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2. State of the Art

2.1. Research on Haptic interfaces:

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(Contribution from ICA-ACROE-UPMF)

As soon as 1978, Jean-Loup Florens presented a new gestural transducer in his PhD thesis [Florens, 1978]. At the opposite of Sutherland [Sutherland, 1965] or Batter and Brooks [Batter and Brooks, 1971] which had more or less the idea to render force feedback to the user, i.e. to provide to the user another sensorial channel to understand the computer (and later to communicate with it), the key idea of Florens was to allow a true interaction between a human and a simulated object, thanks to the design of new gestural transducers. If the modeling of the virtual objects was not yet performed by computer, but rather by the use of finely tuned hardware electronic models, it was possible with only one degree-of-freedom to simulate stiffness, or viscous interaction.

Several retroactive gestural transducers have been further developed at ACROE-ICA, which demonstrate the possibility humans have to interact at deep level with computer- or simulated objects. C. Cadoz later coined this concept as the instrumental relationship.

[Batter and Brooks, 1971] Batter, J. J. and Brooks, F. P. (1971). GROPE-I: A computer display to the sense of feel. In *IFIP congress 71*, pages 188–192 (TA–4), Ljubljana, Slovenia.

[Cadoz, 1988] Cadoz, C. (1988). "Instrumental Gesture and Musical Composition", *International Computer Music Conference* - Cologne 1988.

[Florens, 1978] Florens, J.-L. (1978). *Coupleur Gestuel Retroactif pour la Commande et le controle de Sons Synthetisés en Temps Réel.* Thèse de doctorat, Institut National Polytechnique de Grenoble, Grenoble, France.

[Sutherland, 1965] Sutherland, I. (1965). The ultimate display. In Kalendich, W. A., editor, *Proceedings of IFIP Congress 65*, volume 2, pages 506–508, New York City. Spartan Books, Washington, D.C.

2.1.1. Reactive robots

2.1.2. ...

2.1.3. The ERGOS technology

(Contribution from ICA-ACROE-UPMF)

As early as 1975, ACROE's founders underlined the need to introduce instrumental interactivity with computers for sensitive activities such as music and animation. At the time there were no gestural transducers capable of transmitting gesture data bilaterally between man and machine. Since gesture is both emission (action) and reception (proprioception), gestural transducers must have sensors (for action caption) and motors (for sensitive feedback). These electro-mechanic devices, connected to the computer, allow the user to manipulate virtual objects while at the same time feeling its behavioral properties (weight, rigidity, consistence, etc.)

The first force-feedback gesture transducer (TGR — *Transducteur Gestuel Rétroactif* in french), achieved in 1978, [Florens, 1978] permitted the validation of the force-feedback concept, and the first measures on action-perception gestures.
This device, sensing forces and displacements at its manipulation stick, was able to produce a force-feedback of several tens of N with a time response of about 1ms, and with a displacement range of about 1m. It allowed for the first time to evaluate the importance of the force-feedback in the manipulation of simple virtual objects. It allowed also to highlight, from decisive experiences, the inter-sensory phenomenon and its importance (for example, the influence of the visual perception on a correlated tactile perception, and conversely).

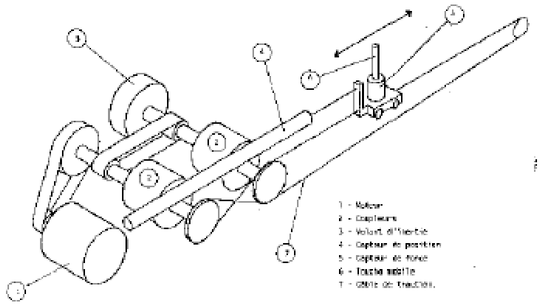

Figure 1 – the first gestural transducer developed by J.L. Florens in 1978

The second TGR, achieved in 1981, named "la Touche" (Figure 2 — left), permitted higher compactness of the mechanism, the first tactile behavior synthesis, and digital physical interaction simulations with sound and animation [Cadoz, Luciani, Florens, 1984, 1989].

The third TGR, named ©*Clavier Rétroactif Modulaire* (Modular Retroactive Keyboard — CRM) presented in 1988 (Figure 2 — right), was designed to improve on compactness and to bring technically “limitless” degrees of freedom. Its associated principle, the *Slice Motor*®, is based on magnetic levitation technology, and allows for the gather of an unrestricted amount of separated 1-dof elements [Cadoz, Lisowski, Florens, 1987, 1989, 1990, Nouiri, 1994, 1995].
This concept solved the two crucial problems within the TGR: modularity in terms of number of degrees of freedom, and modularity in terms of manipulation morphology.

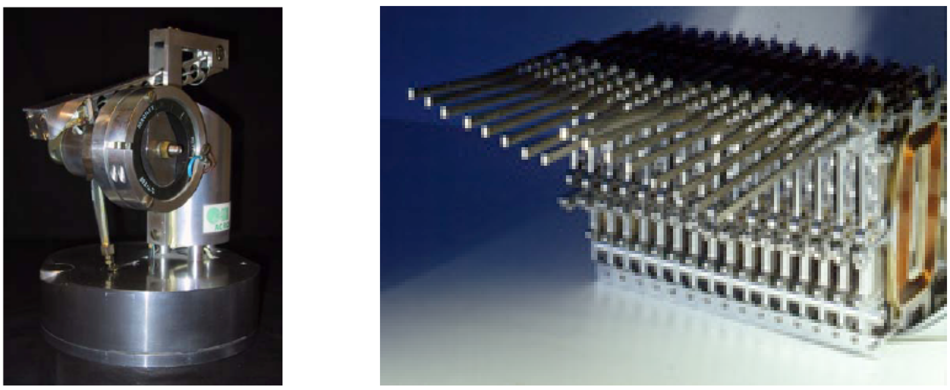

Figure 2 — “la touche”, a one degree-of-freedom device developed at ACROE in 1981 (on the left), and the Clavier Modulaire Rétroactif, presented in 1988 (on the right)

Since the actuation principle is based on a one degree-of-freedom kinematic system, the ACROE developed a set of kinematic adapters (actually, added mechanical components) to truly exploit the human gesture performances (Figure 3).

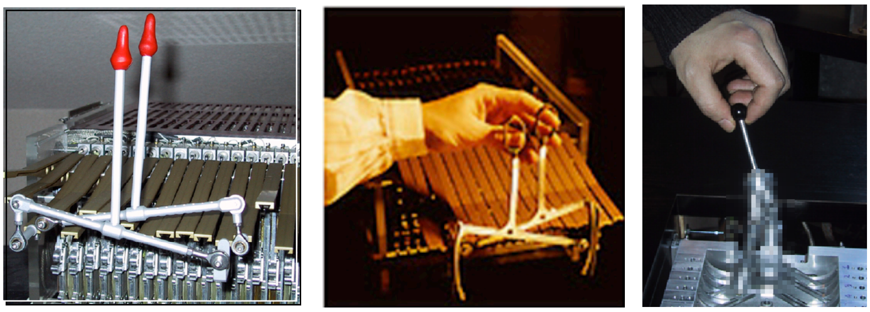

Figure 3 — the ERGOS panoply [Cadoz & al., 2003]

[Cadoz & al., 2003]Cadoz, C., Luciani, A., Florens, J.L., Castagné, N. (2003). Artistic creation and Computer Interactive Multisensory Simulation force Feedback Gesture Transducers, in *Proceedings of the 2003 conference on New Interfaces for Musical Expression (NIME-03), Montreal, Canada.*

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[Florens & al. 1990] FLORENS (JL) & CADOZ (C), "Modular Modelisation and Simulation of the Instrument", International Computer Music Conference - Glasgow 1990.

[Luciani & al., 1994]LUCIANI (A), CADOZ (C), FLORENS (JL), 1994 - "The CRM device: a force feedback gestural transducer to real-time computer animation" - Displays, Vol. 15 Number 3 - 1994 - Butterworth-Heinemann, Oxford OX2 8DP UK, pp. 149-155.

[Nouiri & al. 1994] J. Nouiri, J.L. Florens, C. Cadoz, « Actionneurs modulaires plats à flux reparti », Colloque EPE Chapter Symposium, Lausanne 17-21 Oct. 1994, pp. 331-334

[Nouiri, 1995]NOUIRI (J) "Etude pour la conception de transducteurs gestuels à retour d'effort et de modèles de systèmes mécaniques pour leur contrôle", Thèse de l'INPG, Spécialité Signal-Image-Parole, Grenoble Nov. 1995.

2.2. Research on Audio

2.2.1. .....

2.2.2. Reactive systems in artistic creation

(contribution from ICA-ACROE-UPMF)

The gesture of the musician is often qualified as an "expert gesture", since the ability of the musician to play of its instrument comes from a long process of learning. As the gestures of the musician are demanding for a high-level of dexterity, the ACROE early studied the gestures performed for artistic purpose as exemplary tasks for research in this field [Cadoz & Luciani, 1981]. Thus, the applications involving sound and gesture, and image and gesture, were at the core of the laboratory activities.

Hence, the new paradigm introduced by Cadoz and his colleagues [Cadoz & al., 1981] was based on a deep analysis of the instrumental mechanisms. One side is the development of gestural devices [Cadoz & al. 1990] (see previous part of this document as well), and the other is the design of a suitable paradigm for the implementation of sounding objects into computer [Cadoz, 1979] [Cadoz & al., 1989], [Florens & Cadoz, 1990]. This paradigm (named CORDIS-ANIMA) is a generalized approach to physically based particular formalism. It uses generalized particle physics paradigms based on the physical interaction between punctual masses. These masses are linked to each other and perform linear elastic and viscous interactions combined with finite state automata processes allowing the description of any kind of non-linear interaction. It is a software engine for the simulation of dynamical phenomena. The dynamic behaviors are displacements and mechanical strains one may **hear** with a speaker, **see** on a screen and **touch** and **feel** through a force feedback device. It can be used as well as a plug-in in tools for animated image synthesis, sound synthesis and for real time and interactive simulation of dynamic properties.

The main field of research involved in the manipulation of virtual sounding objects still dealt with the modeling of objects thanks to the CORDIS-ANIMA physically based modular formalism, and their manipulation, taking into account the gesture formalism coined by Cadoz. A few examples of implementation are the following:

[Florens et al., 1986] used this paradigm for the simulation in real-time of sounding objects that could be manipulated: bowed string, plucked string and maracas. If at that time the manipulation could only be performed along one degree-of-freedom, the quality of the gestural device and the 'realism' of the produced sounds, according to the gestures of excitation performed where yet very convincing manipulation.

[Cadoz & al., 1994] presents the techniques that have been used to perform the music film "Esquisses". This film was entirely performed by computer, thanks to the CORDIS-ANIMA system. The physically-based particle modelling technique, yet rather simple for the model designer, permits to construct virtual objects which soundly and visually behave in a 'natural' and realistic manner. Hence, the "Esquisses" artistic piece is composed of scenes representing natural phenomenon such as dunes of sand, winds, rains, and a clock. In this music film, the music part was partially created by human-computer interaction.

Because of the particular difficulties raised in the implementation of a bowed string (stability, sufficient gestural range of dynamics, expressiveness, etc.), the ACROE studied for a long time this particular sound-gesture situation. Beyond the musical interest of these synthesis process, the tuning possibilities of the gesture interface and the general context of the modular simulation system were shown to provide new means for evaluating and understanding some of the complex gesture interaction features that characterize the bowing action [Florens, 1993].

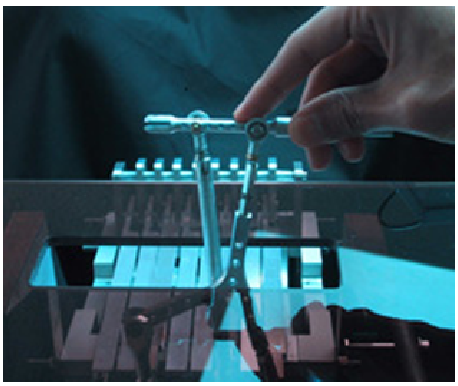

Figure 4 — the bowing gesture using the TGR [Florens, 2003]

[Cadoz, 1979]CADOZ (C), "Synthèse sonore par simulation de mécanismes vibratoires", Thèse de Docteur Ingénieur, Spécialité Electronique - I.N.P.G. - Grenoble 1979.

[Cadoz et al., 1981] CADOZ (C), LUCIANI (A) & FLORENS (JL), "Synthèse musicale par simulation des mécanismes instrumentaux. Transducteurs Gestuels Rétroactifs pour l'étude du jeu instrumental", Revue d'Acoustique N° 59, pp. 279-292. Paris 1981.

[Cadoz &Luciani, 1981] CADOZ (C), LUCIANI (A), "Study of the relation between Instrumentalist and Instrument in Computer Music", Acoustical Society of America 101st meeting, Ottawa 1981

[Cadoz et al. 1990] CADOZ (C), LISOWSKI (L) & FLORENS (JL), "Modular Feedback Keyboard", International Computer Music Conference - Glasgow 1990.

[Cadoz et al., 1989] Cadoz C., Luciani A., Florens JL. (1989). Responsive input devices and sound synthesis by simulation of instrumental mechanisms: the CORDIS system. Computer Music Journal, 8, N°3, pp. 60-73.

[Cadoz & al., 1994] CADOZ (C), LUCIANI (A), FLORENS (JL), "Physical Models for Music and Animated Image. The use of CORDIS-ANIMA in ESQUISSES a Music Film by ACROE" - ICMC 94 12-17 Sept Aarhus, Denmark. ICMC 94 Proceedings - 1994 pp. 11-18

[Florens et al., 1986] Florens, J.-L., Razafindrakoto, A., Luciani, A., and Cadoz, C. (1986). "optimized real-time simulation of objects for musical synthesis and animated images synthesis". In Proceedings of the 1986 International Computer Music Conference, pages 65–70, San Francisco. International Computer Music Association, International Computer Music Association.

[Florens &Cadoz, 1990] FLORENS (JL) & CADOZ (C), "Modular Modelisation and Simulation of the Instrument", International Computer Music Conference - Glasgow 1990.

[Florens, 1993] FLORENS (JL), Expressive Bowing on a Virtual String Instrument, A. Camurri and G. Volpe (Eds.): Gesture Workshop 2003, LNAI 2915, pp. 487–496, 2004.

[Florens, 2003] Florens, J.L. (2003). Expressive Bowing on a Virtual String Instrument, A. Camurri and G. Volpe (Eds.): Gesture Workshop 2003, LNAI 2915, pp. 487–496, 2004.

2.3. Research on Vision

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2.3.5. Real Time Animation

(contribution from ICA-ACROE-UPMF)

As soon as 1984, the implementation of animated objects in computer and their manipulation, thanks to the first gestural transducers with force feedback, was possible. [Luciani and Cadoz, 1984] presents the ANIMA system, an environment for the creation of animated objects. The Figure 5 shows the manipulation of a plucked string along one degree-of-freedom. Thanks to the force-feedback gestural transducer and the use of a simple model of string using the modular physically based modeling technique, it is possible to obtain a very convincing representation of the simulated object. Furthermore, there is in this system design a real interaction between the user and the computer: the vibration behavior and the sound of the string depend on the plucking movement performed by the user, and the stiffness and the modal properties felt by the user depend on the physical properties of the implemented model, and of the reactiveness of the system.

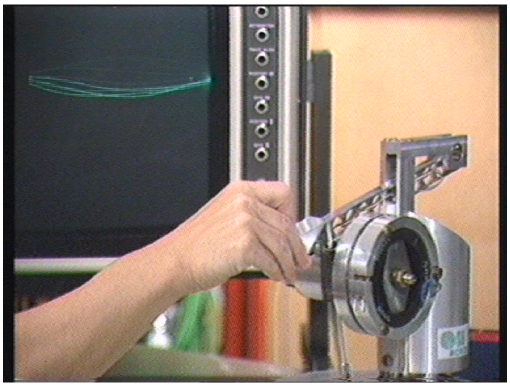

Figure 5 — the ANIMA and the second version of the 1-dof gestural transducer: manipulation of a plucked string with audio and visual feedback [Luciani and Cadoz, 1984]

The CORDIS-ANIMA system was later introduced for the creation and the simulation of objects capable of producing sound and movement (that is, animated images), as an extending of the ANIMA system [Luciani & al., 1991]. In 1995, Uhl & al [Uhl & al., 1995] dealt with the issues raised by the introduction of computer as an element of the Instrumental Communication Interface, particularly in the real-time constraints and simulator hardware architecture requirements. Three bottlenecks were described then analyzed: time constraints in the gestural transducer (TGR), in the simulation representation and its software computation, and in the input/output capabilities and its hardware computation.

Another example of manual interaction with reactive systems is Figure 6, which shows a physically based model of a plastic paste [Luciani & al., 1991]. 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 1kHz, which is also the calculation step of the simulation of the plastic paste.

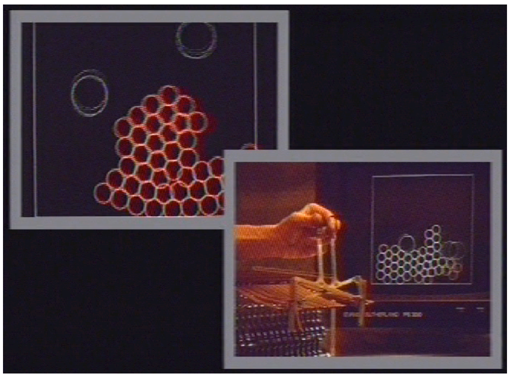

Figure 6 —Real time kneading a simulated plastic paste with gestural feeling [Luciani & al., 1991]

With the help of a very simple "tadpole" model, it was possible to obtain a very simple model of a frog [Delnondedieu & al., 1993]; the non-linear viscosity environment allows for rapid movements of extension bring more energy than the slow movements of contraction do. This model represents in a simplistic manner the movements performed by a frog to move in the water. Linked to a gestural transducer with force feedback, it allows quickly for the user to intuitively understand how propulsion and orientation of the frog's body are possible that way (Figure 7).

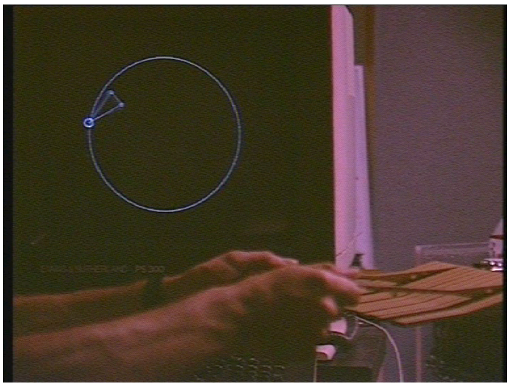

Figure 7 — two-hand manipulation of an elementary frog model [Delnondedieu & al., 1993]

In the simulation field, [Chanclou and Luciani, 1996] showed that physical models, coupled with gestural transducers could be of good help. In vehicle design for use in natural environments where the soil is loose and the rocks can move, they showed that once the model of the vehicle and its environment is achieved, the simulation process revealed realistic phenomena: wheels track on the soil, packing of the soil under a spinning wheel, wheels are getting locked or are sliding on slopes. The manipulation of the simulated vehicle in a 2-D real time simulation process enabled to study the obstacle clearing capacities of many rovers and their dynamic behaviors according to a specific terrain. If the realism of the simulation suffered from the lack of a 3D simulation in real time, the 2D simulation in real time, coupled with the gesture interaction, helped the user to deeply understand the processes involved in the tuning of a suitable vehicle for off-road, and was considered in a first step as sufficient for that goal.

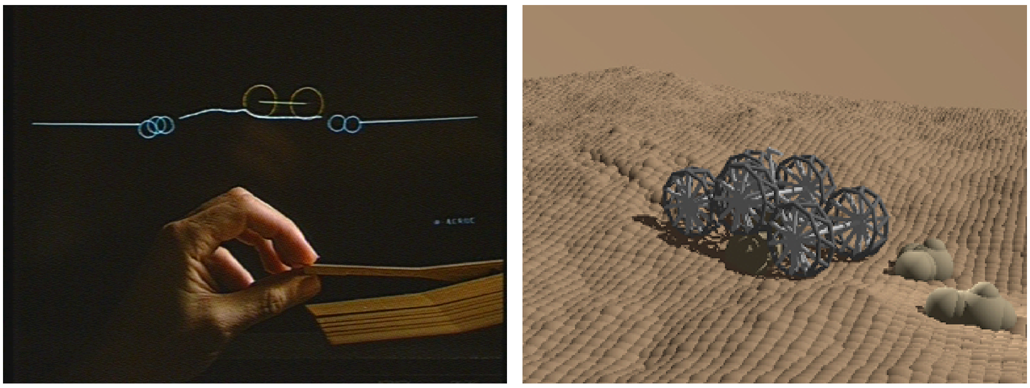

Figure 8 — manipulation of a vehicle on a loose soil in real time and in 2D (left) — simulation in differed time of the same vehicle in 3D (right) [Chanclou and Luciani, 1996]

[Chanclou and Luciani, 1996] Chanclou, B., Luciani, A. (1996) "Physical modeling and Dynamic Simulation of Off-Road Vehicles and Natural Environments" - Proc. of the 1996 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS'96, IEEE ed, 1996, pp 505-512

[Luciani and Cadoz, 1984] Luciani, A. and Cadoz, C. (1984). Animation by means of

objects modeling and gestural control — the ANIMA system. In *First Image Symposium*, pages 183–189, Biarritz, France.
[Delnondedieu & al., 1993] Delnondedieu, Y., Luciani, A., Cadoz, C. "Physical elementary component for modelling the sensory-motricity. The primary muscle", 4th Eurographics Workshop on Animation and Simulation, Ed. A. Luciani & D. Thalmann - Barcelone - Espagna - September 1993.
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[Luciani et al., 1994] Luciani, A., Cadoz, C., and Florens, J.-L. (1994). *Cyberworlds*, chapter 17. Towards a complete Representation by Means of Computer — the Instrumental Communication Interface Concept —, pages 269–271. Springer-Verlag, Tokyo.
[Uhl & al., 1995] UHL(C), FLORENS JL, LUCIANI (A), CADOZ (C) - «Hardware Architecture of a Real Time Simulator for he Cordis-Anima System: Physical Models, Images, Gestures and Sounds» - Proc. of Computer Graphics International '95 - Leeds (UK), 25-30 June 1995 -, Academic Press. - RA Ernshaw & JA Vince Ed. - pp 421-436

2.4. Cognition for Reactive Interfaces and flexible HCI

(contribution from ICA-ACROE-UPMF)

2.4.1. Multisensoriality in Reactive Interfaces (INPG)

Multisensory differs from multimedia and multimodal in the sense that it addresses a genuine correlation between senses and between actions and resulting sensory events. Some specific questions can advene in such multisensory-motor interactions. An exemplary case is the pseudo haptic *pseudo-haptic* phenomenon in visuo-haptic integration [LÉCUYER, 2000, 2003, 2004, CRISON, 2004]. The canonical experiment about pseudo-haptic feedback is the following one: A *Spaceball* is used to measure the pressure that the user applies with a spring embedded in a piston (*real spring*). The spring displacement is visually displayed on a computer screen (*virtual spring*). The displacement of the virtual spring is a function of the pressure applied on the *Spaceball* with the real spring. For a same pressure applied on the *Spaceball*, the authors have then displaced more or less strongly the virtual spring on the screen. They observed that the more the visual displacement of the virtual spring is important, the more the real spring is perceived as soft – although the stiffness of the *Spaceball* is constant. Conversely, if the visual displacement is less important, the spring is perceived as stiffer. Lécuyer et al. conclude from this effect that « the visual deformation is so much misleading the user that the visual displacement on the screen partly acts as a substitute for the perception of the displacement of the finger pressing on the interface. This phenomenon appears to be an illusion of the proprioceptive sense, which is blurred by the visual feedback. » [LECUYER, 2003].

In a similar way, Cadoz, Luciani, Florens and al. [LUCIANI, 2004] [CADOZ, 1984] [FLORENS, 2004] [CADOZ, 1993] shows some phenomena convergence or divergence in multisensory manipulation of virtual objects. Multisensory events cooperate to allow the perception of a single non-contradictory object (or phenomenon). They can diverge producing contradiction in the cognitive interpretation. They can work complementarily.

2.4.1.1. Divergence between the forces and the visual deformations: the "paradoxical matter" experiment

The following simulations (Figure 9) illustrate that "an impossible matter" (i.e. a matter having rheological parameters not possible to implement in the real work), is considered as a true matter, when the physico-visual experiences exhibit consistent physical behaviors in time.

On the upper row, simulations are of a matter that is too hard to really goes through the bottleneck (the forces felt by hands are very high) although the deformations can be very large. On the lower row, simulations are of matter that is too soft, too much fluid to be felt by fingers. The feeling is very delicate. According to the energetic consistency that is clearly revealed by the visualization as well as by the feeling of the force, this non-realistic object seems unanimously possible and "real".

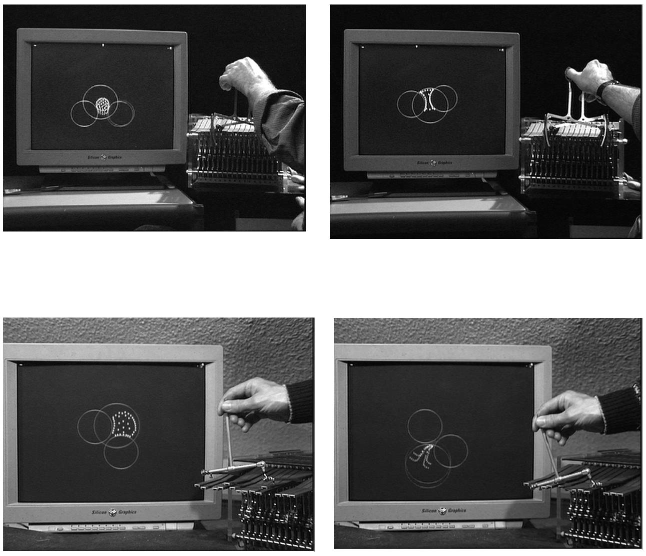

Figure 9 —« Paradoxical matter » experiment

2.4.1.2. Complementarity between vision and the perception of force: the "little train experiment"

In this experiment (Figure 10), a user is guiding a small physical simulated train, with a lot of DOF, by pulling it from its "nose", in a labyrinth composed of rigid obstacles and a straight free way.

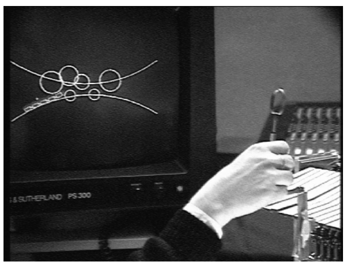

Figure 10 — Vision as a sense of topology and force as a sense of physical global state: the "little train" experiment

The complementary of the vision and the force is emphasized. When the little train is blocked in the labyrinth, the force, which integrates all the behavior of the train on the manipulated point, indicates how much the little is blocked. The experimenter knows immediately if he can push (or pull) or if it is worth trying. But it is unable to indicate where are the blocking points and to find strategies to get out. Conversely, the vision shows on what segments of the train this blocking occurs, allowing him to define strategies of driving. It allows identifying the topological features of scene, which are features more abstract than geometrical ones.

2.4.1.3. Masking effect of the visual geometry by the haptic geometry: the "Child's Rattle" experiment

The following experiments show that the morphology of the manipulation and of the visual space can be different according to the presence (or not) of a force feedback. The two simulations represented on the left and on the right of the Figure 11 are the same. They are composed of small sharp pyramids moving in a ball manipulated by hand with force feedback. Only the morphology of the manipulation differs.

On the left, the co-ordinates (x, y) of the sphere are manipulated by two independent keys displaced vertically. The motion of manipulation is non-usual and it is very different of the visual motion of the sphere. On the right, the manipulation is by means of a 2D stick and the motion of manipulation is similar to the visual motion of the sphere. Without force feedback, the first manipulation (left) is impossible, as in the game in which we try to draw by manipulating two independent knobs. But, when we added a little drop of consistent force feedback, all the experimenters perform accurate manipulation of the ball and of the pyramids.

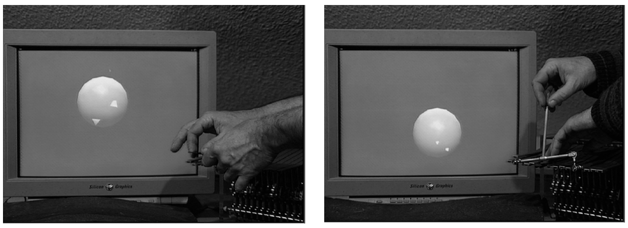

Figure 11 — The "child's rattle" experiment: Two morphologies of manipulation: different (left) ant homothetic (right) to the visual motion

More surprisingly, in such situation, the manipulation is more accurate than with the second (right) with an usual morphology: in the first case, persons are able to control the shocks of the pyramids on the ball producing expected auditory rhythmic sequences.

This means that in the presence of a sufficient energetic consistency between all the multisensori-motor events, the manipulation that allows feeling it more precisely, leads to more accurate manipulation. That is the case when the two coordinates are manipulated separately, the two components Fx and Fy of the force being also felt separately.

2.4.1.4. Multisensory convergence for believable object beyond the non-realism of the visual and auditory rendering: The "little bouncing grains" experiment

The following pictures (Figure 12) show two similar experiments in which little objects are moving inside a ball manipulated by hands with force feedback. The shocks of the grains on the ball produce sounds. On the left, the simulation was made in 1989. The visual quality of the image and the acoustical quality of the sound are low. On the right, the simulation was made ten years after in 1999 with a better rendering of image and sound. These experiments show that the quality of the sound and of the image does not increase the believability of the represented scene. More, the new visual rendering (on the right) underlines the synthetic images, revealing the artificial process and thus, the scene is said technically speaking better than the first but not more believable.

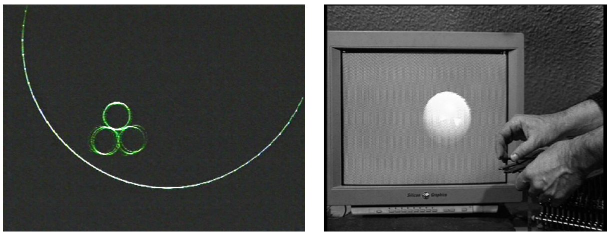

Figure 12 — Believable dynamics vs. realistic rendering

2.4.1.5. Conclusions

All these experiments are based on physically based modeling and a high fidelity rendering of dynamics. They lead to assume that the dynamics, as the representation of the matter effects, are predominant in such manipulatoris multisensory simulations on geometrical features. More generally, in addressing most cases of the daily life, emphasizing mainly the dynamical properties may lead to reduce in a relevant manner the geometric and spatial complexity of the scene (virtual objects and haptic devices). New prospects are opened in better-balanced specification of the tasks, from spatially oriented tasks to dynamically oriented tasks. This may enlarge the field of haptics.

[CRISON, 2004] F. Crison, A. Lécuyer, A. Savary, D. Mellet-d'Huart, J.M. Burkhardt, and J.L. Dautin (2004). The Use of Haptic and Pseudo-Haptic Feedback for the Technical Training of Milling. Poster in EuroHaptics Conference (Eurohaptics), June 5-7, Munich, Germany.

[LÉCUYER, 2000] A. Lécuyer, S. Coquillart, A. Kheddar, P. Richard and P. Coiffet (2000). Pseudo-Haptic Feedback : Can Isometric Input Devices Simulate Force Feedback ? IEEE Int. Conf. on Virtual Reality, pages 83-90, New Brunswick, US.

[LÉCUYER, 2003] A. Lécuyer, C. Andriot, A. Crosnier (2003). Interfaces Haptiques et Pseudo-Haptiques. Proceedings of JNRR'03 (4ème Journées Nationales de la Recherche en Robotique) (*in french*)

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[LUCIANI, 2004] Luciani A. "Dynamics as a common criterion to enhance the sense of Presence in Virtual environments". Conference "Presence 2004". Valencia. Spain, oct 2004

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