second using some numerical analysis technique in order to digitalize these equations to compute them. The digital model is then only seen as an approximation of the first, which is presented as ideal. A recurrent aim is to evaluate and minimize the divergence or numerical bias. Many such one-shot physically based models of a specific object or phenomenon are obtained through such a methodology (examples: fluid effects, smoke, water; acoustic strings; etc.).

Though this one-shot model methodology is still quite common, it would not be sufficient to have a specific physically-based algorithm for every category of phenomena to be generated in the contexts of animation, sound synthesis, movement synthesis, virtual realities, etc. More generic methodologies are needed.

Hence, as opposed to one-shot models of a specific phenomenon or object, a major research direction in physically-based modelling deal with the design of generic physically-based techniques and methodologies that allow the building of a model for various categories of phenomena and objects. As well as a number of signal-based synthesis schemes have been proposed over years, various physically-based techniques have been introduced, each one allowing the design of models for various categories of objects and phenomena.

Problematics

The problematic of physically-based techniques can be analysed through optimality, quality, genericity, and usability [Castagne et al., 03].

- Optimality

An optimal technique should allow a minimal computing coast, i.e. be efficient enough to allow huge models to be computed in real time.

- Quality

An optimal technique should permit the design of high quality models, i.e. allow

expressing models that generate phenomena as convincing, vivid, believable as wanted [→ BELIEVABILITY_1&2].

- Genericity

An optimal technique should maximize the richness and diversity of the obtainable phenomena, so that a large panel of physical behaviours may be obtained by using it. Additionally, as an important point, the technique should not be restricted to a single sensoriality, but allow the design of models that can be at the same time heard, seen and manipulated. This goal is particularly difficult to reach, since the awaited phenomena, and the corresponding physical properties of object, may differ radically. It is also particularly important, in order to obtain multisensory virtual objects based on physical modelling [→ PHYSICALLY-BASED MODELLING TECHNIQUES FOR MULTISENSORY SIMULATION].

- Usability

Research aims no only at developing models and techniques, but also at developing physically-based modelling know-how in the end user communities. A physically-based modelling technique usually comes along with a specific approach to the modelling process. It provides – and imposes - a support and a guide for the modelling activity itself, and often consists more or less in a modelling language. Hence, the search of a usable technique is a major goal: an optimal technique should be usable enough to be implemented by end users (eg: a musician, or an animator, etc.), and to be learnable in a reasonable manner.

Usability first calls for intuitive parameters, and more generally for the possibility of an efficient mental model regarding the technique. It also implies, importantly, that the technique should be robust against the modelling process: it should guaranty some quality in the obtained behaviours, whatever the model is, and however it was build, as long as it relies on the technique. Finally, [Castagne et al., 03] assumes that usability strongly relates with modularity: an optimal technique should hence be modular, allowing the build-

ing of a model by assembling elementary building blocks.

Categories

Physically-based modelling techniques developed in parallel in computer graphics, computer music, virtual realities, haptics, etc. Most techniques are dedicated to a category of model depending on the synthesized phenomena. Hence, one can distinguish upon [\rightarrow PHYSICALLY-BASED MODELLING TECHNIQUES FOR MOVEMENT SYNTHESIS AND ANIMATION] and [\rightarrow PHYSICALLY-BASED MODELLING TECHNIQUES FOR SOUND SYNTHESIS].

Finally, a few techniques, though, are usable in all the previous cases, but may also apply the important case of multisensory simulation.

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RELATED ITEMS

BELIEVABILITY_1&2
HAPTIC RENDERING OF VIRTUAL OBJECTS
PHYSICALLY-BASED MODELLING
PHYSICALLY-BASED MODELLING TECHNIQUES FOR MOVEMENT SYNTHESIS AND ANIMATION
PHYSICALLY-BASED MODELLING TECHNIQUES FOR MULTISENSORY SIMULATION
PHYSICALLY-BASED MODELLING TECHNIQUES FOR SOUND SYNTHESIS

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PHYSICALLY - BASED MODELLING TECHNIQUES FOR MOVEMENT SYNTHESIS AND ANIMATION

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Among the many physically-based modelling techniques, various have been designed in computer graphics for movement synthesis and animation. In the following, we present the main of them based more on the types of principles and techniques than on the type of objects: particle-based methods (particles systems, particle modelling, mass-interaction generic formalism, smooth particles), numerical resolution of mathematical continuous equations, solid-based methods (finite elements method, solid physics).

Particles systems

It exists several different approaches within the framework of particle modelling. A first type of approaches has been introduced in computer graphics by Reeves [Reeves, 83] in order to render behaviours of fuzzy geometrical objects. Reeves's particles are actually non physical particles, that evolve by following a path defined by global fields such as uniform fields, velocity fields etc. and various lifetime rules. They do not interact physically. Only since recently, such particle systems have acquired a physical behaviour by adding inertia and gravity. This scheme is today implemented in many computer graphics software, and is widely used for various peculiar models, e.g. explosions, fires, fireworks, etc. Basically, particles are independent from each-others, and the technique is

not adequate for the modelling of interactions.

Particle modelling

[Greenspan, 73] introduced the term of particle modelling to simulate physical phenomena within a totally discrete formalism, by opposition to the classical continuous expressions usually used in Physics. Greenspan's particles are physical punctual masses that physically interact with each other through a generic family of interactions functions based on the attractive-repulsive Van der Waals function.

Mass-interaction generic formalism

The Greenspan's formalism has been generalized by the mass-interaction formalism [Luciani et al., 91], by extending the interaction functions with dissipative interactions and with a generic modelling of their non-linearity, with the aim of modelling a larger variety of dynamic phenomena, visual or not. Being very generic, the mass-interaction framework is indeed adequate to model any type of dynamic object and phenomena: natural phenomena such as deformable and plastic objects, pasts, fluids and other phenomena such as crowd behaviours, etc. It is also an efficient way to simulate multisensory object including acoustical deformations and force feedbacks. It is hence discussed with more detail in the item [→ PHYSICALLY-BASED MODELLING TECHNIQUES FOR MULTISENSORY SIMULATION].

Smooth Particles

To improve the limitation inherent to the two first point-based approaches (particle systems and particle modelling), [Desbrun & Gascuel, 96] has introduced in the domain of computer graphics the principle of Smooth Particles proposed in hydrodynamics. The technique starts from a discretization of an object whose macroscopic behaviour equations are known, in a sum of particles, each of them representing a piece of the matter. Each particle possesses a core that represents the matter distribution around it, and its

action area on others particles. A force field is added to spatially extend the particle determined by the macroscopic behaviour equations.

Numerical resolution of mathematical continuous physical model

This approach is based on continuous formulation of a specific physical phenomena. In computer graphics, these equations are digitalized to become computable. The most typical example of the use of this approach is the modelling of fluid behaviours by solving the Navier-Stokes equations of the fluid mechanics [Kass & Miller, 90]. Generally, the technique used is a discretization of the space in Voxel (volume elements) to locally solve the equations at hand.

Finite elements method

The finite element method is dedicated to the computation of deformable solid objects, when the continuous equation is not directly computable. In finite elements method, deformable solid objects are decomposed in a mesh of geometric discrete regions (the finite elements) [Gascuel et al., 89] of which the physical behaviours are computable. It is then a geometrically mesh-based physical model. The core of the method is to guaranty the continuity between elements. A common use of the finite elements method is determining stresses and displacements in mechanical objects. This technique has also been used in computer graphics to deform bodies, skins, organs. However this method is often considered as too much time-consuming for animation goals and for real-time purposes.

Solid physics

This technique is based on the simulation of solid primitives on which forces and torques are applied. The primitives can be independent or linked through solid-solid interactions. Solid physics is often linked with collision detection (geometrical determination of inter-penetrations, see [Teschner et al., 05] and collision rendering algorithms

(forces are applied to prevent interpenetration) [\rightarrow COLLISION DETECTION ALGORITHM].

Solids physics and collision detection are widely used and implemented in most of computer graphics software and in video games' physical engine. It is efficient enough to render the dynamic of geometrically complex solids and articulated solids. However, when considering living articulated bodies like characters, animators face with control problems: finding the appropriate control forces to apply on solids to obtain a desired global movement is very difficult. This problem is generally solved by inverse dynamic methods [Barzel & Barr, 88]. The animator defines in terms of constraints and geometrical paths the way he wants the object to behave, and an algorithm pre-computes the forces and the torques to apply.

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RELATED ITEMS

COLLISION DETECTION ALGORITHM
COMPUTER GRAPHICS
MOTION CONTROL, HIGH-LEVEL
PHYSICALLY-BASED MODELLING TECHNIQUES FOR
MULTISENSORY SIMULATION

RELATED DOCUMENTS

El_ComputerAnimation_Luciani_040930.doc
El_Enaction&ComputerTechnologies_Luciani.pdf

PHYSICALLY-BASED MODELLING TECHNIQUES FOR MULTISENSORY SIMULATION

Nicolas Castagne [ACROE&INPG]

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Physically-based modelling techniques developed in parallel in computer graphics, computer music and virtual realities. Most of them are dedicated to a category of model depending on the synthesized phenomena: sound, movement, etc.

When one needs to build a multisensory scene (for example to be manipulated by using a force feedback transducer), most often, various exogenous models are used, one for each sensory modality. Models are

then inter-related by some inter-control means, often asynchronous. As an example, in virtual realities, sound is most often simply obtained by triggering pre-recorded samples – and, eventually, processing them (e.g.: apply a spatialization algorithm) – when an event occurs in the visual scene.

The framework of enactive interfaces, however, emphasizes the unicity of human perception, and in parallel the need of a particularly high and thin correlation between the gesture of the user and the various multi-sensory stimuli generated. Indeed, implementing exogenous interconnected sound model, visual model, and sometimes haptic models, hardly enables the close interaction needed between the various stimuli feedback one need. Making these models behave in a truly coherent manner in order to let the user believe that he perceives/manipulates an object is still a major difficulty.

Conversely, though it is still rarely done and difficult, one can also try to design a single multisensory physically-based model. In such a case, as a vis-à-vis of the unicity of human sensori-motricity, the model is unique and generates all the sensory outputs in response to gesture in one shot. However, only a very few modelling framework qualify for such multisensory simulation. We review below the mass-interaction framework.

The Mass-interaction framework

Within the mass-interaction modular framework (also called particle modelling), a model is obtained by assembling, as a network, modules of two types: masses and physical linear and non-linear interactions. The technique differs from mass-spring meshes. It relates more to works like the pioneering [Greenspan, 73], or the more recent [Cadoz et al., 93] [Greenspan, 97] [Luciani et al., 91], since it consists in a specific algorithmic implementation of Newtonian mass-point physics. More precisely, differences include:

- It comes along with a number of linear and non-linear interactions (collisions, bow-like interaction, Newtonian interactions, fric-

tion interaction, plastic interaction...) instead of featuring only linear spring-dampers. In the models, the design of interaction is prominent.

- It promotes a constructivist, network-like, mesh-free, modelling process, rather than a mesh-discretization methodology. The physical modelling process starts from scratch. The designer assembles the basic modules as a network, by handling directly the mass-interaction formalism. No geometrical mesh of a volume or a surface needs to be a priori considered.

The mass-interaction technique is sometimes said to be quite expansive in term of processing cost, and not to be very precise – we know, for example, that simulating wave propagation by using masses and interactions introduces some numerical bias as compared to the wave equation model. It is also considered as being unstable, in the sense that a given model may diverge in certain configurations.

On the contrary, the technique is amongst the most modular. The basic masses and interactions are very elementary models of a piece of matter, that remain pertinent for the human senses (they all can be, for example, perceived through a haptic gesture device, or visually represented) and can be easily internalized by any user as representations of very basic objects. The technique is also robust since a stable network of masses and interactions behaves plausibly no matter how it was constructed. It thus enables a relevant mental model. The designer of the model is not required to refer to any continuous model of traditional physics, nor to consider the mass and spring network as a numerical analysis method. He often base his construction work on some intuition, trying to imitate or metaphorize the object he wants to model. Consequently, various modellers usable by the end-user have been introduced [Castagne & Cadoz, 02] [Evrard et al., 06] [Sod], etc.

Finally, the mass-interaction technique can be viewed as particularly generic. It has been successfully used in a large variety of applica-

tions in computer music, animation and virtual realities: sound resonator, wind and string instruments, bowed or plucked interaction, musical gesture generation, fluids, pastes, gels, sands, deformable objects, vehicles, dancing, etc.

Indeed, mass-interaction modelling applies to the modelling of any moving physical objects, particularly those in which the dynamics of the behaviour is prominent. So doing, it qualifies, as a unique feature, for the modelling of multisensory object and the building of enactive interfaces: a single model built within the mass-interaction framework, eventually multidimensional and multifrequency, may allow the synthesis at the same time of sounds, visual movements, and force-feedback data to be sensed through a haptic device, each of the phenomena being tightly correlated with each others.

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RELATED ITEMS

BELIEVABILITY_1&2
 HAPTIC RENDERING OF VIRTUAL OBJECTS
 MAPPING AND CONTROL VS. INSTRUMENTAL
 INTERACTION
 MULTIMODALITY AND ENACTION

PHYSICALLY-BASED MODELLING TECHNIQUES FOR SOUND SYNTHESIS

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Among the many physically-based modelling techniques, various have been designed in computer music for sound synthesis [Castagne & Cadoz 06]. The following reviews some of the most important.

Wave-guides

A 1D wave-guide is a double delay line, looped on the extremities, with losses and dispersion consolidated at the sparse points [Smith 86] [Smith 92] [Smith 96]. Such a set of filters realizes an elegant and really efficient solving of the linear propagation equation. Extensions toward 2D or 3D meshes are today possible.

Wave-guides are heavily used today for sound synthesis; most physically-based sound synthesizers implement digital waveguides, and much research is devoted to them.

The technique is modular, but its basic module, the delay-filter, can hardly be considered as a physical model in itself. The mental model it enables is meaningful, but is not very efficient when the goal is to let a musician (a end user) handle the scheme at a basic level to design its own models.

Since they model the wave propagation rather than matter in itself, wave-guides are specifically dedicated to the modelling of linear oscillating objects, and particularly sound objects. The technique, though, is not well adequate for the modelling of non-linear

resonators, and does not apply to the modelling of moving objects and solids.

Modal modelling

Modal modelling (or spectral approach) proposes to model an object in the modal domain [Adrien 91].

Within the modal scheme, a vibrating structure is represented through a series of independent elementary oscillators, provided with coupling data. Each oscillator stands for a mode of the structure and is defined by its resonant frequency and damping time. The matrix coupling data encodes the modal shapes of the structure for each mode.

Modal representation is particularly adequate when dealing with linear oscillating objects, in which the oscillatory properties (i.e. the modes) are important. Hence, modal synthesis developed well in the context of computer music and sound synthesis – though a few trials have been published in computer graphics. In these contexts, additionally, the properties of the modes are particularly relevant to manipulate, since they correspond, rapidly said, with the frequency spectrum of the sounds to be produced, which is of primary importance for human hearing [→ AUDITORY PERCEPTION]. The scheme successfully led to software environments, such as Modalys [Morrison & Adrien 93].

Conversely, the modal technique is hardly usable for the modelling of non-linear resonators and for any object that cannot be characterized efficiently through its oscillatory properties. Additionally, the scheme is not really modular; a mode, in itself, cannot be seen as an object, so that a model necessarily corresponds with a pre-built series of modes and coupling data.

Mass-interaction framework

Mass-Interaction modelling [Cadoz et al., 93] is also being used successfully in computer music for sound synthesis, in which context it enables many benefits, including: full modularity, good usability, inherent possibility of non-linear structures, etc.

Being very generic, the mass-interaction framework is in fact adequate to model most dynamic object for generating most categories of sensory phenomena. It is hence discussed with more detail in the item [→ PHYSICALLY-BASED MODELLING TECHNIQUES FOR MULTISENSORY SIMULATION].

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RELATED ITEMS

AUDITORY FEEDBACK IN VR AND HCI
AUDITORY PERCEPTION
PHYSICALLY-BASED MODELLING TECHNIQUES FOR
MULTISENSORY SIMULATION
SOUND ALGORITHMS

PRESENCE, IN COMPUTERIZED ENVIRONMENTS

Annie Luciani [ACROE&INPG]

Is presence a new question?

The distinction of what is real and what is non-real is an usual and long lasting question

of philosophy, as well as of physics. Recently, in his theory of veiled reality, Bernard d'Espagnat [d'Espagnat, 1995] has pointed out that in physics, the reality remains intrinsically unknowable in details but the knowledge developed by physicists as description of the phenomena, enlightens the structure of an underlying reality. Remembering that psychology was in the past a part of philosophy, and that it joined the fields of experimental sciences only recently, with psychologists as P. Piaget, we can assume that the problem of presence, considered from these points of view, is not a novel question.

What about presence in digital technologies?

No explicit problem of presence occurs as long as human beings manipulate real objects, directly or indirectly through mechanical instruments.

In teleoperation [\rightarrow TELEOPERATION / TELEPRESENCE / TELESYMBIOSIS], when objects are mechanically teleoperated, as in the manipulation of blocks of nuclear matter through a mechanical pantograph, since the experimenter feels it mechanically and sees it through the glass that separates the two spaces, the immediate and trivial presence of objects continues to be felt by the experimenter. Conversely, once this direct physical communication has been replaced by electrical communication between the two spaces, the space of the user and the space of the task, the physical continuity of both is broken, causing the lost of the trivial sense of presence of each space to the other.

Similarly, in the context of sensorial data production, representation and transmission, no explicit problem of presence appears, when sensorial data are directly provided by real objects, or indirectly provided through sensors (microphones, telephones, cameras, etc.).

Since the 50's, with the demonstration of Shannon's theorem and its implementation in digital to analog converters, real sensorial data has begun to be producible ex nihilo, i.e.

without any real objects, by abstract and symbolic entities such as numbers and algorithms. Indeed, a new problem of presence appears when human beings are (more and more frequently) called upon to perceive and act on spaces that are increasingly distant or different from our current physical world, by means of new instruments as tools for telecommunication, teleoperation, and computer representation. These new tools raise with growing urgency the question of the presence of these distant spaces.

Presence: "being there" vs. "being with"?

In both cases, the two fundamental properties that have been lost are the same: those that relate to the spatiality and those that relate materiality of the manipulated real objects or recorded phenomena produced by real objects.

Those related to spatiality are known as the sense of "being there". It appears mainly within the virtual environment and immersion paradigms [\rightarrow IMMERSION VS. VIS-À-VIS].

Those related to materiality are addressed by the senses of "being with" and are related closely to the instrumental situation, implemented for example by means of virtual or artificial realities [Luciani 2003, 2004] [Touch-Hapsys FP6 Project].

An instrumental approach of Presence

In the latest instrumental situation, we assume that the quality of presence (more or less presence) could be defined as the capability of the instrumental situation (i.e. of the instrumentally manipulated object to be present for the instrumentalist) to perform the instrumental task.

Hence, presence is assumed to be a pragmatic feature. There is no need to discuss about neither reality nor illusion of the reality, the computerized object being, after all, a part of the real world.

The instrumental interaction with computerized object (with computer simulacrum) is a real situation that must necessarily exhibit the minimal sensorial and handling properties necessary for human instrumental perform-

ance. Presence is then measured through the capability of the instrument to be adapted to the human senses, skills and cognition to perform an expected task.

Hence, presence is one of the properties of the new instrument when based on digital technologies.

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RELATED ITEMS

BELIEVABILITY_ 1&2
IMMERSION VS. VIS-À-VIS
INSTRUMENTAL INTERACTION
PRESENCE, THEORIES OF
TELEOPERATION / TELEPRESENCE / TELESYMBIOSIS

PRESENCE, THEORIES OF

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The notion of presence, in association or in alternative to related notions, such as immersion, realism, transparency, performance, has been introduced in order to characterize and evaluate experiences in virtual and augmented realities.

In non-mediated perceptual experiences, the problem of presence has been referred to as the problem of perceiving complete objects, for instance when the stimulation is incomplete. A haptically perceived object, for

instance, is present as a whole even if we do actually take contact only with a part of it. The completeness of the stimulus condition is thus not a necessary requirement for experiencing objects. It is suggested that movement and the mastery of the connection between movement and its perceptual consequences play a crucial role in the experience of an object as present [O'Regan & Noe, 2001]. The sensorimotor approach proposed by O'Regan actually adds two concepts, namely grabbiness and bodiliness (also called alerting capacity and corporality), to explain why sensory stimulation has the particular sensory presence that people perceive it to have. These concepts allow the feel of sensory stimulation to be differentiated from the feel of other mental phenomena.

In perceptual experiences mediated by electrical systems (as by audio or video records) or computer systems (as virtual, augmented, mixed reality), the concept of presence has been first tackled in spatial terms as the illusion of co-location of the mediated environment and of the subject of the experience.

The term “being there” has here been used as a synonym of presence as the illusion of location of the subject of the experience in the artificial or distant environment. Presence in this case can be considered as a global psychological state [Slater, 2000], as an attentional state [Witmer & Singer, 1998] or as a perceptual state (the illusion of non-mediation) [Lombard & Ditton, 1997].

[Riva & al., 2003] suggested that presence is enhanced by a number of factors related on one side to the subject himself, and on the other to the structure of the medium and to the content of the experience. Between some of the suggested factors: the realness of the experience, the immersion and involvement of the user in the experience, the credibility of the experience, the naturalness of the interaction.

A common trait of these characterizations is represented by the idea that presence is a form of illusion: illusion of reality by which

the user is deceived about the nature of his experience (experience is of real things, or is non-mediated) or illusion of transportation.

The concept of presence has been criticized because of the difficulty in providing a robust, reliable and valid measure of it and because of conceptual difficulties provoked by the fuzziness of the notions of illusion of reality, illusion of non-mediation and illusion of transportation [Casati & Pasquinelli, 2005]. Moreover, the literal illusion of realism is likely to be very rare [Stoffregen et al., 2003] or counterproductive.

A shift of attention has hence been proposed by several authors from the feeling of presence to the effects of presence over the performances of the subject [Zahoric & Jenison, 1998] and from the illusion of reality to the perception of realism.

In particular, [Stoffregen, et al., 2003] propose the concept of action fidelity as a measure of the perception of realism and [Luciani, et al., 2004] pragmatically reduce the problem of presence in special mediated conditions (instrumental interaction) to the capacity of performing the desired task with the involved instrument. Another approach consists in considering the effects of mediated experiences in terms of believability [Pasquinelli, Submitted], that is in terms of the fulfilment of the users' expectations.

The approaches of [O'Regan & Noe], [Stoffregen, et al., 2003], [Luciani et al., 2004] and [Casati & Pasquinelli, 1995] are characterized by the attention towards the behavioural responses and performances of the users in dynamic conditions, by the consideration of the appropriateness of these performance in relationship both with the contents and with the characteristics of the context of the experience (the medium, the instrument, the simulator) and hence by the refusal of the notion of illusion of reality or illusion of non-mediation.

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RELATED ITEMS

ACTION FIDELITY

BELIEVABILITY_ 1&2

IMMERSION VS. VIS-À-VIS

INSTRUMENTAL INTERACTION

PRESENCE, THEORIES OF

SENSORIMOTOR

TELEOPERATION / TELEPRESENCE / TELESYMBIOSIS

PSYCHOPHYSICS

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Psychophysics is an interdisciplinary research field that arose from experimental psychology. It studies the relationship between a person's subjective perception and the physical stimulation of our sensory organs. Research in this field improved knowledge about human perception considerably, e.g., in finding perceptual cues [→ CUES, SENSORY]. Nowadays, creating virtual environments or human computer interactions is not thinkable without maintaining the basic findings of psychophysical studies. Generally, the development of interfaces or applications is appended to or even followed by a psychophysical study to prove the correctness or believability of the presentation. Therefore, basic research in human psychophysics is fundamental.

Psychophysical methods

Gustav Fechner introduced the term 'psychophysics' in 1860 when he published his book *Elemente der Psychophysik* [Fechner, 1860] in which he described methods for precisely measuring the relationship between a (physical, objectively measurable) stimulus and a person's perception of it (a psychic phenomenon). Later, Wilhelm Wundt built on Fechner's work and founded the first laboratory of experimental psychology at the University of Leipzig. Fechner's theories influenced also the work of the physicians Ernst Heinrich Weber (Weber's Law) and Hermann von Helmholtz, but also thinkers as Max Weber, Ernst Mach and Wilhelm Wirth. Seen historically, psychophysics is one of the first disciplines that researched scientifically the processes of consciousness. But there is also a critical view on purely material-

istic science as psychic phenomena are not reduced to physical activities, one just tries to find correlations between those events.

A common method in psychophysics is to conduct experiments that seek to determine how perception changes as a function of changes in aspects of a stimulus that usually can be physically measured (like frequency of sound, weight of an object, or intensity of light). One is either interested in the so-called Absolute Threshold (= the smallest amount of stimulus energy necessary to detect the stimulus) or the so-called Difference Threshold (= the smallest difference between two stimuli that a person can detect). The experimenter sets up the experimental conditions by very carefully controlling the stimulus construction and presentation in order to avoid every possible source of interference. It is also important to consider that every perception is influenced by different cognitive factors as already existing knowledge, memory and expectation. The participants' task is usually to detect a stimulus, identifying it, differentiate between it and another stimulus, or describing the magnitude or nature of this difference. Hot and cold, for example, are perceptual correlates of temperature for which such physical measures as degrees Celsius provide physical units.

As noticed before, traditional aspects of a psychophysical investigation include the determination of sensory thresholds, methodological validation, and analyses based on signal detection theory. Psychophysics can and has been used in combination with neurophysiological methods to study neuropsychological properties and sensory processing mechanisms. So one can differentiate between psychophysical research in which the relation stimulus-perception is analyzed and the perception is presented in a communicable way (words, gestures, a phenomenological approach) and a way of research where one focuses on the relation stimulus and (neuro-) physiological activity.

Tasks

In psychological experiments, a subject is asked to complete some assignment while being presented a stimulus. This assignment is called a task, and it is traditionally strongly related to the experimental question underlying the experiment. The task is determined by the general experimental methodology (i.e., what stimuli are presented, how they are presented, etc) and the input devices used. Some tasks are primarily verbal: force-choice selection, a free writing, or subjective rating. These responses take any of a number of forms, including answers on questionnaire, spoken answers, or typing the answer into a computer. Other tasks require the participants to execute body motions, like pointing, drawing, grasping, driving a car, adjusting things (e.g., knobs or toggle switches), or building or creating something. Some tasks are primarily physiological and require non-overt, intentional behaviour from the participants. In these cases heart rate, galvanic skin response, body temperature, or brain function are measured.

The task has to be carefully selected as it can influence the response of the participant. The tasks should not to be too complicated for the participant to understand. Tasks are mostly described to the participants verbally (either in spoken or written form). The responses to the task are analyzed and lead to the conclusions related to the experimental question of the study.

Stimulus

The stimulus is arguably the most important aspect of the experimental design. It is the input presented to the participant which is causing, or can be regarded as causing, a response from the participant. The stimulus can be an item, agent, action, or condition and can address one or more human senses. In a psychophysical experiment, the participant's task may be to determine if the stimulus is present, to identify it, to differentiate between it and another stimulus, or use the

stimulus signal in a control task (e.g., driving or flying).

It is necessary but difficult that all possible relevant parameters of the stimulus are known and carefully controlled. This is important to ensure that the participant's response arises from the desired changes in the stimulation, and not from some ancillary factors. The functional relationship between the systematic manipulation of the stimuli and the resulting response of the participant can then be analyzed. For psychophysics, this helps to elucidate the mechanisms that underlie perception and interaction with the environment [Robson, 1994].

Since the control and presentation of auditory or visual stimuli is technically quite easy, a lot of research has been done to investigate the processing of these stimuli even in a combined multi-sensory interaction [see Goldstein, 2006]. Conversely, other senses are more difficult to approach. The haptic sense [Appelle, 1991], for instance, is currently the focus of a large number of research and technology groups, including enactive interfaces [→ HAPTICS, HAPTIC DEVICES] [→ HAPTICS, IN COGNITIVE SCIENCES]. They are confronted with the difficult task of properly stimulating the sense of touch, and there is still fundamental research needed in the field of multi-sensory interaction and integration including this sense. The work on enactive interfaces faces these problems by developing devices for a controlled manipulation of these multi-sensory stimuli for studying these aspects of perception.

In the field enactive interfaces, the collaboration between experimental works and the development and improvement of interfaces and application is an important requirement. Nearly every project of enactive interfaces contains a psychophysical study of the topic and issues to concern. This coexistence of both technology and experimental work has big advantages for both fields to improve the development of believable applications and the knowledge about human perception as well as the interaction with virtual interfaces.

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RELATED ITEMS

COGNITIVE SCIENCES

COMPLEXITY IN HUMAN MOTOR BEHAVIOUR

CUES, SENSORY

HAPTICS, HAPTIC DEVICES

HAPTICS, IN COGNITIVE SCIENCES

PERCEPTION, DIRECT AND INDIRECT APPROACHES

R

REACHING

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Ronan Boulic [EPFL]

Reaching is the action for a human being of stretching the whole or part of the body in order to touch or grasp a point or an object in space.

Understanding the reaching behaviour has important implications for the ergonomics design of work places and devices used by human beings (e.g. automobile, plane cockpits, etc). Predicting how people reach and move object is still an important topic of research [Chaffin, 2001]. Studying reach movements is strongly connected to motion modelling because it allows extracting some patterns. Those patterns further on permit to do prediction on how different groups of people move for performing different tasks. A research issue is also to investigate what is behaviour of the head or the gaze while performing a reach task.

Fitts has pioneered reach studies for the arm on simple trajectories and has established the well-known Fitts's law [Fitts, 1954]. The main characteristics of such a movement are straight path and a bell-shaped speed. The Fitts's law tells us that the movement duration is a logarithmic function of distance when target size is held constant, and that the movement duration is also a logarithmic function of target size when distance is held constant.

A large body of studies have investigated complementary parameters of the reach movement including 3D reaching [Murata & Iwase, 2001] and the recruiting of additional body segments to perform distant reaches [Rossi et al., 2002]. This field of research is still very active as no theory of motor control

can explain and predict the very rich human reach abilities.

In virtual Reality, the perception of distances in the virtual space is altered, leading to a phenomenon of spatial compression as established in [Knapp, 1999]. Such additional factor has to be taken into account when VR is part of an interface for evaluating a 3D task. Moreover [Sander et al., 2006] show that the hardware chosen for a VR immersion has a strong impact on the ability of the subjects to perform correctly reach activities: HMD is to avoid and it is recommended to use immersive projection technology such as CAVE [→ DEPTH, PROBLEMS OF RENDERING].

The ability to manipulate objects with ease (i.e. so in the first place reach them) is strongly related to the sources of sensory information that one gather prior to and after contact with objects, more specifically visual and haptic feedbacks [MacKenzie & Iberall, 1994]. Therefore, simulating reaches in a virtual world requires special care for the haptic and visual rendering.

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RELATED ITEMS

COMPLEXITY IN HUMAN MOTOR BEHAVIOUR
DEPTH, PROBLEMS OF RENDERING
DISPLAY, VISUAL
GESTURE / MOVEMENT / ACTION
HAPTIC RENDERING OF VIRTUAL OBJECTS

REALITY, AUGMENTED AND MIXED

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Augmented Reality is the idea that an observer's experience of a real environment can be augmented with computer-generated information. Thus it differs from virtual reality that completely isolates the user from the real world using only synthesized perceptual information.

The virtuality continuum, as described by Paul Milgram [Milgram & Kishino, 1994], spans from reality in one extent to virtual reality at the other extent. In between lie the areas of augmented reality and augmented virtuality. Mixed reality is defined as everything that lies between the two extremes of the continuum. It is often used interchangeably with augmented reality and so is often considered to be equivalent, however, this is not always true. Mixed reality may also be used to describe other combinations of realities, such as a virtual reality that incorporates live visual elements of the real world (i.e., augmented virtuality). A comprehensive survey of research done in the area maybe found in [Azuma et. al, 2001].

More specifically, augmented reality is the idea that an observer's experience of a real environment can be augmented with com-

puter-generated information. Thus it differs from virtual reality that completely isolates the user from the real world using only synthesized perceptual information.

Usually this refers to a system in which computer graphics are overlaid onto a live video motion picture or projected onto a transparent screen as in a see-through head-up display [→ COMPUTER GRAPHICS]. But, sometimes it could also refer to the audio sensory channel by adding sounds to an environment that has existing sound sources and giving to the user the feeling that no sound is generated [→ AUDITORY FEEDBACK IN VR AND HCI].

An augmented reality system generates a composite environment for the user [Milgram & Kishino, 1994], made of virtual content mixed with real content. Because usually, augmented reality refers to the sense of vision, we then consider that such a system provides a composite view to the user [Aukstakalnis & Blatner, 1992]. The ultimate goal is to create a system such that the user cannot tell the difference between the real world and the virtual augmentation of it [Valino, 1998]. In this sense we could distinguish mixed reality from augmented reality: mixed reality contains the augmented reality but do not precise this notion of realistic blending between real and virtual parts. A mixed reality system could overlaid virtual on real without any desire of aligning them.

Application can be found in the field of medical [Rosen et al., 1996] or military simulation for learning, training, entertainment, design or maintenance.

Two typical visual augmented reality systems could be described: first, one can use a screen that displays both real and virtual scene. Thus the screen could be either a head-mounted display or a standard CRT or LCD screen. And in this case, the real world is usually acquired through a video camera. Second, a setup may use see-through screens to superimpose virtual parts on real scene. Moreover a tracking system (software using computer vision techniques or hardware) should be used to correctly align both worlds,

and today, it is the main subject of a wide array of research.

Augmented reality systems are supposed to be run in real time, and in this case the user can modify the point of view on the fly by moving his body. This is the basis to ensure that an augmented reality system is enactive: the user is part of the system in the sense that his own movements alter the information generated by the system. Mixed reality environments are often used as enactive interfaces in order to communicate/interact with the user. The mixing of various medias with computer-generated imagery to create an immersive environment is a very active area of research.

For a better contextualization in the area of enactive interfaces see also [→VIRTUAL REALITY AND VIRTUAL ENVIRONMENT].

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RELATED ITEMS

AUDITORY FEEDBACK IN VR AND HCI
COMPUTER GRAPHICS
DISPLAY, VISUAL
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

REPRESENTATION

John Stewart [COSTECH]

The term representation can cause a lot of trouble, because it is a highly polysemic word in natural language.

In cognitive science [→COGNITIVE SCIENCES], there are two conditions for speaking correctly of a representation:

- there should be two clearly distinct entities: the representation on the one hand, and its referent (i.e. that which is represented) on the other;
- and there should also be a clearly defined mechanism which sets up an adequate correspondance relation between the two.

These conditions can well be satisfied in the case of external representations. For example, a map is a representation of the countryside (or the streets of a town, etc.); and it is clear how the correspondance relation is set up, because that is precisely the work of geographers and cartographers. Noticeably, in most case, computers are actually used to build such external representations of the world. Computer models, and computer simulation [→SIMULATION], which are important in enactive interfaces, fall obviously in the category of external representations (Luciani 1993). More generally, in sciences, representation (external representation) is a major preoccupation.

Indeed, the question that is problematical and controversial is that of internal mental representations. These are a necessary part of the computational theory of mind [→COMPUTATIONAL PARADIGM]; but as it turns out, there are great difficulties in specifying how the appropriate correspondance relations between the (symbolic) representations in the mind (/brain?), and their external referents in the (real?) world can be ensured.

For this reason, particularly in the framework of the alternative paradigm of enaction, a certain number of cognitive scientists con-

sider that it is better to dispense with the notion of internal mental representations altogether. Thus, when there is clearly a mental event, but there is no pre-existing external referent, it is better simply not use the term representation (for example, perceptions are presentations but not representations; there are also dreams, or imagined possible future scenarios, etc, but none of these require using the term representation).

A possible exception is the anticipated sensory consequences of motor actions; here, the internal representation is the anticipated consequences, and the referent is the actual consequences when the action is actually performed. This is important for the possible mastery of sensori-motor contingencies [\rightarrow SENSORIMOTOR CONTINGENCY OR DEPENDENCY] (O'Regan & Noë 2001); see also [\rightarrow SENSORIMOTOR THEORY]. Here, it may well be correct and useful to employ the term representation because there are a large number of learning examples (actions actually followed by sensory consequences), and neural networks are well-equipped to generalize on the basis of such examples. But note here that both the representation and its referent are internal. The problematic case is that of representational relations across the internal/external frontier.

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RELATED ITEMS

COGNITIVE SCIENCES
COMPUTATIONAL PARADIGM
CONSTRUCTIVISM
ENACTIVE COGNITIVE SCIENCES_ 1&2
SENSORIMOTOR CONTINGENCY OR DEPENDENCY
SENSORIMOTOR THEORY
SIMULATION

S

SENSORIMOTOR

Julien Lagarde [UM1]

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[INSTNICOD]*

The term refers to the fact that an organism is endowed with certain sensory and motor faculties that determine its interaction with the environment. What sensation or stimulation the organism/system receives is dependent on what action it performs and what action the organism/system performs is influenced by what sensation or stimulation it receives. The sensorimotor interactions are often conceived of as being of the nature of rules and some recent theories considering experience to be action and not a state have endeavoured to explain it in terms of these governing rules of sensorimotor interaction.

The use of the term sensorimotor often emphasizes that perception of motion of the body and the generation and control of the actual movement of the body are distinct but tightly related. This notion rests on the distinction between signals efferents (outflow), or commands, and afferents (inflow), or sense of movement, respectively coming out and in with respect to the central nervous system. This distinction leads to the need of exchange of information between the subsystems dedicated to efferent and afferent to get coherent behaviour. The motor M1, the area responsible for the so-called motor commands, and the somatosensory S1, receiving sensory input related to motion and position of the limbs, are right next to each other, respectively anterior and posterior to the central sulcus, and the whole area is named sensorimotor cortex. Corresponding to the anatomical classical distinction, neuronal activity spatially segregated was measured

with MEG before the actual movement, the so-called premotor motor field, and after the movement, the so-called movement evoked fields (for an accurate spatial-temporal description of the sensorimotor cortex functioning, see Cheyne et al, 2006). Moreover the dynamics of specific brain waves (alpha, 8-14 Hz) have been recently related to sensorimotor integration (Chen et al, 2003). However the functional role of sensing motion, like sensing velocity or position, and producing motion (electrical action potential to muscle fibers) is a controversial issue. The generation of a movement trajectory can be seen as emerging from the coupling between sensing and moving, not as the mere sequential ordering of commands, sensing, and then corrected commands and so on.

Another line of reasoning is to consider that muscles are at the same time actuators and measurement devices, which possess for instance position sensors, making motion the outcome of directly, almost continuously, connected efferent and afferent subsystems. Recent studies showed that motor commands contribute to human position sense (Gandevia et al, 2006).

Finally, sensorimotor is to be understood in relation to the problem of the actual control of movement, which has to be considered relative to frames of references or coordinates. What is actually controlled by the central nervous system? What is the functional or operational or task space? If what is controlled is not the movement of the limbs per se (the body in joint space coordinates) but the relation between the body in motion and the environment in relation to a goal, then what is to be controlled may be a variable that quantify the relation between body and the relevant environmental dimensions, this could be eventually expressed in external coordinates (earth frame) and in some cases may not require the integration of body-internal information (proprioception) with environmental information, for instance a visual control of a distance between an end effector (the index finger) and a target in the external space.

The perspective that efferent and afferent subsystems are mutually exchanging information, opens the way for a wealth of dynamical properties, and fits well with earlier positions about biological movement generation and control (Turvey, 1990).

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RELATED ITEMS

MOTOR CONTROL
 MULTIMODAL (MULTISENSORY) INTEGRATION: THE BINDING PROBLEM
 PERCEPTION, DIRECT APPROACHES: THE SENSORIMOTOR APPROACH
 PERCEPTION, MOTOR THEORIES OF SENSORIMOTOR THEORY

SENSORIMOTOR CONTINGENCY OR DEPENDENCY

Kevin O'Regan [CNRS]

The term sensorimotor contingency was coined by the cybernetician D.M. MacKay (1962). It refers to the lawful relationship that governs the way a bodily action modifies incoming sensory information. For historical reasons the word contingency is used in the opposite sense than it is in normal philosophical parlance. For that reason it is may be less confusing to use the term sensorimotor dependency or law.

The importance of the notion of sensorimotor contingency derives from its use in the sensorimotor theory of phenomenal consciousness advanced by O'Regan & Noë (2001, 2006). This theory proposes that the phenomenal quality of a sensory experience should be identified with the accompanying sensorimotor contingencies. Different sensory modalities will, it is claimed, be accompanied by different experiential qualities because different modalities differ in the sensorimotor contingencies that are put into play during sensory exploration using these modalities. Furthermore, even within a modality, the differences in felt quality should, it is claimed, be due to the difference in accompanying sensorimotor laws.

A problem in this approach is the question of what should be defined as sensory input: should we take the information directly at the sensor output or after some degree of processing? Successive stages of brain processing following sensing will result in progressive loss in information. What do we need to use to define the law? The same question can be asked for effector output. It seems that one should consider the whole sensorimotor loop, going from the outside environment to sensors to brain to effectors, back to outside environment (or the other way), and consider as a law the properties of that loop that are available for categorization and manipulation by the cognitive processes of the system. More work is required to clarify this issue.

Another problem: sensorimotor contingencies can be described using different codes — for example the law linking changes in auditory input as a function of distance from a sound source will be expressed in a different way depending on the units one uses to code the sound energy and the distance. We would like to retain in the notion of law only those aspects of the description of the sensorimotor skill that are independent of the code used to describe the law. The reason we require this is that we require that the only entities that the cognitive system of the agent has access to should be facts about the system's interaction with the environ-

ment. If we allowed the opposite, that is, if the reasoning done by cognitive system was reasoning about particular codes used somewhere in the system, then the system would have no natural metric to compare these entities, nor no way of making the link between these entities and experiences of other agents. (This argument is related to D. Dennett's idea of heterophenomenology: a system has no privileged access to its own internal states).

Of course the code used to describe sensorimotor contingencies determines to some extent the possible variations in sensorimotor behaviour that can be described, and may limit the calculations that the agent's cognitive system can perform with regard to the law. More work is needed to be clear on these problems.

Examples of sensorimotor contingencies of seeing are facts like: when you blink there is a big change in sensory input; when you move forward the sensory input changes in a special way (an expanding flow field); when you move your eyes, there are certain changes which are typical of seeing.

The notion of sensorimotor contingency is of particular interest within the field of enactive interfaces. In such systems, new modes of interaction with the environment are devised which make use of tools or prostheses or completely new input-output systems as compared to normal human sensors and effectors. Sensory substitution systems [→ SENSORY SUBSTITUTION SYSTEMS] are also examples of such systems. The sensorimotor contingencies involved in such interactions may have similarities with the sensorimotor contingencies involved in normal perception, in which case the experienced quality of sensation in the new devices should then resemble the normal sensory experiences. The principles needed to build tools or devices that give sensations of space, of texture, of sound, for example, should be based on these notions.

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RELATED ITEMS

CONSCIOUS ACCESS AND COGNITIVE ACCESS
 PERCEPTION, DIRECT APPROACHES: THE
 SENSORIMOTOR APPROACH
 PERCEPTION, MOTOR THEORIES OF
 SENSORY SUBSTITUTION SYSTEMS
 SENSORIMOTOR THEORY

SENSORIMOTOR THEORY

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Sensorimotor theory is a theory about sensory phenomenology that proposes a way of bridging the gap between physical processes in the brain and the "felt" aspect of sensory experience. It is based on the idea that experience is not generated by brain processes themselves, but rather is constituted by the way these brain processes enable particular sensorimotor skills, or ways of exploring the environment. The main proponents of the doctrine are J. Kevin O'Regan and A. Noë who following D. MacKay call the laws describing the sensorimotor interactions the sensorimotor contingencies [→ SENSORIMOTOR CONTINGENCY OR DEPENDENCY]. However, scholars like Ryle, Pessoa, Maturana, Varela, Thompson, Rosch, Järvilehto and Gibson have expressed similar ideas and in general have stressed the importance of action in perception.

The sensorimotor theory provides a unifying framework in which to consider the differences in sensory experience within and

between different sensory modalities (and this includes unusual cases such as sensory substitution), and the relation between the "felt" nature of sensory experience as compared to experiences involved in other human activities. The theory also provides insights into the so-called binding problem, and, within the domain of vision, into the question of how vision can seem perfect despite what would seem to be the glaring imperfections of the visual system (perturbations due to eye saccades, retinal scotomas, non-homogeneities in spatial and color sampling). Among other empirical results that the theory relates to is the issue of the nature of the internal representation of the visual world, and the phenomenon of change blindness.

The interest of the theory within the Enactive framework is that it provides a way to understand how new sensory interfaces or remediation devices will be perceived by users, in particular the extent to which such devices will be perceived as providing an experience of reality or presence.

Under the sensorimotor approach, experiencing a raw sensory feel is defined as: having cognitive access to the fact that one is currently engaged in exercising a sensorimotor skill. The phenomenal quality of the experienced feel is then considered to be constituted by the laws of sensorimotor contingency that govern the skillful sensorimotor interaction involved. This explains why vision seems visual, audition seems auditory, touch seems haptic, etc.: the sensorimotor interaction underlying vision, for example, obeys particular input-output laws which are typical of, and unique to, vision.

Several terms in this definition of raw sensory feel need clarification.

Sensorimotor skill

The notion of sensorimotor skill is used in the sensorimotor theory to designate a sensorimotor interaction in which a system built for a purpose controls the interaction in a skillful way, that is, it can modify the input-output in a way that is in some sense adapted

to one of its purposes. (Example, a baby moves its arms to grasp the approaching bottle. Another example: a thermostat operating properly turns the heating on and off as a function of the temperature in the room). Clearly the notion of adapted contains profound premisses about the viewpoint from which one is analysing the system. It seems to require that it make sense to say that the system is built for a purpose. The issue is tricky and needs careful consideration.

Sensorimotor skills are the foundation of interactions that users have with enactive interfaces. Quantifying the types of interaction and understanding how they can give rise to a "felt" or phenomenal experience, and how this depends on the laws or sensorimotor contingencies underlying the skill, are issues that are important in designing new tools and devices to extend the human sensory systems or in sensory remediation.

Being engaged

A second notion in the sensorimotor theory that needs clarification is the notion of being engaged in exercising a sensorimotor skill. Whereas the concept of engagement makes sense in an intuitive way, it becomes less clear when we think about agents other than humans, or when we think of humans when they are not paying attention to what they are doing. It is therefore helpful to attempt to define this concept more precisely.

The notion of being engaged requires having the possibility of not being engaged. The idea is that the concept makes sense when applied to a system that is invoking its cognitive resources to exercise a particular sensorimotor skill that it has chosen among other skills. Thus, it makes no sense to say that a thermostat itself is engaged in regulating the temperature in a room (it has no choice, no cognitive resources to invoke). But consider an automatized home environment that can dim lights, regulate the heating, open and close blinds, etc. Then in winter, when the heating is turned on, it would make sense to say that the automatized home

environment was engaged in regulating the furnace. But in summer the system would not be engaged in doing this, rather it would be engaged in operating the air conditioning.

The sensorimotor theory of phenomenal consciousness makes use of this precise definition of engagement in order to clarify the conditions under which a person can be said to be having a sensory experience. Under this approach, being engaged in exercising a sensorimotor skill is what constitutes having a sensory experience. In enactive interfaces the concept of engagement and its accompanying notion of choice are clearly important factors that determine the degree to which the experience of using the device will be felt to be real.

Raw sensory feel

Another notion in the definition of raw sensory feel that needs clarification is the notion of cognitive access.

The definition of experience must allow for the possibility that animals with even minimal cognitive capacities should have feels. Clearly the degree to which it makes sense to say an animal has feel depends on the degree to which it makes sense to say it can have cognitive access to something.

Presumably a dog has some degree of cognitive access to the fact that it sees the cat. But presumably the fly has less cognitive access to the fact it is chasing another fly. A tic tac toe playing program has cognitive access to its move, but the move is not a sensorimotor skill, so one cannot say that the program "feels" it. What about if the tic tac toe machine had a robot arm which automatically made marks on the paper -- would it "feel" the pencil it clenched in its robot fingers? Probably not, because it would have to have cognitive access to the skill of clenching. This would require there to be different modes of clenching and it would require the system to have a choice about clenching this way or that, and for it to be poised to make use of this clenching skill in its planning, decisions and communication. But presumably the system is not wired up to

think about the way it clenches, only about the actual moves it's making. It does not feel the pencil in its clench...

Finally, an important aspect of sensorimotor theory is how it explains the difference between the experienced quality of sensory stimulation (like seeing, hearing, taste, etc.) and the apparent lack of sensory presence associated with other mental activities like thinking and remembering, and with other brain processes like those involved in controlling visceral functions. In order to make this distinction the theory appeals to the notions of alerting capacity and corporality.

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RELATED ITEMS

CHANGE BLINDNESS
CONSCIOUS ACCESS AND COGNITIVE ACCESS
PERCEPTION, DIRECT APPROACHES: THE
SENSORIMOTOR APPROACH
PERCEPTION, MOTOR THEORIES OF
PHENOMENAL QUALITY: THE SENSORIMOTOR
APPROACH
PRESENCE, IN COMPUTERIZED ENVIRONMENTS
PRESENCE, THEORIES OF
SENSORIMOTOR THEORY
SENSORY SUBSTITUTION SYSTEMS

RELATED DOCUMENTS

<http://nivea.psych.univ-paris5.fr/OREGAN-NOE-BBS/OREgan;Noe.BBS.pdf>

SENSORY SUBSTITUTION

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One of the more elaborated theories on sensory substitution is Bach-y-Rita's theory of brain plasticity (1972; a recently updated discussion is presented by Bach-y-Rita & Kercel, 2003). A basic idea in this theory is that persons who have lost a sense organ have not lost the sense totally, but only its peripheral part. Information to the sensory centres in the brain can be obtained via other channels. Other sense organs and artificial receptors can substitute the lost peripheral receptor. This capacity of the brain to change its way of functioning is called brain plasticity. Bach-y-Rita and Kercel give examples of what they call seeing with the ears, seeing with the skin receptors, and balancing via skin receptors. They stress the importance of training and motor control for successful substitution.

The concept of sensory substitution is open to criticism from several points of view. Firstly, it embodies the classical assumption that there exist, indeed, separate senses [→ MULTIMODAL (MULTISENSORY) INTEGRATION: THE BINDING PROBLEM]. From the perspective of the global array [→ ARRAY, GLOBAL] (Stoffregen & Bardy, 2001; 2004) the concept of sensory substitution is incoherent. If perception operates through sensitivity to patterns in the global array, then the traditional hypothesis that there are separate senses is wrong and, instead, there is only one, unitary perceptual system. Sensory substitution typically is invoked relative to persons who have lost the use of one or more types of receptor systems, e.g., through blindness or deafness. Blind people (to take one example) are sensitive to the global array, but are unable to pick up patterns in the global array that specify position and motion relative to

the illuminated environment. With technology, we can attempt to capture information about position and motion relative to the illuminated environment and convert it into information about position and motion relative to some referent to which the perceiver remains sensitive. Critically, the artefactual stimulation is still part of the global array and (from our perspective) is still detected as being part of the global array.

Secondly, the term is misleading because it implied that perception arises from sensory input alone. However, according to the paradigm of enaction, perception does not arise from sensory input alone but from the sensory-motor dynamics as a whole; what O'Regan and Noë (2001) have called sensorimotor contingencies. However, if perception is based on the sensory consequences of motor actions, then it follows that there is no perception without action. Thus, the repertoire of actions which modulates sensory returns must be taken into account.

These non-classical views have important implications for enactive interfaces. In particular, it follows that a novel device will not in general be a substitution, but rather a supplement. Hence, the term perceptual supplementation, introduced by Lenay and colleagues (2003) is preferable. In this perspective, any technical device which functions as an interface between a human being and the world will give rise to an augmented reality.

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RELATED ITEMS

ARRAY, GLOBAL
MULTIMODAL (MULTISENSORY) INTEGRATION: THE
BINDING PROBLEM
SENSORIMOTOR THEORY
TECHNICAL ARTEFACTS AND PERCEPTUAL
EXPERIENCE

SENSORY SUBSTITUTION SYSTEMS

Kevin O'Regan [CNRS]

Sensory substitution systems allow information coming from one sensory modality to be processed by a different modality (Bach-y-Rita, 2003). For example, information which would normally have been handled by a defective sensory organ can be processed by an intact sense organ. Thus, visual information could be provided to the brain via a substitutive sensory system, for example the auditory or the somaesthetic system. The sensory substitution device acts like an artificial transducer. The most studied classes of sensory substitution devices are visual-to-tactile substitution devices that convert visual pictures into tactile pictures, and visual-to-auditory substitution devices which convert visual (often static, rarely moving) images into sounds.

Sensory substitution is a particular kind of Enactive interface, and as such provides an interesting theoretical testbed for understanding such interface.

Visual-to-tactile sensory substitution

Visual-to-tactile sensory substitution was invented by Paul Bach-y-Rita in the 1960's (the Tactile Visual Sensory Substitution System, TVSS), but has more recently become a much more active research field, due to technical advances.

Many visual-to-tactile sensory substitution devices have been developed. In most systems, optical images picked up by a video camera are translated into electrical or vibratory stimulation applied on the skin of a part of the body (abdomen, back, fingertip, forehead, and tongue...). Many studies have shown the feasibility of sensory substitution of vision by somaesthetic stimuli. Studies have shown the possibility of simple form recognition, the possibility of reading (Craig, 1983), of localisation, some have also shown that subjects using tactile-vision sensory substitution were able to make perceptual judgements using visual means of perception such as perspective, parallax, looming and zooming, and depth estimates (Epstein, 1985).

Numerous studies have thus shown the possibility of achieving many perceptual skills via electrotactile or vibrotactile stimulation. These visual-to-tactile substitution systems are faced with some technological limits such as the choice of a highly sensitive skin surface, and problems such as skin irritation or pain and also with the large energy consumption that limits the autonomy of portable versions of these devices (Lenay et al., 2004).

More recently tactile stimulation through the tongue (tongue display unit), which provides a more reliable interface than vibration on the skin, has been successfully experimented with in surgical and robotic applications as well as in vestibular rehabilitation.

Visual-to-auditory substitution devices

- *Echolocation devices.*

Echolocation devices are based on the same principles as sonar. An ultrasound source / receptor emits a stream of frequency modulation signals. Receptors use a telemetry method in order to determine the distance between the source and the distant object. This method consists in calculating the time taken by an ultrasonic impulsion to reach an object and to come back by reflection to the generator. Signals are then converted into auditory signals and transmitted

to the ears via headphones. The conversion of signals into sounds gives subjects an indication about the distance and direction of a distant object (for example the distance can be coded by intensity and the horizontal position can be coded by inter-aural disparity). (eg. ultra sonic torch, sonic glasses, and recent developments, Sonic Pathfinder). These systems can be helpful for locomotion and the guiding of movements of blind persons and can also give information about spatial layouts of three-dimensional scenes.

- *Image-to-sound translation.*

In these systems, optical images picked up by a camera are converted into sound and transmitted to subjects via headphones. Three main systems have been studied. The codes used in these systems convert the vertical position into frequency and the luminosity into sound intensity/amplitude. The three systems differ mainly by their horizontal coding. All of them use or can use inter-aural disparity in order to code the horizontal position of objects. The Prosthesis Substituting Vision by Audition (PSVA) developed by Capelle et al. (1998) adds another frequency relationship concerning vertical position. Furthermore, in order to more resemble the structure of the visual system, their receptor field has a higher resolution in the center of the picture. *The vOICe* developed by Peter Meijer (1992) and the device developed by Cronly-Dillon (1999) use a temporal left-right scan in order to code horizontal position. The latter device also has a system for feature extraction.

Studies done with auditory devices have shown the possibility of simple pattern recognition (Arno et al. 2001 for the PSVA). See Petra Stoerig (unpublished work) for static form recognition with *The vOICe*. Interestingly, some studies also demonstrated the possibility to recreate visual illusions with the PSVA.

Extensive testing of *The vOICe* has been done by Auvray, Hanneton & O'Regan (2007), showing that users are able, after about 15 hours of training, to navigate, point,

and recognize simple objects using the device. A video demonstration is available on the Internet (see related document).

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RELATED ITEMS

OBJECTIVITY
 SENSORIMOTOR THEORY
 TECHNICAL ARTEFACTS AND PERCEPTUAL EXPERIENCE
 ZOOM, HAPTIC

RELATED DOCUMENTS

Video available at: <http://nivea.psych.univ-paris5.fr/demos/SensorySubstitution-O'Regan.mpg>

SHAPES AND CONTOURS

Annie Luciani [ACROE&INPG]

Shape and contours: Optical vs. mechanical? A paradoxical concept.

Shapes and contours are usually considered in their geometrical features. We can say that an object presents a spherical shape for example. This is equivalent to say that it presents a stable spherical contour that separates two parts of the space: the inner of the object and the external world. The object corresponds then to the stable experience of this inner part of the space.

Hence, the concept is related first to the spatial properties exhibited by an object. However, it can be extended to others correlated spatial properties, such as size, orientation, or texture considered as micro-local properties of the contour of an object. There are a lot of work addressing the question of the recognition of such parameters, the considered senses being the sight and the touch. It is often considered that except the texture, which is sensed equally by the touch and the vision, the others are more reliably encoded by the visual than by the haptic system [Klasky et al 1987]. Developmental psychology points out other results as those in very young infants, when transfers from touch to vision and not only from vision to touch are observed in the recognition of shapes (prism or cylinder): “*Results did not show transfer from vision to touch*” [Nadel, Steri, 2004].

Does that mean that there are two notions of shapes, one purely geometric, more related to vision, and another physical, more related to the resistance of matter, the texture being the frontier between the two spaces? Indeed, shapes have, as the Janus figure, two faces or two determinants. They emerge from two completely different processes, optical and mechanical, pointing out the underestimated ambiguity of the notion of shape.

In [Luciani, 2004], addressing the paradoxical ambivalence of the notion of shape, the author writes: “shape do not exist as single pattern affected to an object”. Shapes have two faces, one looking to the physical materiality of the object, one looking to its optical property.

More generally, a single object can paradoxically exhibit several shapes, or several contours: the visual shape, along with several mechanical shapes.

More, the visual shape and the mechanical shapes of a single object have no reason to be always identical. Several situations illustrate this paradox. A rainbow, or the mirage of an oasis in the hot desert, have both a visual shape but do not have any mechanical contour. We can traverse them, or walk through them. Conversely, a perfectly transparent door has no visual contour, but has a hard mechanical shape.

Basically, the visual features are nothing else but the singularities of the interaction between photons and electromagnetic matter. The visual shape (the visually experienced flatness, the visually experienced spherical shape etc...) is the geometrical locus of the spatial singularities of the interaction between light and optical matter. Thus, visual events are intangible. Other classical examples could be geometrical drawing and synthetic 3D images produced by pure geometrical representations.

In usual rigid objects, the visual shape seen by the eyes is at the same spatial location as the mechanical shape “seen by the body”. Although these objects are common, they are indeed very specific cases where the matter is 100% (99,99...%) mechanically rigid and simultaneously 100% (99,99...%) electromagnetically rigid (opaque).

But what about flames, rainbow, water, fluids, translucent pastes, glasses etc?

Furthermore, what about objects like cat fur or hair, that are not 100% (99,99%) mechanically rigid, and thus exhibit several mechanical contours?

For example, in the experience of touching a cat, we distinguish several types of contours; a penetrable zone (the fur of the cat), that we feel very smooth when we caress it or in which our hand can penetrate: then a deformable contour (the skin) when we press a little more; and finally a rigid contour, when we press stronger, and when we feel for example the very thin and rigid bones of the chin of the cat.

If you put a force sensor on the palm of the hand when stroking your cat, the force detected will be very low when the hand is in the fur, higher when it is on the deformable skin and higher when it is touching the skeleton. This means that a single entity - your preferred pet - may exhibit several mechanical contours, described by several thresholds in the singularities of the physical interaction.

When doing this strange experiment to press strongly a cubic piece of ice within your hand (and try to avoid the coldness to focus on the shape), you will feel simultaneously a very rigid (for example cubic) contour with very precise shape, and a kind-of-something-of-smooth (corresponding objectively to the very thin film of water which is between your skin and the piece of ice), and paradoxically a sort of deformable and penetrable object, as if your fingers seem to penetrate within the ice (due probably to the surfusion physical phenomenon).

In other words, and in a funny way, all what is happening in terms of contour as a primary cue of space organization, depends probably:

- on the percentage of the optical and of the mechanical rigidity;
- and on the intensity and the nature of the forces describing the mechanical interaction.

We can say that the optical contour is the experience of the singularities in the interaction between the light and the electro-optical matter, and the mechanical contours are the singularities in the interaction between the two mechanical bodies.

From this observation, it appears that the critical frontier in visual representation is not the distinction between morphology (shapes) and rendering (light) as usually considered in computer graphics, but between optical matter, represented by electromagnetic field, and mechanical matter represented through forces, in which the first produces pure visual features (color, shadows, etc.) and visual shape, and the second produces mechanical shapes and motions. Visual features are then related more to the geometry of the space, whereas mechanical shapes and motion have to be represented by dynamics.

One of the challenge - central for experimenting enaction and designing enactive interfaces - is that virtual realities and haptic interaction allow to experiment precisely the ambiguity of the notion of contours and shapes and their role in the constitution of the concept of object.

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RELATED ITEMS

COMPUTER GRAPHICS
HAPTIC RENDERING OF VIRTUAL OBJECTS
HAPTICS, HAPTIC DEVICES
HAPTICS, IN COGNITIVE SCIENCES
VISUAL PERCEPTION

SILHOUETTE, IN MOTION ANALYSIS

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The design of many enactive interfaces needs, more than traditional human computer interfaces, a precise estimation of human motion. The reason is the necessity to understand, not only the motion kinematics itself, but also the nature and meaning of the motion and the enactive knowledge it corresponds to.

For this typology of interfaces, silhouette-based algorithms are a very powerful mean for estimating human motion, especially because with such algorithms it is possible to avoid subtracting too many information during the tracking process, for example by considering a rigid body as done in some stick tracking algorithms - see [Rosenhahn et al.] for an overview.

The silhouette is normally a bidimensional image, obtained after a segmentation of the background from the image sequence, representing the active subject of the scene. More in detail using background subtraction and color subtraction algorithms, it is possible to obtain a blob that represents the subject. This blob contains different information such as the contour of the subject, the body parts (included joints) and the shape.

In human motion analysis a variety of approaches has been studied. Following [Rosenhahn et al.] such work can be categorised in different areas depending on the type of used model (stick figures, cad models etc.) or abstraction levels (edges, silhouette etc.) or object part.

These various approaches are not mutual exclusive but traditionally are used in different research areas, for example, stick figure or joint representation in clinical studies,

silhouette for surveillance systems and skeleton models in computer graphics. Nevertheless, during the evolution of computer vision it appears that the simplifications of some object modelling are too restrictive for representing natural movement, and often required manual intervention. Facing these problems, the silhouette approach seems to maintain, instead, important information that are loosed when using other methodology, even if it works on 2D image that convey postural mistakes due to occlusion problems.

In the well-known work of Wren and colleagues [Wren et al., 1997] for building the 3D blob-model of the human, authors start from the 2D contour in order to identify the silhouette, and they use it for labelling the body parts. Also in the work of Haritaoglu [Haritaoglu et al., 1998], a silhouette-based model of the body is used for estimating human body posture.

Within the various activities performed in the enactive framework the silhouette approach to human motion analysis corresponds with an important research area for evaluating high level motion feature such as the fluidity or intentionality of the motion. Furthermore, silhouette based algorithms has been used also in the evaluation of the believability of virtual humanoids reconstructed from kinematical information about joints. This analysis confirmed our theoretical hypothesis that the joint-model/marker-based approach removes some of the information conveyed by motion. With the silhouette-based approach, these missing information are still present.

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RELATED ITEMS

GESTURE ANALYSIS
GESTURE ANALYSIS: LABAN'S KINESPHERE
GESTURE SEGMENTATION
INVERSE KINEMATICS
MOTION CAPTURE

SIMULATION

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In the context of computer [→ ALGORITHM], the primary situation in which the term simulation is used is when the result of the computation of an algorithm produces data that are similar to data produced by a real (non-computerized) system, considered as a reference system. In such case, the original data are measured by sensors, and then compared with the data produced by the computational process. An acceptable difference (evaluated by absolute or relative errors) is defined. When the difference between data are smaller than the acceptable difference, the computational process can be called a simulation of the reference system. The algorithm at hand is then said to be an algorithmic model of the reference system. Hence, one of the major aims of computer simulation is to attempt to model a real-life situation in order to understand how the real system works. By changing variables, predictions may further be made about the behaviour of the system.

Computer (or virtual) simulation is used in many contexts, including the modelling of natural systems or human systems, in order to gain insight into their functioning. Other contexts include simulation of technology for performance optimization, safety engineering, testing, training and education. Simulation can be used to predict the eventual real effects of alternative conditions and courses of action. Key issues in simulation include acquisition of valid source information about

the referent, selection of key characteristics and behaviours, use of simplifying approximations and assumptions within the simulation, and fidelity and validity of the simulation results. Such simulation is an objective simulation in the sense that the comparison with the reference system does not depend on human appraisal.

A subtle, but nevertheless significant, difference can be done between computer simulation and other computer processes producing data similar than those acquired or observed in the real world.

Let's take here an example: there are several methods (algorithms) to compute a given sound produced by a given object. They can be classified in two categories:

- Algorithms that aim at modelling the sound itself.

They are based on sound analysis and sound computer synthesis. A typical example here is the Fourier analysis and synthesis. Sound signals are decomposed in Fourier components and can be re synthesized by the inverse method.

- Algorithms that aim at modelling the object that produces the sound.

A typical example is the simulation, of the instrument by means of a physically-based model of that instrument [→ PHYSICALLY-BASED MODELLING].

It is generally accepted in computer sciences, that the word simulation refers to the second approach. Consequently, the word simulation is dedicated to the computation of the cause that produces a given phenomenon, and not to the computation/synthesis of the phenomenon itself. We have here to be aware that the term cause does not address the real cause of the phenomenon, as this real cause is not – or, better, cannot completely be – known. The cause, indeed, corresponds more to a generative system that could play the role of a partial or a plausible cause, than to a hypothetical real cause itself. For recent discussions on that point in physics, one can refer to the concept of Veiled Reality [d'Espagnat, 1995].

In the middle of 60s, research started by the development of computer algorithms dedicated to the synthesis of sensory auditory and visual phenomena. While the request of realism developed, computer algorithms evolved toward simulation processes. A clear example is the computing of visual appearance of virtual object, that evolved from rendering techniques such as shape or texture mapping to physically-based model of the light-matter interaction. In the same way, in computer animation, physically-based models have been introduced in the beginning of 80s in order to have at disposal more complex and more expressive motions. The trends from synthesis to simulation have been reinforced by the introduction of interactive real time simulation, as implemented in virtual reality systems [→ VIRTUAL REALITY AND VIRTUAL ENVIRONMENT], and of instrumental simulation [→ INSTRUMENTAL INTERACTION]. In such uses, differently than in the case of conventional objective simulation discussed before, evaluating the results of the computation process has to be mainly, or at least also, performed through the human senses and action, we can say subjectively.

Two different cases must be distinguished:

1) When a reference system or reference situation exists in the real world, such as a real object having shapes, producing sound, motions, objects manipulated by hands, etc.

In this case, the subjective evaluation led to the notions of perception fidelity, believability and action fidelity [→ ACTION FIDELITY]. The simulation is considered successful when the simulacrum resembles with the real phenomena or the real-life reference according to these criteria. The computed algorithm is then said to be an algorithmic model of the reference system, and the whole newly implemented situation is a computer-based representation of the whole real reference situation.

2) When the computer process is not related to any real phenomena, real object, or real life situation, or real task.

In this case, no comparison (either objective nor subjective) is possible and no fidelity criteria can be defined. The subjective appraisal is then related to the acceptance of the computed sensorial data and behaviour, and/or of the new active situation by the human. This acceptance can be the pure sensory appraisals or the possibility to achieve a task. The term of simulation continues to be used, meaning here simulation of a non pre-existing phenomena, object, etc - based on the fact that what is computed is a generic cause able to produce the expected sensory phenomena, rather than the signals representing a phenomenon themselves. The term simulation is here related to the computation of a non-existing but “possibly possible” real object. The extreme case is when any real object cannot exist (either really or possibly), as in the case of very new creative situation. The term still continues to be used, referring to a simulation of a mental imagined object, sensorial phenomenon, situation and task, able to be sensed or acted by humans. In all these creative cases, the evaluation criteria cannot be other than believability, presence, achievement of the task, playability of the simulacrum, intimacy, etc...

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RELATED ITEMS

ACTION FIDELITY
ALGORITHM
BELIEVABILITY_ 1&2
INSTRUMENTAL INTERACTION
PHYSICALLY-BASED MODELLING
VIRTUAL REALITY AND VIRTUAL ENVIRONMENT
TRANSPARENCY_ 1&2&3

RELATED DOCUMENTS

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El_ComputerGeometry&Light_Carozzino_041001.pdf
El_Enaction&ComputerTechnologies_Luciani.pdf

SIMULATION OF HUMAN MOVEMENT

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In virtual reality, human simulation is present in applications such as virtual presenters, crowd simulation, medical visualization of human body, computer games, etc. These simulated humans, also called virtual humans are supposed to act and move like humans in the most realistic possible way. Human movement simulation can be tackled at different levels of abstraction, from skin deformation until behavioural simulation. A typical example of human movement simulation is the walking motion [Glaridon et al, 2004].

Movement simulation by means of character animation is applied to a 3D human-like character. Such a character is constituted by a skeletal structure and a skin (3D mesh), which simulates by analogy the anatomy of the human body. The movement primitives are basically mathematical transformations: translation/rotation of all the body (root); rotations of the articulations of the skeletal structure (called joints); and translations of the 3D vertices of the mesh for deforming skin. Some of the difficulties to simulate realistic character movements are due to the high dimension of the skeletal structure (186 degrees of freedom) and to the complexity of modelling joint limits, joint coupling, skin deformation, self collision avoidance, etc.

There are several available techniques to simulate human movement using the body structure described before; e.g. by using pre-recorded motions (e.g. key frame interpolation or motion captured) or procedural animation, using inverse kinematics or physically-based algorithms (direct or inverse dynamics, etc.) to drive specific movements such as walking, reaching, falling, etc.

The most popular technique is motion capture, because it provides natural results; but it is very expensive in terms of time and resources. This technique consists in tracking the motion of a real person using sensors and copying the movement to a 3D character [→ MOTION CAPTURE]. During this process some problems have to be solved such as filtering and foot planting. And if the motion has to be applied to different morphologies, then motion retargeting is used. Another disadvantage of motion capture is that it is difficult to modify without altering drastically the motion. For this problem, one can use a motion editor that exploits additional techniques such as inverse kinematics [→ INVERSE KINEMATICS] to modify the motion.

To animate several characters performing different actions, it is necessary to have a large database of pre-recorded motions. If there are not enough motions to provide variety we can perceive a repetitive movement, which reduces realism. It is possible to combine animations to produce new ones, or generate a smooth transition between them, by using motion blending and warping. These techniques control the interpolation or transition between two different animations.

On the other hand, procedural animation techniques are much more complex to implement and they tend to be computationally expensive. The most common technique of this type is inverse kinematics, which is good to achieve desired postures; but it tends to provide unnatural movements.

Therefore, presently the combination of animation techniques is the state of the art in human movement simulation, for example applying dynamic forces to a motion captured sequence [Zordan et al, 2005] to achieve physically realistic movements without losing the details of the original motion. A recent trend is to use biomechanical-based approach [Lee & Terzopoulos, 2006].

Finally, human simulation problem in general is much more complex when aiming to simulate also behaviour, as the body movement should be coherent with the (also simu-

lated) internal mental state of the virtual human [→ INTELLIGENT CHARACTERS] [Thalmann, 2004].

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RELATED ITEMS

AGENT, AUTONOMOUS
INTELLIGENT CHARACTERS
INVERSE KINEMATICS
MOTION CAPTURE
MOTION CONTROL, HIGH-LEVEL

SONIFICATION

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Shortly defined, sonification, sometimes called auditory display, consists in the acoustic representation of non-audio data with the aim of offering a user a specific access or understanding.

Sounds in human-computer interfaces have historically played a minor role as compared to visual and textual components, while in every day life we continuously use auditory feedback to interact with the envi-

ronment. People interpret auditory messages every day: this human skill can then be used to interpret information about data and relation among data conveyed by sounds. Indeed, sound can be an opportunity to provide information to a user that would be hardly understandable through other modalities.

In 1994, C. Scaletti proposed the following working definition of sonification: “*a mapping of numerically represented relations in some domain under study to relations in an acoustic domain for the purposes of interpreting, understanding, or communicating relations in the domain under study*” [Kramer,1994].

In other words, sonification aims at making accessible/understandable to human being information from several non-audio domains of investigation in the form of non-speech audio patterns.

Due to the specific dimensions of auditory perception [→ AUDITORY PERCEPTION], as compared to vision or language, (pitch, loudness, timbre, brightness, material of sound source...), sonification offers the possibility to convey new types of information or to enable new ways of data understanding, allowing to develop a deeper knowledge on data, quantitative relations among data, or processes.

Given the importance of gesture and movement in the field of enaction, one can note that some sonification processes have already been exploited successfully in order to enhance the degree of perception accuracy and reproduction of movements (e.g. [Effenberg, 2005]). In this framework, we can assume that sonification can be a useful and promising concept for action-driven interfaces like the enactive interfaces.

The most common techniques of sonification are: Audification, Earcons, Auditory Icons, Parameter Mapping and Model-Based Sonification. A short description of these techniques follows.

Audification

Audification is the simpler approach to sonification and consists of the direct use of

data values as a series of sound pressure values [Hermann & Ritter, 2004]. This strategy is usually applied to time series data, when data set is naturally sorted by a time attribute [Hermann & Ritter, 2004] and results very useful for data in which important regularities are already reflecting temporal variations which happen to match well with the perceptual capabilities of the human ear [Hermann & Ritter, 2004].

Earcons

Earcons are auditory patterns that represent a message in a short musical motive [Hermann & Ritter, 2004].

Auditory Icons

Auditory Icons are similar to earcons, but the auditory patterns are real-words sounds (natural or synthesized). These icons are more intuitive than earcons because user can exploits everyday listening.

Parameter Mapping

Parameter mapping is a more complex approach. This technique performs a mapping of the data stream under study to a stream of acoustic attributes such as, for example, frequency and loudness. A key concept for the success of this approach is the mapping function $[\rightarrow \text{MAPPING}]$ that generally consists of a combination of linear and non-linear functions.

Model-Based Sonification

Finally, model-based sonification [Hermann & Ritter, 2004] is a framework for sonification developed with the idea to overcome the limitations of the other approaches (in particular audification, earcons, auditory icons) to deal with data sets that present a high degree of dimensionality. In model-based sonification there is a dynamic model connecting data and sound, here, *“data determines the set up of a dynamic system whose temporal evolution is the only process that generates sound”* [Hermann et al, 2005].

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RELATED ITEMS

AUDITORY PERCEPTION
 MAPPING
 MAPPING, IN HUMAN-COMPUTER SYSTEMS
 SOUND ALGORITHMS

SOUND ALGORITHMS

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We call sound algorithms the categories of algorithms that deal with digital sound signal. Sound algorithms appeared in the very infancy of computer. Sound algorithms present strong specificities that are the consequence of two dual considerations:

- The properties of the digital sound signal itself, and its uses, as compared to signal in general (e.g. sampling frequency, need for real time, etc.).
- The properties of auditory perception $[\rightarrow \text{AUDITORY PERCEPTION}]$.

One can distinguish roughly sound processing, sound spatialization, sound analysis and sound synthesis algorithms, which are reviewed briefly below.

Sound Processing

The terms digital sound processing refer to digital techniques involved in the transforma-

tion of a digital audio signal into another one, e.g. delay, reverb, filtering, equalization, ring modulation, distortion, pitch shifting, time-stretching, flanger, compression, etc. The biggest field of applications of sound processing is perhaps recording, musical production, and audio broadcasting. However, digital sound processing is also of major importance in music creation (it has a central role in some music styles), and in human-computer interaction, virtual reality, etc.

Sound Spatialization

Amongst sound processing algorithms, sound spatialization algorithms call for a special attention, given their importance in research in the recent years. Sound spatialization refers to a process by which audio engineers add features in the sound material in order to project sound events in space, so that the listener can perceive sound sources localization, and sound propagation environment (room effects, etc.).

Several features are used by auditory perception in a set of spatial cues to identify the position of the sound source, as well as some other information about the ambient in which the listener is. Interaural Intensity Differences (IID), Interaural Time Differences (ITD) and the direct/reverberation ratio are the most important cues concerning the position. Other cues, such as elevation of the source and back sources, are often rendered by using filtering techniques that simulate the effect of ears, head and body of the listener on sound waves before they reach the tympanum. Many techniques are used to render spatial effects according to the system used: headphones or loudspeakers. The most effective rendering technique using headphones is the Head-Related Transfer Function (HRTF). It respects Head Shadow and ITD, Shoulder Echo, Pinna reflections.

Sound spatialization gained a large attention in virtual environments recently because spatial cues of a sound, especially source position, are important for human hearing, and because the use of sound spatialization algorithms proved to be a valid mean to

improve the subject sensation of immersion in the virtual immersive environment.

Sound analysis

Sound analysis corresponds to any operation used to extract information from a sound signal in order to give a signal interpretation. The aim is to give a characterization of the sound signal or to extract some fundamental parameters that characterize the signal. Given the time-domain signal that represents a sound, it is possible to analyze it in several other domains in order to better investigate its properties.

The most commonly used techniques represent the sound signal in the frequency domain with the aid of the Fourier Transform. Other important techniques that are today topics for research are: pitch and tempo detection, score following, sound source extraction, etc.

The recent Music Information Retrieval (MIR) research domain offered a new vitality to the sound analysis topic. The goal is to accompany audio data with a series of music/audio descriptors, at various levels of abstraction (tempo, harmony, categories of instruments, musical genre...). These descriptors should most often be computed automatically from the audio data, hence necessitating new sound synthesis algorithms.

Finally, one can note that analysis and synthesis can be considered as one the counterpart of the other. Quite often, once a natural sound has been analyzed and the main characteristics of the sound found out, it is possible to apply specific sound algorithms to re-synthesize a modified version of the original sound.

Sound Synthesis

Given the importance of sound synthesis for enactive interfaces, a dedicated item [→ SOUND ALGORITHMS - SOUND SYNTHESIS AND SOUND MODELS] treats this topic. Please, refer to this item.

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RELATED ITEMS

AUDITORY PERCEPTION
ILLUSIONS, AUDITORY
MAPPING, IN DIGITAL MUSICAL INSTRUMENTS
PHYSICALLY-BASED MODELLING TECHNIQUES FOR
SOUND SYNTHESIS
SOUND ALGORITHMS – SOUND SYNTHESIS AND SOUND
MODELS

SOUND ALGORITHMS – SOUND SYNTHESIS AND SOUND MODELS

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Digital sound synthesis can be defined as each kind of procedure which [Smith, 1991]:

- Presupposes a sound generative model.
- Defines an algorithm based on this model.
- Implements the algorithm on a computing equipment.
- Outputs an digital audio signal (that is, a signal with frequency content ranging from 20 to 20.000 Hz).

A sound generative model is a model that gives computational form to abstract objects, thus representing a sound generation mechanism. Sound synthesis can be employed for the imitation of acoustic instruments and/or the creation of new sounds with novel timbral properties.

A fundamental classification of sound synthesis methods can be traced by means of the generative model; in particular, these models can be divided into signal models and physics-based models. A signal model is based on

a description of the sound pressure signal as it arrives at the human ear. Well-known signal-based sound synthesis techniques are: additive synthesis, subtractive synthesis and granular synthesis. A physics-based model [De Poli & Rocchesso, 1998] [Cadoz et al. 1984] aims at describing the physical objects and interactions that have generated an acoustic event. In order to describe the different kinds of sound production mechanisms, several techniques have been developed including: lumped/distributed modelling, waveguide structures, finite difference methods (see also, [→ PHYSICALLY-BASED MODELLING TECHNIQUES FOR SOUND SYNTHESIS]).

Recent literature has shown that sound synthesis techniques based on physical models of sound generation mechanisms allow for high quality synthesis and for a high degree of interactivity.

For example, physics-based sound models can be more naturally controlled by the gestures of a user than signal-based models. Most often, a physics-based model will generate relevant sound cues in response to directly inputted forces and positions, without the need to modify the physical parameters of the model itself (its inertia, etc.).

At the same time such a fine and consistent tune between gesture and sound model require a complex interfaces because of the large number of parameters involved. A better comprehension of enactive knowledge could provide the proper correlation among parameters in order to create simpler and effective interfaces.

Conversely, to obtain such a relevant sound feedback, a signal-based model usually requires an arbitrary mapping from the gesture to various parameters in the model, such as frequency partials, level of harmonicity, level of distortion, etc. [→ MAPPING, IN DIGITAL MUSICAL INSTRUMENTS].

In the context of enaction, having an interface that reacts also with relevant sounds to our gestures and movements, as in our everyday life, is very important. For instance reaching a given object can be easier when

we have also the information of the acoustic distance of this object, the manipulation of a virtual object can be more realistic if we can hear the sounds produced by it (with accurate variation in the sound in relation with the gesture), perceiving characteristics like the texture or the material that could be ambiguously detected with the feedback form just one sensory channel. Such example, however, require the sound model at hand to be able to react relevantly to the gesture. Indeed, physics-based sound models are a promising mean to build interfaces that produce such trully informative auditory feedbacks.

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RELATED ITEMS

AUDITORY FEEDBACK IN VR AND HCI
 AUDITORY PERCEPTION
 ILLUSIONS, AUDITORY
 MAPPING, IN DIGITAL MUSICAL INSTRUMENTS
 PHYSICALLY-BASED MODELLING TECHNIQUES FOR
 SOUND SYNTHESIS

STABILITY

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In the interaction between humans and real mechanical world, there is usually no stability problem. Conversely when electro-mechanical machines mediate such interaction, the physical real bilateral interaction is

transformed into electro-mechanical input/outputs signal processes. This transformation introduces causality between the variables exchanged between the two interacting bodies (for example between forces and positions), whereas such causality does not exist in the real mechanical interaction. This may lead to introduce a specific question identified as the question of stability. In particular, in the case of digital processes, the effect of this causality is directly related to the temporal sampling of the signals, the temporal sample rate being a quantitative expression of the causality.

Consequently, when haptic interactions between a user and a physical object is mediated by haptic devices, or when manipulating a virtual object by means of an haptic device, an essential prerequisite is to preserve the stability of the whole haptic system. Indeed, unstable behaviours of the system can damage the user and the system itself.

From a theoretical point of view, stability is the ability of a system to maintain equilibrium under the influence of external factors. More precisely, there are two ways to mathematically assume that a system is stable:

1. The output signal is bounded for every bounded input to the system.
2. The response – i.e. the output signal - to an impulse input signal tends to zero along time.

Condition 1 considers that a system with limit-cycles in the output (sustained oscillations) is stable; while condition 2 does not. From control theory point of view, as developed in Automation Sciences, a system is stable if all the poles of the Laplace transfer function of the system are placed in the left-half of the S-plane. For condition 1, the poles of the system can be placed on the imaginary axis of the S-plane.

Numerous studies [Minsky et al, 1990] [Gillespie, 1996] [Salcudean et Vlaar, 1997] [Gil et al, 2004] [Hulin et al, 2006] [Gil et al, 2007] dealing with ensuring stability for haptic interfaces have been presented so far.

Some interesting conclusions of all these studies are reported in the following.

Stability imposes a limit to the stiffness of the virtual objects that can be manipulated by the human through haptic devices. For this reason, the typical benchmark to check stability is to interact with a very hard wall. A possible way to rank haptic devices is to evaluate the maximum value possible for the stiffness of the virtual objects. If one implements a stiffness larger than this maximum stable value, users would be bounced from the wall with undamped oscillations.

In the same way, stability imposes a limit to the viscosity of the virtual objects. More precisely, for low values of viscosity, the effect of viscosity has the natural effect of damping the system. On the contrary, for very high values, increasing the viscosity tend to make the system become more unstable.

The sampling rate of the haptic loop is very important to ensure stability. Forces must be rendered as fast as possible (much faster than the graphical refresh rate). The faster the frequency rate is, the larger the value of the simulated stiffness can be. Usual frequency rates are 1 or 2 kHz, but some high quality force feedback systems, such as the ACROE ERGOS technology systems or the Mc Gill Pantograph system, are built to run with higher frequency rates, possibly more than 10 KHz.

Both physical and virtual damping can also contribute to maintain stability. Increasing the damping of the physical haptic device enlarges the upper limit of the virtual stiffness and of the virtual damping values that can be simulated.

The shorter the delay in the haptic loop – i.e. the time between the inputs and the outputs of the haptic device – is, the larger the simulated stiffness value can be. The delay of the haptic loop directly depends on the sampling rate of the haptic loop. This is a challenging issue in haptic systems, because it imposes that all the computations are made within a short time, typically no more than one sample at the sampling rate. Computa-

tions include typically collision detection algorithms, the simulation of physical contacts, and the simulation of the physical manipulated object. Computing all these in such a short time (typically less than 1 ms) is really difficult. This becomes very critical when computation involves several interconnected computers, which introduces supplementary delays and relaxed synchronisations, particularly when using standard networking communication protocols.

Finally, the inertia of the haptic device is usually considered to play no significant role in the stability of the system. Low inertia is only desired for good transparency [→ TRANSPARENCY_3].

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RELATED ITEMS

ALGORITHM
CHANNEL, AFFERENT / EFFERENT
EFFECTOR
FORCE
HAPTICS, HAPTIC DEVICES
TRANSPARENCY_3

STIFFNESS, AUDITORY PERCEPTION OF

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When a generic solid object engages in some external interactions (e.g. it is struck, scraped, and so on), the forces at the contact point cause deformations to propagate through the body, and consequently its surfaces to vibrate and emit sound waves. The auditory feedback provides several information about the properties of the two object involved in the collision.

Stiffness is one of the properties that can be provided through auditory feedback, using in particular sound synthesis techniques based on physical models of sound generation mechanisms that allow for high quality synthesis and interactivity, since the physical parameters of the sound models can be naturally controlled by user gestures and actions.

Sounds generated by solid objects in contact are especially interesting since auditory feedback is known in this case to provide relevant information about the scene (e.g., object material, shape, size).

Moreover multisensory information is essential for designing immersive virtual worlds, as an individual's perceptual experience is influenced by interactions among sensory modalities. As an example, in real environments visual information can alter the haptic perception of object size, orientation, and shape. Similarly, being able to hear sounds of objects in an environment, while touching and manipulating them, provides a sense of immersion in the environment not obtainable otherwise, reproducing the closed loop interaction that characterize our everyday life. Enactive interfaces in particular are based on the concept of learning by doing,

providing to the user the needed feedback to act and react in a natural way. Properly designed and synchronized haptic and auditory displays are likely to provide much greater immersion in a virtual environment than a high-fidelity visual display alone. Moreover, by skewing the relationship between the haptic and visual and/or auditory displays, the range of object properties that can be effectively conveyed to the user can be significantly enhanced.

A demo illustrating this discussion about bimodal stiffness perception is available on the Internet (see related documents). This demo allows the user to explore this material property by using the phantom device to play an instrument, composed by several virtual bars simulating different materials (which have different stiffness values). The user can experience the effects of auditory feedback in stiffness perception by playing the stiffophone. The visual interface has been made with XVR and the auditory feedback is provided by physical modelling in Pure Data.

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RELATED ITEMS

AUDITORY FEEDBACK IN VR AND HCI
AUDITORY PERCEPTION
ILLUSIONS, AUDITORY
ILLUSIONS, HAPTIC
IMMERSION VS. VIS-À-VIS

RELATED DOCUMENTS

<http://nmontecchio.ifastnet.com/stiffophone.html>

T

TACTILE DEVICE

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The sense of touch (the tactile sense) is sensitive to area of contact on the skin, local deformation and curvature of the skin, stretching of the skin, and stick-slip events at the skin-object interface. In the context of human-computer interaction, a tactile device addresses one or more of these aspects. It is potentially capable of reproducing the sensations experienced when touching a real object by applying deformations or vibrations at the surface of the skin. If a tactile device is incorporated into an enactive interface, tactile cues are generated during active exploration of a virtual environment. These cues can give information about the nature of virtual objects, for example, surface texture and position of edges and corners.

To make good use of the perceptual abilities of the sense of touch, a tactile device must be provided with appropriate hardware and software for stimulation of the skin. For synthetic tactile stimulation, information may be encoded as the intensity or the frequency content of the stimulus, or in terms of its spatial distribution over the skin. To deliver stimuli which are characterised by spatial distribution over the skin, some sort of tactile array is required, i.e., a distribution of actuators over the skin surface.

There are two distinct classes of array stimulators. The first – known as a shape display – reproduces the curvature of the object at the skin/object interface [Wagner et al., 2004]. This requires actuators which can move with amplitudes up to 5 mm or so. The second – known as a tactile display – is designed to produce small-scale deformation of

the skin surface (up to 100 microns or so). The intention is not to reproduce the small-scale surface topology of the virtual surface; instead the intention is to reproduce the perceptual consequences of the small-scale surface topology, i.e., appropriate excitation patterns over the various populations of mechanoreceptors in the skin. The design requirements for such a stimulator array – contactor spacing, working bandwidth and output amplitude – are largely determined by the response of these mechanoreceptors.

The hairless skin which is found on the fingertips and the palms of the hands contains four populations of mechanoreceptors: pacinian receptors and three types of non-pacinian receptor. These populations differ in terms of their frequency response and their temporal response [Gescheider et al., 2001]. The optimal spacing of contactors in a simulator array is determined by the spatial acuity of the sense of touch – around 1 mm on the fingertip.

In order to produce realistic touch sensations, a working bandwidth of around 10 to 500 Hz is required for the drive mechanism of each contactor, corresponding to the frequency range over which the various mechanoreceptors are sensitive [Gescheider et al., 2001]. Pacinian receptors are expected to respond most strongly to frequencies in the upper part of this frequency range (100 to 500 Hz, say); stimulation at lower frequencies is expected to stimulate mainly non-pacinian receptors.

It is difficult to closely specify the amplitudes of contactor movement which are required to produce particular levels of touch sensation, because sensation level varies with the extent of the area stimulated, particularly when pacinian receptors are involved. However, it is possible to give approximate figures. For example, comfortable sensation levels are produced by amplitudes of a few microns at frequencies around 300 Hz and a few tens of microns at frequencies around 50 Hz.

Design requirements for contactor spacing, working bandwidth and output amplitude may be satisfied by a variety of electromechanical drive mechanisms. Hafez and colleagues [Hafez & Benali-Khoudja, 2004] have developed arrays of drivers, based on shape-memory alloy or moving-coil technology, which apply normal forces to the skin. Hayward and colleagues [Pasquero & Hayward, 2003] [Levesque et al., 2007] have used piezoelectric-bimorph actuators to apply tangential forces. [Summers et al. 2005] have used similar actuators to apply normal forces, as have [Kyung et al. 2006].

During active exploration of a virtual tactile environment it is necessary to implement a scheme for tactile rendering to generate in real time, in response to actions of the user, a drive waveform for each contactor of the stimulator array which is in contact with the user's fingertip.

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RELATED ITEMS

HAPTIC RENDERING OF VIRTUAL OBJECTS
 HAPTIC TEXTURE PERCEPTION
 SENSORY SUBSTITUTION SYSTEMS
 TACTILE RENDERING
 TOUCH, ACTIVE / PASSIVE
 ZOOM, HAPTIC

TACTILE RENDERING

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Contributors: Alan Brady [UNEXE]

During active exploration of a virtual tactile environment it is necessary to implement a system for tactile rendering. A tactile-rendering system generates in real time, in response to actions of the user, a drive waveform for each contactor of the tactile device which is in contact with the user's fingertip. The intention is to produce time-varying excitation patterns in the various populations of mechanoreceptors in the skin, so as to reproduce the touch sensations which are experienced during real tactile exploration. These touch sensations may vary according to the contact pressure and the speed of tactile exploration over the surface. (In the absence of a specific tactile device, surface properties may be represented by small-scale modulation of force feedback – for example, to give the impression of surface roughness.)

A significant problem is the current lack of knowledge on the origin and nature of excitation patterns in real situations of tactile exploration of an object. The mechanical stimulation of a given receptor has a complicated relation to the mechanical properties and topology of the object's surface, to the mechanical properties of the skin and its local topology (especially skin ridges, i.e., fingerprints), and to the precise nature of the

exploratory movement (speed, contact pressure and direction). Although it may be possible to produce an accurate software model of an object's surface, it is not at present possible to augment this with an accurate model of the skin/surface interaction. This situation may change in the near future: research is currently underway to develop an artificial finger with embedded transducers to mimic mechanoreceptors; improved finite-element models may also provide useful data. (This problem relates to the reproduction of real surfaces; it does not apply to the case of purely synthetic surfaces, which may be synthesized from components intended to represent roughness, smoothness, and so on.) For the particular case of the manipulation of textiles, the situation with respect to excitation patterns is more promising: information on the nature of the mechanical input to the skin's mechanoreceptors is available from the Kawabata system for evaluation of textiles [Kawabata, 1980]. Kawabata measurements have been used as the basis of a virtual textile by [Govindaraj et al. 2003].

A considerable amount of data must be generated on-the-fly during active exploration of a virtual tactile environment. Multiple contactors on the skin require independently specified analogue drive signals, in principle each with a bandwidth of around 500 Hz. However, because of the limited temporal resolution, frequency resolution and phase sensitivity of human touch perception [Rabinowitz et al., 1987] [Formby et al., 1992] [Summers et al., 2005], there are possibilities for a significant reduction in the data flow. For example, each drive signal may be reduced to the sum of a limited number of sinusoidal components, distributed across the working bandwidth. The drive signal may then be simply specified in terms of the amplitudes of these components, which require an update every 20 ms or so.

In the HAPTEX project [Allerkamp et al., 2007] the tactile renderer generates, for each digit, 24 drive signals for the 24 contactors of the stimulator array. Each drive signal is the

sum of components at only two frequencies: 40 Hz and 320 Hz. Input and output data are specified in 25 ms time steps. The input data are: (a) a small-scale description of the object surface, represented as 2D k-space, derived from a pseudo-topology at 0.01 mm resolution over an area of a few mm²; (b) a large-scale description of the object surface: a representation of the non-uniformity of the surface, specified as pseudo-amplitudes at 1 mm resolution over an area of several tens of cm²; (c) position and orientation of the finger pad on the virtual surface; (d) speed and direction of the movement of the finger pad over the virtual surface.

The operation of the HAPTEX renderer is as follows: Taking account of the direction of movement, a spatial-frequency spectrum is calculated from the 2D k-space of the small-scale description of the virtual surface. Information about the speed of movement of the finger pad is used to convert spatial-frequency components into temporal-frequency components. The resulting temporal-frequency spectrum is converted to a reduced representation of components at 40 Hz and 320 Hz, using appropriate bandpass filters. Distribution of stimulus intensity over the array is determined by the large scale model.

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RELATED ITEMS

HAPTIC RENDERING OF VIRTUAL OBJECTS
HAPTIC TEXTURE PERCEPTION
HAPTICS, HAPTIC DEVICES
TACTILE DEVICE
TOUCH, ACTIVE / PASSIVE
ZOOM, HAPTIC

TEACHING TOOLS, FOR ENACTIVE TASKS

José Ignacio Barbero [LAEIN]

Generally speaking, a teaching tool is a tool that imparts knowledge or skills. It may be a passive tool, that is, the person uses the teaching tool and learns a specific topic in a passive way, without practising. Or it may be an interactive tool, that is, the person learns while performing the specific task: learning by doing (enactive learning). It may also be a static tool, the knowledge or skill being defined by an expert and then it fixed until the next release of the tool. Or it may be dynamic, the tool adds best practices along its use.

The learning by doing is a common approach in the learning of manual tasks. The transfer of knowledge related to manual procedures is a complex task, involving different cognitive and perceptual aspects. Usually the transmission of this kind of knowledge relies on the practice. At this point, enactive systems can play an important role since they can stimulate users through multiple and intelligent channels and receive and interpret their feedback according to their needs and training/teaching purposes.

Examples of enactive teaching systems can be found in several areas, mainly in the medical, industrial and artistic fields. Different

haptic interfaces for medical simulation may prove especially useful for training of minimally invasive procedures such as laparoscopy [CAMS]. A particular advantage of this type of tool is that the surgeon can perform many more operations of a similar type and with less fatigue. It is well documented that a surgeon who performs more procedures of a given kind will have statistically better outcomes for his patients. Another example in this area is a bovine rectal palpation simulator for training veterinary students [Baillie et al., 2003]. In the industrial field, we can find different enactive systems for training in the maintenance tasks of mechanical assemblies [Borro et al., 2004]. Performing arts, such as in music, in fine arts or all the manual craftworks requiring accurate craftsmanship (glass-maker, carver, licemaker, etc.) are privileged sectors in which teaching tools based on action can have a great impact. The current technology and its price are limiting factors for the penetration of such tools in that applicative domains, except in high level artistic practices [Florens, 2002].

Enactive human computer interfaces for teaching and learning manual tasks is an important topic for the network and different exemplary examples have being considered, such as, but not limited to:

- Simulation of mechanical assemblies using haptic platforms to explore the role of different modalities for triggering the enaction of “getting your hands in-there” for manipulating and assembling.
- Manual tasks requiring sensorimotor coordination and multisensorial integration (visual, auditory, spatial and haptic) in virtual environments, such as pool gaming, musical instrumental playing, sculpting and carving, etc..
- Learning and teaching metaphors for understanding non tangible concepts or phenomena, such as nano-physics complex dynamic phenomena or interaction forces among molecules, manipulation of graphs or abstract concepts or physical interaction at the micro-scale.

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RELATED ITEMS

HAPTICS, HAPTIC DEVICES
LEARNING AND ENACTIVE INTERFACES
LEARNING AND TRAINING METHODS
MANUAL TASKS
TRANSPARENCY_1

TECHNICAL ARTEFACTS AND PERCEPTUAL EXPERIENCE

Armen Khatchatourov [COSTECH]
John Stewart [COSTECH]

The basic scheme for considering enaction is the dynamic sensory-motor coupling between an organism and its environment. The sensory inputs are used to guide the actions; the actions modify the environment and/or the relation of the organism to its environment, and hence modify in return the sensory input. This basic scheme applies already to animals. In the 1920's the German ethologist von Uexküll [von Uexküll, 1966] characterized animal worlds (for example, the "world of the tick") on the basis of sensori-motor contingencies as they function in ecological context.

What the world "is" for the organism amounts to neither more nor less than the consequences of its actions for its sensory inputs – what [O'Regan and Noe, 2001] call

the sensori-motor contingencies; and this in turn clearly depends on the repertoire of possible actions. Without action, there is no "world", and no perception.

There is a deep affinity between this approach, the enactive approach of [Varela, 1991], and the ecological psychology of Gibson according to which perception is not a matter of computational representation, but rather a direct perception of affordances [→ AFFORDANCES], i.e. potential actions as such. This affinity lies, as we understand it, (a) in the fact that all of them assume a non-representationalist framework, and (b) in the fact that Gibsonian rules, laws of control [→ CONTROL, LAWS OF] [Warren, 1988], contingencies [→ SENSORIMOTOR CONTINGENCY OR DEPENDENCY] [O'Regan and Noe, 2001], all of them are not pre-given but emerge from the interaction between an organism and its environment.

For the purposes of this text, we are not going any further in the description of (discrepancies between) these approaches, we rather propose to consider what is specific to human beings: technical artefacts.

One of the major characteristics of human worlds is that the sensory-motor coupling is mediated by technical artefacts. For animals, the sensory organs and the motor organs are fixed (within any given species), and they are attached to the body. For humans, the mediation of sensory-motor coupling by technical artefacts introduces two radical innovations.

Firstly, the range of possible sensory inputs and the repertoire of possible actions is greatly increased, without any limits other than the invention and fabrication of new artefacts. This is clear for the new possibilities of action which are created by tools, from hammers and screwdrivers to power-tools of many sorts. It is also clear for instruments – microscopes, telescopes, microphones, infra-red detectors, radios and so on resulting in sensory inputs which are strictly impossible without the devices in question. An interesting special case is the sensory

substitution devices [Lenay, 1997]. More generally, but less obviously, technical artefacts *organize* sensory experience: think of the world of skier, which is impossible without the artefact. Even when we are not actually skiing, our perception of the mountain is determined by the possibility (i.e. virtual action) of skiing and the correlative sensations. So this first point can be understood more profoundly: in case of contemporary humans, there hardly any "natural" perceptions or relations to the world: our sensory-motor coupling is always fashioned, at least virtually, by technical artefacts [Khatchatourov, 2005].

Secondly, technical artefacts are not irremediably fixed to the body. More precisely, technical artefacts exist in two modes: in hand and put down. When a technical artefact is in hand, being used, it becomes a prosthetic extension of the body; correlatively, the artefact disappears from consciousness, and the attention of the human subject is focussed on the "world" that comes about (think again of the "world of the skier", for example). Artefacts, like the body, are normally transparent [Merleau-Ponty, 1945] to the subject; as [Heidegger, 1996] has pointed out, they are only noticed when they are dysfunctional (a wobbly hammer or a twisted ankle). However, unlike biological organs, technical artefacts can also be "put down": separated from the body, they can now become objects of attention. In this mode, their objective physical proprieties can be perceived; they can be invented, fabricated, repaired and so on [Lenay & Sebbah, 2001]. The whole question of learning can be seen as the back-and-forth movement between these two modes. This explains also the radical innovative potential of technical artefacts. Over several thousand years, and at an ever-increasing rate, technical innovation has radically transformed what the world is for human beings.

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RELATED ITEMS

AFFORDANCES
CONTROL, LAWS OF
ENACTIVE COGNITIVE SCIENCES_1
EXTERNALIZATION, PERCEPTUAL
SENSORIMOTOR CONTINGENCY OR DEPENDENCY
SENSORY SUBSTITUTION

TECHNICAL ARTEFACTS, A CATEGORIZATION OF

John Stewart [COSTECH]
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Enactive interfaces are technical artefacts. It is therefore useful to situate them with respect to a categorisation of technical artefacts in general, which can be divided into three main types.

The first type of artefact directly mediates the sensory-motor interaction between a human subject and the environment, by modifying the possible actions (e.g. a hammer) and/or by modifying the sensory feedback (e.g. a telescope). Such artefacts, tools and sensory instruments, can be considered as extensions of the body. They modify the sensorimotor contingencies [\rightarrow SENSORIMOTOR CONTINGENCY OR DEPENDENCY], and hence modify what the world is for the subjects in question.

A second type of artefact consists of deliberate modifications of the environment: roads, buildings, fields and so on. It is even more obvious that this second type of artefact also modifies the world that human beings live in.

Finally, there is a third sort of artefact that can be called semiotic artefacts. Here, the actions consist in emitting signals, and the sensory feedback is specifically geared to the reception of these signals. If the conditions that trigger the emission of a signal and the response of the receiver are appropriate, this leads to a co-ordination of actions [Maturana & Varela, 1987], and constitutes the basic form of communication, which exists already in animal world.

Concerning semiotic artefacts, the human inventions are: first of all, language itself [Vygotsky, 1986]; and then a whole series of clearly technical inventions, writing, printing; and in our era computers. It is important to note that the computers are not only semiotic artefacts, but also sensori-motor devices. The computer comprises a certain repertoire of real actions (from punching cards in the early computers to mouse movements, joysticks, etc.) with, in return, an increasing range of sensory feedbacks (from reading printed output to visual patterns, sounds and so on); regularities are established between action and sensation in this case just as for the first type of artefacts.

This categorization can be useful for analytical purposes; but it is important to note that in practice, technical artefacts do not

function in isolation from each other, but form technical *systems* with a synergy between these three types. For example, roads (type 2) go together with cars and lorries (type 1), their synergy being organized by maps and plans (type 3). A possible use of the term technology (techno-logos) is to designate the situation where there is linguistic communication about the design, fabrication and use of technical artefacts.

Finally, it must be noted that this categorization is neither exhaustive nor exclusive. In particular, it is interesting to compare it with the category of ergotic interfaces [\rightarrow INTERFACE, ERGOTIC].

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RELATED ITEMS

ENACTIVE COGNITIVE SCIENCES_1
 ERGOTIC/EPISTEMIC/SEMIOTIC ACTION-PERCEPTION
 LOOPS
 INTERFACE, ERGOTIC
 SENSORIMOTOR CONTINGENCY OR DEPENDENCY

TECHNICAL ARTEFACTS, MODES OF

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Contributors: John Stewart [COSTECH]

It may be useful to give a distinction between the two modes in which technical artefacts can be seen (in-hand and put-down). The difference between in hand and put-down is not simply between attached/not attached to the body [Heidegger, 1996].

There are two relatively independent levels of dividing:

- Between put-down and in-hand.

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 [Merleau-Ponty, 1945].

- Between a normally functioning and a broken artefact.

Now comes the situation in which the artefact is broken. In this situation, the artefact switches from in-hand to put-down: instead of riding the bicycle and being engaged in the sensory-motor activity, one examines the broken chain as something having being made of the material with bad resistance, etc.

It is the same case with the computers, even in virtual reality. As a user, one does not care about what is going on in the computer, which becomes a transparent equipment. When the artefact is broken or in case of a malfunction, the user will check cables, electricity, etc. He/she will then consider the computer as an object of science and technology, and the artefact is no more a transparent mean of action.

So one can as he/she wish be in different attitudes to artefact: consider it as in-hand or put-down (when maintaining the technical device, one puts it in the put-down mode). But the situation when the artefact breaks is particular, because it forces the user to consider it as put-down.

The difficulty comes when we consider the fact that in the put-down mode, the designer is also engaged in the activity. But in a different way: the artefact is not a mean of action. In fact, when one is maintaining/designing or doing scientific research, he/she is using other artefacts (pencils/computer aided design/hammer or measurement instruments), which are in-hand as means of ac-

tion, and which are transparent to the user. So one can see the put-down mode of the artefact as a derivative from the most fundamental one, which is in-hand.

Now the in-hand mode was provisionally defined as an attachment to the body, in order to underline the fact that it is transparent and fits into action. But in fact the artefact can be not attached to the body, but still in-hand. The road for example is not attached to the body, but is still in-hand as a transparent mean of action. Being on the road, one does not consider the road as the physical proprieties of tarmac in the way the science/technology do, but rather as a possibility to get there he/she wants to; the lighting pole on the road is not attached to the body, but it is still in-hand because it is also a mean of action of going there, and it (a) structures one's actions and (b) is transparent in the sense mentioned above.

If one agrees that the perception is not something independent from the action, then every artefact is the artefact that "help us do": the means of lighting probably change the sensory-motor loops (the light coming a certain way, one takes it into account without explicitly thinking on the proprieties of the light, and adapt his/her sensory-motor posture when riding a bicycle; when there is no sufficiently light, one can be more focused on the auditory modality). So, as for the bicycle, the lighting pole is in-hand because it fits into one's action and changes the sensory-motor activity.

It stands to reason that there is still a difference between the artefact that are actually attached to the body, and which are not, but the first level of distinction seems to be between in-hand (in a broad sense) and put-down. In this broad sense, the artefacts are in in-hand mode when they (a) fit into action, (b) change sensory-motor loops, (c) are transparent, i.e. not explicitly noticed, disappear from consciousness in aid of the world they bring forth.

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RELATED ITEMS

ERGOTIC/EPISTEMIC/SEMIOTIC ACTION-PERCEPTION
LOOPS
ERGOTIC/EPISTEMIC/SEMIOTIC FUNCTIONS
INTERFACE, ENACTIVE
LIVED BODY / LIVED WORLD: PHENOMENOLOGICAL
APPROACH
SENSORIMOTOR CONTINGENCY OR DEPENDENCY
TRANSPARENCY_1

TELEOPERATION / TELEPRESENCE / TELESYMBIOSIS

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In parallel with the evolution of visual tools of Computer Graphics for representation and interaction with computers [→ COMPUTER GRAPHICS], the link between action and vision has been also fundamentally questioned in teleoperation.

Teleoperation (almost synonymous to telemanipulation) means physical manipulation of materials and objects located in distant worlds, in one piece of time, i.e. with no need of memory in the teleprocess. Teleoperation inherently introduces a separation between two distant spaces: the user's space and task's space. Usually distant means distant in space. However, as explained in [Luciani et al., 2004], distant may benefit from being understood in a larger sense, as not accessible immediately to our senses: distant in space (far away as a distant planet), in scale (at a larger or upper scale than the world at our scale, called macroscopic scale), or in nature (with different laws of physics, such as

world under the nanoscale, chemical, electrical, but also mathematical (virtual)).

Telesymbiosis - Telepresence

The teleoperation process was historically the first to address the question of presence [→ PRESENCE, IN COMPUTERIZED ENVIRONMENTS]. [Vertut & Coiffet, 1986] coined the term telesymbiosis in the teleoperation context in 1974. Since 1950's, the manipulation of dangerous materials, such as nuclear materials, had required a distant manipulation in two different spaces: the user's space and the task's space. As long as the manipulation remained mechanical, i.e. as long as the two spaces are near in space, in time and in nature, there was no problem of presence. The experimenter manipulated the block of nuclear matter through a mechanical pantograph, feeling it mechanically and seeing it through the glass that separates the two spaces. When this direct physical communication got replaced by electrical communication between the two spaces, and when the both spaces became more and more distant, the immediate and trivial presence disappeared. The question of presence of the distant world for the user came into the way.

Telepresence in electrically-equipped teleoperation systems

With the separation of the manipulation space from the task space described before, the classical (i.e. mechanical) teleoperation instrument has been decomposed in three parts: the part which is in the user's space, the part is in the task's space, and the communication between them. Establishing an appropriate communication between these two different worlds first necessitates equipping correctly each of the three part of the communication chain.

As stated in [Luciani et al., 2004], firstly, both sides are equipped with actuators and sensors that work in pair: sensors on one side and corresponding actuators on the other side (figure 1.2 in the related document) and vice-versa: from microphones to loudspeakers, from cameras to displays, from mechani-

cal sensors to register the user's actions to mechanical actuators to perform these actions, etc. Each pair of sensor/actuator is dedicated to a sub-part of the sensory-motor human apparatus: vision, audition, haptic perception and action. Thus, the physical reality of the each space is necessarily split into different channels clearly segregated according to the pairs of transducers employed. Continuing, the perception of the physical reality of each space is drastically impacted by this splitting: hearing through a specific device (loudspeakers), seeing through another device (display), touching through another (tactile stimulator, force feedback device, etc.) and acting through keyboard, stick, mouse, etc.). Once these two realities is conveyed by separate signals between each side, layers of signal processing are inserted on each part in order to reconstruct some parts of one space in the other that have been lost or degraded during the capture and transmission processes. As long as the user can build a sufficient mental representation of the distant space, as long as this space remains an alter ego space, one can say that the reduced information is sufficient to restore the distant space.

Teleoperation and VR

However, sometimes, the real phenomena cannot be sufficiently reproduced to enable presence of the distant world, either because the above means are not sufficient, or because the distant scene cannot, intrinsically, be equipped accordingly. This is the case, for example, when teleoperating microscopic world. In such a case, a third module has to be inserted in order to reconstruct locally, in real time, the lost information. This third module that handles the re-creation of the unknown information by inserting virtual entities on each side (virtual objects, virtual humans, etc.) is, typically, a computer synthesis/simulation system.

At this point, one may notice that each space is being equipped by a similar platform (figure 1.2 in related document). On both sides, there is a VR-equipped teleoperation

system composed of pairs of sensors and actuators corresponding to all the sensory-motor capabilities (for the human on one side, for the physical object on the other), extended by real-time computation systems, including signal processing from and to the alternate distant world, but also simulation/re-synthesis means and virtual representations.

Perspectives

The complete specification and implementation of this type of platform is yet nowadays pending, but it is with no doubt a promising evolution for the future, able to lead to a strong convergence between teleoperation, virtual reality systems enhanced with augmented reality and mixed realities functionalities [\rightarrow REALITY, AUGMENTED AND MIXED], and further to the design of an extended teleoperated mixed reality architecture, as a generic architecture for all the our computerized instruments to observe and act on the world.

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RELATED ITEMS

- COMPUTER GRAPHICS
- PRESENCE, IN COMPUTERIZED ENVIRONMENTS
- PRESENCE, THEORIES OF
- REALITY, AUGMENTED AND MIXED
- VIRTUAL REALITY AND VIRTUAL ENVIRONMENT

RELATED DOCUMENTS

- EL_Action-Vision_Cornerstones_Luciani_040915

TOUCH, ACTIVE / PASSIVE

Gunnar Jansson [UPPSALA]

Touch used to be described as a skin sense, and, in fact, it is still so in many present textbooks. This presentation is often combined with considering the observer as a passive receiver of stimulation from the environment. In opposition to this view, in his seminal work Katz (1989/1925) emphasized that observers are active explorers of the environment with their hands. The hand is regarded as a perceptual system based on active exploration to collect information. Even if the existence of passive touch has not been denied, active touch was considered as the natural mode. To stress the importance of activity the sense is often called active touch. In many contexts haptics is used synonymously with active touch.

Even if the importance of activity has often been recognized, it has sometimes been doubted that activity is a necessary condition for touch to function well, and several experiments have been performed to study if this is the case. The results have shown that the answer is not that simple. Symmons et al. (2004) examined 73 experimental comparisons between active and passive touch and found a complex picture. 42 studies suggested that active touch is better, 11 that passive is better and 20 that there were no significant differences. Even after a close analysis of the quality of the studies the authors found a majority to suggest active superiority. However, there were well controlled experiments, such as Lederman (1981) with a result of equivalence. Magee and Kennedy (1980) found in an experiment on identifying objects in raised line drawings even better results for passive than for active touch. They interpreted this to depend on favourable conditions for attention to the perceptual task in the passive case, as you

have not the task of guiding the movements in the passive case.

There does not seem to be an all or none answer to the question of active or passive touch superiority. Hughes and Jansson (1994) made an overview of studies of the importance of active and passive perception for perception of texture and found several unsolved issues, including what kinds of information are available in the two cases. Johnson (2002) suggested that passive touch requires more concentration, and that the difference between the two kinds of touch is similar to the difference between situations with dim and bright light in vision. Symmons et al. (2004) concluded that the result to a large extent is task-dependent, for example, passive touch being advantageous for reading of simple pictures, active touch for reading of more complicated pictures.

In a further experimental analysis of what information is available under passive conditions, Richardson et al. (2004) used a special device, the Tactile Display System, which allowed a careful control of the information available for a passive observer. In the passive mode a finger was firmly but comfortably held in a clip and moved over the display in a path earlier registered from an active participant. Five different combinations of three kinds of information were arranged: kinaesthetic information and two kind of tactile information originating either from the shear forces or the embossed line. Among the results were that performance was best when all the three kinds of information were available, but that there was no difference in the performance in the conditions with cutaneous only or kinaesthetic only information.

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RELATED ITEMS

ACTIVE PERCEPTION / TOUCH
 HAPTICS, HAPTIC DEVICES
 HAPTICS, IN COGNITIVE SCIENCES
 PSYCHOPHYSICS
 TACTILE DEVICE
 TOUCH, THE SENSE OF REALITY

TOUCH, DYNAMIC

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The link between action and perception is a fundamental issue for the understanding of enactive knowledge, beautifully illustrated by the experiments on dynamic touch. There is a long history of theories of human perception and action that aim at separating perception and action, in particular that specific perception mechanisms are dedicated to identification of external objects or environment properties, and other to perception for the production and control of movement. The dynamic touch paradigm has been very productive in demonstrating limits of validity of such a divide. Typically the authors of a long of careful experiments had blindfolded par-

ticipants manipulating a rod to recognize shape and length of these objects. To perceive the shape and the length of the object participants had to move the rod. This experimental paradigm is a showcase to demonstrate that the action can be necessary for perception of specific features of external objects.

Research on dynamic touch conducted in the context of the ecological view of perception uses the modification of the distribution of masses of hand-held objects as a privileged instrument for the identification of the invariance the dynamic system is sensitive to. Invariance proper to dynamic touch are in fact identified with quantities that are related to the rotational inertia of the hand-held object, that is to the resistance the object opposes to being moved (movements performed with the arms are rotation, in virtue of the anatomical structure of the joints).

The relevance of rotational inertia for the haptic perception of object properties is demonstrated in several experiments using an experimental setting of this kind: one or more rods connected one with the others with attached masses. The masses can be displayed in different positions so to change the masses distribution without modifying the shape or the weight of the so-composed object.

In experiments about length perception, for instance, it is shown that a rod with a mass attached near the hand which holds the rod feels shorter than the same rod with the mass attached at the end far from the hand. The described phenomenon is systematic and is used to reveal the functioning conditions of the haptic dynamic system. Nevertheless, the phenomena that are provoked in this way are not considered as illusions by the ecological approach.

Experiments of this kind regard:

- Weight.
- Length.
- Width.
- Shape.
- Orientation.

- Grasping position of hand-held objects (exteroceptive properties).
- Position of the hand and limb relatively to the hand-held object (exteroception or proprioception via exteroception).

From an enactivist point of view, the dynamic touch example can count as a strong argument against un-careful perception-action divide; however, how can this example be extended to perception and action in general? In particular one could defend instead that such a case is more the exception than the rule. One may argue that the dynamic touch is a very explicit illustration of the very intricate functioning of perception and action that is underlying the role of enactive knowledge. Instead of restricting one's efforts in separating perception and action, one must keep in mind that whatever is once separated has to be related at some point to allow for coherent and adaptive behaviour. The link between separated entities like perception and action has to be elucidated by careful scientific research, both separation and co-ordination of components are the basics of thoughtful scientific reduction.

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RELATED ITEMS

COMPLEXITY IN HUMAN MOTOR BEHAVIOUR
 HAPTICS, HAPTIC DEVICES
 HAPTICS, IN COGNITIVE SCIENCES
 TOUCH, ACTIVE / PASSIVE

TOUCH, THE SENSE OF REALITY

Elena Pasquinelli [INSTNICOD]

Touch modality has often been described as the sense of reality.

In 1754, Condillac [Condillac, 1984] attributed to touch the property of distality in perception. A pretended statue, which senses are opened one after the other, would not be able to distinguish between itself and the objects it is perceiving until the touch modality isn't activated; when the statue begins to tactually explore the reality, two types of sensation arise: those regarding the object and those regarding the body, and this allows the separation of the self from the world, and the perceptual constitution of the distal object.

In his seminal study of touch of 1925, Katz [Katz, 1989] was re-editing the tradition of the objectifying capacity of touch modality by describing touch as the sense of reality. Katz insists on the fact that the tactual sense is bipolar: a stimulus on the dorsal part of the hand can be perceived both as a subjective, proximal, local sensation or as the sensation of the object which causes the experience (this same reflection has been made in the philosophical domain by Merleau-Ponty

[Merleau-Ponty, 1943]: touch is a reciprocal sensory modality in that it is impossible to touch without being touched; the activity of touching implies then the involvement of the body in the knowledge about the world). The objective pole dominates when touch is accompanied by movement, then in active tactual exploration. When, for instance, one hand touches the other, the static hand is perceived as touched (subjective pole of the sensation), while the hand which is moving is perceived as touching (objective pole). It is then movement, associated with touch, that produces the impression of the reality as external. Touch can be considered the sense of reality in that its connection with movement is particularly strong.

The objectifying role of movement is also recognized in the use of visuo-tactile substitution displays [Bach-y-Rita, 1982]. It seems in fact that the possibility of actively guiding the sensors (the camera) produces a shift from the sensation of a local, tactile stimulation to the (visual) perception of a distal object placed in the external reality.

Active movement, more than touch itself then, would constitute the proper sense of reality.

Some questions can be asked: Is it true that touch is more strongly connected with movement than the other senses, and that active touch contributes to the process of objectification of the stimulus more than, say, active vision? What is the role of the expectations of the user relatively to the consequences of its movements (the behaviour of the object in response to his movement)?

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RELATED ITEMS

EXTERNALIZATION, PERCEPTUAL
HAPTICS, HAPTIC DEVICES
HAPTICS, IN COGNITIVE SCIENCES
OBJECTIVITY
PERCEPTION, DIRECT AND INDIRECT APPROACHES
SENSORY SUBSTITUTION

TRANSPARENCY_1

John Stewart [COSTECH]
Armen Khatchatourov [COSTECH]

In very general terms, a technical artefact becomes transparent when the sensorimotor contingencies [→ *SENSORIMOTOR CONTINGENCY OR DEPENDENCY*] have been assimilated and become second nature; concomitantly the interface itself, as such, drops out (disappears) from consciousness, to be replaced by a presence of objects and the actions that the user is performing in the world.

A classical illustration is the case of a blind person who does not feel the stimulations by the cane in her hand, but rather senses the pavement directly at the end of the cane.

Another classical example is the tactile-vision substitution systems [→ *SENSORY SUBSTITUTION SYSTEMS*]. Initially, the subjects are conscious of the interface device itself, and tactile stimulations are felt on surface of the skin. Progressively, with increasing familiarity, the subjects no longer feel the tactile stimuli; instead, they have a perception of an external object located out there in a distal space (see also [→ *EXTERNALIZATION, PERCEPTUAL*]).

The situation is similar for the actions the person performs: when driving the car, I do not pay attention to the car itself, which is a transparent mean of my action. [Merleau-Ponty, 1945].

Conversely, if there is a breakdown or a dysfunction, the interface as such will come

back into consciousness, and obliterate the world of objects [→ TECHNICAL ARTEFACTS, MODES OF]. A profound philosophical discussion of this issue is provided in Heidegger's *Being and Time*. See [Dreyfus, 1990] for an accessible presentation in English.

This scheme applies both to interfaces with the real world and with virtual reality. Transparency, as thus defined, is closely related to believability [→ BELIEVABILITY_1&2].

It follows that the transparency is not a term which applies to a tool or to an interface, as such; rather, it applies to the whole situation of interaction, and it corresponds to the degree of mastery of the sensorimotor contingencies achieved by the subject. This leads to the vast subject of learning, and the developmental acquisition of skills.

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RELATED ITEMS

BELIEVABILITY_1&2
 EXTERNALIZATION, PERCEPTUAL
 INTERFACE, ENACTIVE
 INTERFACE, ERGOTIC
 SENSORIMOTOR CONTINGENCY OR DEPENDENCY
 SENSORY SUBSTITUTION SYSTEMS
 TECHNICAL ARTEFACTS, MODES OF
 LEARNING AND ENACTIVE INTERFACES
 LEARNING AND TRAINING METHODS

TRANSPARENCY_2

Annie Luciani [ACROE&INPG]

Jean-Loup Florens [ACROE&INPG]

In the mechanical manipulation chain, we act on a physical object that is a part of the physical universe through a physical interaction. The performer and the object are present within the same space, at physical,

perceptual and cognitive levels. Fifty years ago, the manipulation of dangerous materials, such as nuclear materials, began to implement the need of a distant manipulation, setting-up two different spaces: the user's space and the task's space. Once the direct physical communication has been replaced by electrical communication between the two spaces, once both spaces become distant, the classical teleoperation instrument is transformed in a more complex manipulation chain [→ TELEOPERATION / TELEPRESENCE / TELESYMBIOSIS]. Basically, the instrument has been decomposed in three parts: a part which is in the user's space, a part which is in the task's space and a part that support the communication between them. The question of transparency got into the way.

Transparency in robotics/teleoperation

In robotics and teleoperation, the paradigm of transparency seeks at evaluating the identity of the mechanical manipulation chain as compared to the electrified, decomposed. Transparent is understood as: "The components added when electrifying the manipulation chain have to behave as if they did not exist", or, similarly, "they should allow producing the same man/environment interaction as in the direct natural interaction situation". Ideally, a transparent manipulation chain has to be identical to the reference situation.

In the aim of designing such transparent teleoperation components, a more technical definition of transparency has been proposed, which is founded on the equality of two impedances: on one side the impedance Z_c of the remote environment seen by the teleoperation medium; and on the other side the impedance Z of the teleoperation medium as seen by the human. The teleoperation chain is transparent if and only if $Z=Z_c$.

Anyhow, in Robotics, transparency is only an ideal specification that is unreachable. It means in particular that the teleoperation link should transmit instantaneously from one side to the other the mechanical constraints created by the interacting protagonists (the

human and the environment). Because of the inherent lags of digital signal transmission systems, this is not possible. In addition, the mechanical parts on the two sides of the teleoperator system cannot be completely neutralized by any active control system. In these conditions, obtaining a good transparency simply consists in minimising the impedance error $Z-Z_c$ while preserving acceptable trade off with stability. In these conditions, the functional properties of the remaining non-transparent part of the human environment medium cannot be considered. Hence, the meaning of transparency that developed in the field of Robotics works at the phenomenological analysis level, using notions originated in control-command paradigms, such as error minimization, stability, etc. In VR, the usual understanding of the concept of transparency can be viewed an extension of the transparency in real-real teleoperation.

An instrumental to the notion of transparency

Conversely, in the instrumental paradigm [Cadoz, 1994], the new chain is considered as a new instrument. Consequently, the true goal is the design of the instrument so that the user is able to perform a task, rather than trying to make the new instrument similar to a hypothetical previous one. This is related to an anthropological point of view of the notion of instrument – or tool –, saying that instruments are designed as to have functional features allowing a human to perform a task (for a discussion, see [→ ACTION FIDELITY]). An instrument is designed as an adaptor to human capabilities, including learning and human adaptation. This vision assumes that there is no necessity of an instrumental reference that would be a priori the best to perform the task. It leads to investigate new methods for designing and implementing such new instruments – a kind of new ergonomics. The computer-based technologies such as simulation are considered as one of them. The research activity shifts from the measure of the similarity between two in-

strumental chain, and the transparency of the new instrument to the investigation of the properties of the man / instrument / manipulated object (if any) chain.

Transparency in the instrumental approach, hence, shifts from the specification of transparency introduced in teleoperation. The new instrument is considered as an intermediate object that can be physically characterized in order to reach the best adaptation possible with the humans and with the task. This approach fits more to the Leroi-Gourhan [Leroi-Gouhan, 1964], anthropologist & philosopher, in which there is no importance for an instrument to be transparent in the sense of the teleoperation chain. The most important point is that instrument design must be guided by considering that a new instrument must realize the best adaptation between human's capabilities and the new task. In other words, the first functionality of an instrument is to be a necessary intermediate between human and world.

The instrument: a second nature

This leads to introduce an instrumental approach to the concept of transparency. An instrument is the result of a technical, material and cognitive process in which an object is transformed to adapt humans and physical world in order to perform tasks. This process is intimately accompanied by several others in the operator himself: learning, appropriation, and finally embodiment. The ultimate point of the process of becoming an instrument, and reciprocally becoming an instrumentalist, is when the instrument has successfully become a second nature, a prolongation of the human organology, being really transparent in the sense of being usable in an intimate and non-conscious manner by instrumentalists, craftsmen, artists, and dexterous users [→ TRANSPARENCY_1].

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