Designing the ground for pleasurable experience

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Abstract. In this article we present a theoretical framework and some models for assisting the conception of tactile communication devices. In order to propose relevant concepts and successful innovative products, designers and more generally design teams need to anticipate as early as possible the user experience that will emerge from actual use of the product they are developing. The way the designer imagines the qualities of the product inevitably has strong consequences for the possible experience that will be available to the user. However, it is very difficult to accurately anticipate the actual experience of the user; and the lack of knowledge concerning the final user is particularly drastic in the case of high-technology applications, where the potentialities of the technology are hugely superior to the acceptability of the final users. In order to remedy this difficulty, this article presents research from the fields of design, cognitive science and Virtual Reality, in order to understand how lived experience is constituted by the use of a technological device. The aim of this interdisciplinary research is to provide guidelines for anticipating user experience in the design process. In section 2 of this article, we present the fundamental theoretical notions which are the basis for defining the constitution of lived experience when a user takes hold of a perceptual interface. In section 3, we examine the constitution of the emotional values which accompany such lived experience. This enables us to propose some elements for understanding the social adoption of a perceptual interface. On the basis of some deliberately minimalist experiments, we address the question of the collective constitution of emotional values in communities which share common means of perceiving and interacting. We found that there are two kinds of perception over time: perceiving the other as part of environment, versus perceiving the activity of other perceiving me. It is by switching between these two kinds of perception that it becomes possible for one subject to understand the position from which the other subject perceives the scene. We call this process the constitution of a « point of view ». From this ability to constitute a system of “points of view”, the feeling of sharing a common space with another intentional being can emerge. Finally, in section 4, we present the application of these considerations to the design of devices for interindividual interaction. We present the prototype of a device where the space of interaction is such as to afford "perceptual crossing", a key emotional factor in interpersonal interactions.

1 Introduction

The object of this paper is the conception of devices for interaction at distance which incorporate the emission and reception of tactile signals. Systems which provide a form of touching at a distance via digital networks represent a radical innovation which cannot be based on already existing devices. The design of this sort of innovation therefore poses general methodological problems, which call for fundamental theoretical reflection on technical mediation in general. The challenge for design lies in the conjoint conception both of new interfaces, and of unprecedented modes of interaction. This poses a double difficulty.

What is important in order to capture the interest of the user is not only the interface itself, but above all the type of lived experience that it gives rise to. The point is that in the course of this experience, the interface itself as such becomes invisible: when I am talking to someone on the phone, I no longer see the telephone itself as a physical object; when I am immersed in the plot of a film, I no longer see the television set as such. It follows that one of the challenges facing design teams today, within the context of the increasing development of high-technology products, is to anticipate the experience people will constitute when using the product or the service that has been designed. The classical approach is to rely on studies, observations and surveys of actual use. The problem is that in order to carry out such tests, the device must already be widely distributed in a stable commercialized form – which means that the user experience was not actually taken into account during the design process. On the other hand, if one tries to rely on already existing practices, and to extrapolate in order to guess future uses, then there is no real invention or innovation. This sort of tinkering by trial and error produces evaluations which always lag behind the design process itself, and it is only by a lucky fluke that they can provide a source of inspiration for the success of new products.

For these reasons, it seems to us that it is necessary to define a certain number of theoretical principles concerning the way in which taking hold of a tool participates in the constitution of lived experience, and in particular under which conditions the use of a tool can be the ground for pleasurable experience in interindividual interactions. Our research team has been engaged for some time in fundamental research on the psychology of prosthetic perception, and in particular the use of perceptual supplementation devices. This article presents the main results of this research, and goes on to show how these results may serve to guide the design of prototypes for tactile interaction and communication.

As a basis for understanding prosthetic perception, we first recall the main elements of theories of active perception, in particular concerning spatial localization and the recognition of shapes. This leads to the theme of an “in hand” mode of existence for tools, in which they amount to a modification of the “lived body” of the user. With these basic notions in place, we then go on to examine the conditions under which a technical device can become the bearer of emotional values.

In order to elucidate principles which are sufficiently general for application to the context of design, we have employed a deliberately minimalist experimental method which makes it possible to exert a precise control over the possibilities for acting and feeling. In order to do this, we have employed virtual reality systems, since these make it possible to vary freely and to model both the devices which are to be taken in hand, and the way in which, once they are grasped, they transform the modalities of interaction.

At the same time, the theoretical principles we have elaborated can have consequences for the actual design of virtual reality environments, in particular collaborative environments or video games with multiple players. For example, in an industrial setting, during the conception of a new product, designers, engineers and more generally all the actors involved in the process of conception engage in important discussions on the basis of plans, prototypes and mock-ups, which traditionally were real but which now are increasingly virtual. In order for the co-presence of multiple users in a common virtual world to be effective, it is important that each user should have the means to understand, intuitively, the point of view of the other participants. It should therefore be possible to test the generality of the theoretical principles elaborated in the context of tactile interactions, which we present below, by examining their relevance when applied to predominantly visual modes of interaction. As we shall show, these principles lead to an original proposition in order to solve the problem of sharing a common space of interaction.

2 Prosthetic perception

The theoretical framework of active perception has been variously developed in the ecological approach to perception (Gibson 1966, 1986), in phenomenological approaches (Merleau-Ponty 1945), and in sensori-motor or enactive approaches (Piaget, 1936; Varela 1979; Noe 2006). This is the theoretical framework best suited to our present concerns, since it makes it possible to take into account the modifications of lived experience that arise from the use of technical interfaces. In order to demonstrate this, we shall consider the extreme and highly revealing case of perceptual supplementation devices [Lenay et al., 2000].

These devices (that have also been called “sensory substitution systems”) were initially developed as an aid for persons with sensory handicaps. The general principle consists of transforming the stimuli that are initially associated with one sensory modality (for example vision) into stimuli in another sensory modality (for example touch). The exemplary system of Tactile Vision Sensory Substitution (TVSS) invented by Paul Bach y Rita consists of a square matrix of 400 tactile stimulators connected to a digital camera. The image captured by the camera is simplified and converted into black and

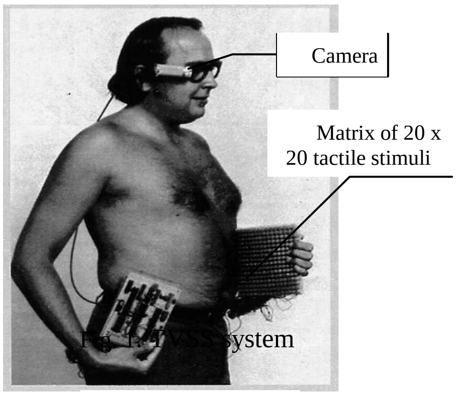


Fig. 1. TVSS system

white pixels (without intermediate grey levels), and then used to control the activation of a “tactile image” of 20 x 20 pixels, i.e. 400 tactile stimulators which are raised or not according to whether the corresponding element of the image is black or white. This tactile matrix is applied to the skin, either on the back (the first version), or on the chest or the forehead [Collins 1973], and more recently on the tongue [Bach y Rita 2004].

Early trials with this system rapidly showed that, on condition that the user was active (moving the camera by translations and rotations, and zooming), he developed spectacular capacities for recognizing shapes. After fifteen hours of practice, he discriminated increasingly complex familiar objects, to the point of being able to recognize faces. Moreover, this capacity to recognize shapes was accompanied by an *external projection* of the percepts. The user no longer noticed tactile stimuli on the skin, and instead perceived stable objects “out there” in front of him [Bach y Rita 1982]. The perception of a stable object “out there” is quite distinct from the succession of variable sensory stimuli that the subject receives as he constantly moves the camera.

The sensory substitution systems such as the TVSS thus make it possible to observe, in the adult, the genesis of a novel prosthetic perceptual modality; and in particular, to follow the constitution of a *space of perception* in which objects can be perceived as being external (Pacherie, 1997 ; Auvray et al., 2004).

In order to study the way in which the use of a tool can lead to the constitution of an encompassing distal space, we have employed a deliberately minimalist method in which the repertoires of action and the sensory returns are drastically reduced to a bare minimum. This makes it possible to control quite precisely what are the objects that can be constituted in each case, and what are the operations that are necessary for this constitution. We have thus reduced the system of Bach y Rita to a single photo-electric cell connected to a single all-or-nothing tactile stimulator. When the total luminosity in the incident light field (a cone of about 20°) is greater than a certain threshold, the tactile stimulus is triggered.

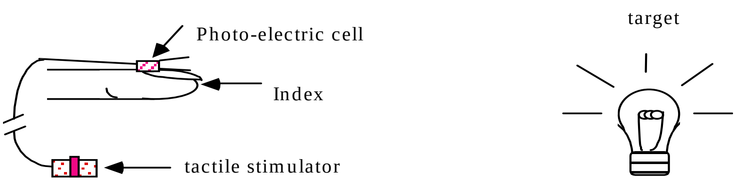


Fig. 2. Distal perception glove

At each moment in time, the subject (who is blindfolded) thus receives only a minimal information, 1 bit corresponding to the presence or absence of the tactile stimulus. We have been able to show that even with such a simple device, the spatial location of luminous targets was still possible. Initially, the subject only perceives a succession of tactile stimuli which accompany his movements. But quite soon, as he becomes familiar with the device and starts to master it, he no longer notices these sensations which are replaced by the perception of a target at a certain distance in front of him. Here, it is quite clear that perception cannot be grounded merely on an internal analysis of the sensory information; the latter is simply a temporal sequence of all-or-nothing 1's and 0's which has nothing intrinsically spatial about it.

In such conditions of minimal coupling, it is quite easy to replace the physical reality which triggers the tactile stimuli according to the orientation of the photo-electric cell, by a digital motion capture device placed on the finger which defines the position of a receptor field in a virtual space. In the situation defined by this system of minimalist perceptual supplementation, the passage from the real world to a virtual world makes practically no difference to the subject (Thouvenin et al., 2003). The advantage is that in a virtual environment it is far easier to record the perceptual trajectories, and also to modify the conditions of coupling by changing, for example, the shape, the arrangement or the number of receptor fields.

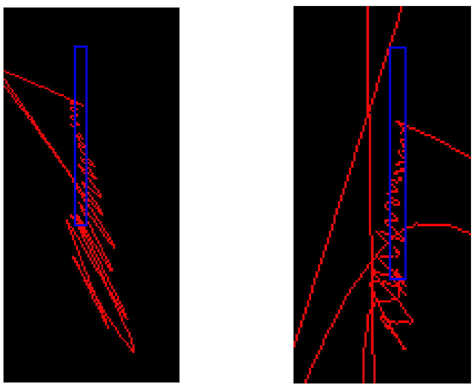


Fig. 3. Projection of the pointing movements on 2 planes which include a luminous target.

In order to maintain the perception of a target placed in front of him, the subject must act continually, moving the photo-electric cell so as to aim at the target in different ways. As soon as the movements stop, the perception disappears. This can easily be understood if we look at things from the point of view of the subject. If he is immobile, there are only two possibilities: either he receives a continuous stimulus, or he does not. If he is pointing away from the target, he has only the memory of a perception which fades away. If he pointing at the target, he receives a continuous stimulation – but this does not give rise to the perception of an external object. Spatial perception requires the *synthesis* of a temporal succession of actions and sensations. The spatial exteriority of the target can only be constituted by the possibility of freely and reversibly coming

and going around it, alternately leaving and refinding contact with it (Poincaré 1905, 1907). The target is localized in direction and depth when the law governing pointing towards it is mastered. This is a good illustration of what Kevin O'Regan has called a "law of sensori-motor contingency" (O'Regan & Noë, 2001). Any given position of the target corresponds to a particular *sensori-motor invariant*, i.e. a *law* relating sensory feedback to the actions performed; this law itself is stable over and above the constantly varying actions and sensations. If the subject is immobile, and can only perform rotations at arm's length (without translations), he can maintain a sense of the orientation of the target, but it is no longer possible to localize the distance of the target; *depth* has disappeared from the perceived world (Lenay 1997). Perception depends not only on sensory input, but just as much on the capacity of the lived body for *action.* In order to give rise to a perception, a prosthetic device must be an instrument of coupling which modifies the lived body by defining new repertoires of action and sensation.
This conception of active perception can be schematically illustrated as follows:

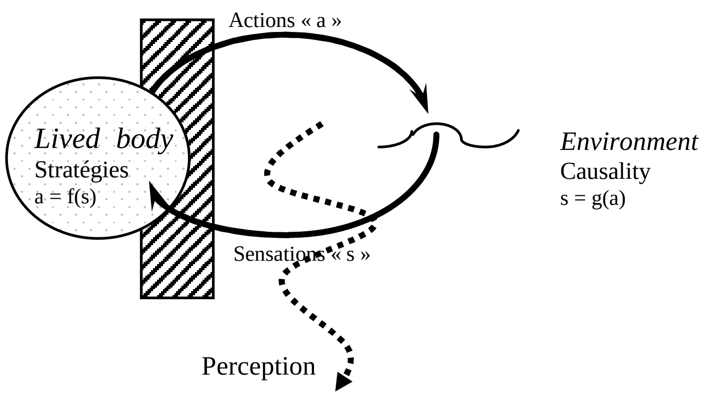


Fig. 4. Scheme of sensori-motor coupling. The system of prosthetic perception is a "coupling device" which modifies the lived body by defining the repertoires of actions and sensations which are available to the subject. Via the environment, the actions "a" give rise to sensory feedback "s" : s = g(a) ; concomitantly, the organism implements a strategy for generating its actions and modulating them as a function of its sensations : a = f(s).

On this view, perception is not an internal representation, but the result of dynamic coupling between the organism and its environment. This is why we situate perception at the heart of the coupling, and not unilaterally within the organism. In this conception of perception, there is an important distinction to be made between "sensation" and "perception". The "sensation" is defined as the sensory input delivered to the organism; this is quite different from the full "perception", which is based on the law defining the sensory feedback for a full range of performed actions.
These considerations apply equally to natural vision. The latter requires a functional eye, but also the activity of ocular muscles which produce micro-saccadic movements (on a time-scale of 10-20 milliseconds). If the eye is completely immobilized, it appears that vision is no longer possible: the perceived image fades away in a few seconds (Ditchburn 1973, Steinman 1990). The same is also true for touch, which only

gives rise to the perception of *objects* if there are constant exploratory movements. We insist again on the fact that when attention is focussed on the perception of an object, the *sensations* delivered by the coupling device (be it natural or artificial) disappear from consciousness. Thus, when we perceive a stable object at a certain distance in front of us, by using our eyes and their movements, we have absolutely no consciousness of the variable sensory stimuli on our retina.
The perceptual actions of a subject correspond to movements of his "point of view", i.e. the site from which the object is perceived. According to the coupling device that is employed, this site can be different from that where the sensations are delivered. We will illustrate this point by another system that we have developed with the aim of providing blind persons with access to digital forms present on a computer screed. The "Tactos" system (Hanneton, 1999) consists essentially of a device for controlling tactile stimulators (Braille cells which electronically generate the movements of small pegs) as a function of the movements of a cursor on a computer screen.

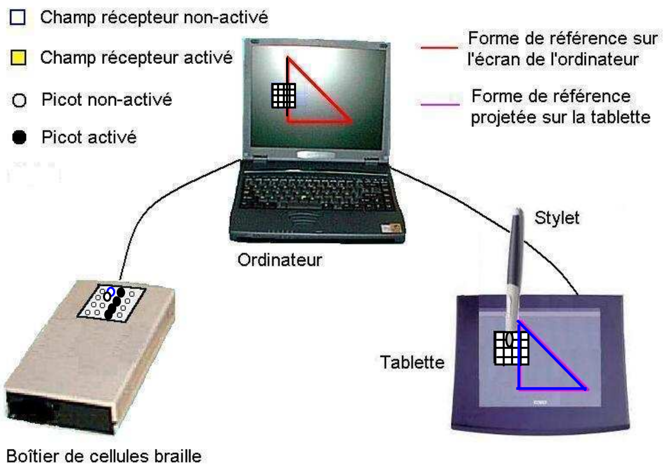


Fig. 5. Tactos system including the stylus and the graphic tablet, the computer and the Tactos software, the braille piezoelectric cells matrix

The cursor here corresponds to a small 4 x 4 matrix of 16 receptor fields.
When one of the receptor fields encounters at least one black pixel, this triggers the all-or-none activation of the corresponding peg on the Braille cell. The subject is blindfolded, and moves the cursor by means of an effector (mouse, stylus on a graphic tablet, touchpad….). The tactile stimulation is delivered to the *other*, free hand – but this does not hamper the perception of the forms.
For practical applications, it is possible to increase further the number of receptor fields and the corresponding tactile stimulators; but from the point of view of fundamental research it is actually more interesting to *reduce* the sensory information to the limiting case of a single stimulator corresponding to a single receptor field. Even in this minimal version, we observe that subjects are able to perceive forms. These forms are not

given to the sensory system as a complete two-dimensional pattern applied to the skin at each instant of time. When there is only a single receptor field, and thus a single sensation at each instant, there is again no intrinsic spatiality at the level of the input signal. If the subjects succeed in recognizing shapes in space – and they do – this can only be by virtue of an active exploration in the course of which they integrate their movements and the corresponding sensory feedbacks over time. Thus, by limiting the sensory input to just a single bit of information at each instant, we oblige the subjects to *deploy their perceptual activity in space and time*; and in this virtual reality situation it is then a simple matter to record and to analyse this activity. This is what we have called "perceptual trajectories" (figures 6a et 6b). (Lenay, 2002, Sribunruangrit 2003).

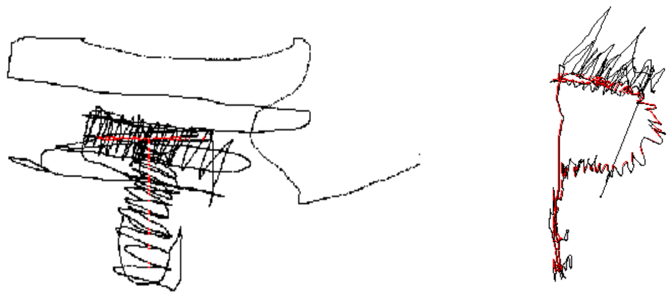


Fig. 6a **Fig. 6b**

Fig. 6. perceptual trajectories with Tactos

The proprioceptive perception and memory of absolute position is too imprecise for the subject to be able to plot the positions of the hand which holds the effector (mouse, stylus…) in egocentric X-Y co-ordinates. It is thus quite impossible for the subject to scan the whole field of the screen, and to integrate the points of stimulation in order to construct a mental image of the form. In fact, if the subject inadvertently leaves the contour of the form he is immediately "lost", and cannot even proprioceptively return to the last point of contact with the form. The subject starts out with large-scale exploratory movements, but as soon as he obtains a contact with a line, he converges to a *micro-sweeping* movement of small amplitude around the source of stimulation. This can be understood as essentially an operation of localization: the position of an immobile spatial singularity is *constituted* by a stable anticipation of the tactile stimulus according to the movements of the receptor field. At the same time, this micro-sweeping movement enables the subject to identify his own position, not in absolute co-ordinates but relative to the form that he is exploring and perceiving.
This localization of the point of action is the condition for being able to project oneself into the space created by the technical mediation. This is what happens, for example, in the now common-place use of a mouse to move a cursor on a computer screen. The fact

that the cursor is blocked by the edge of the screen, whereas the hand can freely continue its movement, is not a hindrance but actually a help because the user defines his actions not by his hand, but by the cursor that he sees on the screen.

If the action is properly characterized not as the movement of a site of inscription, but rather as the movement of a site of perception (in general, a "point of view"), then we can consider that there is "immersion" in an encompassing space. The point of perception is then situated in the same space as the perceived objects. If the point of perception is blocked, the user will understand that he himself is blocked in the virtual space. For example, in a video-game of subjective action, when a panoramic movement is blocked by an obstacle even though the player continues to push on his joystick, he will know that he is blocked and will seek to skirt around the obstacle by taking another route from the place where he was stuck.

In the case of the TVSS, the coupling between the actions (movements of the camera) and sensations (tactile stimuli) passes through the physical environment. By contrast, in the case of a computer mouse, the coupling between the actions (movements of the mouse) and sensory feedback (movements of the cursor on the computer screen) passes by a digital calculation. But in both cases, once the tool has been grasped and mastered, the tool itself disappears from consciousness in favour of the space of perception and action that it gives access to. The tactile stimuli on the skin and the camera in the hand are both forgotten in favour of the perception of an object "out there" in a distal space; the computer screen and the movements of the mouse are forgotten in favour of the perception of the cursor and the operations that it makes it possible to perform in the digital space.

In these two examples, the technical mediation highlights features that are actually quite general in the use of tools of all sorts. When I grasp a stick in order to explore the surface of the ground, it is not the stick that I perceive as an object, but the bumps on the ground at the end of the stick. This has been well described by phenomenology: "The stick of the blind person has ceased to be an object for him, it is no longer perceived as such, the end of the stick has been transformed into a sensitive zone, it augments the range and the scope of action of touch, it has become analogous to vision" [Merleau-Ponty 1945 : 167]. In a similar vein, when I drive a car, I forget for the moment the vibrations of the steering-wheel and the seat, and instead I have the impression that I feel the gravel or the edge of the pavement under "*my* wheels". These examples can be generalized to all the technical "appendices" which transform our power of action.

2.2. In hand / put down

In order to fully understand what is involved in the use of tools in general, and prosthetic perceptual devices in particular, it is important to make a thematic distinction between two "modes of existence" of tools: "in hand", and "put down". A tool is in the "in hand" mode when it is grasped and used; it is then "interiorized" and becomes a part of the lived body, to all practical intents and purposes as much as the natural biological organs of perception and action. Just as my own lived body is invisible to me, and appears rather in the guise of a set of capacities for action, so a tool in the "in hand" mode disappears from my consciousness, which is focussed instead on what I can do *with* the tool. However, unlike organs such as the eyes or the hands, a tool can also exist in a second mode, that we may term the "put down" mode. It is in this mode that human beings can repair tools, make them, exchange them, and above all deploy their imagination to *invent* new tools. To sum up: in first "in hand" mode, a tool is *constitutive*, giving rise to a capacity for perception; but by the same token, in this mode the tool itself is not perceived. I do not perceive my spectacles when I am wearing them, just as I do not perceive my eyes, or my optic nerve, or my visual cortex. In the second "put down" mode, the tool is *constituted*; it has now become an object that I can perceive in the space in front of me.

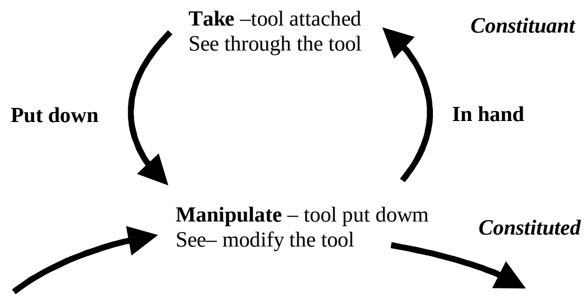


Fig. 7. Model of the tool states. The tool in the « in hand » mode is invisible because it is the means for seeing. The tool in the "put down" mode can be perceived and exchanged.

The fundamental characteristic of tools is that there is a constant back-and-forth movement between these two modes. For example, when I am driving a car my experience oscillates rapidly between moments when the car is an invisible part of my lived body through which I perceive the road I am driving along; and other moments when the car is separate from me so that I can focus my attention on it – for example when I look at the dashboard or fix my safety-belt.

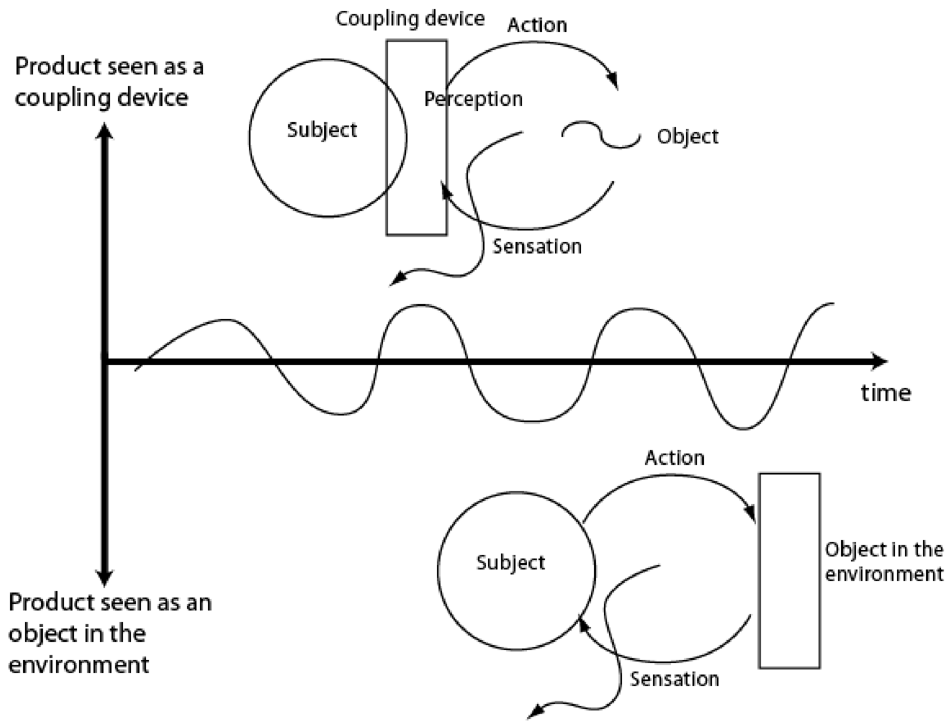


Fig. 8. The dual status of a tool: coupling device / object in the environment. All tools have this double status, and can be seen alternately either as a coupling device, or as an object in the surrounding world.

Having set down these fundamental notions concerning the use of perceptual interfaces, we can now address the question of the emotional values of the lived experience that they give rise to.

3. Space of interaction and emotional values

Here again, the systems of perceptual supplementation will serve as an illustration and a guide. It is notable that although the early sensory substitution systems such as the TVSS were a success from the psychophysical point of view – as described above, they conferred remarkable capacities for the perception of forms – they have been an economic and social failure. The reasons for this are not hard to understand. When they began to discover this new sort of access to objects situated at a distance in space, the blind persons concerned declared that they were disappointed – and on top of that, they were uneasy about appearing as “cyborgs” in the “eyes” of others. Devices such as the TVSS do make it possible to perform certain tasks which would otherwise be impossible. But this does not satisfy the deepest wishes of a blind person who engages in this sort of experiment. At the existential level of personal self-accomplishment, a blind person does not really need to perform this sort of task for which vision is indispensable. In order to be motivated to invest fully in visual tasks, the latter would have to contribute some meaningful progress at the level of lived experience. What a blind person who accepts to undertake the somewhat arduous appropriation of this sort of coupling device is looking for, is something like a direct appreciation of what he hears sighted persons going on about: the *marvels* of the visible world, the *joys* of this realm of existence which is unknown to him or which he has lost. Now in fact there are numerous differences between this sort of artificial coupling with the environment, and the mode of coupling of natural vision: there is no colour, there are only a small number of points in the image, the movements of the camera are rather clumsy and limited…. It is necessary to take into account the fact that such artificial devices never exactly compensate for a deficiency, but rather introduce new and original perceptual modalities.

Each time that a tool is grasped and appropriated in the "in hand" mode, it transforms our capacities to act and to feel, and it opens up a new space of possible perceptions. Whether one grasps a stick or a telephone, whether one puts on a pair of skis or skates or spectacles, whether one manipulates a computer mouse or the bow of a violin,…. in each case the technical mediation gives rise to a specific set of sensori-motor invariants which constitute a specific domain of perception. Now, for each of these examples of technological devices which have been socially adopted, we know that the original domains of possibilities that they give rise to are qualitatively and emotionally differentiated: the *style* of a skating figure, the *sonority* of a Stradivarius,….. With the TVSS, when one shows a person who is blind from birth his own image, or the image of his wife, the result is of no particular interest to him. When blind students were shown the images of nude pin-ups, they were totally disappointed: their perception did not convey any emotion. There is indeed the constitution of an object, a capacity for discrimination and categorization; but there is no emotional value attached to these percepts. What seems to be cruelly lacking in this new perceptual modality are the *qualia*, the *values* of the perceived entities (Bach y Rita 1997). The question of the emotional value attached to the percepts made possible by a prosthetic device cannot be simply reduced to the existence of a neuronal circuit connecting to a brain mechanism for natural emotions. Or at least, if such a circuit does exist, it would be necessary to understand how it can be created in a situation where it did not pre-exist. It is therefore necessary to try and understand the conditions under which a system of specific values and tastes can be constituted, learned and appropriated for each new coupling device.
We can put forward the hypothesis that such values may emerge from a common history, built in the course of interactions between several subjects in a common environment defined by the same means of access [Lenay 2003]. What then are the conditions for the *collective* constitution of emotional values in *communities* which share the same means of perceiving and interacting? It is not possible here to cover the immense psychological, sociological and philosophical literature on these questions. We shall rather take advantage of a specific *minimalist* experimental and technical situation in order to initiate a fundamental study of prosthetic perceptual interactions.

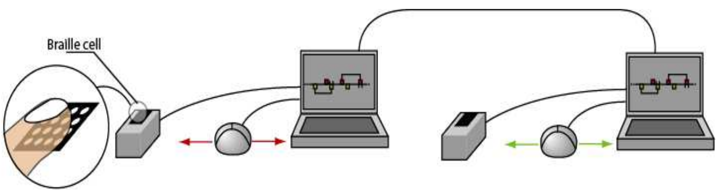
We intend here to discuss two of the conditions for the genesis of emotional values. Firstly, the recognition, by means of a technical mediation, of the presence of another intentionality, of another perceiving subject. Secondly, the recognition, in the context of such an interaction with another person, of the features of the prosthetic image that each subject presents to the other.

3.1. A study of perceptual crossing

The lived experience of the presence of others seems certain and directly perceptual. But even within the framework of ecological theories, recognizing an intentional subject remains a decision which occurs *after* the perception of determinate forms and pattern of movements. In the same way as for representationalism, the recognition of another subject occurs as a result of an inference (Gergely & Csibra, 1997; Gibson, 1963). Here, we suggest that the *direct* perception of others as intentional beings is possible in situations of mutual recognition, such as when we catch someone else's eye (e.g., Argyle & Cook, 1976, Sartre, 1943). A minimalist experiment can be designed to give an empirical content to this hypothesis.

Twenty participants (10 females and 10 males) took part in this experiment. Pairs of blindfolded participants (P1 and P2), placed in separate rooms, interacted via the experimental device "Tactos" that we have described above. The position of each participant corresponded to the position of a receptor field along a shared line (with the ends joined to form a torus) which contained two additional objects: a fixed object and a mobile object. Each time a participant encountered an object or the partner's receptor field, he received an all-or-none tactile stimulation.

The task for the participants was to click whenever they think that they have encountered the other participant's receptor field. In order to make sure that the mobile object had objective trajectories of displacement similar to those of the other participant's receptor field, it was attached by a virtual rigid link at a distance 50 pixels from the centre of this receptor field.



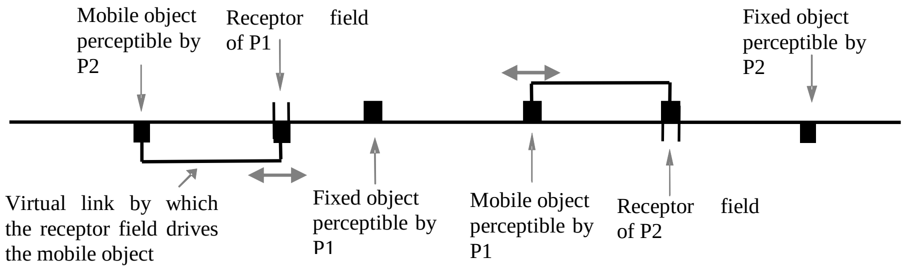


Fig. 9. Illustration of the one-dimensional space of interactions. Each participant drove his /her receptor field with his/her mouse. He/she received an all-or-none tactile stimulation when the receptor field crossed an object (in black): fixed object, other participant's receptor field, or the mobile object attached to this receptor field.

The only difference between the mobile object and the partner's receptor field was that when participant 1 explored participant 2's mobile object, participant 2 did not receive any tactile feedback; but when one of the participants explored the other participant's receptor field, both received tactile stimulation. Despite the absence of any difference in the sensory stimulations, the participants were able to recognize when the succession of tactile stimuli they received was due to their active exploration of another participant rather than the fixed or the mobile object.

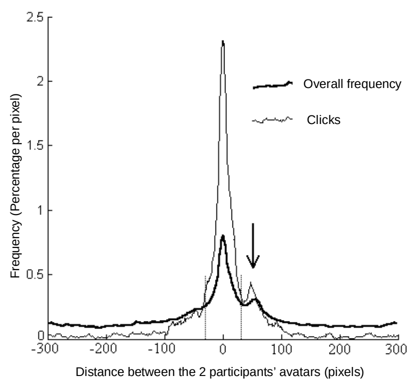


Fig. 10. Frequency distributions as a function of the distance between the 2 participants.

The thick line represents the overall unconditional frequency distribution of stimulations received. The thin line represents the distribution of distances when the participants clicked. In both cases there is a clear peak at a distance of 0 pixel i.e., in situations of mutual perception; showing the existence of an attractor around this point. The slight subsidiary peak at a distance of 50 pixels, marked by an arrow, corresponds to the mobile object.

Thus, participants interacting in a minimalist environment were able to recognize when the succession of all-or-none tactile stimuli they receive are due to meeting the receptor field of another participant. They were able to do so even though there was absolutely no difference in the stimuli themselves (simple all-or-none signals in all cases) and even though the structures of movement were identical. This minimalist paradigm forces an externalization of the perceptual activities. It allows the recording and analysis of the participants' trajectories of displacement. Calculations performed on these trajectories revealed that the large difference observed between clicks on the receptor field and clicks on the mobile object (65.9% vs. 23.0%) must be attributed to the conjoint strategies of movement, which are such that stimulations associated with the mobile object were much less frequent than those due to the receptor field (52.2% vs. 15.2%). The success in the task, that is, the recognition of the presence of others does not correspond to recognition as categorization of the received stimuli. If the participants succeeded in the perceptual task, it is essentially because they succeeded in situating themselves in front of each other. The recognition thus corresponds primarily to an active discrimination: the capacity to build an attractor in the collective perceptual dynamics.

The main condition that creates such an attractor of the situations of mutual perception is the following. My partner, just like me, is seeking to perceive me. That is, he is looking for an invariant in his sensorimotor dynamic (being able to maintain an oscillation around a spatial singularity). The active perceptual activities attract each other just as in everyday situations two people catch each other's eye. The perception of the perceptive intentionality of another subject corresponds to a characteristic pattern in the conjoint sensorimotor dynamics: an attractor with no spatial stability. The gaze of the other maintains its presence but resists attempts at a definite spatial localization.

The results of this experiment suggest that I can perceive another intentional subject, not merely through any determinate pattern of movement, but rather directly as a perceptual activity oriented toward my own perceptual activity.

It is not irrelevant, given our current concern for emotional values, to note that the participants in this study declared that they were *intrigued and amused* by this experiment, in spite of the radical poverty of the sensory data. The meaning and the emotional quality of the percepts do not necessarily depend on the richness of the sensory input, but rather on the dynamics of the interactions, particularly when they give access to the feeling of the presence of another intentional subject.

We therefore consider that affording the possibility of perceptual crossing is a key element for the success of new interactive devices.

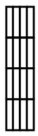
We may now go on to ask whether the body-image that I present to the other person when I use this sort of device, but which I do not directly perceive myself (just as I do not see the spectacles I wear), can nevertheless be accepted and recognized by me. Does the way in which the other perceives me give me the means to guess the image that I present to him?

3.2. A study of reciprocal tactile perception

In order to study this question we have set up a network of two "Tactos systems" which give access to a common virtual 2D space, thus allowing tactile encounters between the blindfolded participants (Lenay 2006). But, contrary to the natural situation where touching and being touched are inseparable, in such a virtual space of tactile interaction it is becomes possible to touch without being touched (and vice versa). In this respect, the situation is closer to vision, where it is quite possible to see without being seen. We therefore have to define, in the virtual space, both a “perceiving body” (the receptor fields of each subject), and a distinct body-image (avatar) that can be perceived by the partner. So, in this experiment, each subject drives with his mouse, simultaneously: i) the movements of a matrix of receptive fields coupled to the same number of tactile stimulators; and ii) the displacements of a virtual body (avatar), i.e. of a body-image that the other user can perceive via his own receptive fields. Each subject explores the virtual space and comes into contact either with objects in the shared environment, or with the body-image (avatar) of the other actor. This setup allows for the constitution, for each user in interaction, of a common space of perceptive coordination. Of course, as for the vision, each subject cannot perceive the image which (s)he presents to the other. The question is whether, via the dynamics of the perceptive interactions, it is possible for a subject to comprehend the image which (s)he offers to the perception of other subjects. We have carried out several experiments in order to study analytically the way in which each subject can guess the image that (s)he presents to others, on the basis of the way in which other subjects perceive them.
In this experiment, each subject controls a 4 x 4 matrix of 16 contiguous receptive fields coupled to 16 tactile stimulators. Subjects can have different perceiving-bodies and different body-images. There are three possible perceiving-bodies, i.e. three matrices of 16 receptive fields of different forms :

Hp : 4 x 4 receptive fields of 20 x 2 pixels

Sp : 4 x 4 receptive fields of 2 x 2 pixels



Vp : 4 x 4 receptive fields of 2 x 20 pixels

Of course, each type of matrix of receptive fields activates an identical set of tactile stimulators; there are thus no sensory differences which would give access directly to the shape of the matrix of receptive fields. There are also three possible body-images, i.e. three forms of avatar which the partner can perceive. These correspond to sets of pixels which move with the perceiving-body:

Hi

Si

Vi

Each subject can receive any possible combination of these bodies. To give just two examples (out of the 9 possible combinations), a perceiving-body Hp and an body-image Vi (figure 11a), or a perceiving-body Sp and a body-image Hi (figure 11b) :

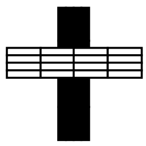


Figure 11a

Figure 11b

Figure 11: possible combinations of perceiving-bodies and body images

Two subjects “A” and “B” passed the 81 sessions corresponding to all the possible combinations of their perceiving-bodies and body-images. The subjects knew the repertoires of possible forms of their perceiving-body and body-image, but of course they did not know which particular forms they were equipped with at the beginning of each experimental session. All the possible configurations were generated randomly. The two subjects shared the same virtual space: when a receptive field of "A" covers a pixel of the body-image of "B", the corresponding tactile stimulator is activated. The two subjects collaborate and seek to facilitate the task of the other as much as they can. Each session can be divided into three stages, for which one successively asks each subject to indicate:

1- First of all, stage 1, each subject seeks to identify himself as a perceiving subject, i.e. to guess the shape of the matrix of his own receptor fields. The number of correct answers is very high: for subject "A": 78/81 and for “B”: 77/81 (a pure random choice would have given on average only 27/81). It is easy to understand that each subject can determine in an autonomous way their own perceiving-body by interaction with motionless objects in the environment. For example, if the perceiving-body is of type Hp, the vertical movement that the subject will have to carry out to pass a square object will be much longer than the horizontal movement necessary to cross the same object.

2- Then, stage 2, each subject seeks to recognize the body image of their partner. The results are nearly as perfect as in stage 1: the number of correct answers for subject “A”: 76/81 and for “B” : 71/81. The subjects collaborate: each one immobilizes themself in turn to let his partner explore him quietly. The success of this stage corresponds to the capacity to recognize simple forms that we have often observed with this device.

3- And finally, stage 3, each subject must recognize their own body-image. The results are as follows: number of correct answers of subject "A": 48/81 ; $\chi_1^2 = 24.5$, $P < 0.01\%$; for subject "B" : 46/81 ; $\chi_1^2 = 20.0$, $P < 0.01\%$. These results are less perfect than in stages 1 and 2, but still statistically highly significant. The number of correct joint answers of the two subjects concerning their own body-image is 32 (a pure random choice of the two partners would have given on average only 9). The significant success of this stage ($\chi_1^2 = 66$, $P << 0.01\%$) is very revealing about the process of reciprocal perception. We may recall that each subject does not have any direct access to their own body-image (just as in vision we have no access to our own face). A subject can only guess as to the form of their own body-image on the basis of the way in which his partner perceives him.

In this respect, it is interesting to analyse more closely the interdependence between the answers at the various stages and between the partners. First of all, we do *not* observe a correlation between the mutual resemblance of perceiving-bodies or body-images of the two partners and their success in the crucial task of recognizing their own body-image. Contrary to what one might have thought, the fact of our resemblance does not help us to recognize us mutually. However, there is a correlation between the successes of the two partners as for the recognition of their own body-images. But there is no clear dependence between success in recognizing the body-image of the other (stage 2) and success in recognizing his own body-image (stage 3). The dependence which one does observe is rather between the success of a subject for the recognition of the body-image of the other (stage 2 of one subject) and the success of the recognition by this other subject of their own body-image (stage 3 of the *other* subject).

This result has an important ethical consequence: my active perception of others helps them to recognize themselves (but does not help me to recognize myself). Conversely, it is the other who, by his way of looking at me, helps me to constitute an image of myself, to recognize my own face.

From the point of view of interactive devices, our experimental study seems to show that, in the case of a reciprocal perception, if each subject reaches the same space of interaction by the same mediations, it becomes possible for each subject, through the use of this mediation, to recognize the image which they themselves present to the point of view of others. This could be the starting point for the social adoption of perceptive interfaces, and to the sharing of emotional values specific to those modifications of the body-image. The coupling device, which is a modification of the lived body that is not directly perceivable by the subject himself, is for other subjects an object in the environment. The white stick used by blind people is a salient example of this double status of an object: it is something used to perceive the environment, but it is also something perceived by others which warns them that the carrier is a blind person. Here again, the social dimension and the development of a community of users are very important. When two individuals share an interaction space, they either perceive the other as part of the environment (when they perceive the modification in the environment which occurs from the other's action); or they perceive *that* the other perceives them. In a phrase: either I perceive your eyes, or I perceive your look. The alternation of these two kinds of perception over time leads to the constitution of a "point of view": it becomes possible to know and to understand the position from which another person is perceiving. This process, and this understanding, can lead to the emergence of a feeling of sharing a common space with another intentional being:

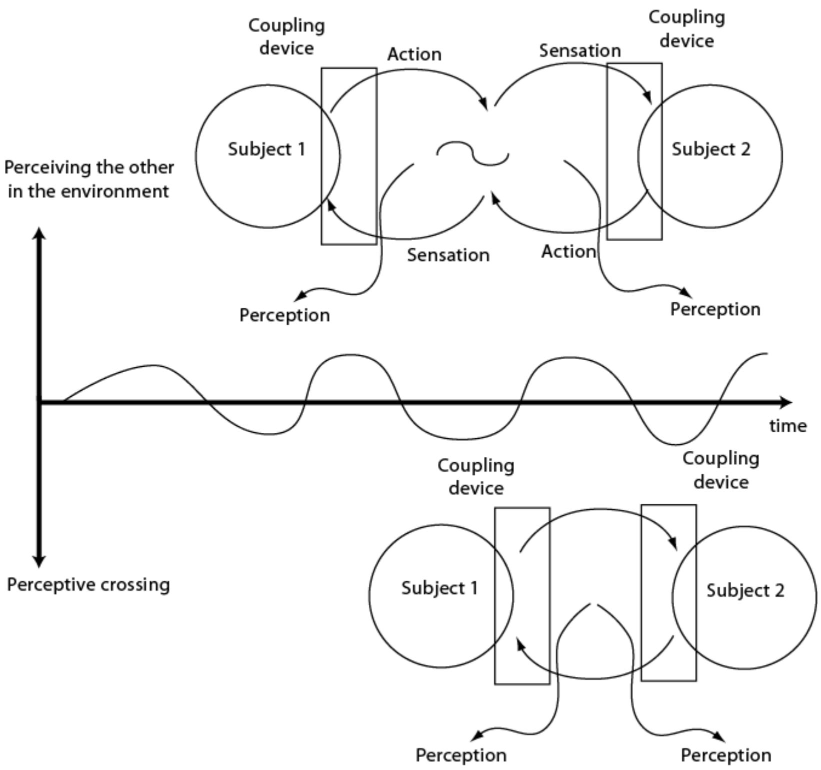


Fig. 12. Sensory-motor coupling applied to interpersonal interaction

4. Consequences for the design of interindividual interaction devices

The interaction space allows the coupling between the actions a user performs via their own interface, the sensory feedback they get, and the stimulation that their partner gets. We propose to differentiate two types of shared interaction spaces, corresponding two ways of coupling actions to sensations.

Type 1 (formal): the interaction space is a shared virtual space containing avatars embodying the subjects (Fig. 13). These avatars can be moved via the actions of the subjects. This type of space allows encounters between the various partners. This type of virtual shared space is found in a large number of video games.

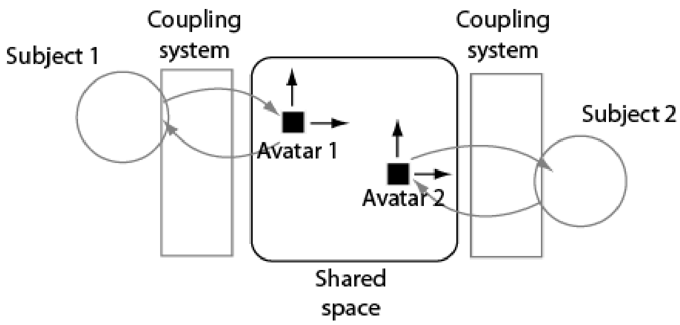


Fig.13. Figure illustrating a 2D virtual shared interaction space in the case of existing devices, such as video games.

Type 2 (intimate): the interaction space ensures a direct coupling between the actions of one subject and the stimulations received by their partner. This type type of virtual shared space allows for the possibility of perceptual crossing (Fig.14).

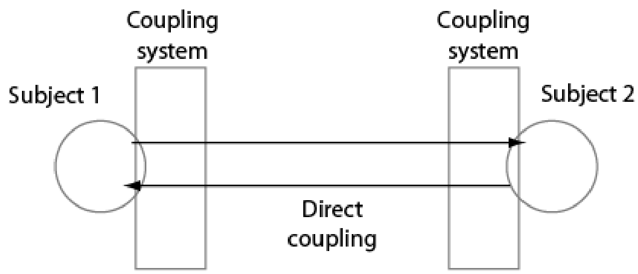


Fig.14. Illustration of direct coupling in the case of existing interpersonal interaction devices such as cell phones

4.1 Application of the Model to Tactile Cell-Phones

We have developed experimental functional prototypes for interpersonal interaction which incorporate a tactile modality. The next figure illustrates the scenario for using our "tactile mobile phone". This device has two sides. On one side there is a screen (for technical reasons we have not implemented a functioning screen, but we use the screen of a computer), while on the other there is a pressure sensing pad. The pressure sensing pad functions in absolute position (each position on the pad corresponds to a position on the screen). Tactile stimulators (Braille Cells) have been integrated on each edge of the device. In addition, a 2D accelerometer gives information on the orientation of the apparatus.

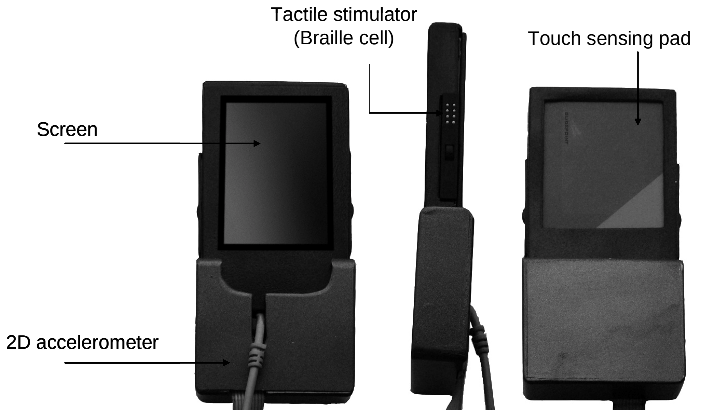


Fig. 15. Components of the product for mediated interpersonal interactions

Fig. 16. Tactile stimulator

Fig. 17. One-hand “type 1 (formal) mode of use of the product

Fig. 18. Two-hand “type 2” (intimate) mode of use of the product

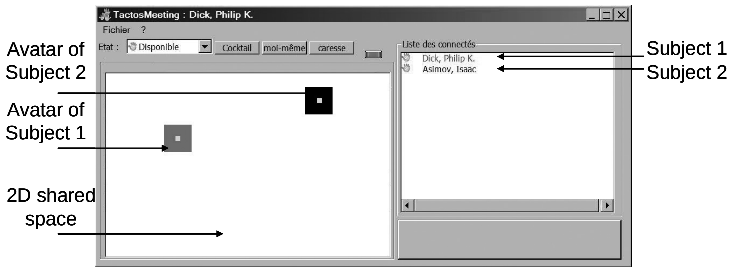


Fig. 16. Displayed interface and virtual shared space

The screen displays the representation of a room, containing avatars of all users connected (up to ten in our application) and thereby present in the room (this is similar to the contact list of an instant messenger). Pitching the device in a certain direction controls the movements of one’s own avatar in that direction at a speed proportional to the angle given by the user. Thus, the user can explore the shared space. Then if they approach the avatar of another user, the audio channel is activated and they will be able to speak to each other. Furthermore, if the two avatars come into contact, the users will feel a tactile stimulation, and be able to exchange “tactile emoticons”. Finally, in the most intimate mode, when users have exactly the same position they can exchange “caresses”, i.e. tactile perceptual crossing: their actions on the pressure sensing pad are coupled to the tactile stimulator of their partner.

4.1 Application of the Model to a collaborative virtual environment

The same theoretical principles can serve to construct collaborative virtual reality environments employing an essentially visual modality. Classically, in order to permit meetings and interactions, each participant can choose a pseudo-humanoïd avatar that that will represent him in the common space (e.g. « Second Life »). However, with this technique it is not all obvious to understand the point of view of another participants (to know what he can see and what he cannot see from his situation in 3D space. Moreover, the feeling of “presence” of the other remains rather weak; in particular, there is nothing to indicate that what is hidden behind the visible avatars of the others is anything other than a computer algorithm.
If one wishes to facilitate the mutual recognition of the presence and the point of view of all the participants, it is important that their avatars give a realistic representation, not of their physical appearance (which in this case has no useful meaning), but rather of their perceptual engagement in the situation. The relevant image of another participant is the visible part of his body that he uses in order to perceive the shared world. We therefore propose to represent each participant, not by an arbitrary figure, but by the actual image that he perceives, an image that will be positioned at the point from which the participant in question perceives that image. This has been done in the following manner.
The MATRICS project (Managing Annotations for Training in an Immersive Collaborative System) [Aubry 2007, Guenand 2005] is the basis for collaborative work between several research laboratories at the University of Technology of Compiègne. The main objective is to provide a platform for working on 3D models, taking advantage in particular of indexing systems and knowledge processing systems. The long-term objective is to propose a complete and well-organized manner of working together at distance on a single project, for teams engaged in mechanical design (designers, engineers etc) and also for training institutions.

This virtual collaborative environment offers the following features: An objective 3D « geometrical » content which is identical for all users, giving them a common vision of the virtual prototype. The possibility of representing participants in the form of avatars integrated in this virtual world.
In order to define an appropriate form for these avatars, it is important to take into account the nature of the interfaces actually used for participating in this virtual environment. The interfaces which make it possible for users to perceive and to interact with this environment can be thought as channels for communication between the user and the model world, and by extension for communication with the other users since

they also perceive the same world. Each participant has his own viewpoint on the world, as with a “camera”; this preferably involves stereoscopic vision in order to enhance the perception of spatiality; Each participant controls his own viewpoint in a spontaneous manner, preferably by means of a mouse. Larger, regular movements, particularly translations, can be controlled by the keyboard or a joystick; Each participant has the capacity to point at objects of his choice, and to perform actions on them.

Now, in order to define the avatars which are useful and appropriate for mutual understanding in the context of collaborative work, the key point is that they should display for the other partners the visible part of what the partner represented by the avatar can himself perceive.

On the basis of these propositions, we hope to have contributed to the occurrence of perceptual crossings, by having rendered explicit the principle on which they are based. The principle of the floating screen is manifestly direct: we literally propose that other participants should be able to perceive our own perception of the situation. The spontaneity and the resolution by which perceptual movements are rendered make this information relevant. Each participant has a perception of the activities of the other participants. The pivotal case is the phenomenon of perceptual crossing, when one of the participants makes the step of connecting with the perceptual activity of his partner. When this happens, he becomes able to see himself in the image that his partner sends back to him; and, notably, this is a reciprocal situation. It is on this basis than we can expect and hope for genuine perceptual interactions: looks which meet and exchange, designating a mutually understood object by a nod of the head, and so on.

This experimental ground will provide the opportunity to test our hypotheses concerning perceptual crossing in a virtual environment.

Conclusion

The design of novel interfaces involves, at least implicitly, the design of unprecedented modes of interaction ; and this introduces a particular difficulty. What is important in order to engage the interest of the user is not (only) the interface itself, but above all the sort of lived experience that it will give rise to; and in the course of this experience, the interface as such becomes quite *invisible* to the user. Thus, one of the major challenges facing design teams today, in the context of developing increasingly high-tech products, is to anticipate the experience people will constitute when actually using the product or the service that has been designed. The aim of this article has been to contribute to this anticipation, both theoretically and experimentally, in the case of prosthetic interpersonal interactions.

We have presented the fundamental theoretical notions that we have taken as the ground for defining what it is that constitutes lived experience when perceptual interfaces are taken “in hand”, and for defining also the basis for the constitution of emotional values that may (or may not) accompany this experience. In particular, we suggest that a key element in the constitution of emotional values is the *collective* dimension, involving communities that share common means of perceiving and interacting.

In a series of minimalist experiments, stemming from this theoretical perspective, we identified two kinds of perception over time: perceiving the other as part of environment, and perceiving the activity of other perceiving me. We found that it is from the alternation of these two kinds of perception over time that the « point of view » is constituted: understanding a “point of view” amounts to understanding the position from which another person perceives the current situation. We further propose that it is from this ability to understand the “point of view” of others, that a feeling of sharing a common space with another intentional being can emerge.
We have sought to present these elements for understanding the social adoption of a perceptual interface, in terms which can be exploited by designers of such interfaces. Finally, we present some application of these considerations to the design of an experimental prototype of an interpersonal interaction device, where the interaction space makes it possible to experience perceptual crossing, a key factor in the constitution of emotional values in interpersonal relations.

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