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17. Towards a Complete Representation by Means of Computer

– The Instrumental Communication Interface Concept –

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Summary.

This paper deals with a project in progress called I.C.I. - Instrumental Communication Interface. This project is supported by the IMAG Institute, which is the Grenoble Computer Science Institute, and by the French Ministère de la Culture. Two of its major aims are artistic creation and man-machine Communication. We will discuss about the fundamental motivation of this new way of communicating and creating with computers, that is the concept of Complete Representation. We will present our technological developments of ICI and our scientific and artistic results: the physical modelling of objects, the force feedback gestural transducers, the real time simulation allowing the user to act on a physically simulated object and to perceive it by its synthetic visual, acoustic and tactilo-proprio-kinesthetic behaviours.

Note: A video tape containing all the concepts and the experiments described in the paper is available at the ACROE laboratory.

Key words: Image synthesis, Sound synthesis, Physical models, Animation, Force feedback, Gestural feeling, Virtual Realities, Virtual Worlds

17.1. The Concept of “Complete Representation”

The term of Virtual Realities, or Artificial Realities, is interesting but it does not represent the contemporary deep evolution, due to the computer, in our representation tools.

We believe that what is happening now in the field of computer uses cannot be fully rendered by the term of Virtual Realities.

As a matter of fact, the virtual as well as the realistic, are not a product of contemporary technologies. Our only way to access reality has been through “virtualities”, through “images”: those produced by our senses, to

begin with retinian and cochlear images, and those produced by the various observations and representation tools made by man such as telescopes, microscopes, microphones.

For us, the term of representation is stronger than virtuality because we always communicate, understand, create, through virtualities, (more generally, representations).

What is happening today is a new stage of the evolution of our means of representation but with an unprecedented speed and depth.

The breakthrough is that the representations can be "total", "complete". What is new is not in the term "virtualities", nor in the term "realism", nor in the term "representation", but in the term "complete": we can see and hear these representations; but also, we can touch them. In addition, they can be dynamic, and even varying themselves; finally, they can act directly on man or on the natural universe.

We have now at our disposal the basis of a kind of general "acting language"; general in the sense that it is independent of the perceptual modalities but it can produce all of them: visual, acoustic, and gestural perceptions, and it can receive our gestural actions.

We think that this evolution -this "acting language" or "total representation"- is equivalent to the birth of writing.

This new computer representation tool is characterized by three aspects:

Make all the signified sensitive. In the past, symbolic representations were to be distinguished from the representations capable of addressing perception. Today it is possible to generalize and make sensitive entities that are a priori not sensitive. The computer appears as a universal tool for sensitive representation.

A multisensorial representation. For the first time, the sensitive representations produced are multisensorial. In the past, images and sounds were on separate supports and were processed independently. Today, the signifier appeals to several sensorial modalities at the same time: sight, hearing, tactilo-proprio-kinesthetic perceptions. As a matter of fact, until now, our senses have been considered as compartmentalized. Each separate sensorial modality can be used in man-computer interfaces. The tools for the use of each of them are available, and in multimedia tools, they are superimposed, with a specific process for each one. We can now take one further step forward and speak of multisensoriality. The perceptual system is a global system in which various modalities collaborate and, even though they can be distinguished, the whole is more than the sum of the components. Multisensoriality and multisensorial synthesis can and must be considered as a whole. And thus the usual communication media (either the sound or the visual signals) can be replaced by a supramodal entity that is none of the three main modalities

(sight, hearing, and touch) but can produce all of them, providing consistent correlation between the three communication signals. Thus it is possible to produce synthetic sounds, images, and gestural signals that are not juxtaposed but correlated in a genuine manner. The objective is to obtain a greater authenticity of the representation and a greater efficiency of action.

The last characteristic of this multisensorial representation is the rise of gestures as a full modality. Historically, sound synthesis for auditive perceptive modality appeared first, then appeared image synthesis for the visual perceptive modality. Both are merely sensorial modalities. Gesture is a sensorimotor modality. Action is necessary for perception. This requires transducers that are technologically more difficult to design and build because they must couple motors and sensors, they are multidimensionnal and they convey energy. These are the reasons why gesture was introduced in computers after sound and image synthesis.

A behavioural representation. An image, a photograph or a sound are only phenomenological events. And only visible or acoustic information are printed on a film or a magnetic tape. All that is connected to their potential transformations and interactions with other objects or with human beings is lost. This is why it is impossible to have a gestural perception of an object only represented by a visual image. Today, what can be synthesized and represented is a multimodal entity, that is the physical object underlying our perceptions. And, precisely because it is physical, this physical object can produce the constant signals stimulating the perceptions. Only physical objects produce perceptions. This is the reason why physical modelling is the next step after visual, acoustic and geometric modelling. This physical model is the supramodal entity that we introduced before.

17.2. Acting with Feeling

The Force Feedback Principle. In the natural perception-action situation, objects are not only perceived by the user by sight and hearing. In the same time that we are acting on an object, we are feeling it by our proprio-tactilo-kinesthetic perception. The specificity of the proprio-tactilo-kinesthetic channel -called in this paper in an abbreviate form "the gestural channel"- is to be a sensori-motor channel. The visual and acoustic sensorial channels convey a specific modality of perception which is the exteroception and they are essentially only perceptive channels. On the contrary, the gestural channel combines actions and proprioceptions. To gesturally perceive objects, you can touch and act on them. One consequence is that the gestural channel is not only a channel which conveys information but it conveys also energy. The user will be informed of the object's behaviour if he displaces or deforms it, in other words, if he spends physical energy.

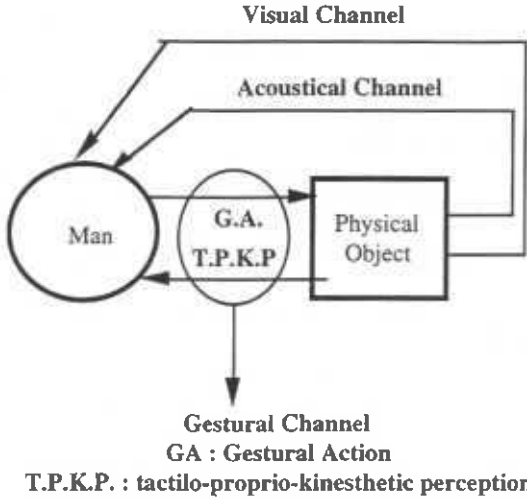


FIGURE 1. The natural instrumental communication. The gestural channel is a sensorimotor communication channel

Let us call “instrumental gestures” the gestures applied on an instrument. These gestures are defined by the physical parameters exchanged between the operator and the objects, such as velocities, displacements and forces.

In a computer context, the device which will convey the instrumental gesture must combine in a specific mechanical structure, sensors and motor organs. Sensors have to capture the physical parameters of the instrumental gestures. Motors have to produce signals conveying the proprio-tactilo-kinesthetic perceptions, enabling the actual fingering of the instrument to be synthesized. According to general considerations on physical systems, there are two dual ways to support gestural computer communication: the sensors can be displacement sensors and then the motors will provide forces, and vice-versa, the sensors can produce forces and then motors will then produce positions. Speeds and accelerations can be calculated from displacements. The first case concerns the force feedback concept and the adequate computer transducers are the force feedback gestural transducers.

To synthesize gestural perceptions, the forces produced from a simulated physical object are sensed by the user through the force feedback gestural transducers. To have a genuine sensation of the physical existence of the object through gestural perception, the input positions representing the actions and the output forces, representing the response behaviour of the object must be correlated in accordance with specific dynamic constraints. One of these major constraints is a temporal constraint: to have the sensation of a hard collision between hand and a rigid object, the bandwidth of the input-output loop must be at least 1 kilohertz and it is also the bandwidth needed to restitute a dry friction between a simulated rough surface and a human finger.

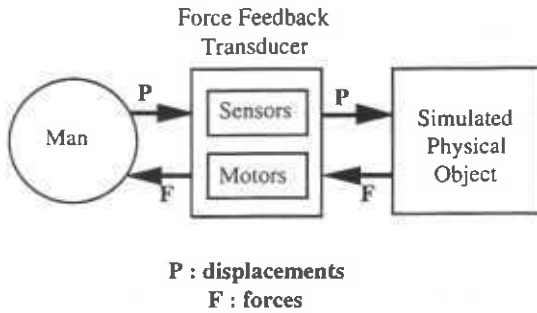


FIGURE 2. The force feedback principle and the force feedback transducer

The ACROE force feedback gestural transducers. ACROE has introduced in 1978 the force feedback principle in a computer sound synthesis context [3]. Its first force feedback prototype was a 1D stick performing large scale displacements (50 cm), large feedback force (60N peak) with high dynamic performance (at least 1kHz). With this device and an analog computer, we realized some experiments, as for instance a highly rigid virtual wall or a highly realistic rack rail with hard notches and holes. The second step of ACROE was in the obtention of compacity [4]. The second prototype had the same dynamic characteristics but in a smaller size, about 15cm*15cm*20cm. Our last prototype [7] -called CRM as Force Feedback Modular Keyboard (“Clavier Rétroactif Modulaire” in french)- has about the same range of dynamic characteristics but in the same range of size, it has sixteen degrees of freedom. The breakthrough is simultaneous in compacity, versatility of the external morphology and in the high number of degrees of freedom. An international licence covers its modularity principles as well as its motor technology, specially developed to achieve the today’s desired performances.

The three contemporary challenges for force feedback gestural transducers are:

- **Compacity:** the size of the device must enable its use in interactive computer workstations and not only in industrial offices. The technological problem is then that, as the intensity of the feedback force is correlated with the size of the eletromechanical components, how can we have a high feedback force in a small bulk?
- **Modularity:** The human physical system -fingers, hands, arms and body- is a deformable system able to present a great number of configurations. In consequence, gestural tasks require various configurations of the instrument, in terms of number of degrees of freedom as well as in terms of their assembly and the geometry of the device. How can we have the most versatile device morphology?
- **Dynamic behaviour:** feeling a rigid object during a hard collision or feeling the gestural texture of a surface when we move on it, requires about 1 kHz

bandwidth for the input-output loop of the gestural signals. How can we obtain this dynamical properties with the force amplitude and the modularity given before?

There are two ways of answering these questions: the first is to design a specific force feedback device for each task, the second is to design elementary electromechanical components able to be assembled. That is the choice made for the CRM device.

The CRM device is built from two basic components: the sliced sensor-motor module and the covering. The sliced sensor-motor module is composed of one displacement sensor, one flat mobile coil and one flat magnet. The slice is sized according to a piano or alphanumeric keyboard key thickness (about 1,5 cm large). All the coils are independent. The internal friction force and the mass of the coil are low, achieving good dynamic performances. A high electromechanical power is obtained thanks to the addition of the magnetic fields of each module. Various mechanical coverings can be mounted on the coil axes providing various external morphologies. We mounted three kinds of coverings: a piano keyboard, a 1D stick, a 2D stick (see photograph 1).

Gestural feeling experiments. An important research field is to try to reconstitute gestural feeling in a computer context [1], [2], [8], [9]. One of the first experiment we carried out was the restitution of feeling between a finger and a rough surface. The rigid surface and the dry friction between the surface and the manipulation point has been physically modelled and implemented in our real time simulator. For this experiment, the CRM has been equipped with a 2D stick covering. In a first step, the user does not touch the surface. He goes towards the surface and feels the hard collisions between his finger and the rigid surface. His finger cannot penetrate into the simulated surface. Afterwards the finger moves on the simulated surface and feels the dry adherence. The greater the pressure is, the more the surface is adherent causing rough sliding.

17.3. Gestures and Sounds

All physical objects are deformable objects, even if the deformations are not perceptible. Some deformations are perceptible by gestural perception, others by sight, others by hearing. Others are perceptible only by their consequences, such as fractures.

By means of physical modelling, all the deformations of objects can be reproduced, whether they are visual gestural or acoustic deformations. Sounds can be considered as the acoustic perceptible effect of a physical deformation of a physical object caused by external forces or displacements. These forces can be either natural forces, or artificial forces produced by manufactured motors, or human forces. The case of human physical intervention is probably

the more subtle type of the instrumental relationship between a man and a physical object. Can we imagine to produce such complex information as a cello timbra variation without such a complex physical phenomenon as a precise dry friction well controlled by a human complete gesture?

With the CRM and physical modelling, we have reproduced the situation of a cello play (gesture and sound) [10]. The string and the dry bowed friction between the gestural transducer and the string is simulated by a physically based model. The user manipulates the force feedback stick, built from the CRM force feedback device. He bows the string and the friction produces acoustical deformations producing the sound of a cello. The player feels the friction and the pressure on the string. The experiment proves that without force feedback, we cannot play cello. Without collision and contact perception, the player presses too hard on the string, such as a bad player causing very hard saturation and deformation. Without the feeling of the friction, the player cannot control the relation between the velocity and the pressure of the bow causing unpleasant creakings.

The technical questions raised by these experiments are:

- (a) To have a sufficient restitution of the gestural perception, the input displacements -Force output loop- must run at 1kHz per degree of freedom. It is very high in comparison with current works in force feedback and it needs specific computers and computer architectures.
- (b) The simulation of the rough surface or the string with dry friction must run at 44,1 kHz to produce sounds, which is the bandwidth of acoustic deformations.
- (c) The real time synchronization process between the gestural loop and the simulated scene is highly dependent on temporal constraints such as the delay between the gestural samples and the related acoustic deformation samples. This delay must not exceed 1 ms.

17.4. Gestures and Images

As said before, movements can be produced by various kinds of forces applied on physical objects. Motions in animated pictures are only the perceptible deformations of physical objects. These external forces can be gravity, wind, turbulences but they can be human gestures as in the marionette paradigm. In the first case, the animator tries to control motions by means of control parameters. In the second case, it is the gestures themselves, in others words, the cause of the motions, which is the way to control the motions. In this way, we can introduce in computer animation, the concept of Instrumental Playing and as in the marionette paradigm or in the musical situation, the concept of performance animation. In this case, the physical object has two roles: firstly, it produces the animated images and secondly, it plays the role of an instrument which transforms the human gestures in images in motion.

Photograph 1 shows a physically based model of a plastic paste [12]. Firstly, this paste has physical properties of plasticity and fractures. Secondly, the animator kneads the paste by means of two force feedback sticks. He can give a shape to the paste. He can break it and stick it back. During the gestural action, he feels the physical resistance of the paste. The gestural input-outputs are sampled at 1 kHz which is also the calculation step of the simulation of the plastic paste.

Having force feedback gestures, having physical modelling for acoustic deformations, having physical visual deformations, with a synchronization process which respects the temporal constraints working on the complete physical object, we modelled multisensorial physically- based objects [?].

17.5. Physically Based Models

As the aim is also to have a large variety of simulated physically-based icons, we have designed since 1984 a computer formalism, called the CORDIS-ANIMA system [4], [5], [14], [11], which combines a physically based modeller and a physically based real time simulator.

The fundamental choices of this modeller-simulator is the particle physics paradigm, based on the physical interactions between punctual masses. In this formalism, a physical object or a set of objects are modelled and simulated in real time as a set of punctual masses linked by centered interaction chains. The most basic ones are linear elasticity and viscosity combined by finite state automata processes, allowing the description of any kind of non-linear interactions. Between masses, interactions can be put in parallel, and the conjunction of these two functionalities allows the creation of very complex interactions. By these means, we can create any kind of deformable materials (rigid, elastic, plastic, friable...), of complex materials (pastes, soils, woods, metals, sand, muds ...) and of complex object assemblies (articulated objects, collisions, dry friction, adherence, sticking...)[12]. With the choice of punctual physics, an object or a scene is calculated as a great number of few simple algorithms able to run in parallel performing real time simulation. Any physical object or set of objects is represented by a network composed of two kinds of components: the mass component and the interaction-without-mass component (Figure 3).

With this modeller-simulator, we have modelled different kinds of physical objects, different kinds of physical interactions between objects, but also physically-based models of non- physical objects -called physically-based metaphores- such as physically based menus and widgets with force feedback pointing, moving and grasping.

Photograph 2a and 2b show a physically based model of a dynamic dune of sand[16]. The simulation restitutes the dynamical behaviour of fine granular material with avalanches and internal collapses. In the same way, photograph 3a and 3b show a physically based model of piles of rocks with structured

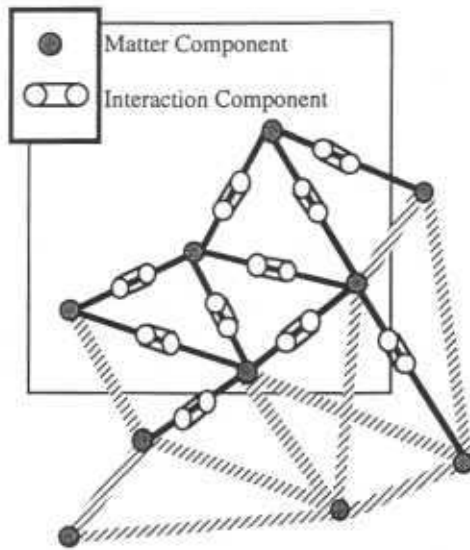


FIGURE 3. A Cordis-Anima network. The grey component is the matter component and the white component is the interaction-without-mass component.

avalanches. Photograph 4a and 4b show the deformations of a physically based model of a surface of water on which pebbles are thrown.

17.6. Physically Based Icons

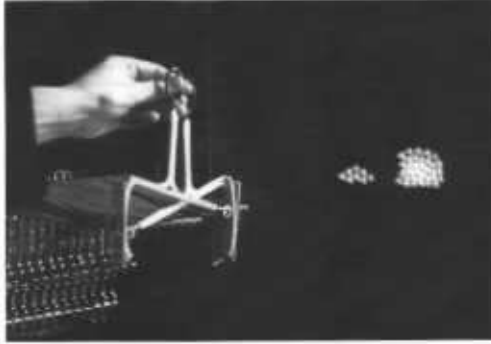
Computer widgets can be represented, not only visually but also physically. This is done by giving them a weight, a resistance to displacements, attractive behaviour... The gestural feeling unloads the visual perception and this permits to have more complex man-computer interfaces. The CRM device has been used in man-machine interface to physically point, pick and grasp physically based widgets. Photograph 6 shows physically-based widgets handled by means of the CRM force feedback gestural device. The operator gesturally feels the limits of the window. He finds the paper basket, located on the lower right corner, without seeing it (the paper basket is not visualized). He feels the frontiers when he changes the menu areas. The use of the physical modelling and the force feedback interaction improves the pointing and the moving and simultaneously relieves the visual activity of the user.

17.7. Conclusions

The I.C.I. has a specific position in the field of Virtual Realities [13]. It represents the vis-à-vis type of interaction with virtual worlds, in which virtuality

is a modality of reality. On the contrary, the immersion paradigm tries to completely replace the real world by a synthetic world, breaking down natural perceptions. But the sense of evidence of a virtual object cannot only be achieved by the realism of the images. The gestural perception is an essential component of world's realism. And if we equip men with gestural force feedback transducers, we alter very much their natural skills. Probably the skill of the "immersed man" will decrease, reducing the interest of the immersive situations. On the contrary, it is a very interesting perspective for us to use all our skills in complex computer aided tasks with all the simulation and representation tools and all the communication media mentioned above. For us the first important acquired fact is the necessity of tools that be more capable of communicating than the previous tools, particularly on the same modalities, that are perceptive modalities. The second important point is the rise of the instrumental communication as a complementary mode of communication next to the symbolic more usual computer communication. All human activities proceed probably from both. For us, artistic creation such as music is the best example.

Note: The works presented here and the patent of the CRM are supported by the french MINISTERE de la CULTURE



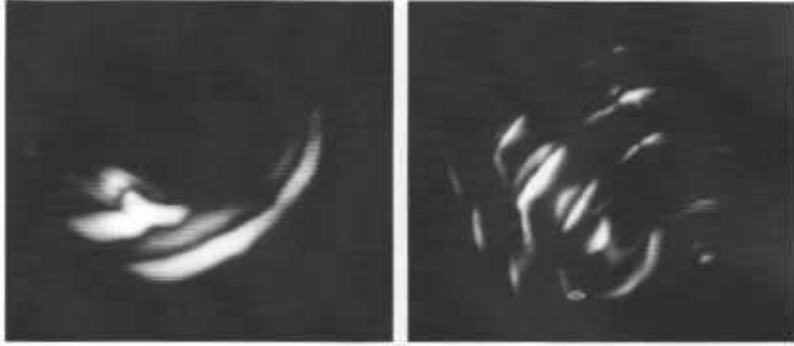
Photograph 1 - Real time kneading a simulated plastic paste with gestural feeling



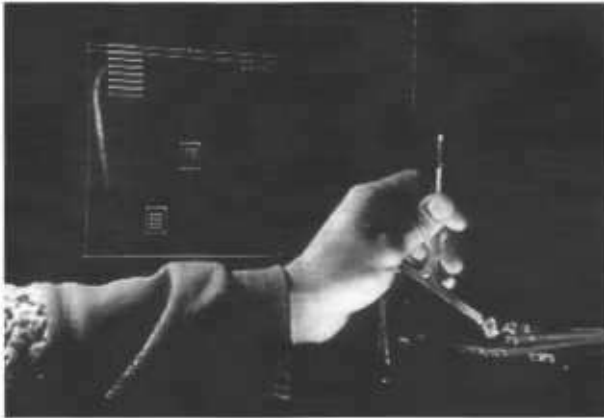
Photograph 2a & 2b - Physically-based animation of fine sand dunes



Photograph 3a & 3b - Physically-based animation of piles of small rocks



Photograph 4a & 4b - Physically-based animation of a surface of water



Photograph 5 - The ICI in man-machine symbolic interaction - The wigdets are physically based models and the user feels them gesturally.

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