Habilitation à diriger des recherches

“Using eyes, hands and brain for 3D interaction with virtual environments: a perception-based approach”

Anatole Lécuyer

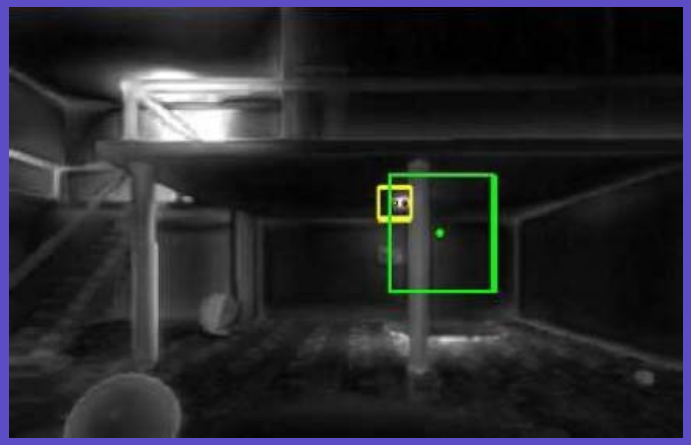
INRIA RENNES

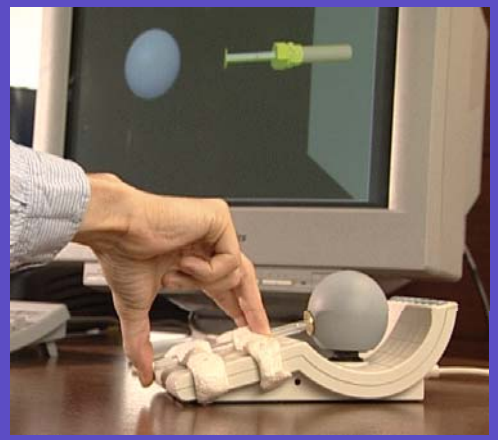
BUNRAKU

UMR IRISA

cnrs Université de Rennes 1 INSA Rennes ENS Cachan Bretagne

Habilitation defense, June 18th 2010, INRIA/IRISA Rennes





Virtual reality?

Strange and controversial terminology, numerous definitions

Source of fascination, phantasm and fear

Strong and well defined scientific field

Numerous and real applications

« Virtual reality is dreams. »
Morton Heilig


NASA


I-O Display Systems

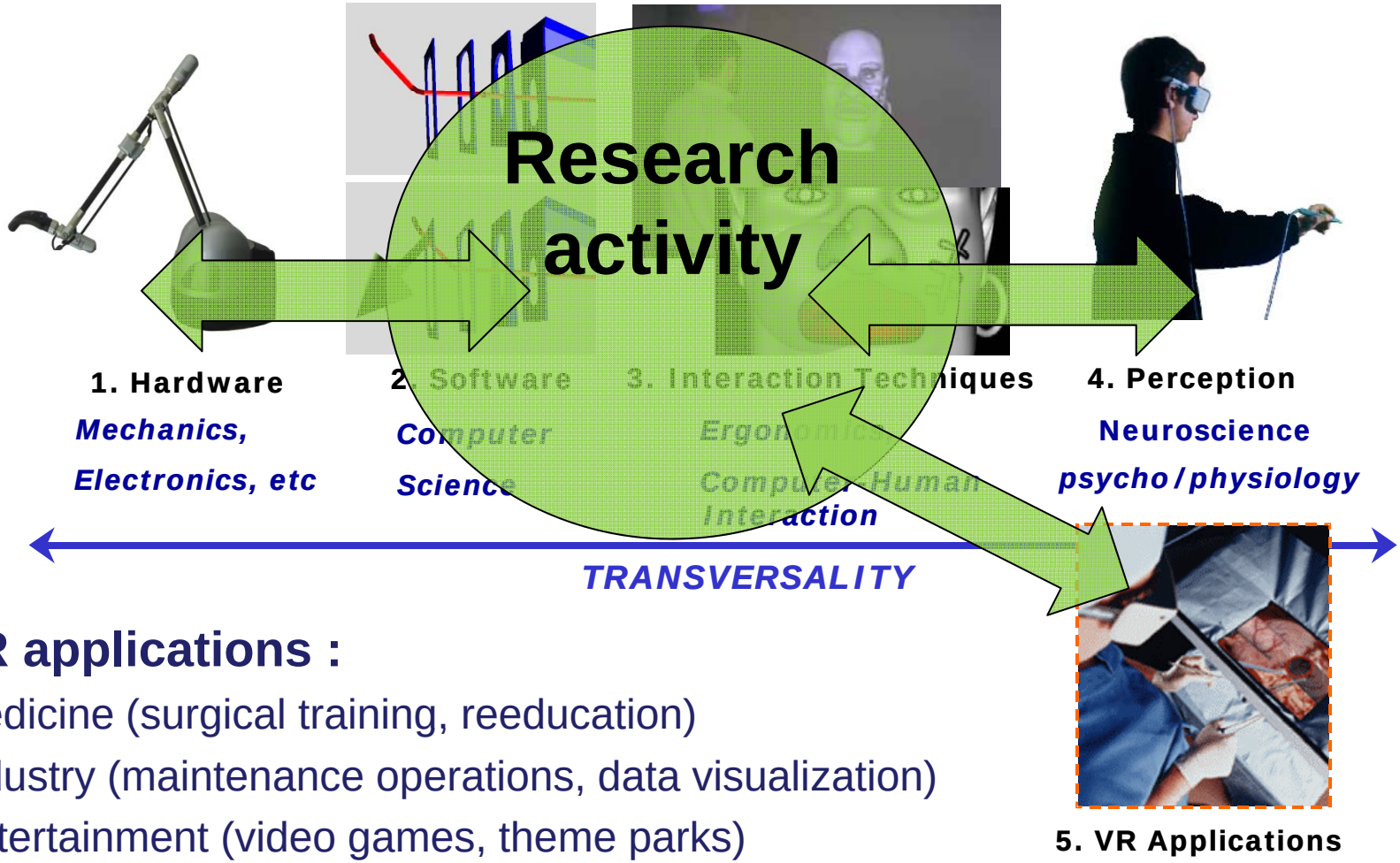
Virtual Reality (VR)

Definition : “a virtual reality system is an *immersive* system that provides the user with a feeling of *presence (the feeling of "being there" in the* virtual world) by means of plausible *interactions with a synthetic 3D environment simulated* in real-time”.

Virtual reality interfaces

- Visual displays : stereoscopic 3D display
- Haptic interfaces : force and tactile feedback
- Brain-Computer Interfaces : control with brain activity

VR challenges



VR applications :

- Medicine (surgical training, reeducation)
- Industry (maintenance operations, data visualization)
- Entertainment (video games, theme parks)
- Arts and design (interactive sketching, CAD, architecture reviews)

Research objective

Improve 3D interaction with virtual environments

Making full use of available interfaces and sensory modalities:

Visual, haptic and brain-computer interfaces

>> “using eyes, hands and brain”

Open questions

1. Sensory feedback : more immersive
2. Interaction technique : more efficient

Perception-based approach

- Use knowledge in human perception
- For design and evaluation
- Collaborations : Univ. Paris 5 (J.M. Burkhardt), Collège de France (A. Berthoz), Univ. Pierre Mendès-France (E. Gentaz), Freiburg Univ. (J. Wiener), INSERM (O. Bertrand, J.P. Lachaux), etc

Overview of research activity

1. Novel approaches for visual and haptic feedback of VE
   - Visual feedback : based on user's gaze
   - Haptic feedback : Spatialized Haptic Rendering
   - Combination of visual and haptic feedback : Pseudo-Haptic Feedback
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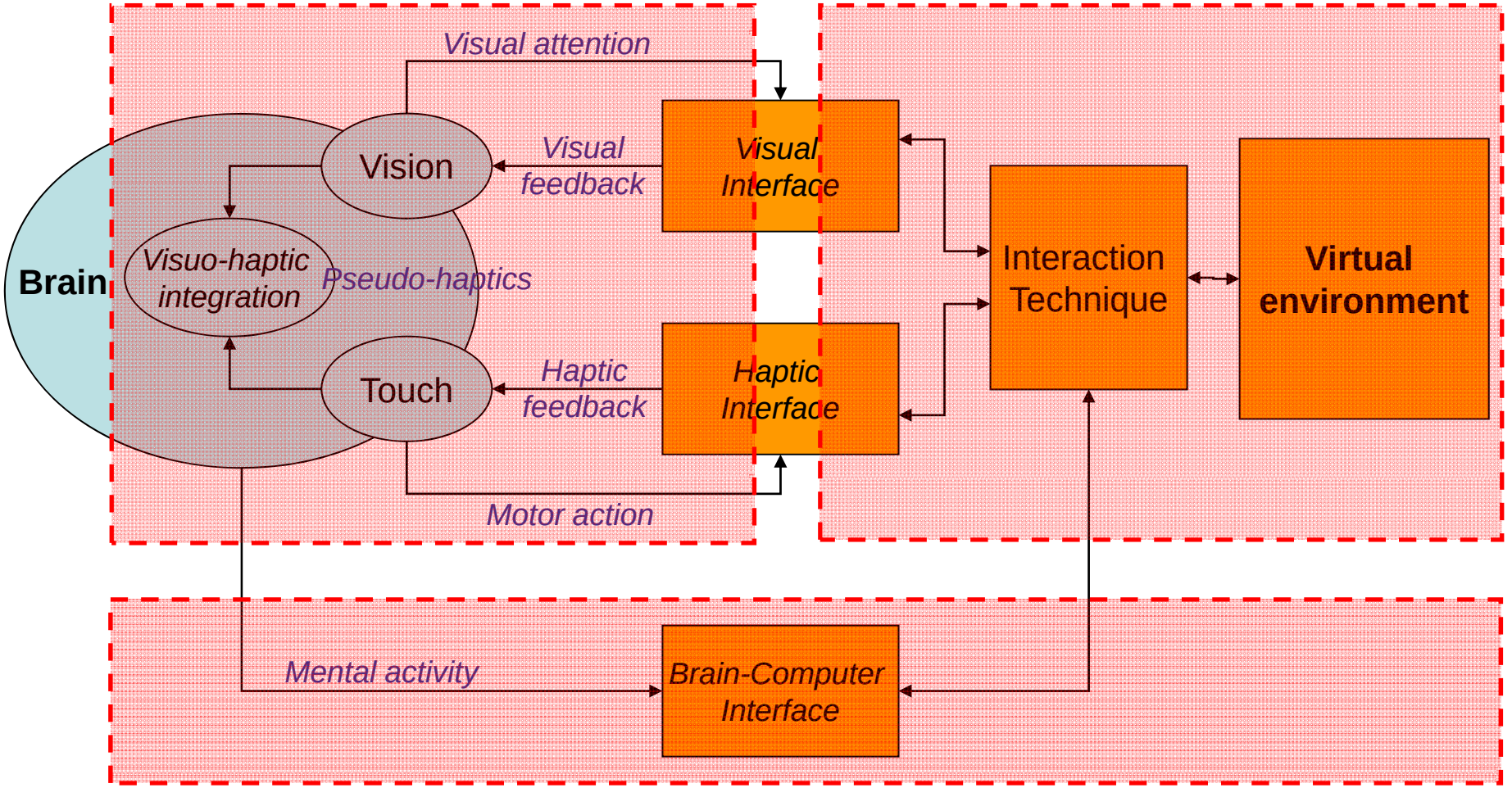
   - Software architecture : multimodal rendering of contacts
   - Hardware configuration : influence of spatial delocation
   - Visuo-haptic interaction techniques : Haptic Hybrid Control
3. Toward brain-based interaction with VE
   - Signal-processing techniques for BCI
   - Interaction techniques based on BCI
   - Evaluations of BCI use
   - Performance models for BCI

Research framework

(1) Sensory feedback

(2) Integration of visual and haptic interfaces



(3) Brain-based interaction

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>> papers, manuscript

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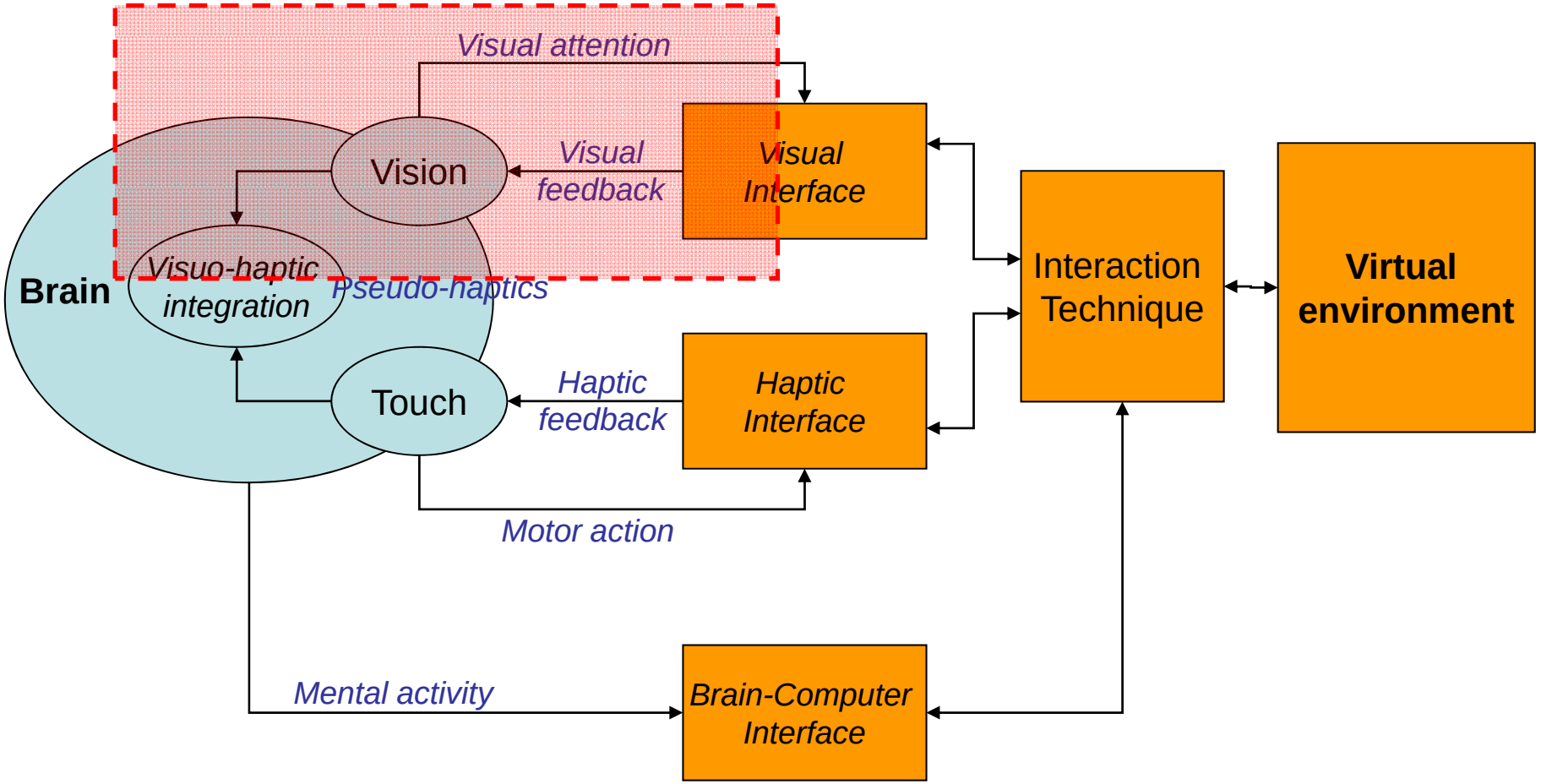
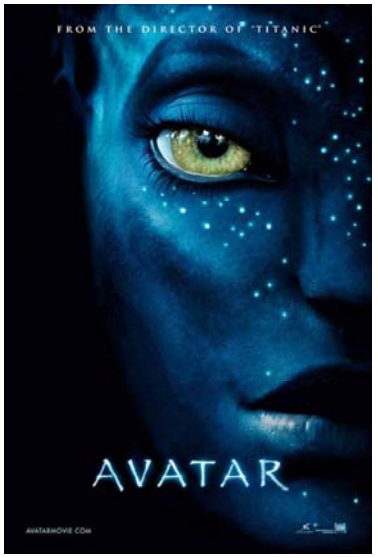
Visual feedback



Visual feedback of virtual environments

Computer Graphics

- Long history of research [Foley95] [Watt99] [Shirley05]
- Impressive results :
  synthetic images ~ real images



Interactive 3D graphics and VE

>> Real-time, interactivity constraints

- Augmented computation capacities [Pharr05]
- Interactive visual effects [Guitton95] [Drettakis97]
- Perception-based rendering [Mulder00] [Devlin05]

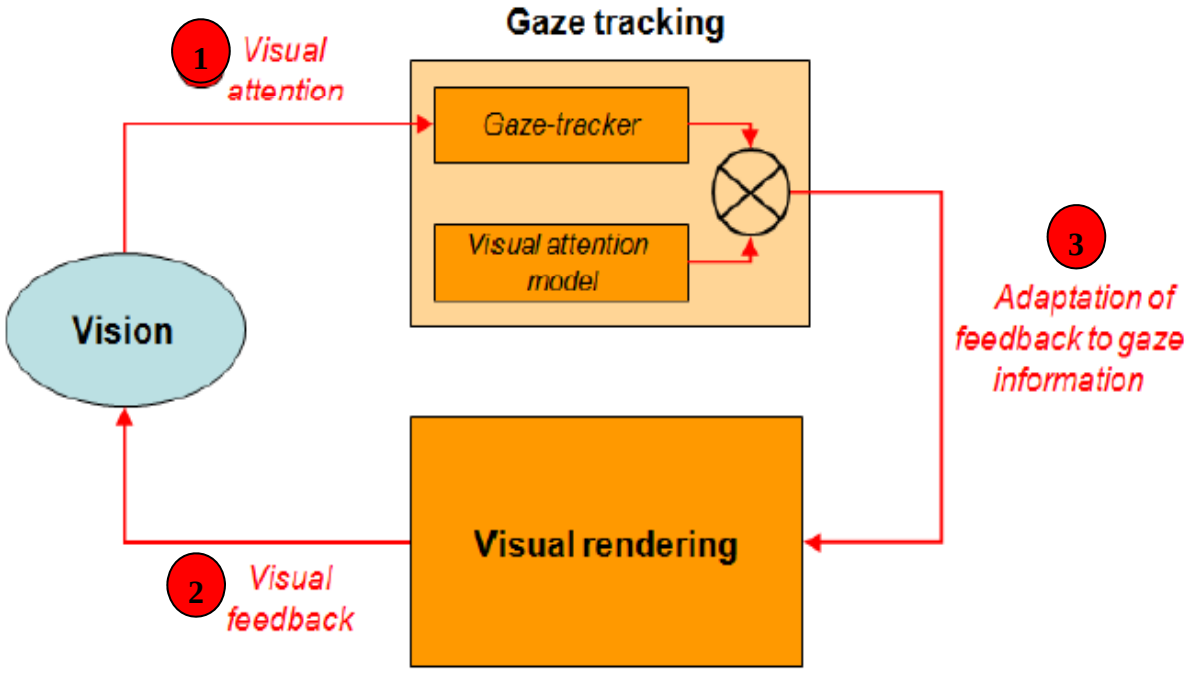
Classical loop

- Visual feedback based on user's actions
- >> Head motions, hands actions

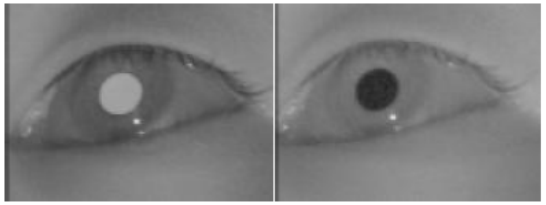
Visual feedback based on user's gaze

Novel visual feedback loop

1. Gaze tracking
2. Visual feedback based on perception
3. Automatic adaptation of visual feedback to user's gaze



Step 1: Gaze-tracking in VE



Existing methods :

Hardware = gaze-trackers

>> Numerous systems [Glenstrup95] [Bohme06]

- Intrusive vs remote technology
- (+) efficient,
- (-) expensive, cumbersome

Software = visual attention models

>> Numerous models [Lee09] [Itti98] [Longhurst06]

- Bottom-up component (color, depth, motion, etc)
- Top-down component (memory, habituation, spatial context, etc)
- (+) no hardware,
- (-) not real-time, not designed for 3D VE

Step 1: Combination of gaze-tracking and visual attention models

Objective : improve gaze-tracking

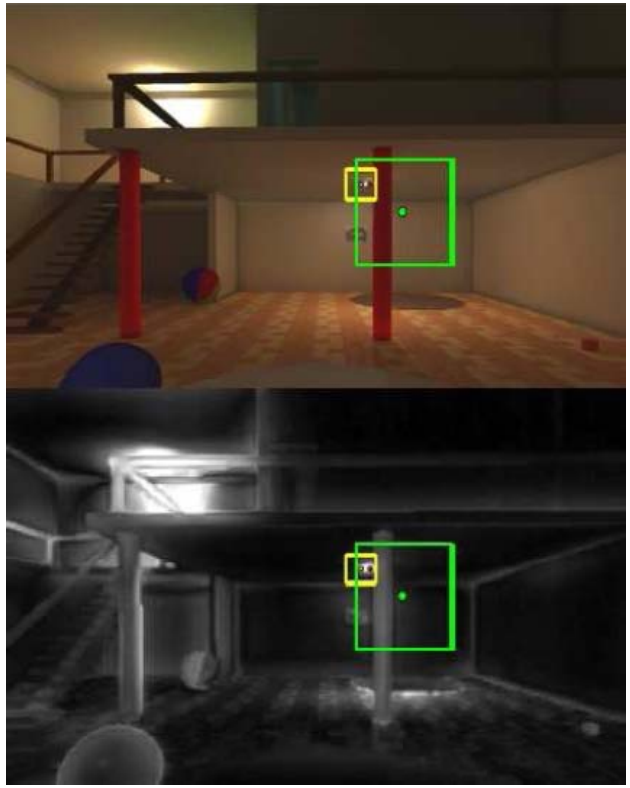
- Combine and associate both technique
- Improve overall performance

Method

- **Read gaze tracking output (pixel P)**
- **Compute uncertainty window (Wu)**
- **Use visual attention model inside Wu**
- **Select the most salient pixel (new P)**

Evaluation

- Comparison with gaze tracker alone
- Improve performance of low-cost tracker



(Hillaire et al., *Computer Graphics Forum*, 2010)

Step 2: Perception-based visual feedback

Objective : simulation of visual perception properties

Effect : Depth-of-Field visual blur

Implementation :

- Lens model [Potmesil81]
- Auto-focus zone
- GGPU technique

Evaluation :

- Interactive, real-time effect
- Well appreciated

(Hillaire et al., *ACM VRST*, 2007)

(Hillaire et al., *IEEE CG&A*, 2008)

Step 3: Automatic adaptation of visual effects to user's gaze

>> Results: strong subjective preference **(Hillaire et al., *IEEE VR, 2008*)**

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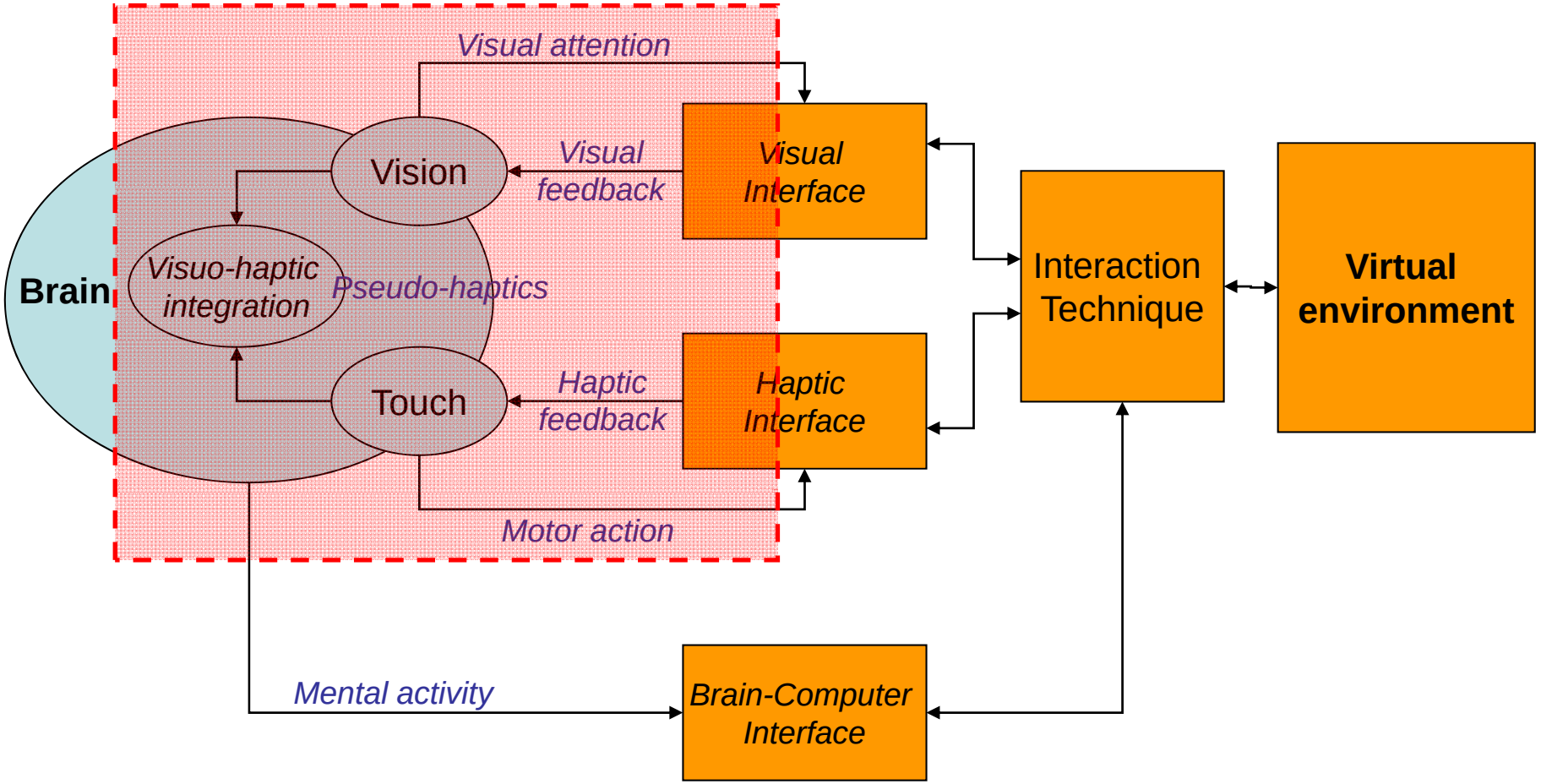
Combination of visual and haptic feedback



Pseudo-haptic feedback

Novel approach for haptic (visuo-haptic) feedback

Initial idea **(Lécuyer et al., *IEEE VR*, 2000)**

- Simulate haptic feedback without a haptic interface
- Compatible with passive input devices (mouse)
- Use visual feedback to generate haptic illusions


Logitech

Concept refinement **(Lécuyer, *Presence*, 2009)**

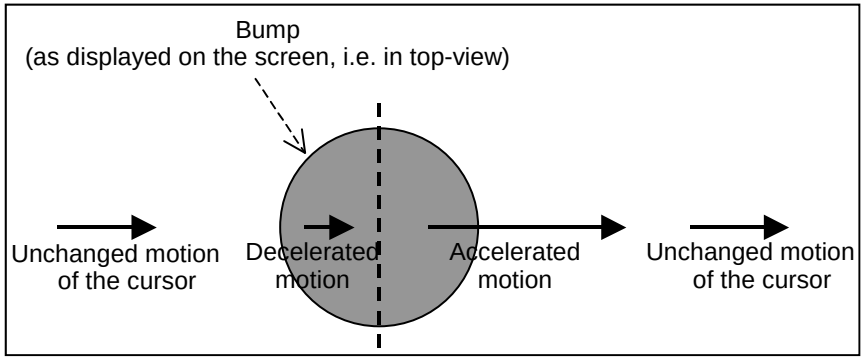
- *”Pseudo-haptic feedback corresponds to the perception of a haptic property that differs from the physical environment, by combining visual and haptic information and proposing a new coherent representation of the environment.“*

Example: pseudo-haptic textures

Objective: Feel the texture of an image with a mouse

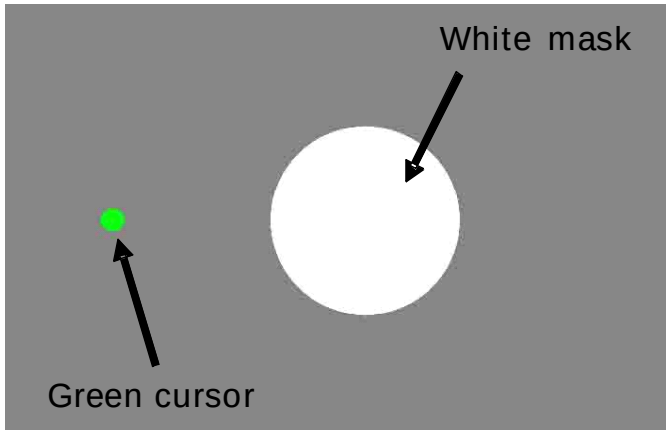
Method **(Lécuyer et al., *ACM SIGCHI*, 2004)**

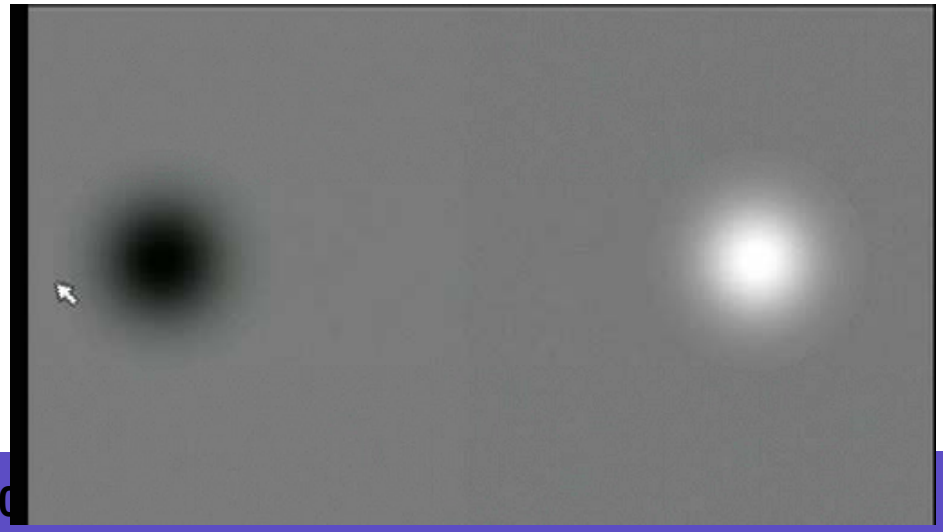
- Change cursor's motion (speed)
- C/D gain function of height/depth



Experimental evaluation

- Ability to perceive bumps/holes
- Fine perception





History

Foundation = my PhD Thesis (1998-2001)

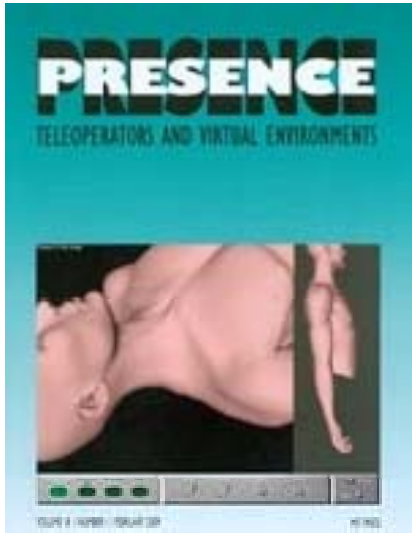
Students = PhD (Dominjon, Bibin) and Master (Tan)

Collaborations = Univ. Paris 5, UPMF, CLARTE, AFPA, etc

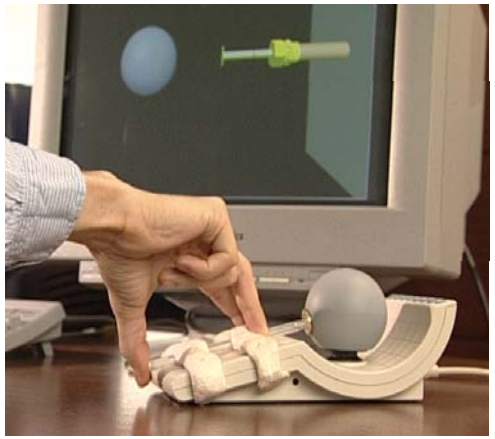
Dissemination = tutorials on « Perception-based haptic rendering »
(EUROHAPTICS 2006, IEEE VR 2007, IEEE VR 2008)

Active field = University of British Columbia,
Lund University, Fraunhofer, etc

30+ papers, recent survey
(Lécuyer, *Presence*, 2009)



Overview of research and applications

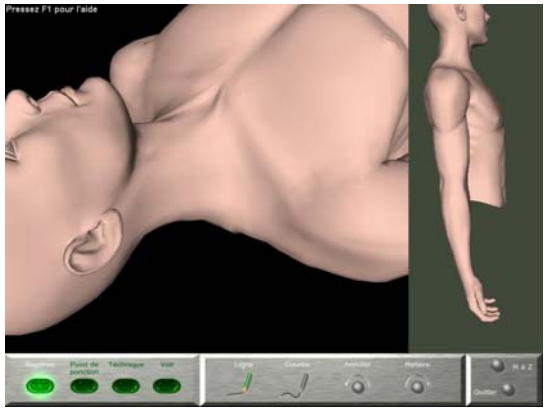


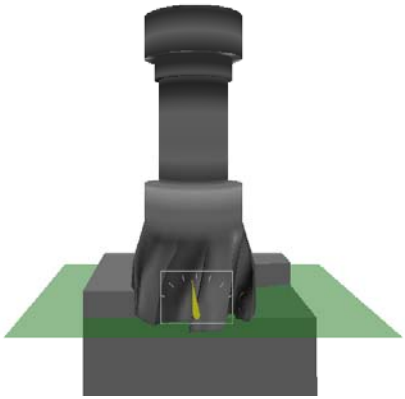
Studies on haptic properties

- Friction **(IEEE VR 2000)**
- Stiffness **(IEEE VR 2001)**
- Mass **(IEEE VR 2005)**
- Textures **(ACM CHI 2004) (Eurohaptics 2010)**

Studies on applications

- SAILOR medical simulator **(ACM VRST 2008)**
- Virtual Technical Trainer « VTT » **(IEEE VR 2005) (Eurohaptics 2004)**





Lessons learned

A novel approach for visuo-haptic feedback in VE

- Specificity of pseudo-haptic feedback
  - Different from : « real » haptics, sensory substitution, tangible interfaces
- Perceptual phenomenon
  - Illusion or not?
  - Inter-individual variability
  - Necessary tuning and calibration

Numerous applications

- Pseudo-haptic method?
  - Use of input devices (preference for elastic devices)
  - Use of Control/Display gain

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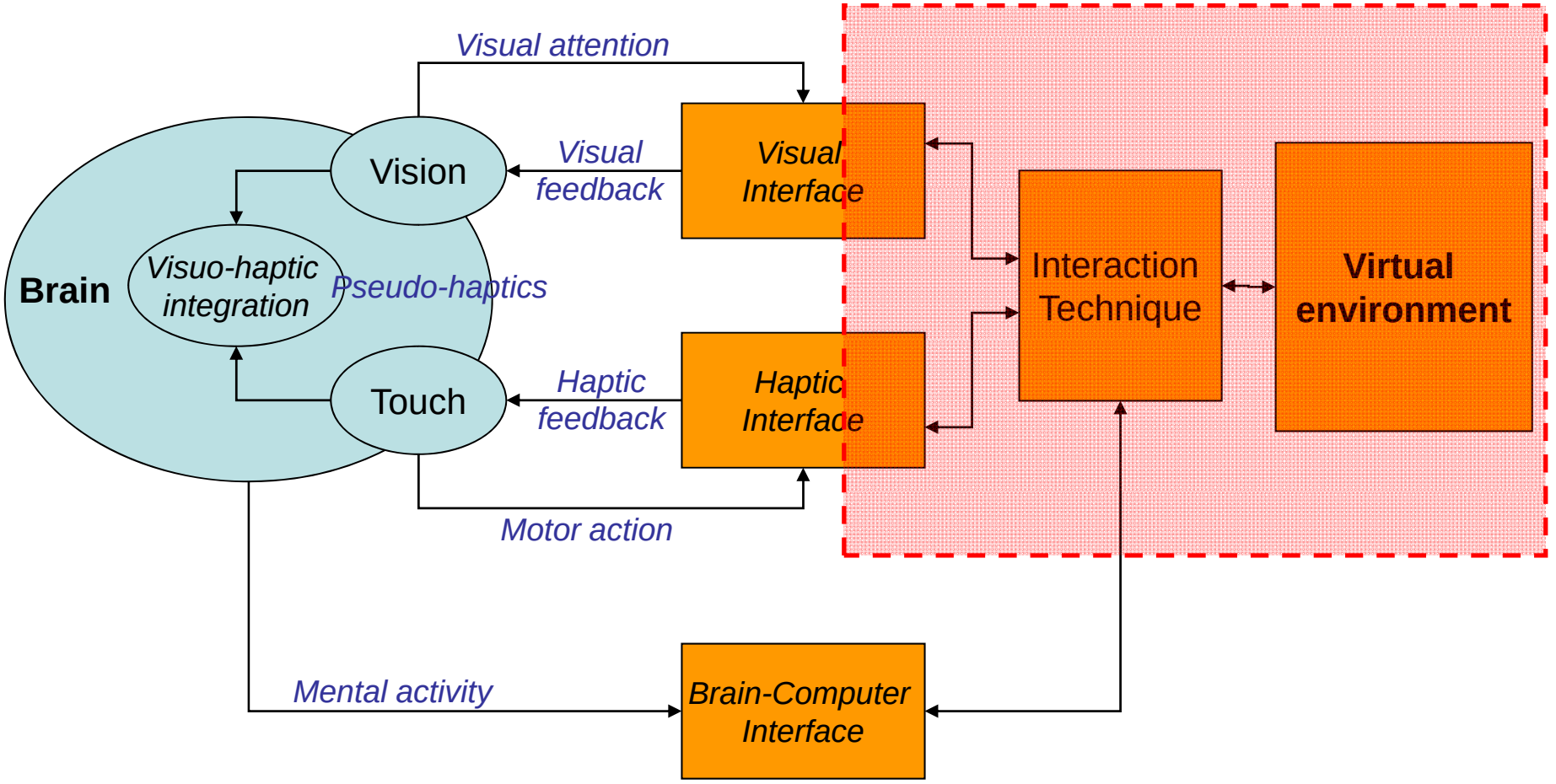
Integration of visual and haptic interfaces



Combination of visual and haptic interfaces

Spatial mismatch : different sizes of haptic and visual workspaces

- Haptic workspace is smaller
- Example : a PHANToM in a CAVE

Hardware solutions

1. Scale 1 haptics [Borro04] [Dominjon07]
2. Wearable haptics [Nitzsche03]

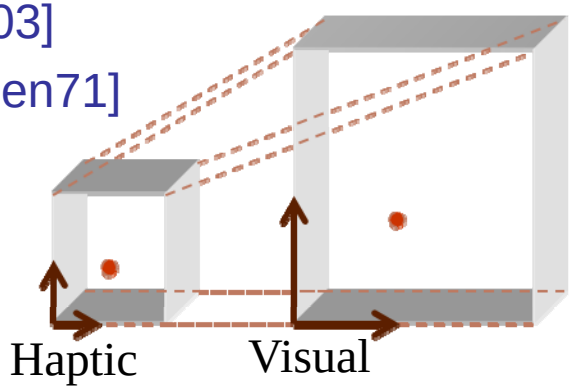
>> no simple solution

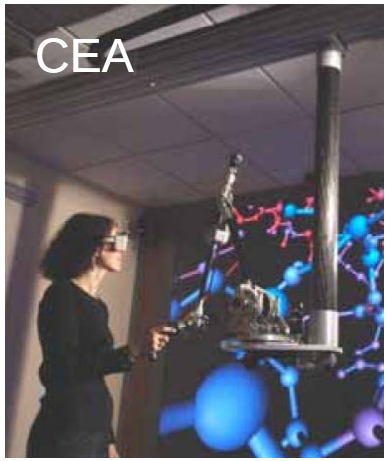
Software solutions

1. Scaling techniques [Fischer03]
2. Clutching techniques [Johnsen71]

>> trade-off = precision / time

>> novel approach :
Haptic Hybrid Control



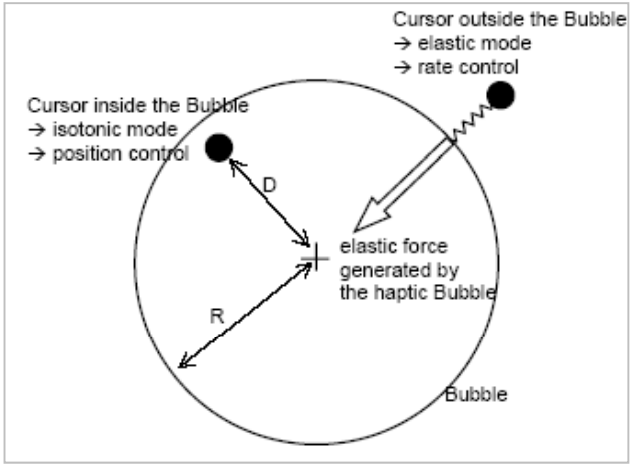


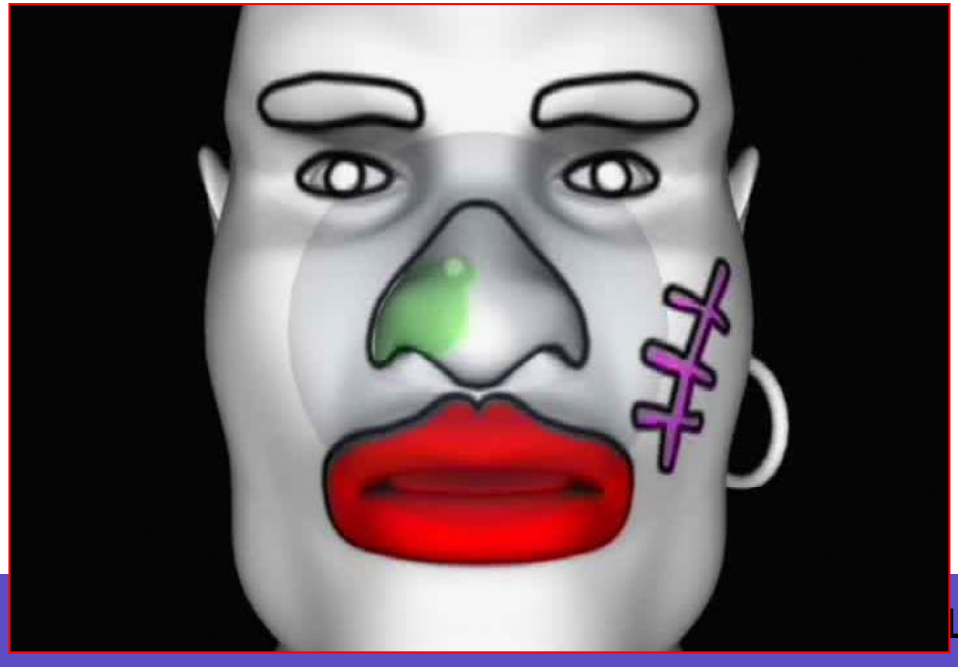
The « Bubble » technique

Context: point-based manipulations
(translations, 3DOF haptics)

Method

- Manipulation workspace = « Bubble »
- Hybrid Position/Rate Control
- Visual and Haptic display of boundary





(Dominjon et al., *Worldhaptics*, 2005)
(Dominjon et al., *Visual Computer*, 2007)

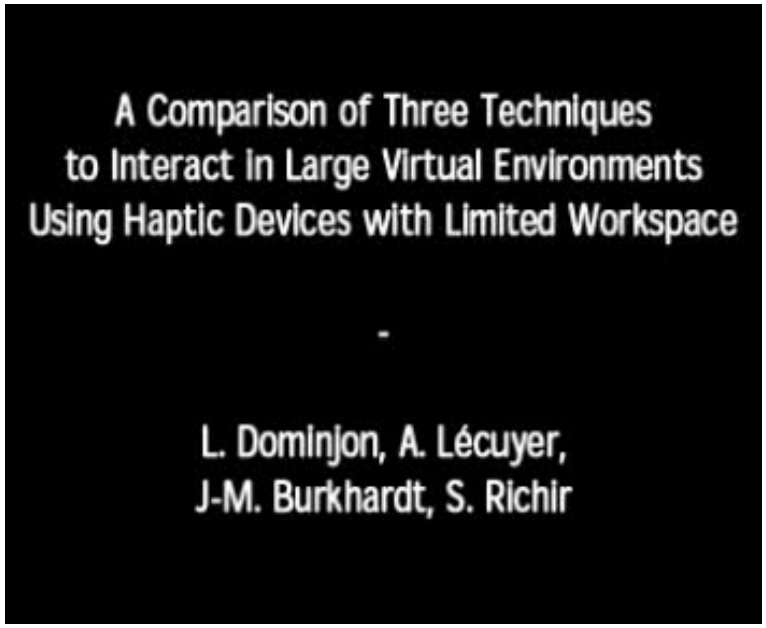
Bubble technique

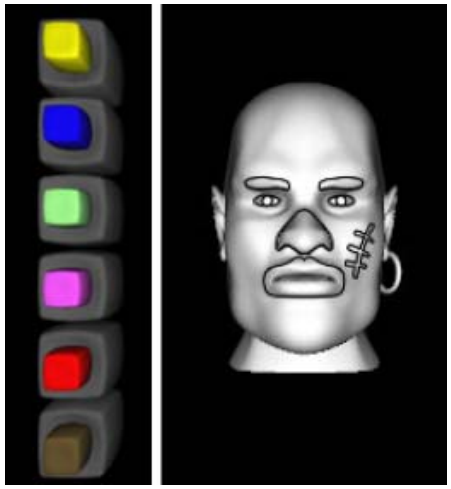
Evaluation

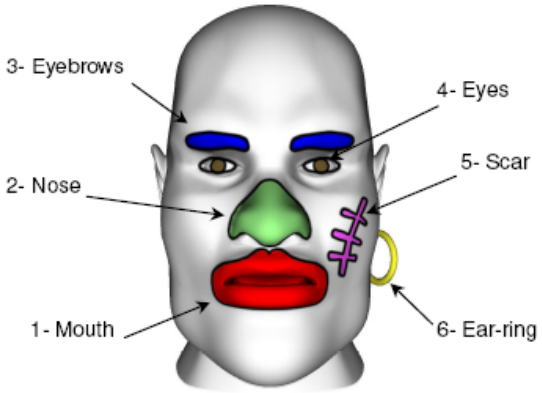
- Setup : PHANToM in a CAVE
- Task : Painting a 3D model
- Conditions : clutching, scaling, bubble

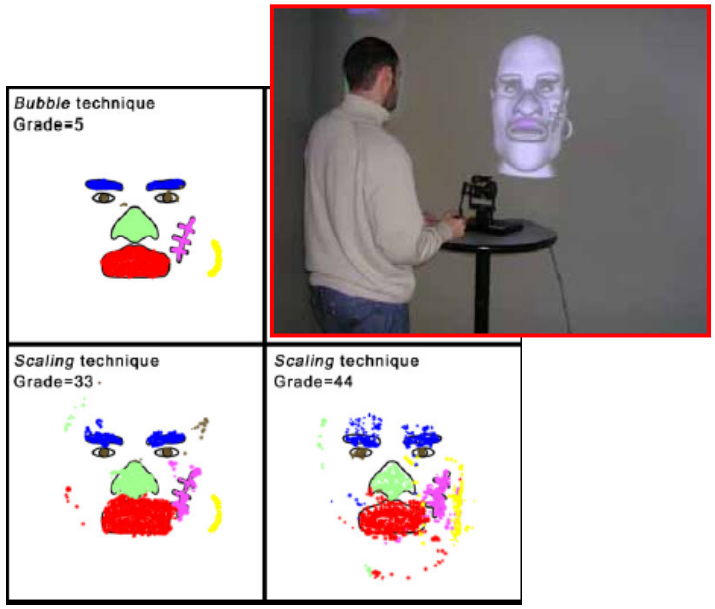
Results

- Faster, more precise, preferred



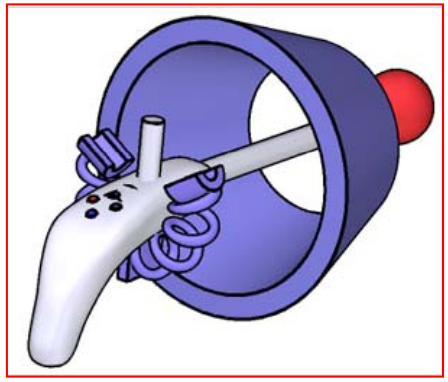






(Dominjon et al., *LNCS*, 2006)

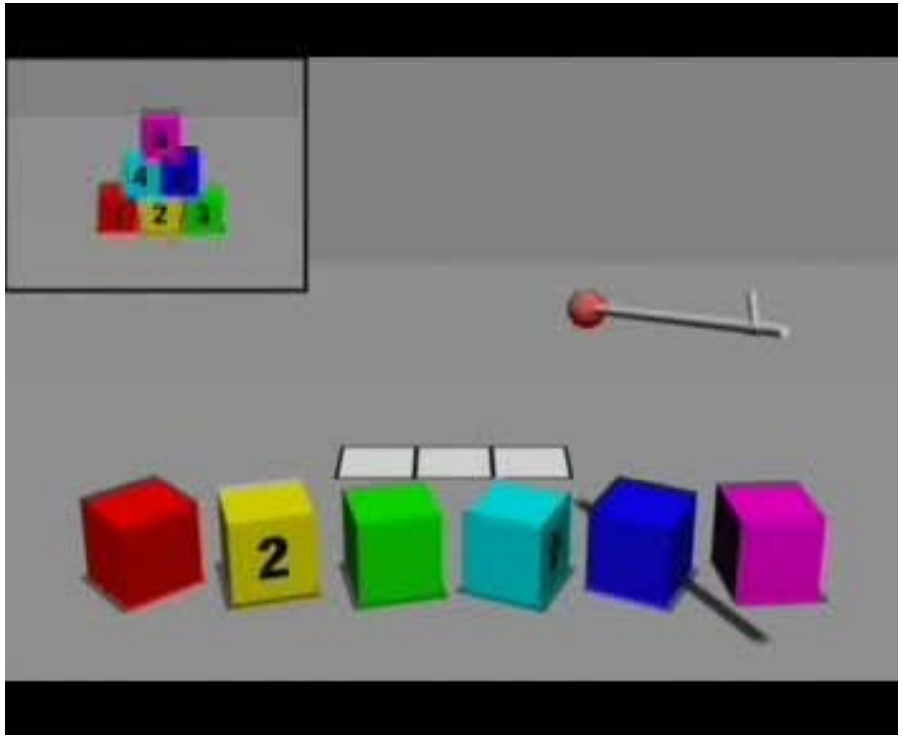
Haptic Hybrid Rotations

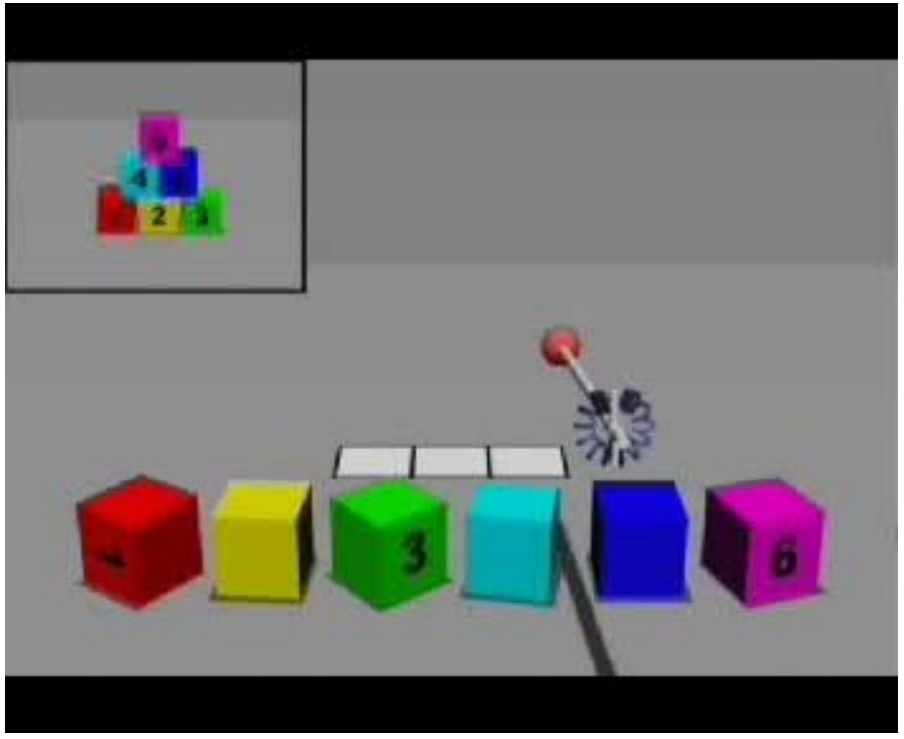


Context : 3D object manipulations (rotations)

Method : DOF separation > cone (2DOF), springs (roll DOF)

Results : fast, precise, preferred **(Dominjon et al., *IEEE VR*, 2006)**





Haptic Hybrid Control

Generic approach for visuo-haptic setup

- Hybrid position/rate control
- Visual display of the boundary between the two control zones
- Haptic display of the boundary with force-feedback

2 Implementations

- Bubble (translations)
- Haptic Hybrid Rotations (rotations)

Other studies

- Tactile pad, 2D Desktop [Casiez07]
- Pen, hand-held computers [Hachet08]

Technological transfer

- VIRTUOSE API (Haption Company)

(Dominjon et al., *Visual Computer*, 2007)

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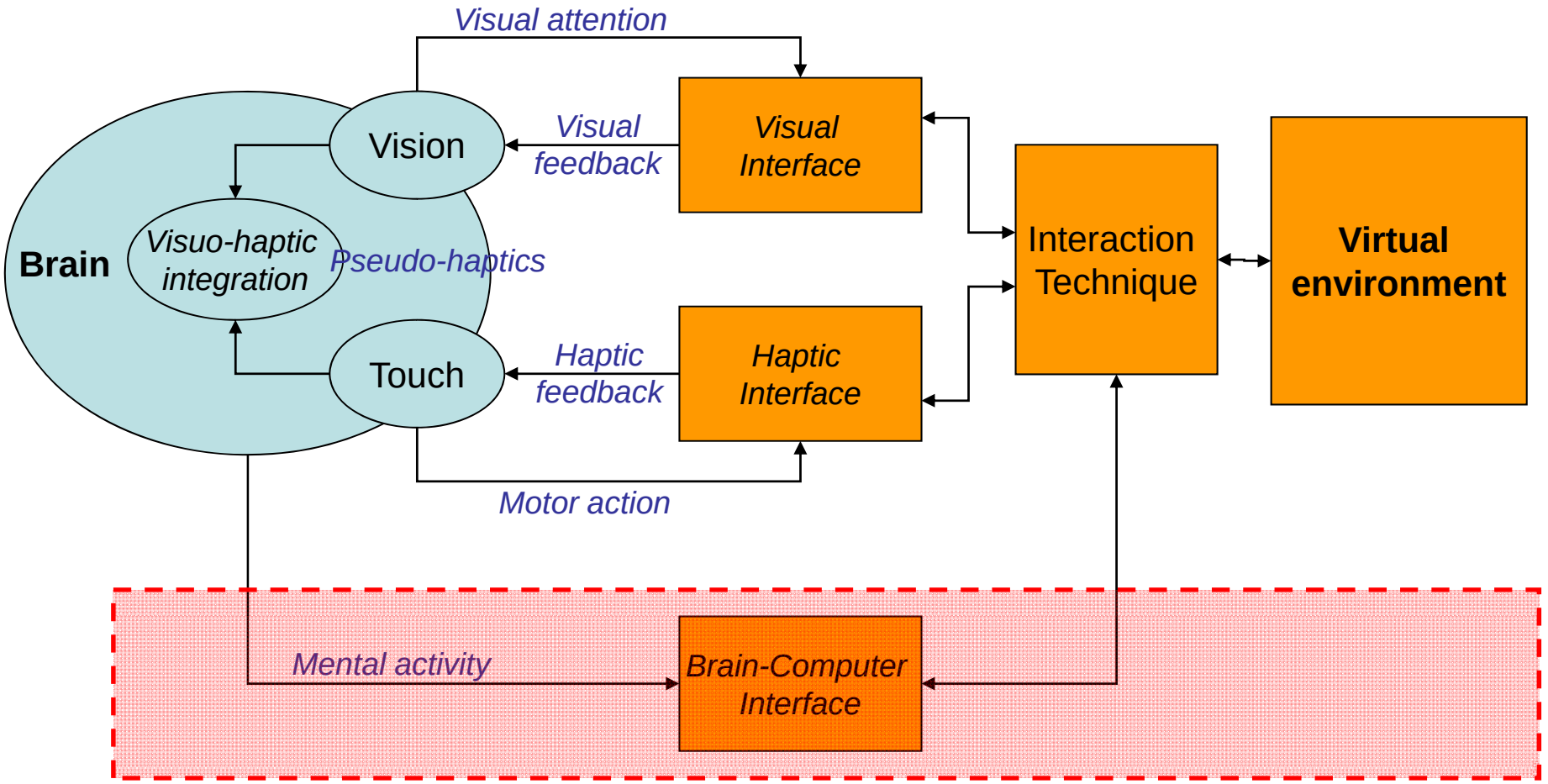
Brain-based interaction



Brain-computer interfaces and VR

Brain-Computer Interfaces (BCI)

- Novel input interface [Vidal73] [Wolpaw02]
- Mental tasks : Motor Imagery (MI), attention

Limited previous work in BCI and VR

- BCI for VR : basic tasks [Bayliss03] [Lalor05]
- VR for BCI : learning/motivation [Friedman07]

(Lécuyer et al, *IEEE Computer*, 2009)

Problem : small number of (robust) commands

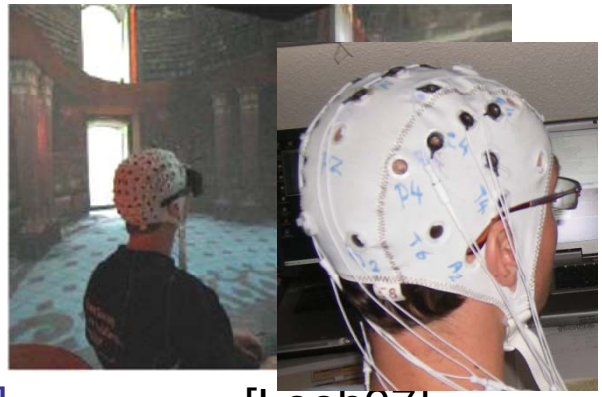
Challenges

(1) Neuroscience/electrophysiology studies

(2) Peripherals and mental sensors

(3) Brain signal processing techniques

(4) Novel and more adapted interaction paradigms



[Leeb07]

[Friedman07]

BCI-based interaction techniques

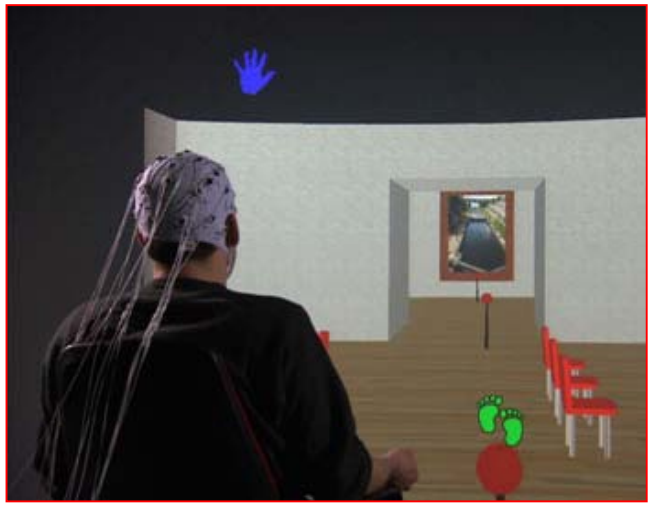
Problem : small number of mental commands

Sate-of-the-art in Navigation [Scherer08]

- 3 mental states : Left/Right hand, Feet MI
- 3 commands : turn left/right, advance

Novel concept : high-level orders

- 3 mental states : Left/Right hand, Feet
- Selection of target point (binary tree)
- Automatic transportation



Evaluation

- Task : Navigation
- 2 conditions : SoA [Scherer08], High-level

Results **(Lotte et al., *Presence*, 2010)**

- High-level orders faster that soa

BCI evaluation

Problem : limitations of current evaluations

- Few subjects, lab conditions, intense training

Need for large-scale studies [Guger03]

- Assess BCI usage and potential
- Real-life conditions (limited learning, out the lab)

Large-scale evaluation (n = 21)

- Entertaining application : “use the force”
- Lift a virtual spaceship with feet MI

Results **(Lotte et al., *BCI Workshop*, 2008)**

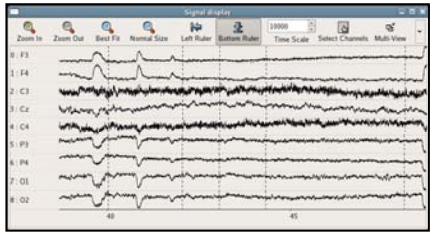
- Real ~50 % success
- Imagined ~25 % success
- Importance of feedback

Cité des sciences (since May)

OpenViBE software

Integration platform

- Open-source software
- Design, test and use BCI
- Real-time processing of cerebral data



ANR Projects

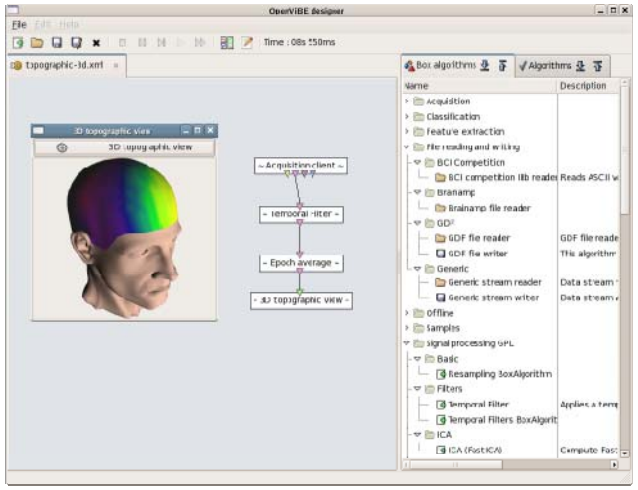
- OpenViBE (2005-2009), OpenViBE2 (2009-2012)

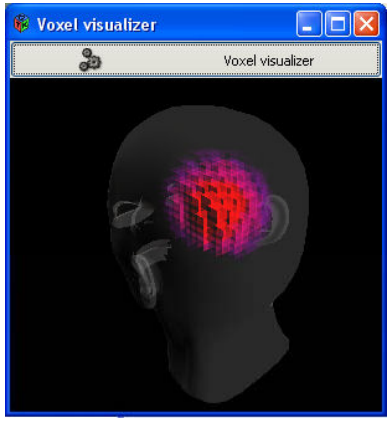
Manpower

- 12 men.year,
- 3 developers (full-time)

Diffusion

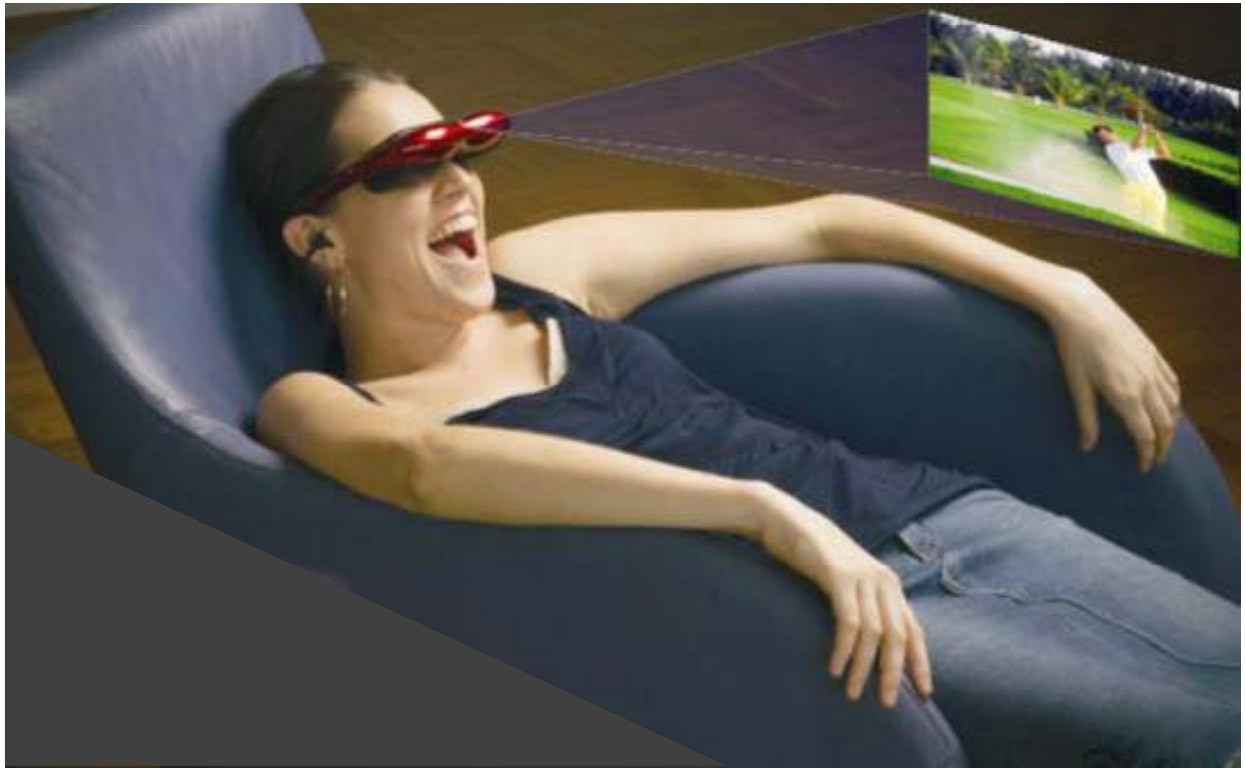
- 1st release in May 2009
- Numerous users
- http://openvibe.inria.fr



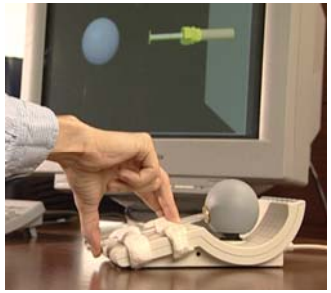


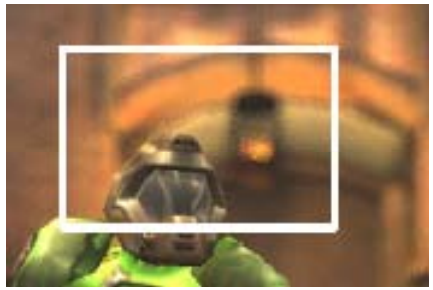
(Renard et al., *Presence*, 2010)

Perspectives



Summary of results





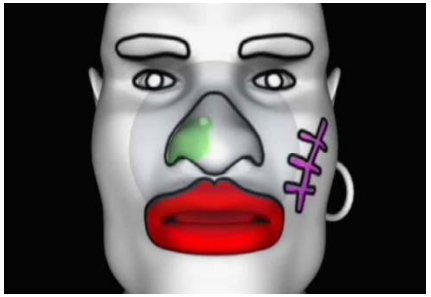
Perception-based rendering of virtual environments

- **Interactive visual feedback based on user's gaze**: (1) novel techniques for **gaze tracking**, (2) novel **visual effects** such as depth-of-field blur
- Novel visuo-haptic technique: "**pseudo-haptic feedback**" using vision to distort haptic perception

>> Perspectives

- Novel **visual attention models:** more adapted to VE (taking into account VR interaction), simulating eyes movements (saccades, smooth pursuits, etc). Novel **visual effects** : realistic camera motions.
- Investigation of **pseudo-haptic phenomenon**: other modalities (auditory?), perceptual perspective/understanding (integration model? use of other tools: neuroimagery, electromyography, etc)

Summary of results



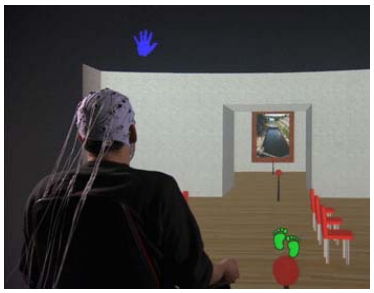
Optimal combination of visual and haptic interfaces

- Novel **interaction paradigm**: "**Haptic Hybrid Control**" to solve problems related to spatial discrepancies

>> Perspectives

- Study of **temporal** delay : perceptual integration models (Postdoc Nizar Ouarti, collaboration LPPA/Alain Berthoz)? Design guidelines?
- Next generation of visuo-haptic interfaces/hardware

Summary of results



BCI-based interaction with virtual environments

- **Novel 3D interaction techniques** based on high-level orders to make up for small number of commands
- **Large-scale BCI evaluations** assessing the usage and potential of BCI

>> Perspectives :

- **Hybrid BCI** : « combining rather than selecting », with multiple signal processing and **multiple brain signals**
- **Advanced sensory feedback** : using VR for improved motivation, closing the loop with multi-sensory rendering

Technological transfer

Design of VR applications/prototypes

- *Medical simulator, aeronautics maintenance, vocational training, assistance to disabled, etc*

Patents

- (1) pseudo-haptics, (2) haptic motion

Softwares

- OpenViBE, SAMIRA (EADS/Airbus), Multimodal rendering platform (CEA)

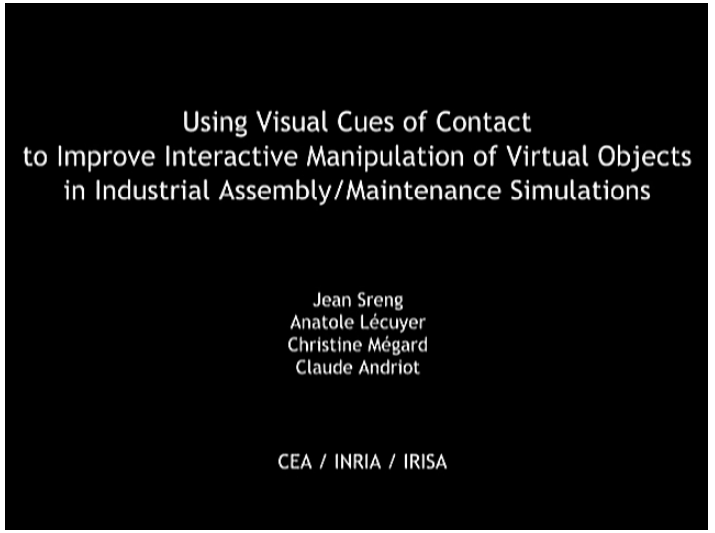
Industrial collaborations (PhD/projects)

- Orange Labs, CEA, UBISOFT, etc

Transfer of interaction techniques

- « Haptic Hybrid Control » (Haption company), « Magic Barrier Tape » (CEA)

(Lécuyer et al., *IEEE VR*, 2003)



(Sreng et al., *IEEE TVCG*, 2006)
(Sreng et al., *ACM VRST*, 2007)

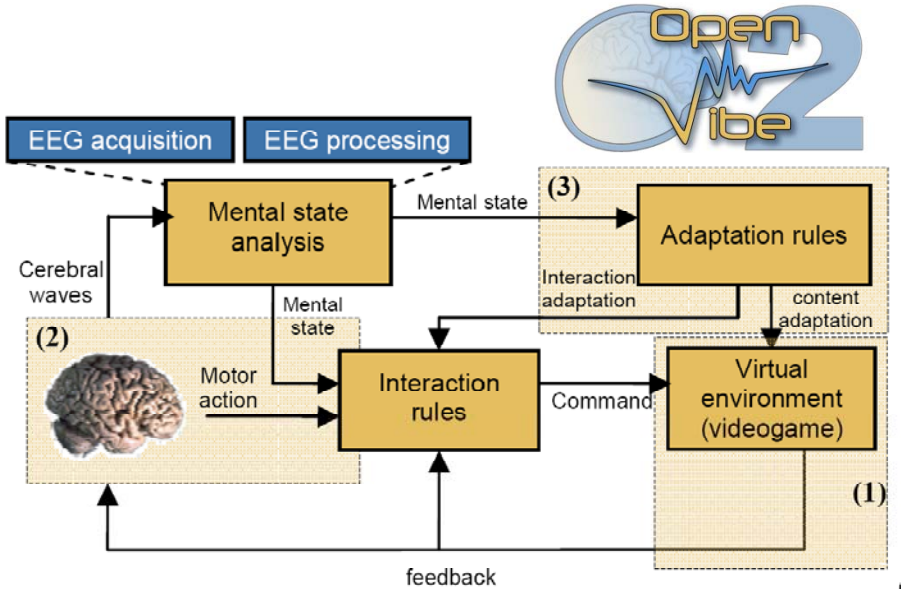
Long-term perspectives

Incorporate other modalities..

- Body motion, Feet : interaction and feedback
- « Natural Interactive Walking » EU Project (2009-2011)
- PhD theses: Gabriel Cirio, Léo Terziman

Towards 3D interaction based on perception and cognition..

- Implicit BCI : automatic adaptation of interaction
- OpenViBE2 ANR Project (2009-2012)
- PhD thesis Laurent George



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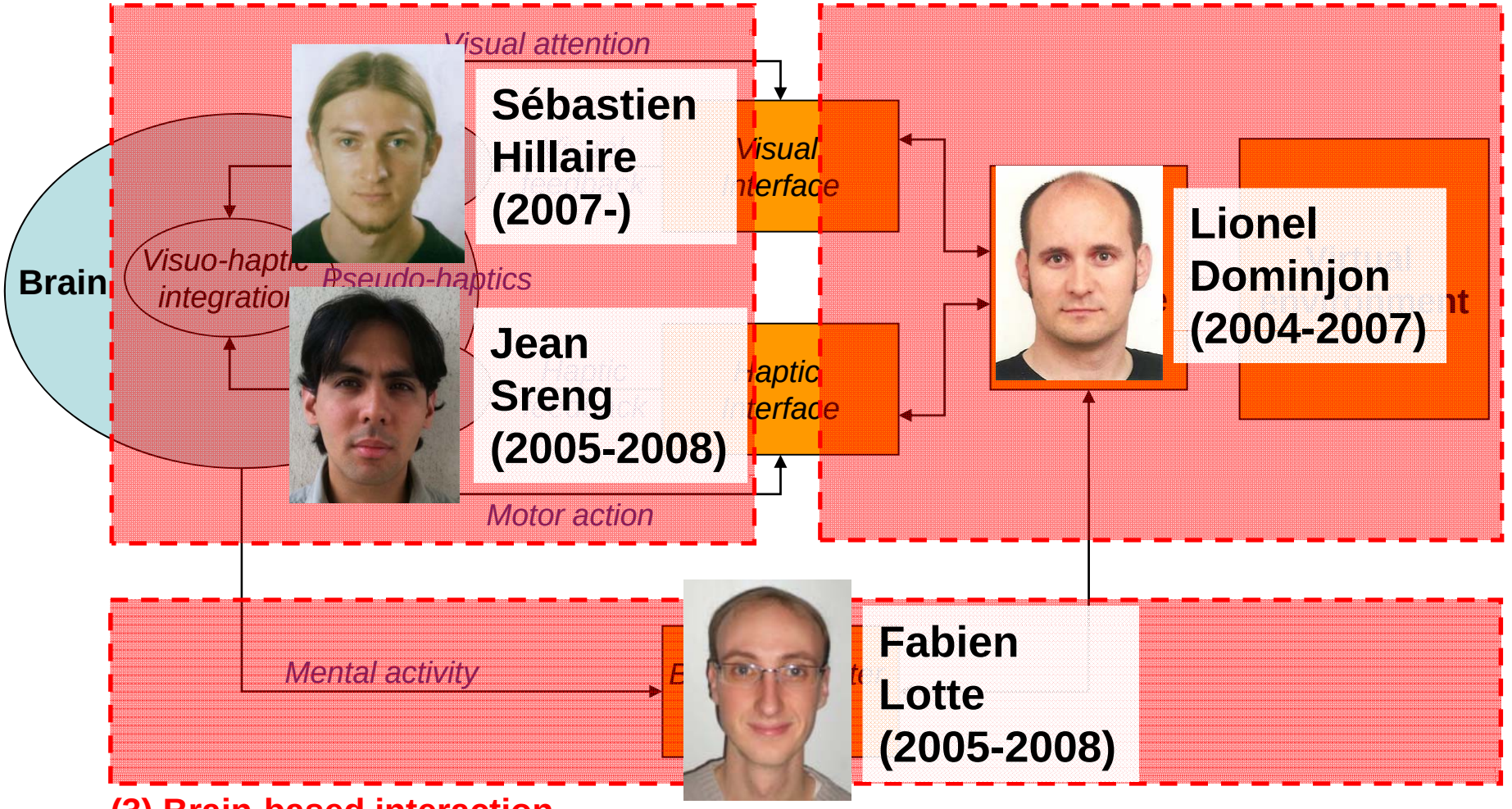
Acknowledgements

(1) Sensory feedback

(2) Integration of visual and haptic interfaces



(3) Brain-based interaction

Thank you

Habilitation à diriger des recherches

“Using eyes, hands and brain for 3D interaction with virtual environments: a perception-based approach”

Anatole Lécuyer

INRIA RENNES

BUNRAKU

UMR IRISA

cnrs Université de Rennes 1 INSA Rennes ENS Cachan Bretagne

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