3D Multimodal Interaction with Physically-based Virtual Environments

Maud Marchal

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Habilitation à Diriger des Recherches

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES RENNES
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Short CV

- **2006**: PhD, Univ. Joseph Fourier, Grenoble, France
- **2007**: Post-doctoral position at Univ. of British Columbia, Vancouver, Canada
- **2008**: Post-doctoral position at Inria Lille, France
- Since **September 2008**: Assistant professor at INSA Rennes
  - Affiliation: Member of IRISA, Hybrid team

The virtual as a reality

- From highly-specialized research labs…

[Catmull 72]

[IBM 63]

[Sutherland 68]

- … to wide availability among the general audience

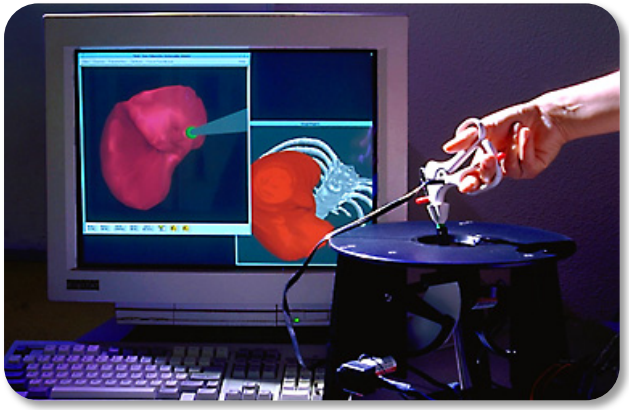
[Avatar 09]

[Leap Motion 08]

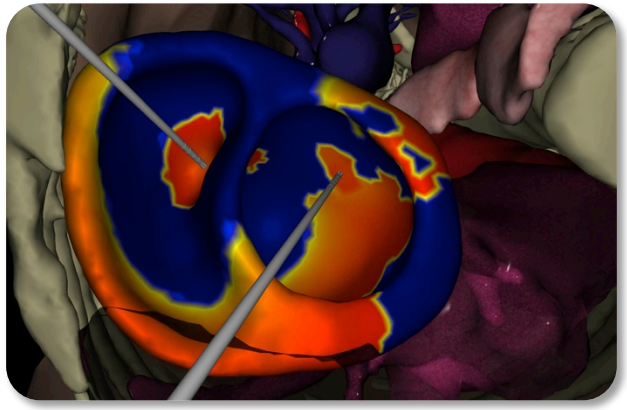
[Oculus Rift 12]

Virtual Reality

- Virtual Reality (VR) technologies **simulate** digital environments with which users can **interact** and, as a result, **perceive** through different modalities the effects of their actions in **real time**



[Cotin 96]

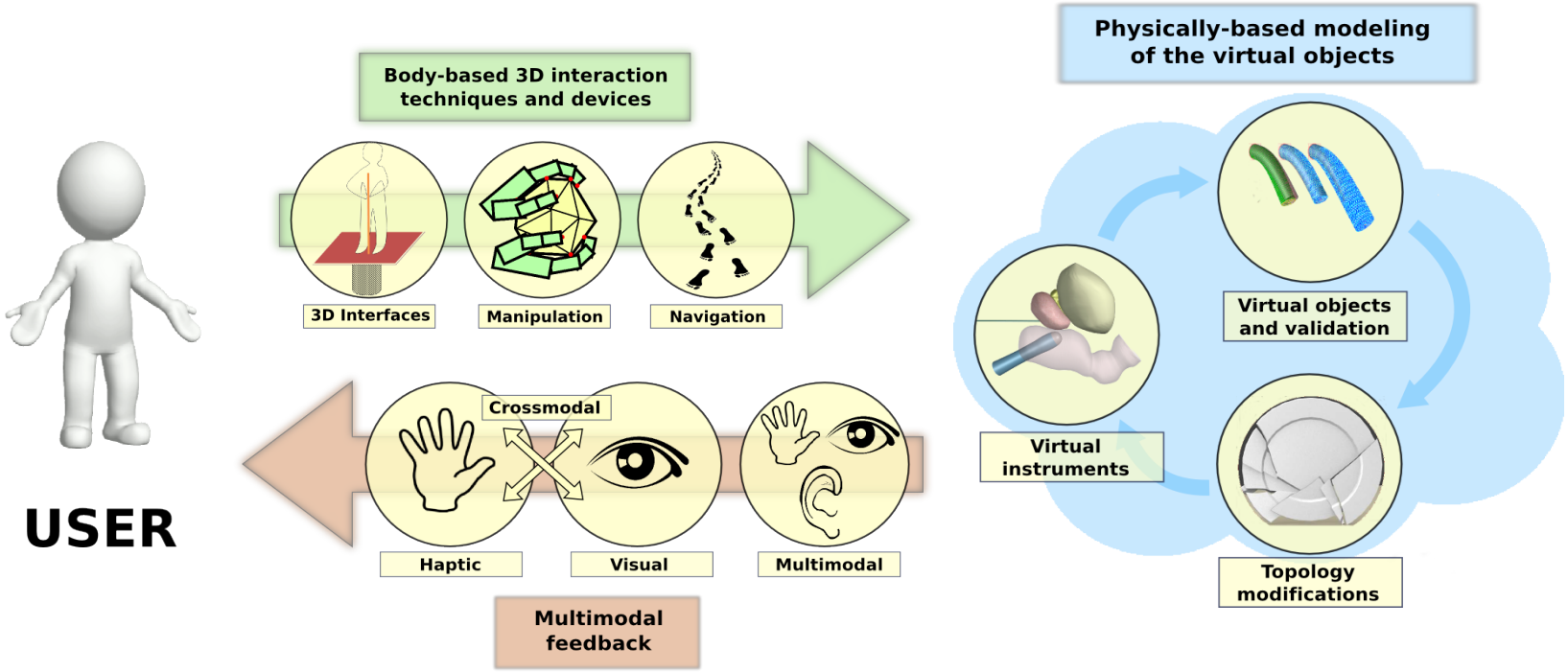


[Pernod 11]

The complexity of the real world, the perception of the virtual world

=> Modeling, feedback and interaction challenges

Research framework



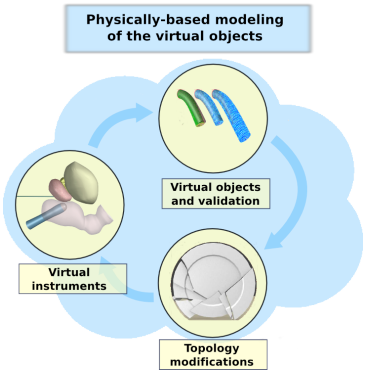
Objective: improving 3D interaction with complex virtual environments

Research axes:

- **Axis I**: **Modeling physically-based** virtual objects in interaction with their environment
- **Axis II**: Rendering **multimodal feedback** using the different user sensory modalities
- **Axis III**: Designing **3D interaction** techniques and devices using user's **body** skills

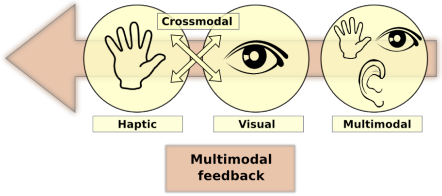
Overview of my research activity

Axis I: Physically-based modeling of virtual objects and their interactions



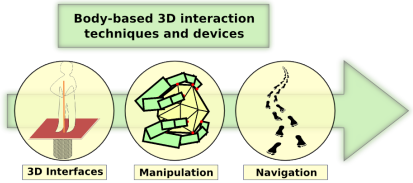
- Deformable objects modeling and validation methodology
- Topology modifications of virtual objects
- Interactions through deformable instruments and virtual hands

Axis II: Multimodal feedback with complex virtual environments



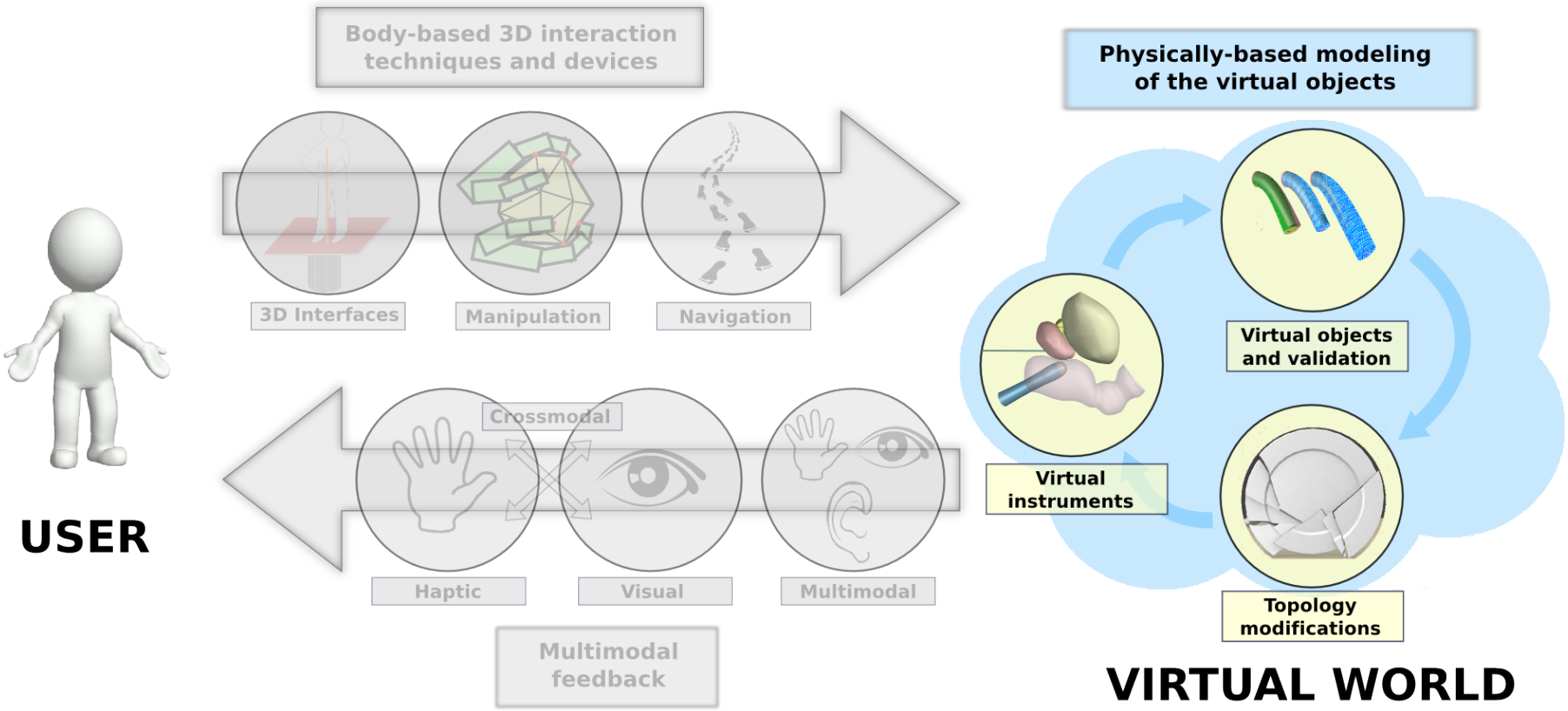
- Haptic feedback
- Visual feedback
- Multimodal feedback
- Crossmodal feedback

Axis III: 3D interaction with virtual environments using body skills

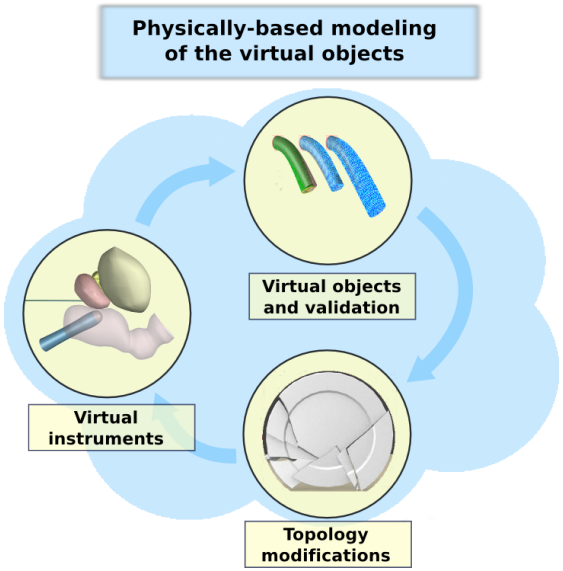


- 3D interaction devices
- 3D manipulation techniques
- 3D navigation techniques

Axis I: Physically-based modeling



Axis I: Physically-based modeling



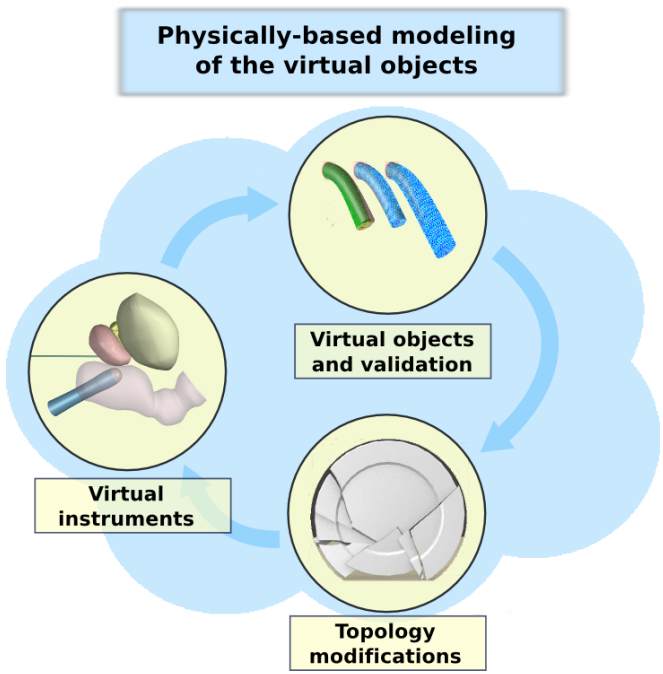
- Context:
  - Virtual environments with various media
  - Focus on medical applications

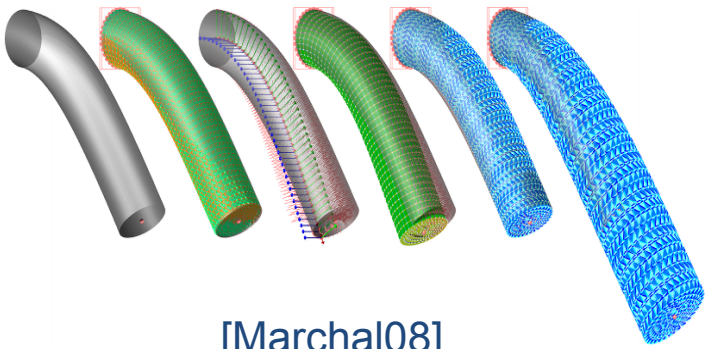
- Challenges:
  - Connecting the 3D geometry to the mechanical properties
  - Evaluating the behaviors of physically-based models and comparing them to real data
  - Simulating complex interactions with highly-specialized objects

Outline

Axis I: Physically-based modeling of virtual objects and their interactions

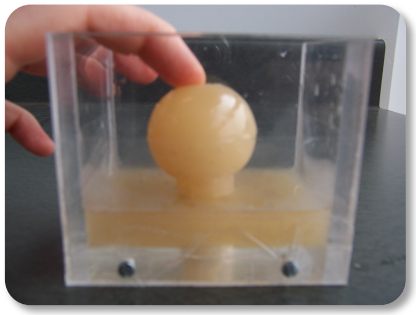
- Deformable objects modeling and validation methodology
- Topology modifications of virtual objects
- Interactions through deformable instruments and virtual hands





[Marchal08]

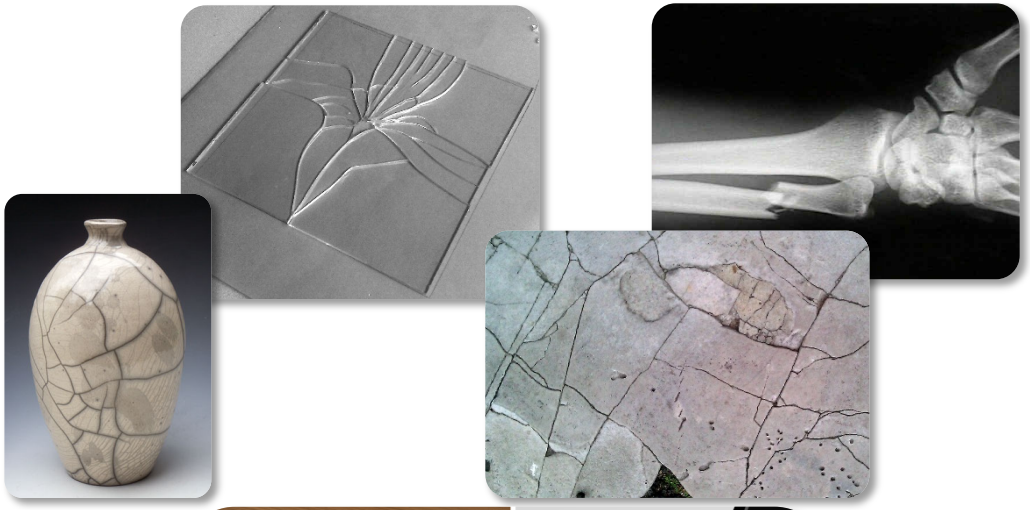
[Chen12]



[Dehghan08]

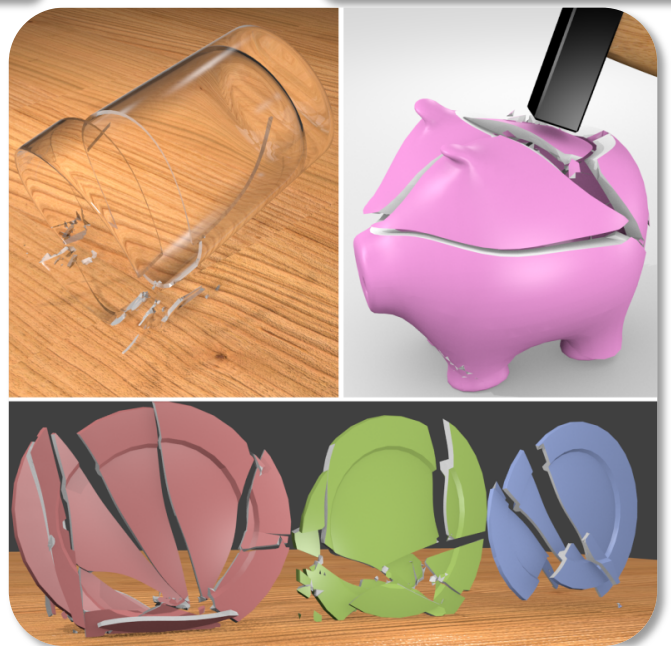
Topology modifications: brittle fracture

- Brittle materials:
  - No plastic deformation
  - Brief fractures

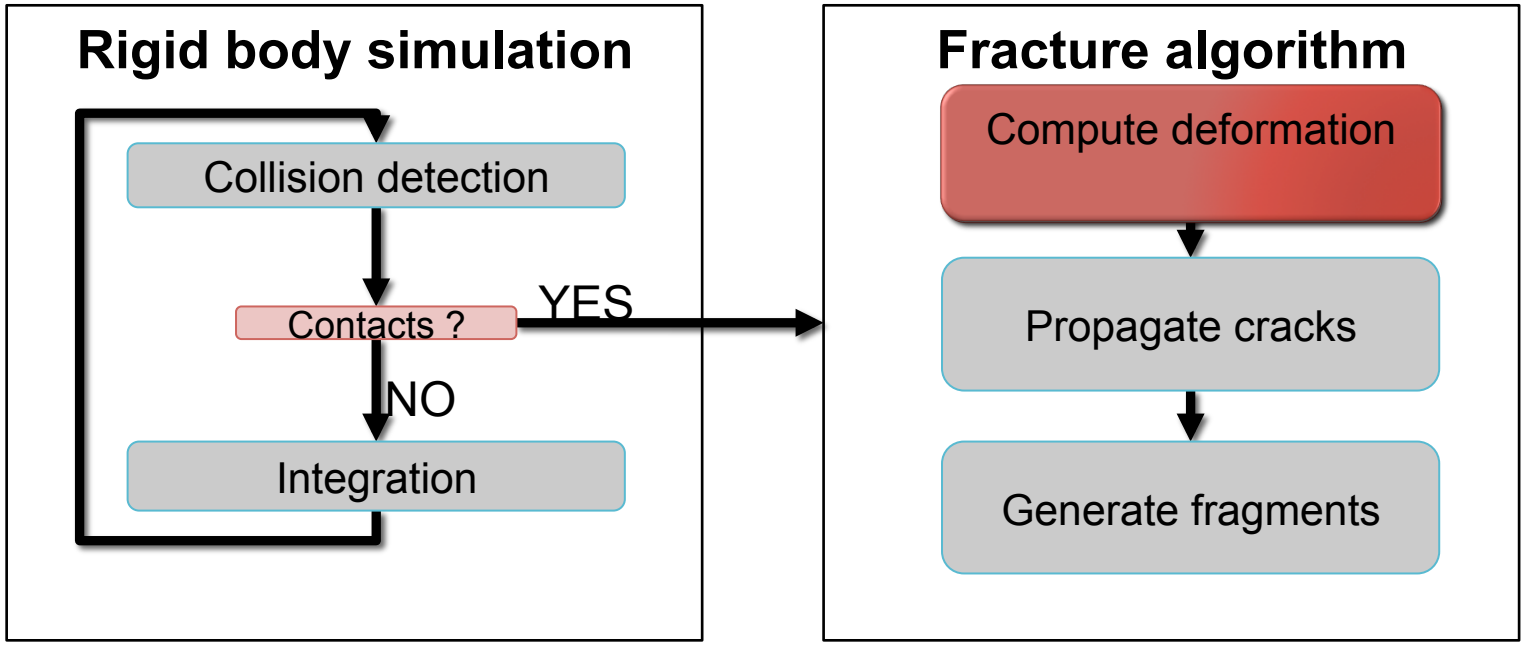


- **Contribution**: real-time and physically-based simulation of brittle fracture

  [Glondu12, Glondu13, Glondu14]
  - Design of a fracture model
  - Real-time simulations for haptic feedback

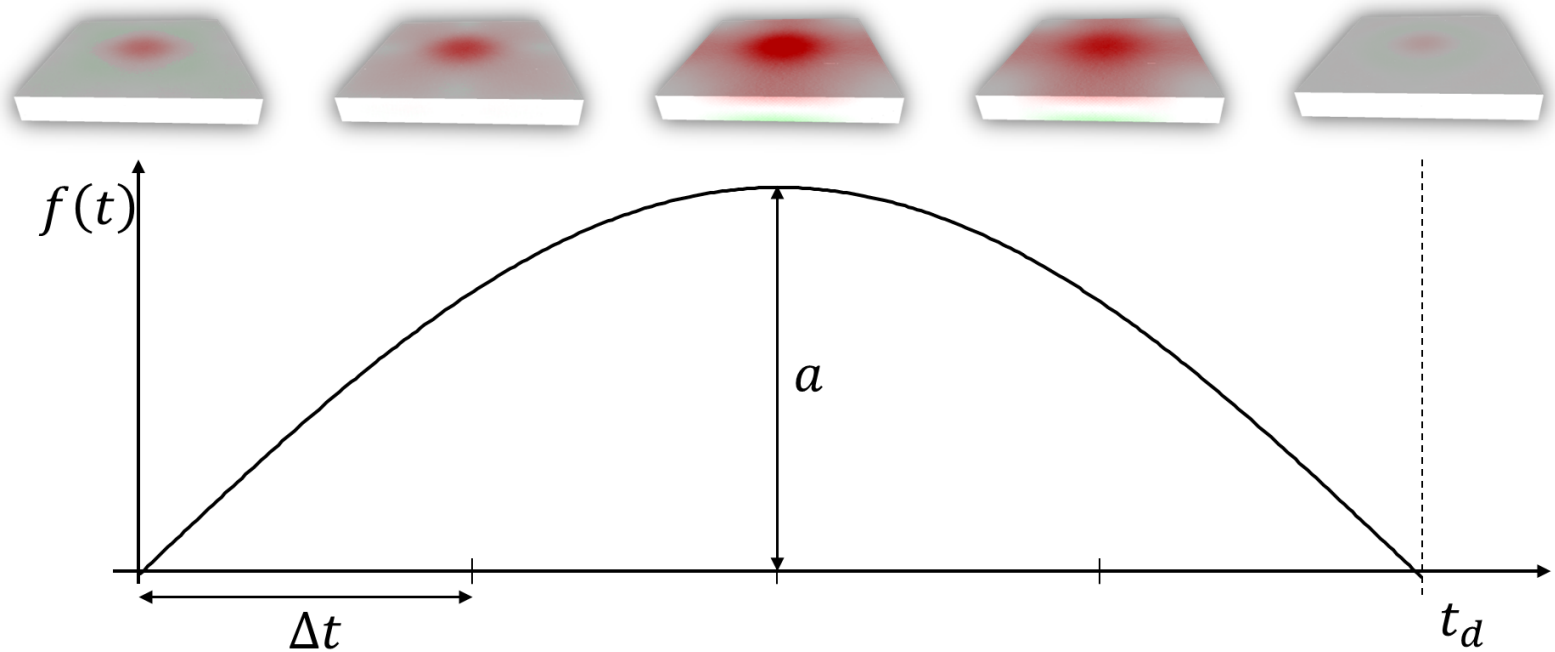


Topology modifications: brittle fracture



- Deformation due to contacts based on modal analysis: [Glondu13]
  - Estimation of contact durations
  - Adaptive time step
  - Dynamic simulation of the deformation waves

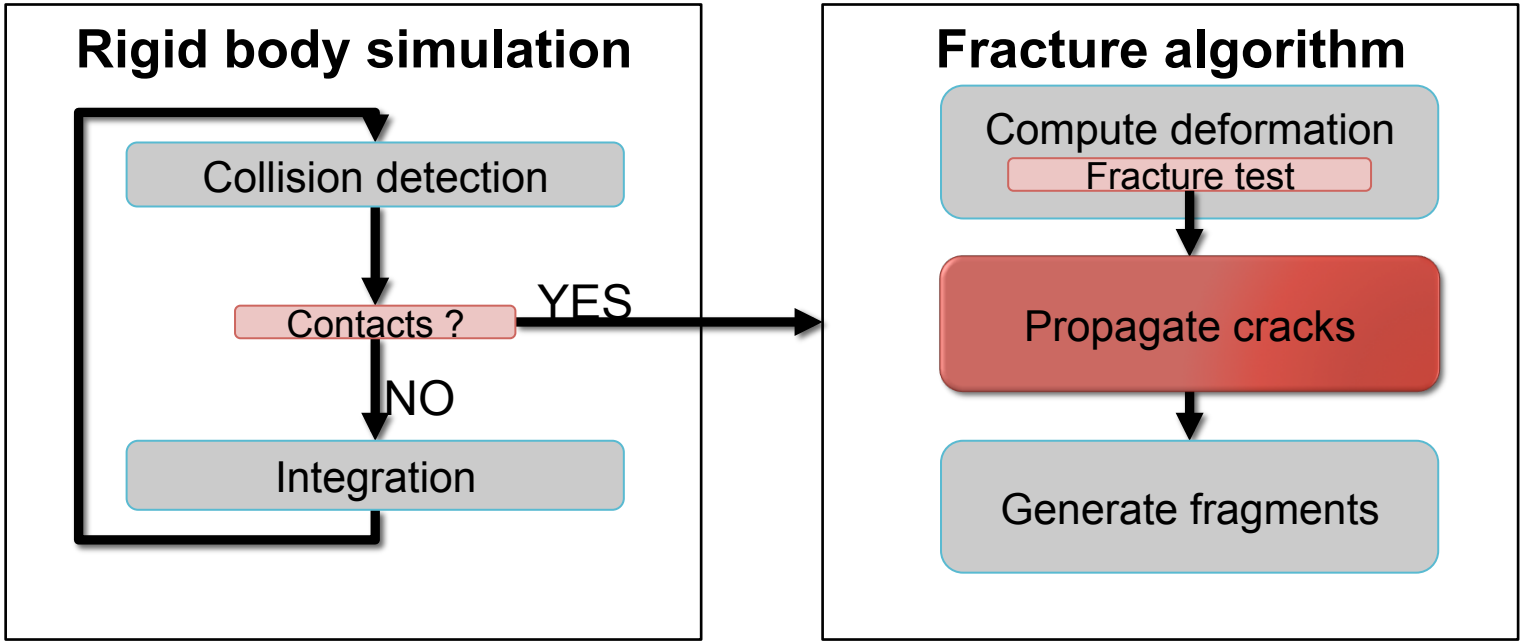
Topology modifications: brittle fracture



- Deformation due to contacts based on modal analysis: [Glondu13]
  - Estimation of contact durations
  - Adaptive time step
  - Dynamic simulation of the deformation waves

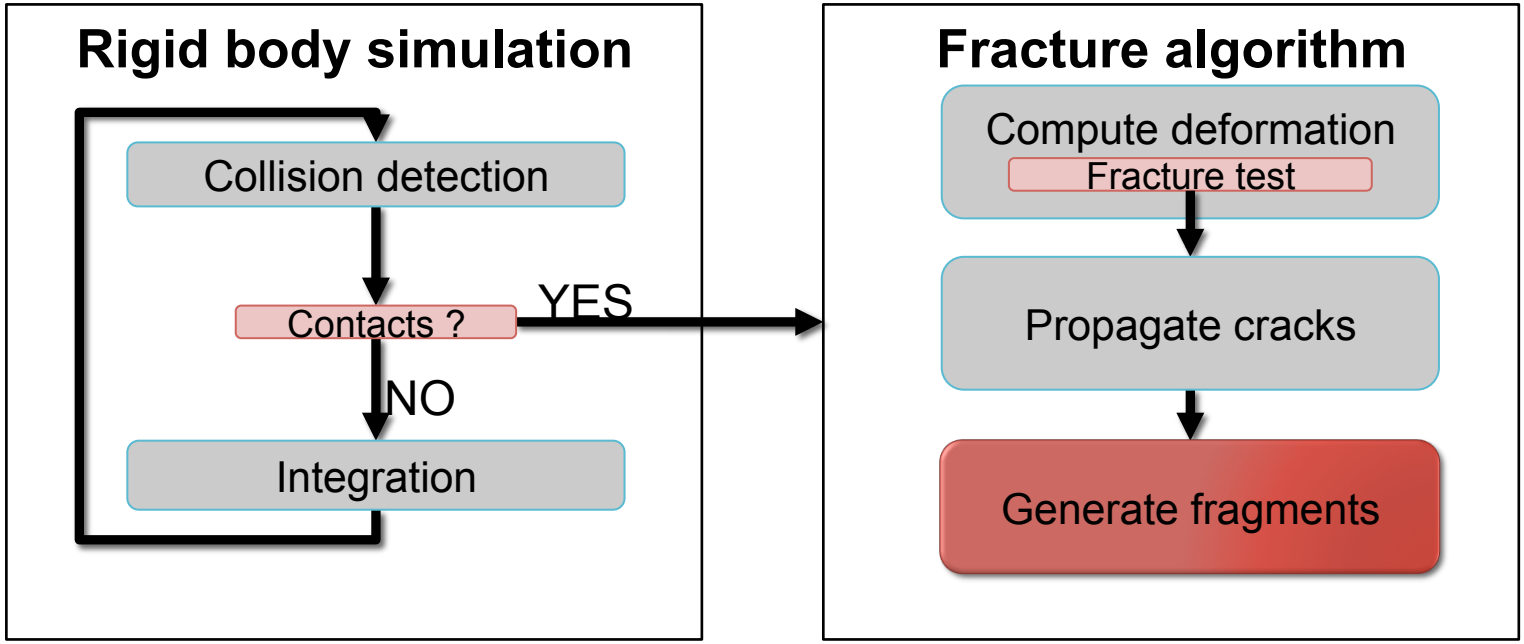
$$t_d = c.\left(\left(\frac{2\pi}{Im(\omega_{max})}\right)^2 . \frac{1}{v_{rel}}\right)^{1/5}$$

Topology modifications: brittle fracture



- Fracture propagation with energy stop criterion: [Glondu13]
  - Using implicit surfaces
  - Robust crack collision handling using the volumetric mesh

Topology modifications: brittle fracture



- Fracture generation and collision detection:
  - Efficient triangulation (node marking) and sampling of the fracture surface [Glondu13]
  - Efficient collision detection based on a combination of distance fields and sphere trees [Glondu12, Glondu14]

Topology modifications: brittle fracture

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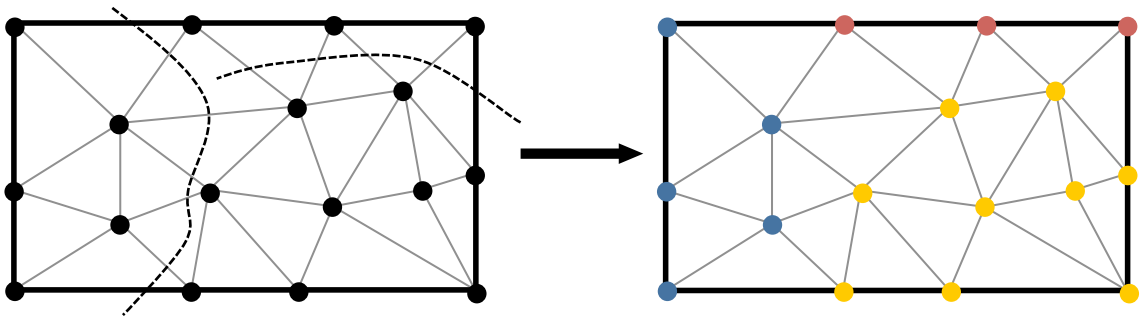
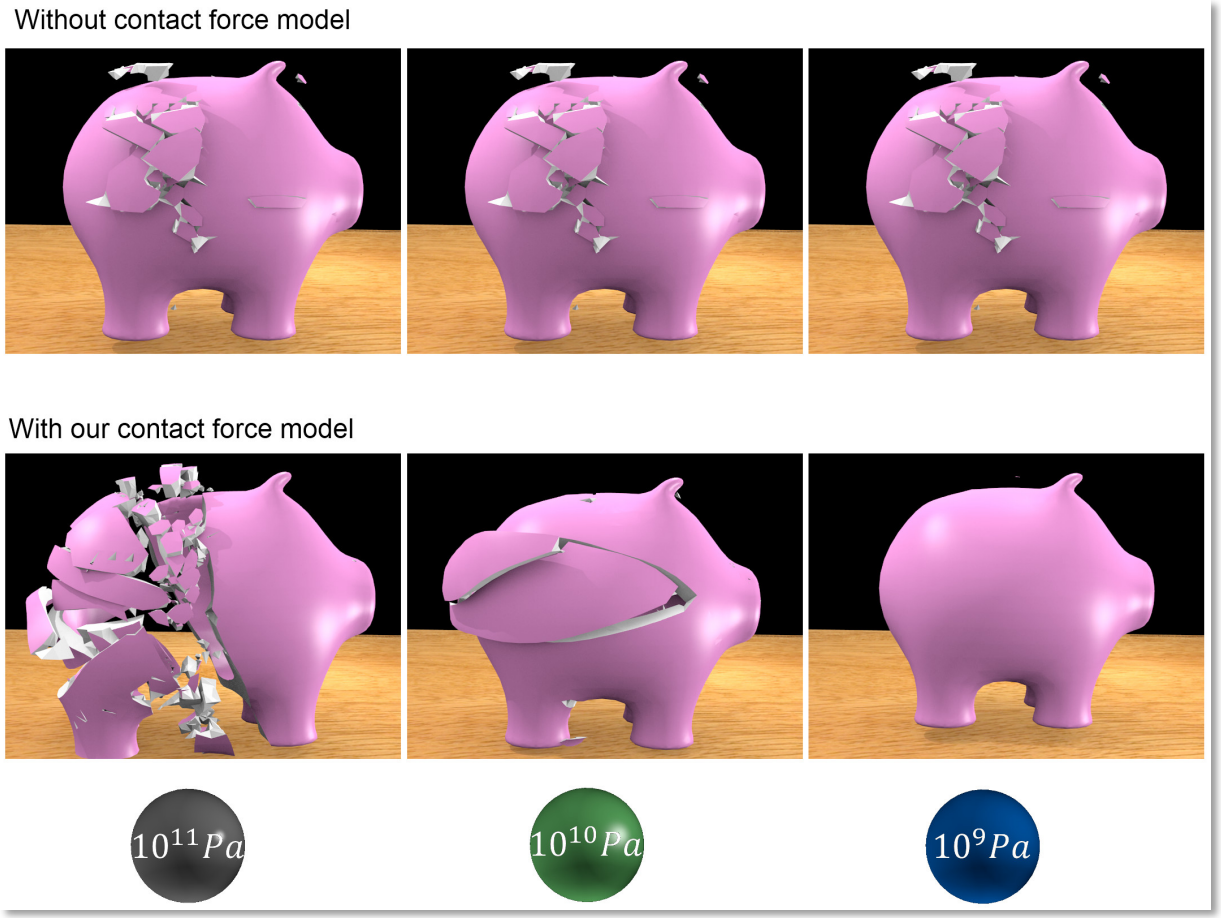


  - Efficient collision detection based on a combination of distance fields and sphere trees [Glondu12, Glondu14]
    - Novel algorithms for fast reconfiguration

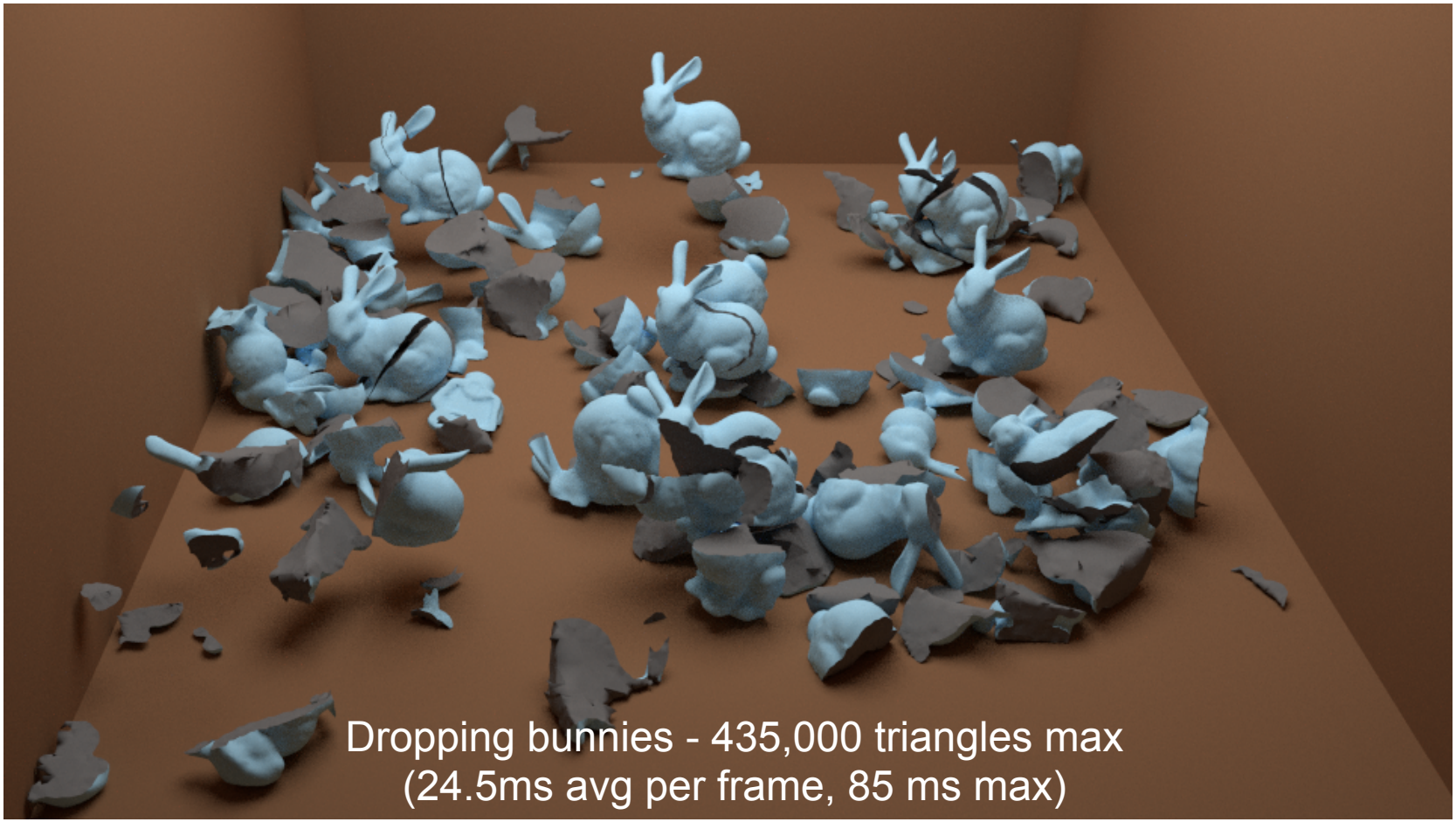
Topology modifications: brittle fracture

- Results: contact force model and damping effects: [Glondu13]



Topology modifications: brittle fracture

- Results: collision detection: [Glondu12, Glondu14]



Outline

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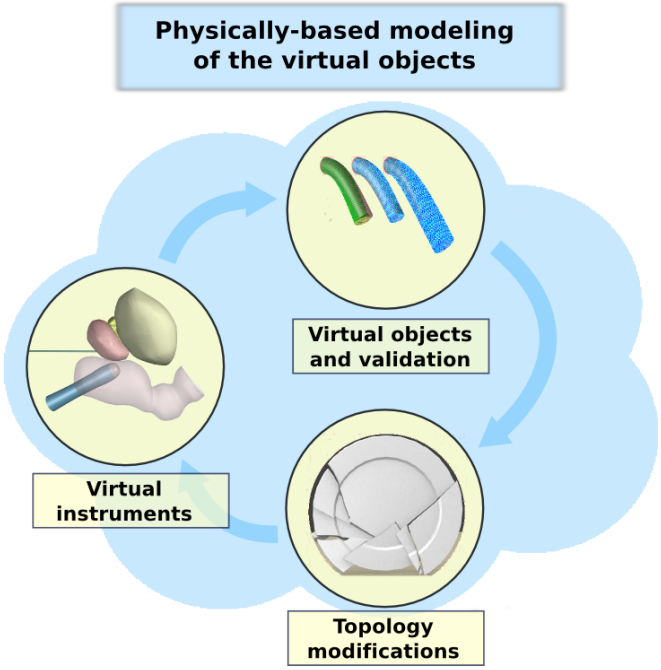
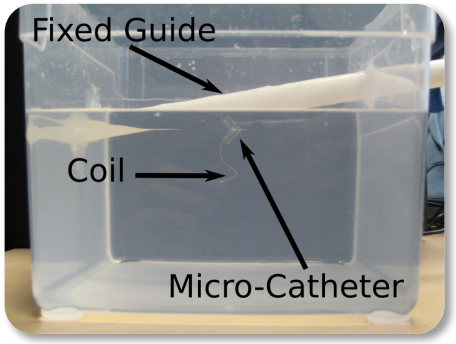
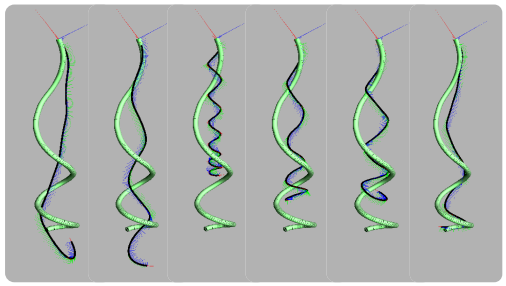


Interactions with virtual instruments

- Context: medical applications involving thin and deformable instruments:
  - Needle insertion during prostate brachytherapy
    [Marchal07, Dehghan07a, Dehghan07b, Dehghan08, Duriez09]
  - Coil deployment for coil embolization
    [Dequidt08]

- Common approach: validation of the simulations against real data
  - Design of phantoms
  - Optimization methodology

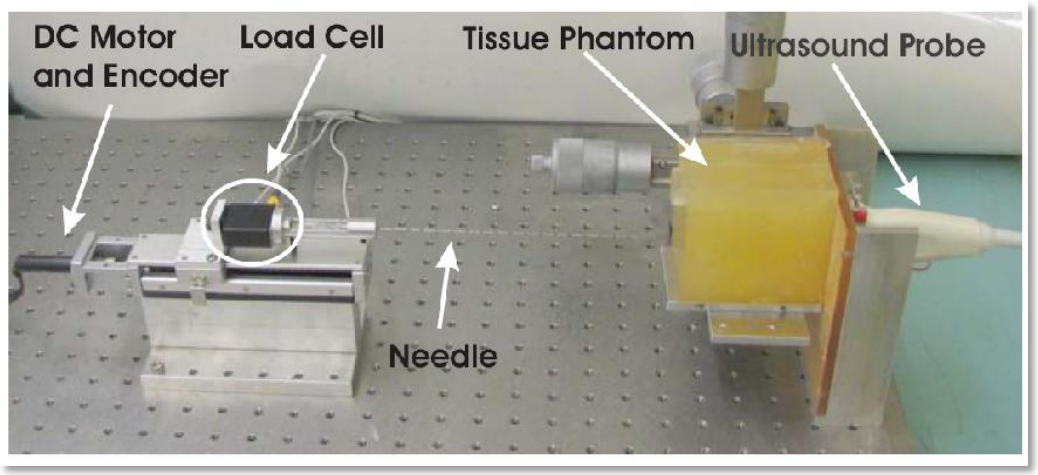


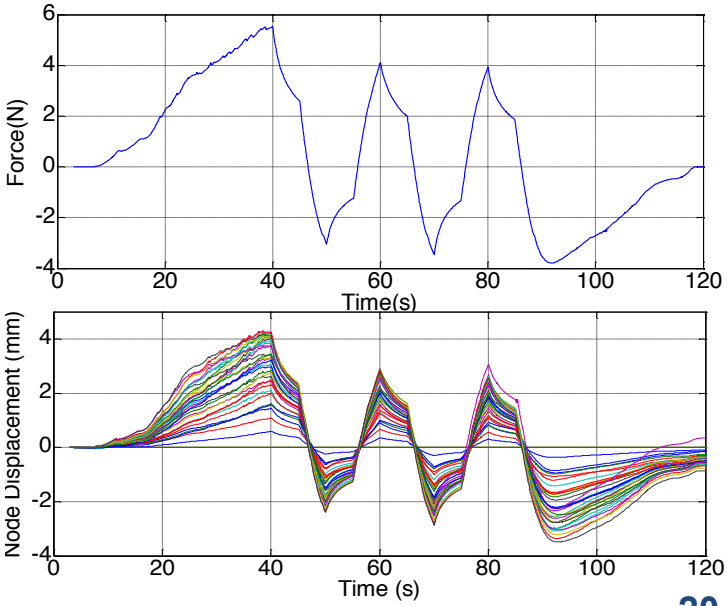


[Dequidt08]

Interactions with virtual instruments

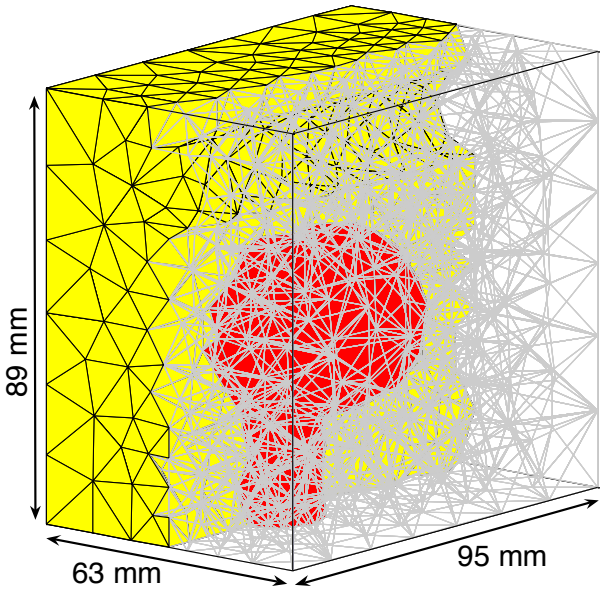
- Needle-tissue interactions: [Dehghan07a]
  - Tissue and needle force model parameters identified from tissue motion and needle base forces
  - Tissue deformation estimated using ultrasound imaging

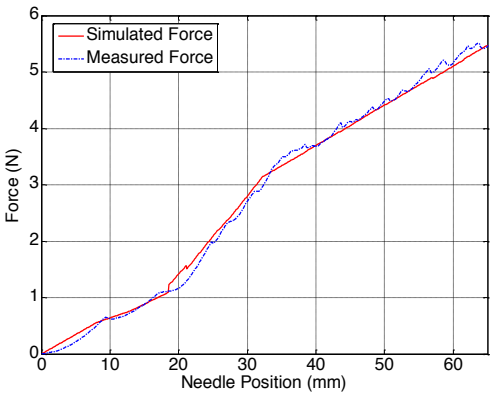


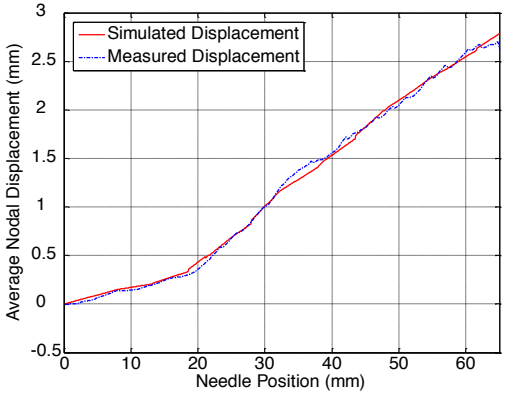


Interactions with virtual instruments

- Needle-tissue interactions: [Dehghan08]
  - Force distribution model inspired by the real data
  - Parameter identification using a FEM simulation

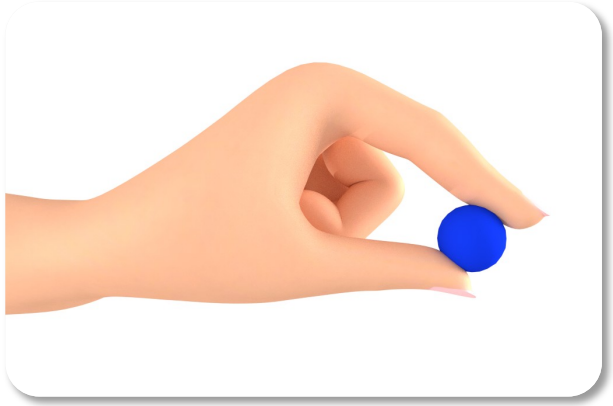


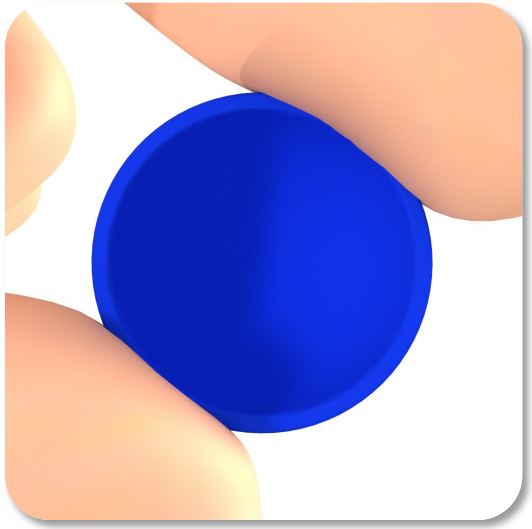




Interactions using a deformable hand

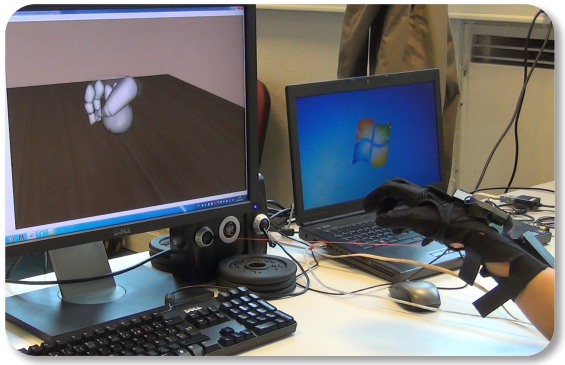
- **Contribution**: Aggregate constraints for the simulation of dexterous grasping [Talvas15, conditionally accepted]
  - Non-uniform pressure distribution
  - Torsional friction using Coulomb-Contensou formulation

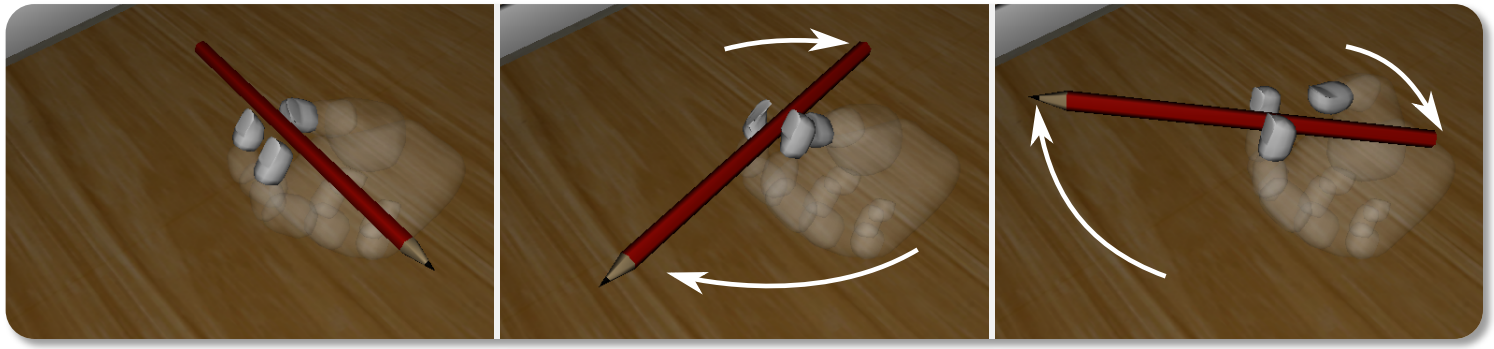




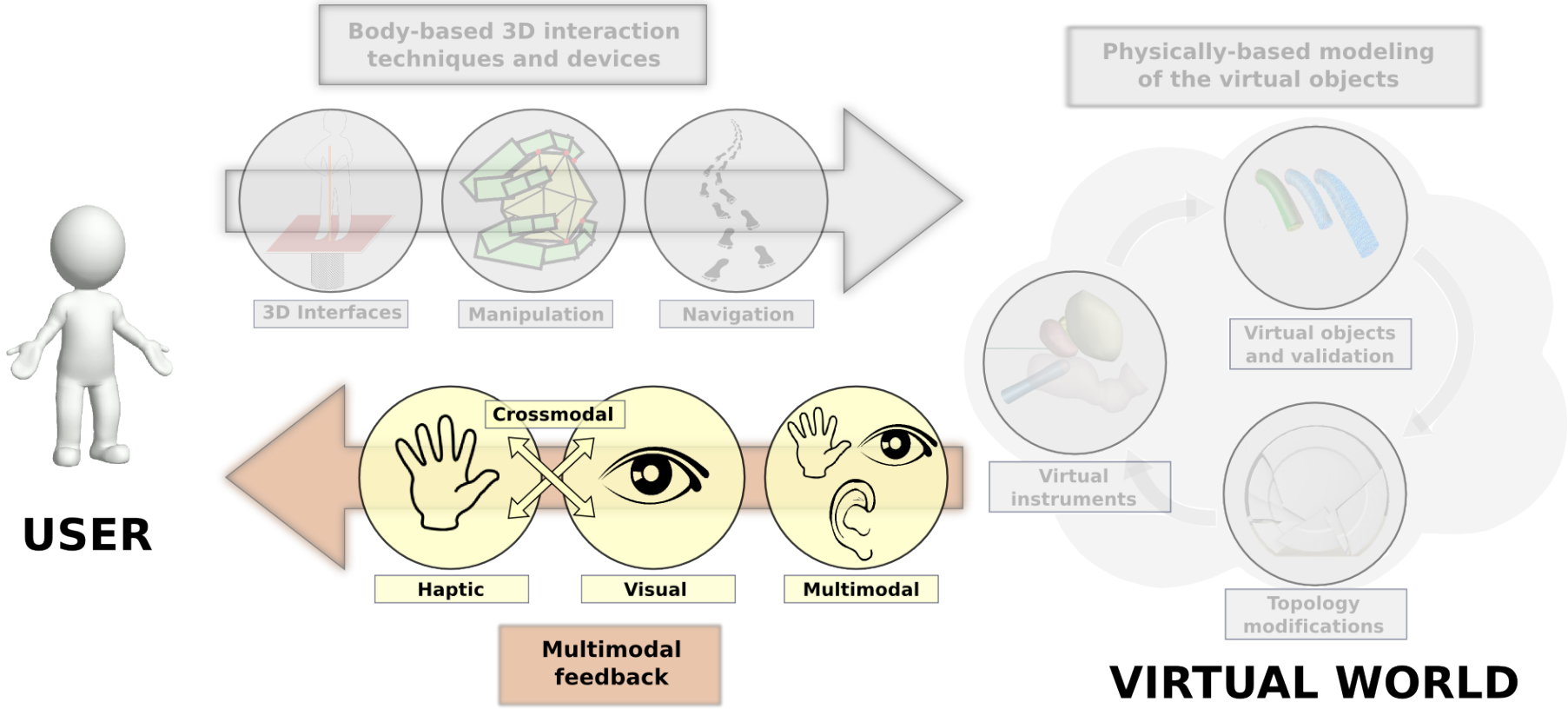
Interactions using a deformable hand

- Results: [Talvas15, conditionally accepted]



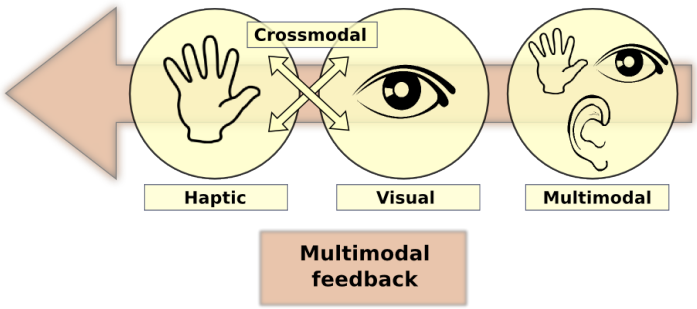


Axis II: Multimodal feedback



Axis II: Multimodal feedback

- Context:
  - Three sensory modalities: vision, hearing and touch
  - Specificities of VR technologies for the different sensory modalities

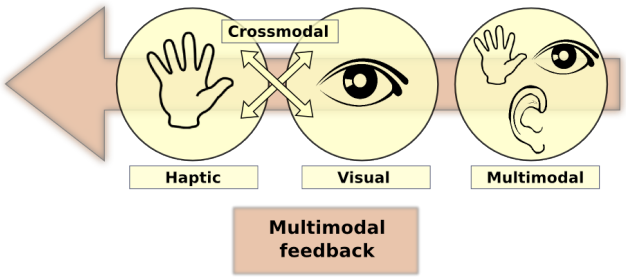


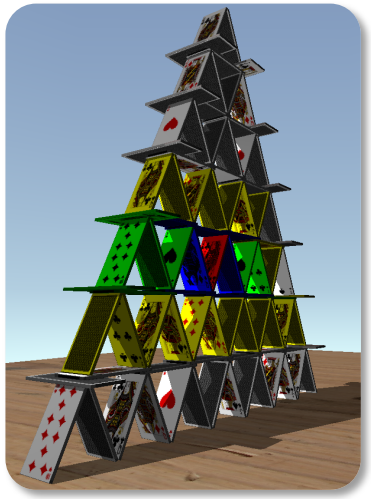
- Challenges:
  - Combining sensory modalities into a multimodal answer
  - Designing appropriate models for all the sensory channels

Outline

Axis II: Multimodal feedback with complex virtual environments

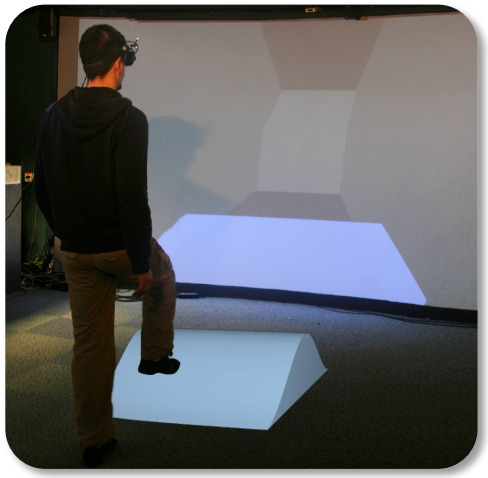
- Haptic feedback
- Visual feedback
- Multimodal feedback
- Crossmodal feedback





[Glondu09]

[Talvas13]

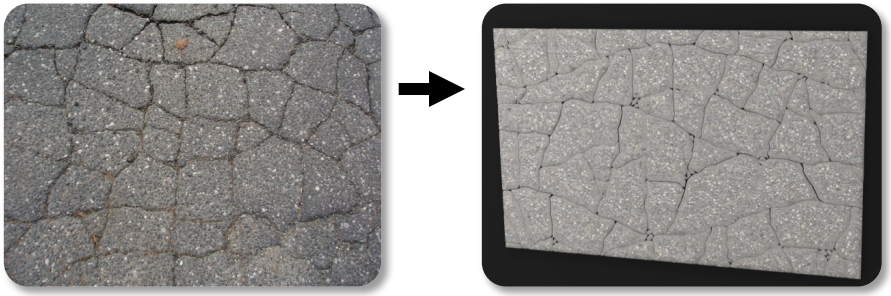


[Marchal10, Marchal12]

Visual feedback

Contribution: Example-based fracture appearance [Glondu12]

- Context:
  - Reproducing a specific fracture pattern with simulation can be a tedious task
  - Obtaining the same pattern is often not necessary

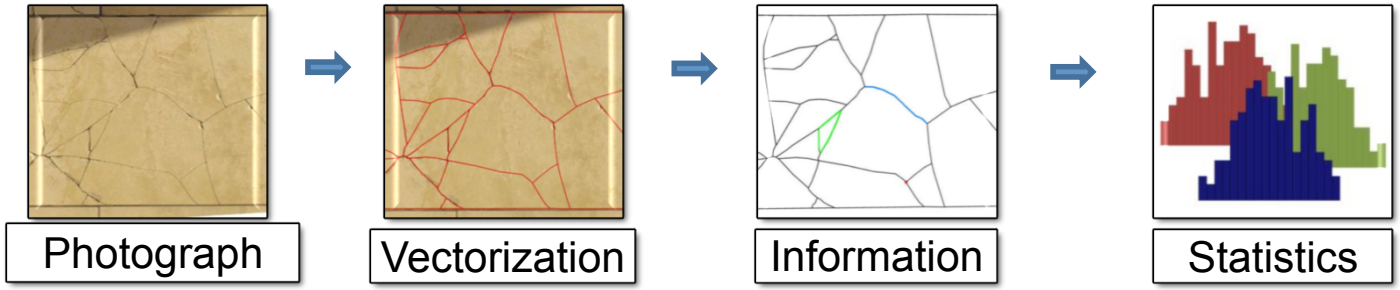


Photograph Simulation

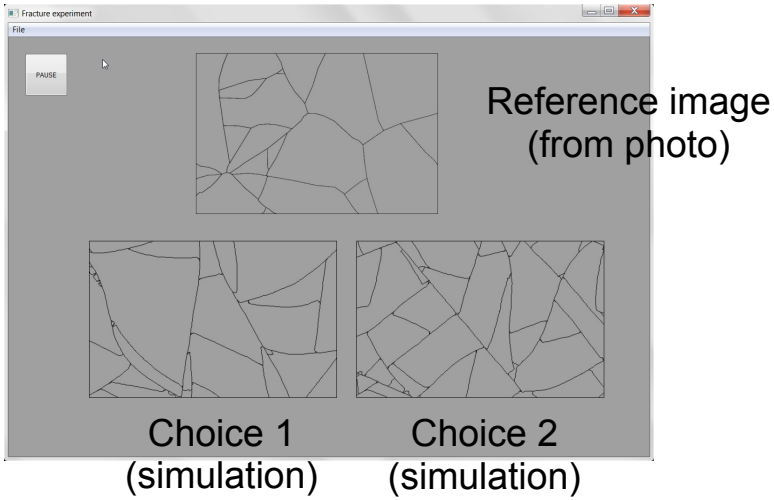
- Approach:
  - Estimate fracture simulation parameters from photographs
  - Match summary statistics rather that exact patterns
  - Perform a user study to weight statistics and use them as a metric during optimization

Visual feedback

- User study on statistical pattern similarity:
  - Processing patterns:



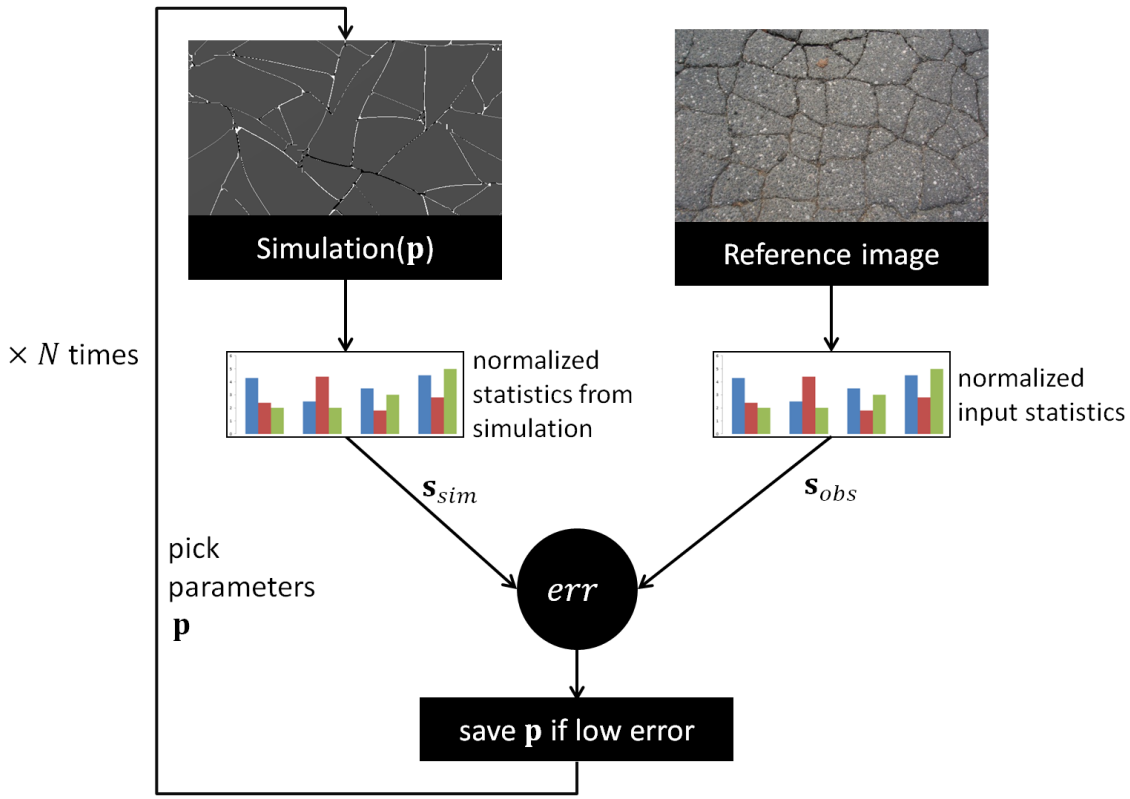
  - Performing a user study to define similarity between fracture patterns:



Which simulated pattern is the most similar to the reference pattern ? (2-AFC)

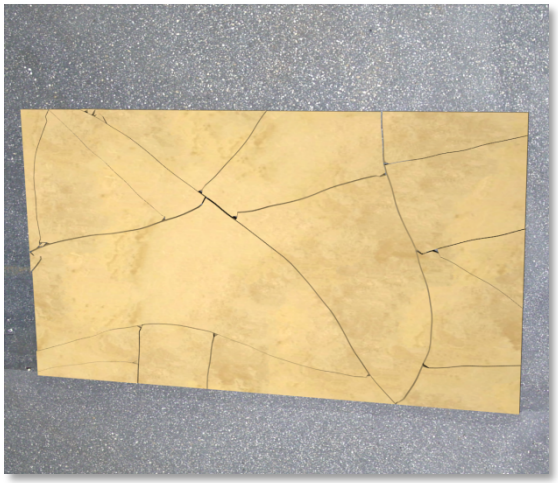
Visual feedback

- Optimization using a Bayesian approach:
  - Optimized parameters based on fracture mechanical properties
  - Metric: Earth Mover's Distance with weighting coefficients based on user study



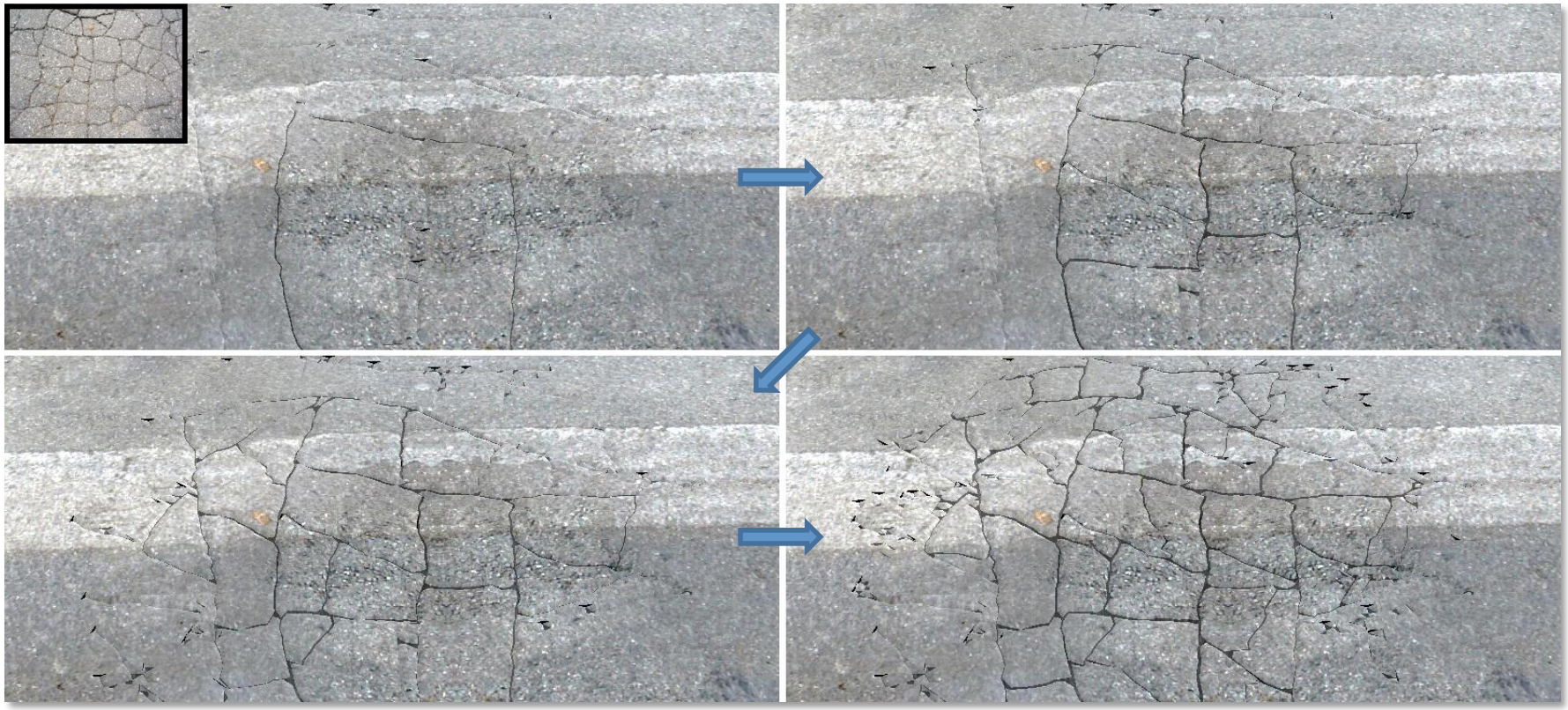
Visual feedback

- Results:



Visual feedback

- Results on fracture evolution:



Visual feedback

- Interactive modeler:

Outline

Axis II: Multimodal feedback with complex virtual environments

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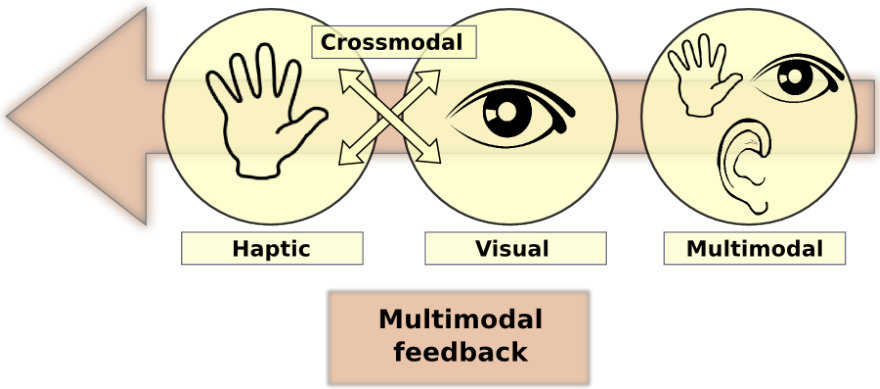
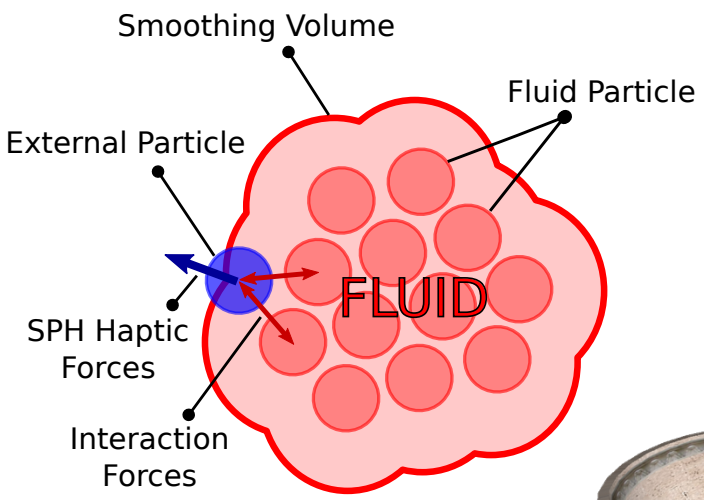
- Visual feedback
- Multimodal feedback
- Crossmodal feedback

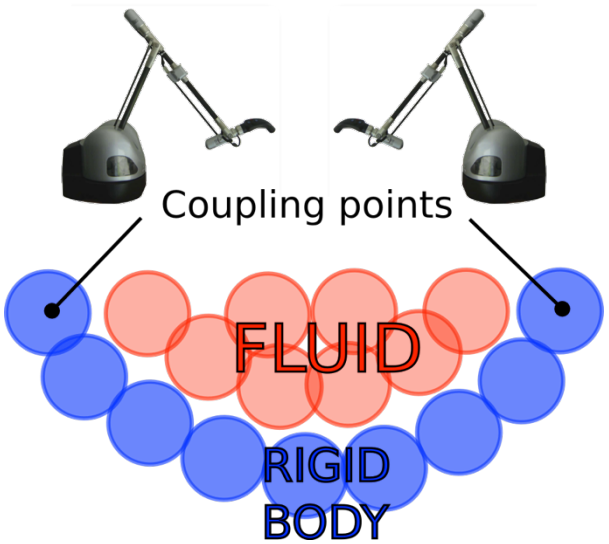


Multimodal feedback

Contribution: 6 DoF haptic interaction with fluids [Cirio11a] and different states of the matter [Cirio11b, Cirio13]

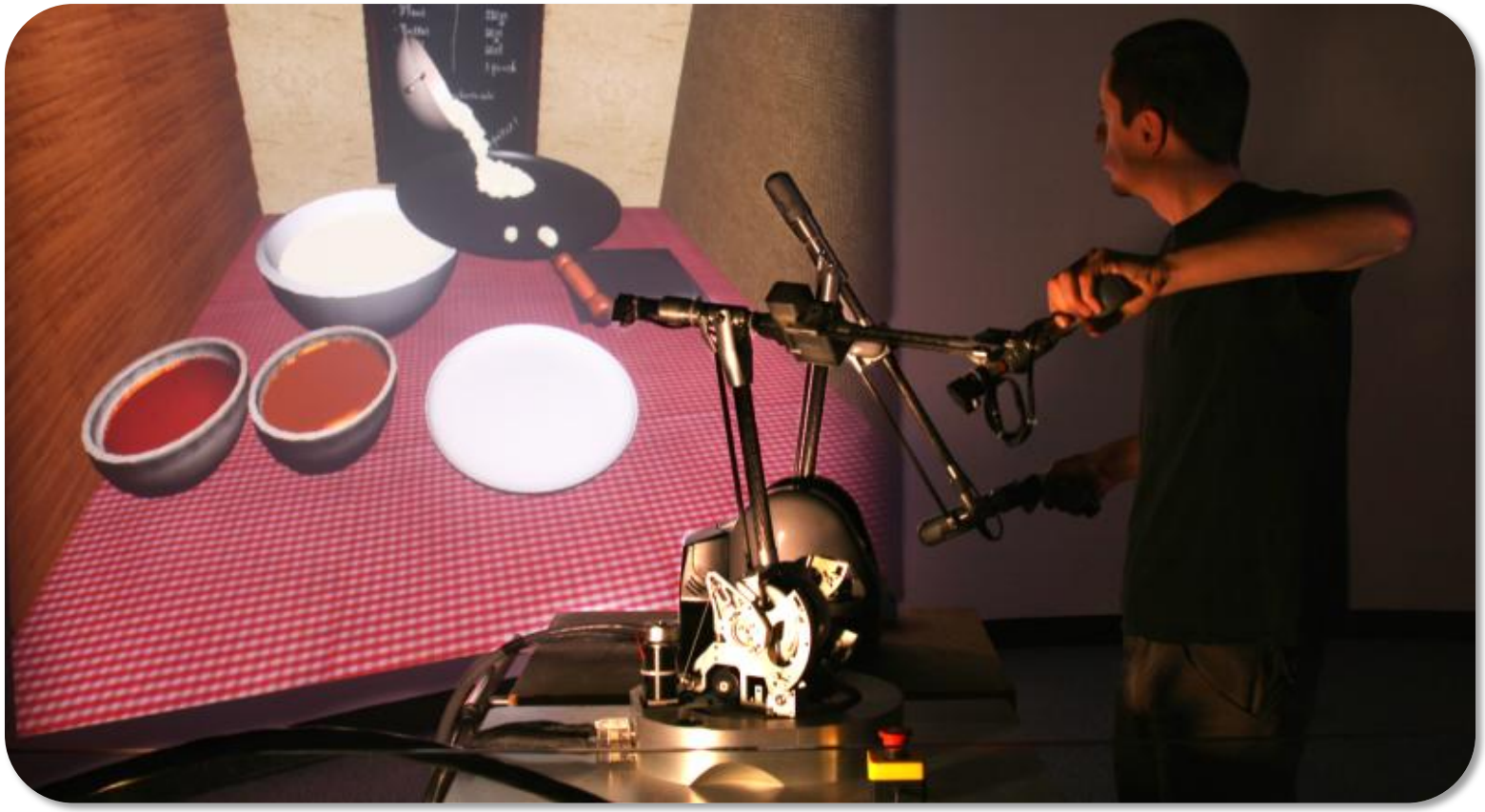
- Smoothed-Particle Hydrodynamics (SPH) for fluid, deformable and rigid bodies simulation
- Force feedback computation based on fluid-fluid interaction forces
- Multiple haptic coupling





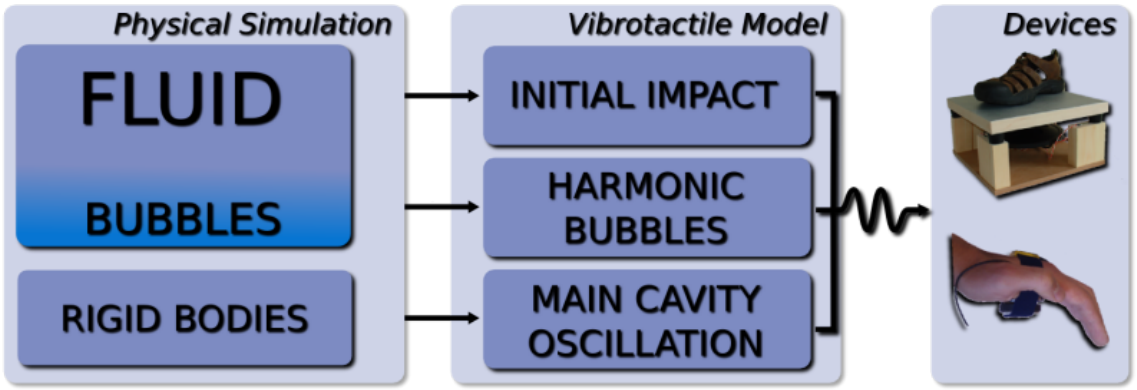
Multimodal feedback

- 6 DoF haptic interaction with fluids [Cirio11a, Cirio11b]



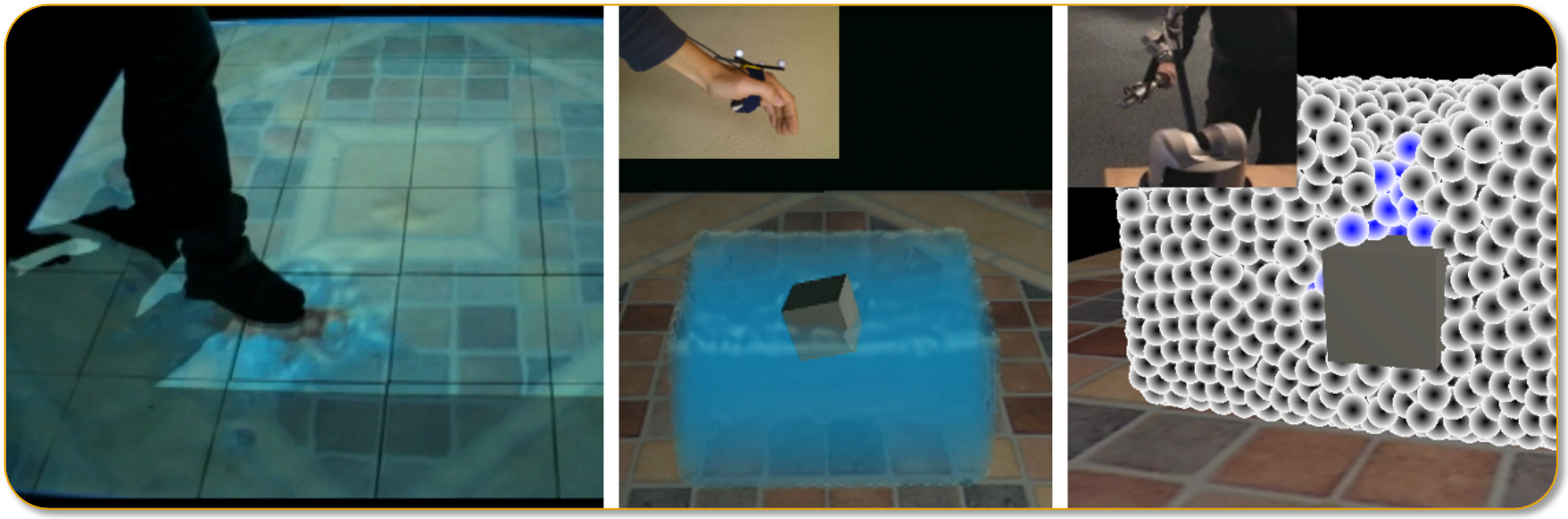
Multimodal feedback

- Extension to vibrotactile and acoustic rendering with a physically-based model of fluid air bubbles [Cirio13b]:
  - Bubbles responsible for most audible phenomena
  - Extend fluid simulator with real-time bubble and cavity simulation

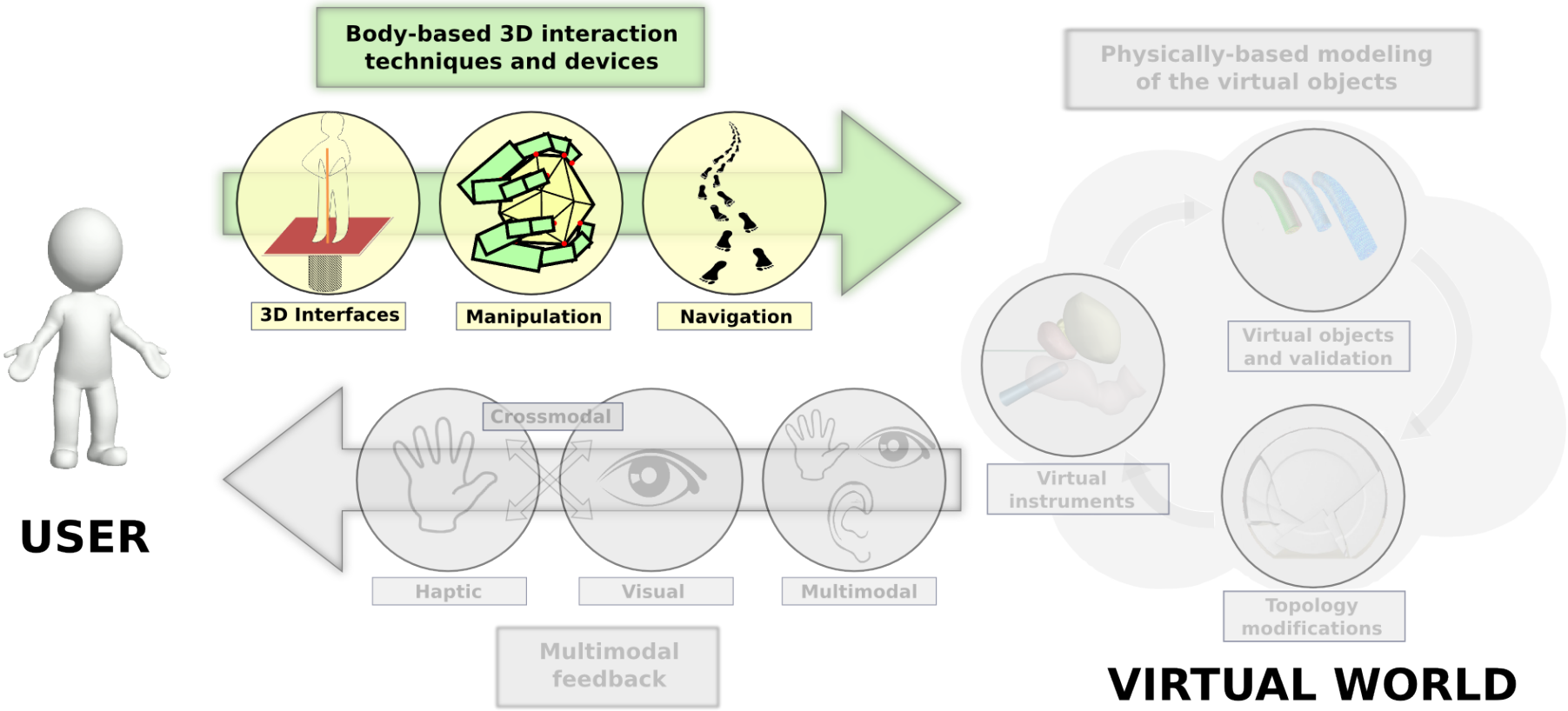


Multimodal feedback

- Multimodal rendering of fluids: [Cirio13b]

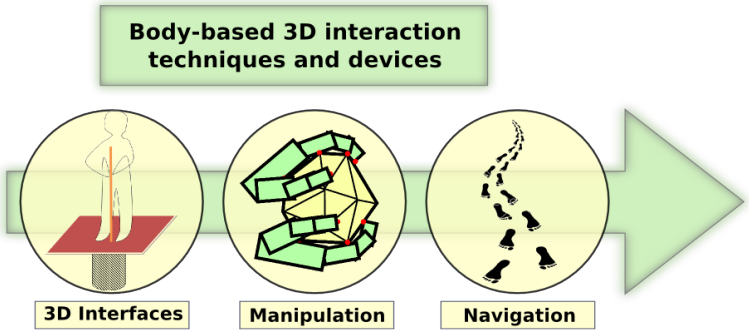


Axis III: Body-based 3D interaction



Axis III: Body-based 3D interaction

- Context:
  - Focus on navigation and manipulation tasks [Bowman04]
  - Emergence of novel setups and tracking systems opening the measurements of the whole user's body

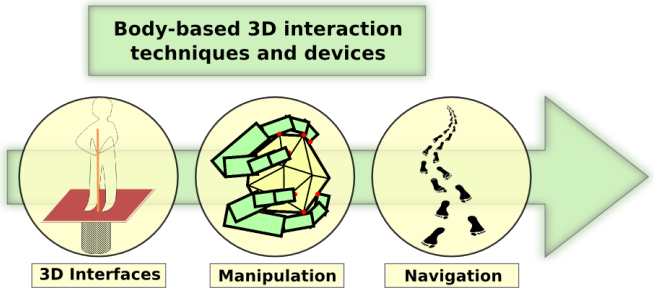


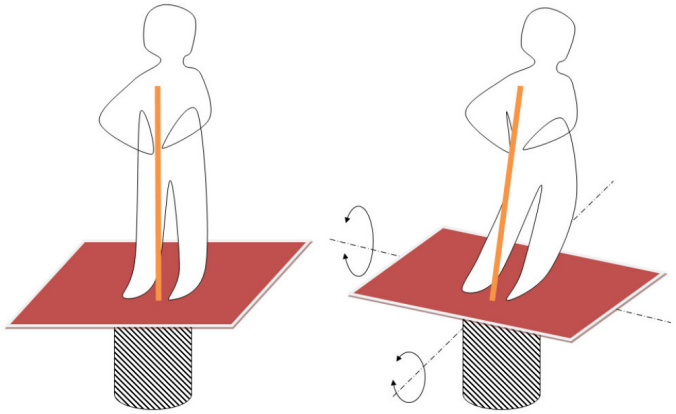
- Challenges:
  - Designing interaction techniques and devices that exploit all the user's body skills
  - Introducing interaction techniques that integrate different body parts in a natural manner

Outline

Axis III: 3D interaction with virtual environments using body skills

- 3D interaction devices
- 3D manipulation techniques
- 3D navigation techniques





[Marchal11]

[Ardouin13]

Manipulation

Contribution: The Virtual Mitten [Achibet14]

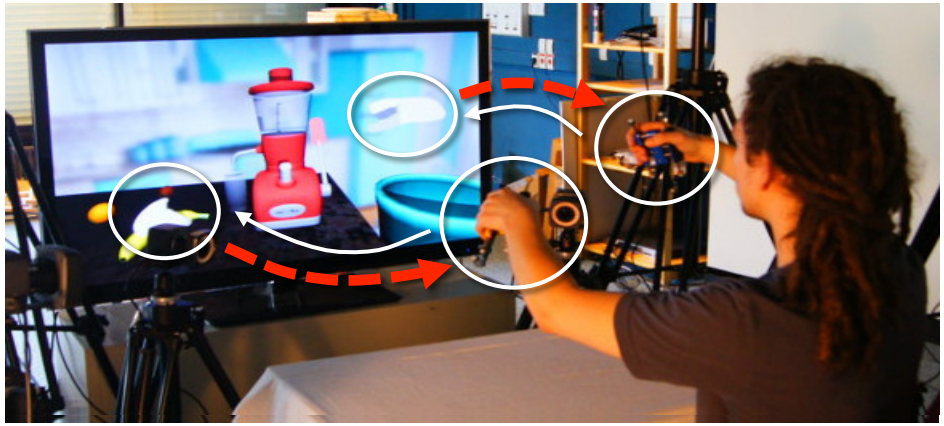
- Context: object manipulation in virtual reality

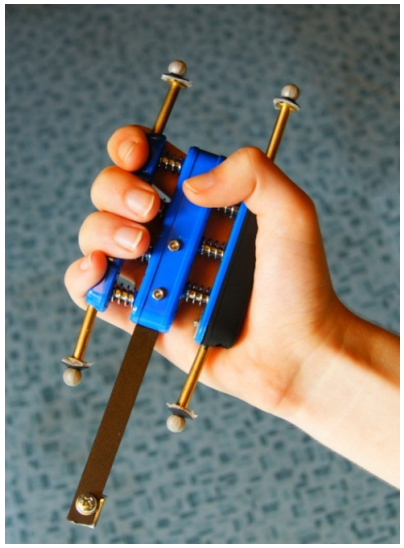
Manipulation

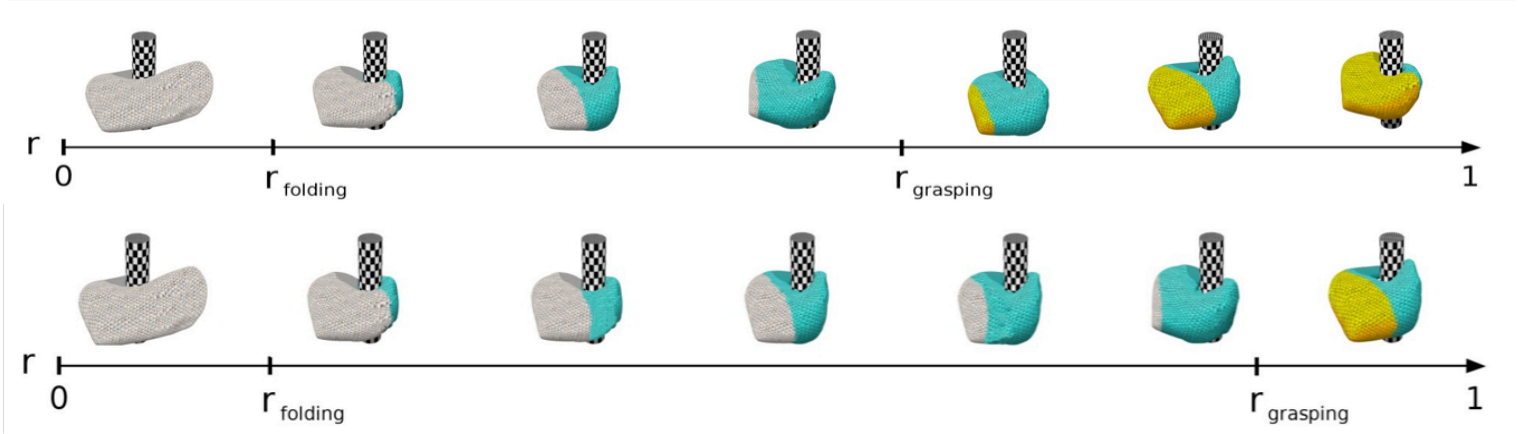
- Contributions [Achibet14]:
  - Real hands represented by virtual mittens
  - Lightweight and low-cost device device to control the mitten
  - Visual feedbacks and pseudo-haptic effect to modulate perceptions

Manipulation

- The Virtual Mitten components:

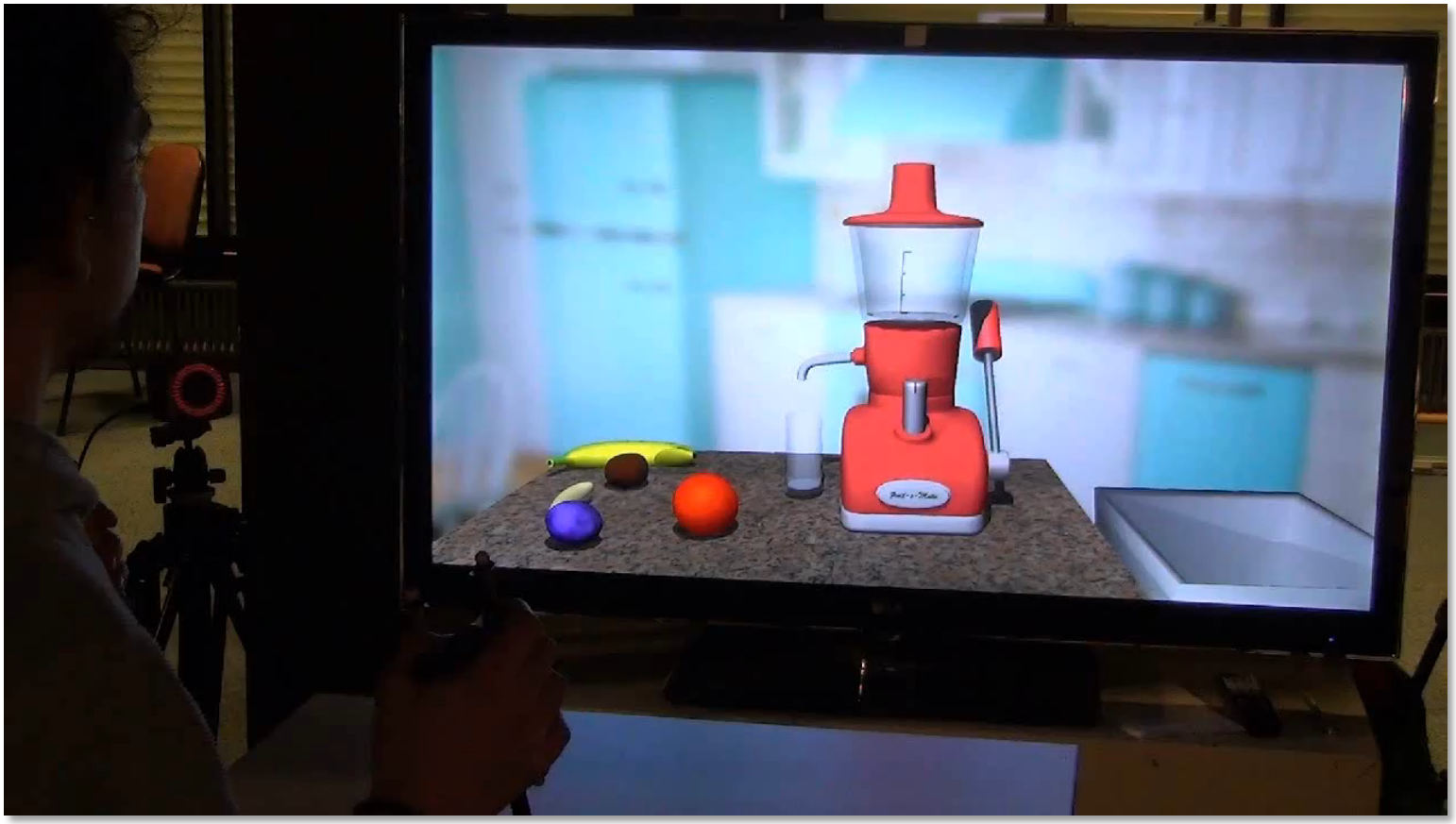






Manipulation

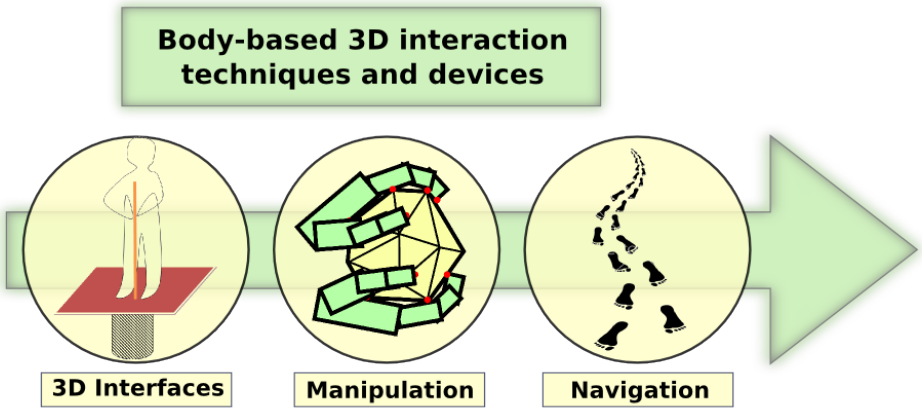
- Illustrative scenario: Fruit-O-Matic [Achibet14]



Outline

Axis III: 3D interaction with virtual environments using body skills

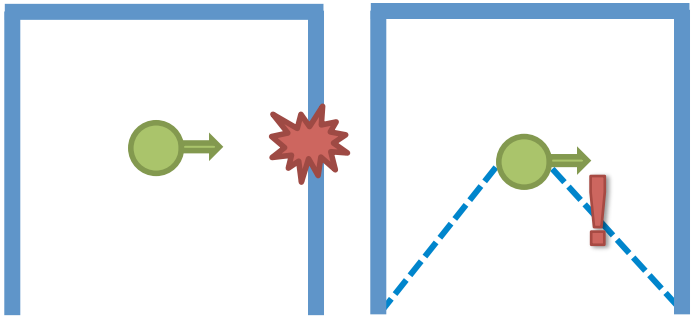
- 3D interaction devices
- 3D manipulation techniques
- 3D navigation techniques



Navigation

Contribution: Walking in a cube [Cirio09, Cirio12]

- Context:
  - Walking navigation issues with restricted workspaces



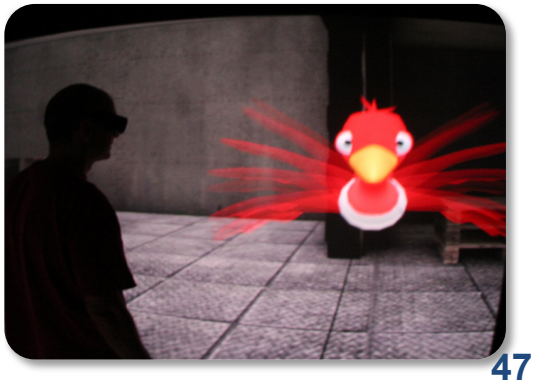
  - Possible solutions:
    - Hardware: locomotion interfaces *[Hollerbach 02]*
    - Software: walking navigation techniques

Navigation

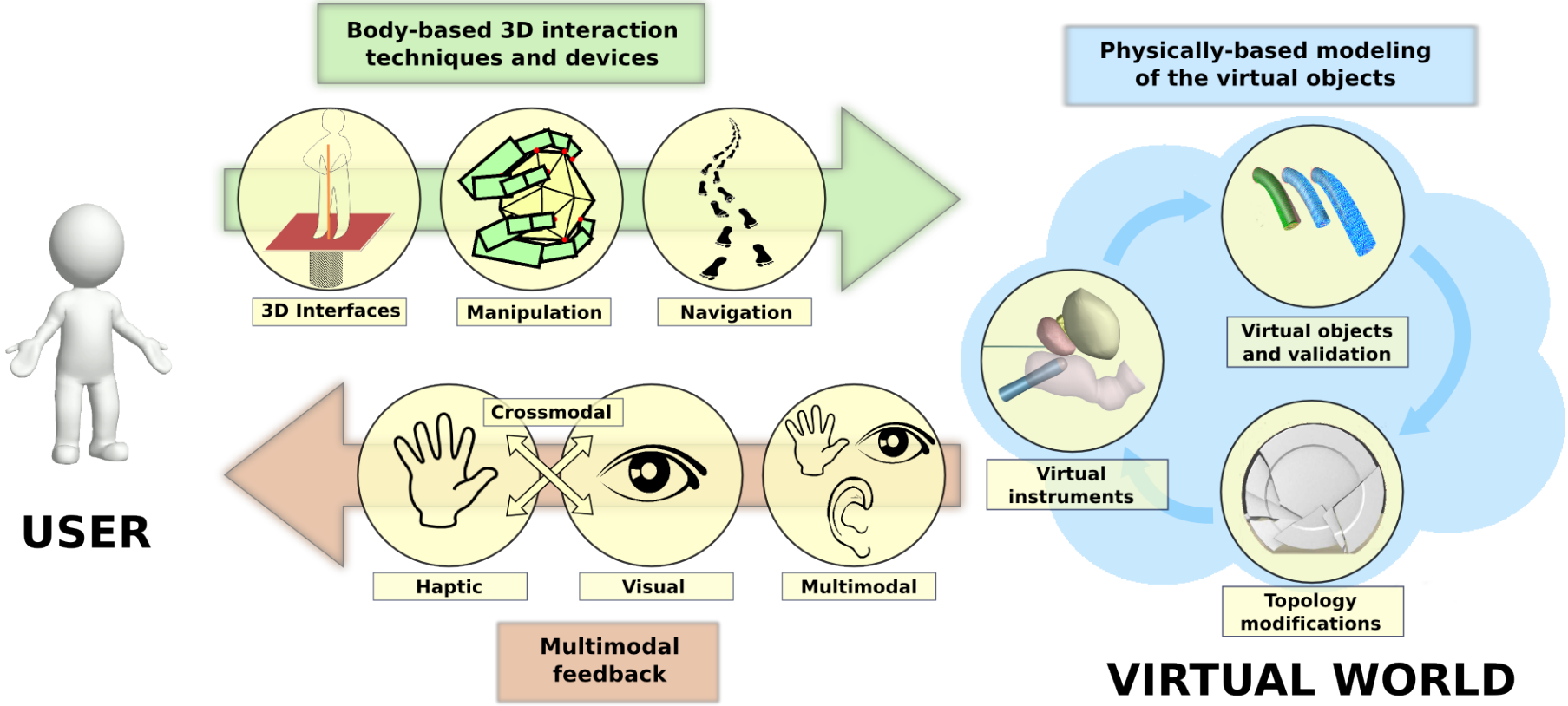
- Objectives:
  - Keep the user safe
  - Walk whenever possible
  - Provide an enjoyable and ecological paradigm

- Three novel metaphors for navigating in workspaces restricted in translation and rotation:
  - Constrained Wand & Signs
  - Extended Magic Barrier Tape
  - Virtual Companion

- A common approach with 2 components:
  - A warning technique:
    - Visual cues
  - A navigation technique:
    - Hybrid position/rate control



Summary of results

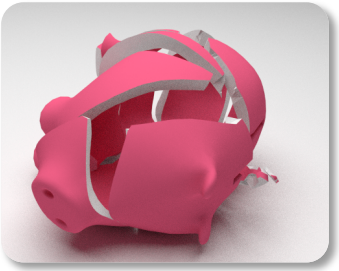


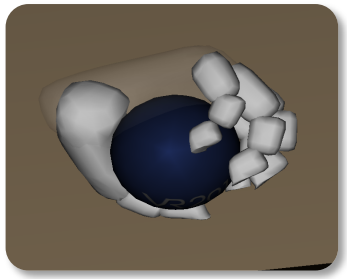
Summary of results

Axis I: Physically-based modeling of virtual objects and their interactions

- Design of physically-based models for various media and their interaction
- Introduction of a validation approach through comparisons with real data
- Development of algorithms for interactive simulations of virtual environments

Publications: 1 book chapter, 6 journal papers, 17 international conferences





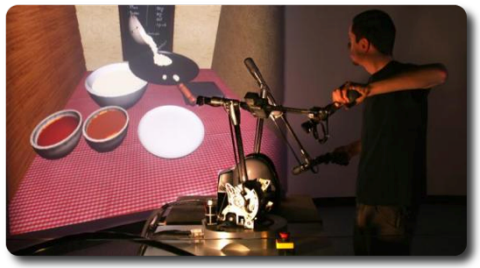
- Perspectives:
  - Real data collection and validation
  - Physically-based simulation of complex mechanical phenomena for interactive applications
  - Rising the hand as a multi-tool interaction interface

Summary of results

Axis II: Multimodal feedback with complex virtual environments

- Design of haptic rendering methods for physically-based feedback of complex scenes
- Parameter identification based on user's perception for sensory feedback
- Introduction of models and real-time algorithms for combining different sensory modalities

Publications: 4 book chapters, 6 journal papers, 18 international conferences



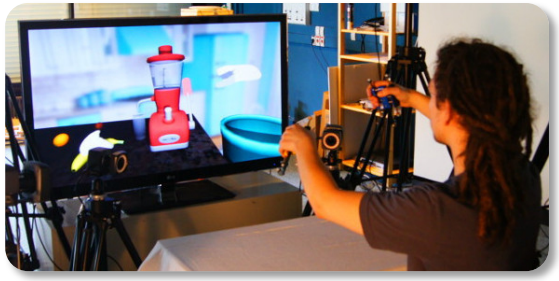
- Perspectives:
  - Multimodal feedback for multi-scale interaction
  - Feedback enhancement through physiological measurements

Summary of results

Axis III: 3D interaction with virtual environments using body skills

- Design of 3D hardware interfaces enhancing the user's body skills
- Introduction of interaction paradigms for manipulation and navigation tasks in virtual environments
- Validation and comparison through user studies

Publications: 2 book chapters, 6 journal papers, 15 international conferences

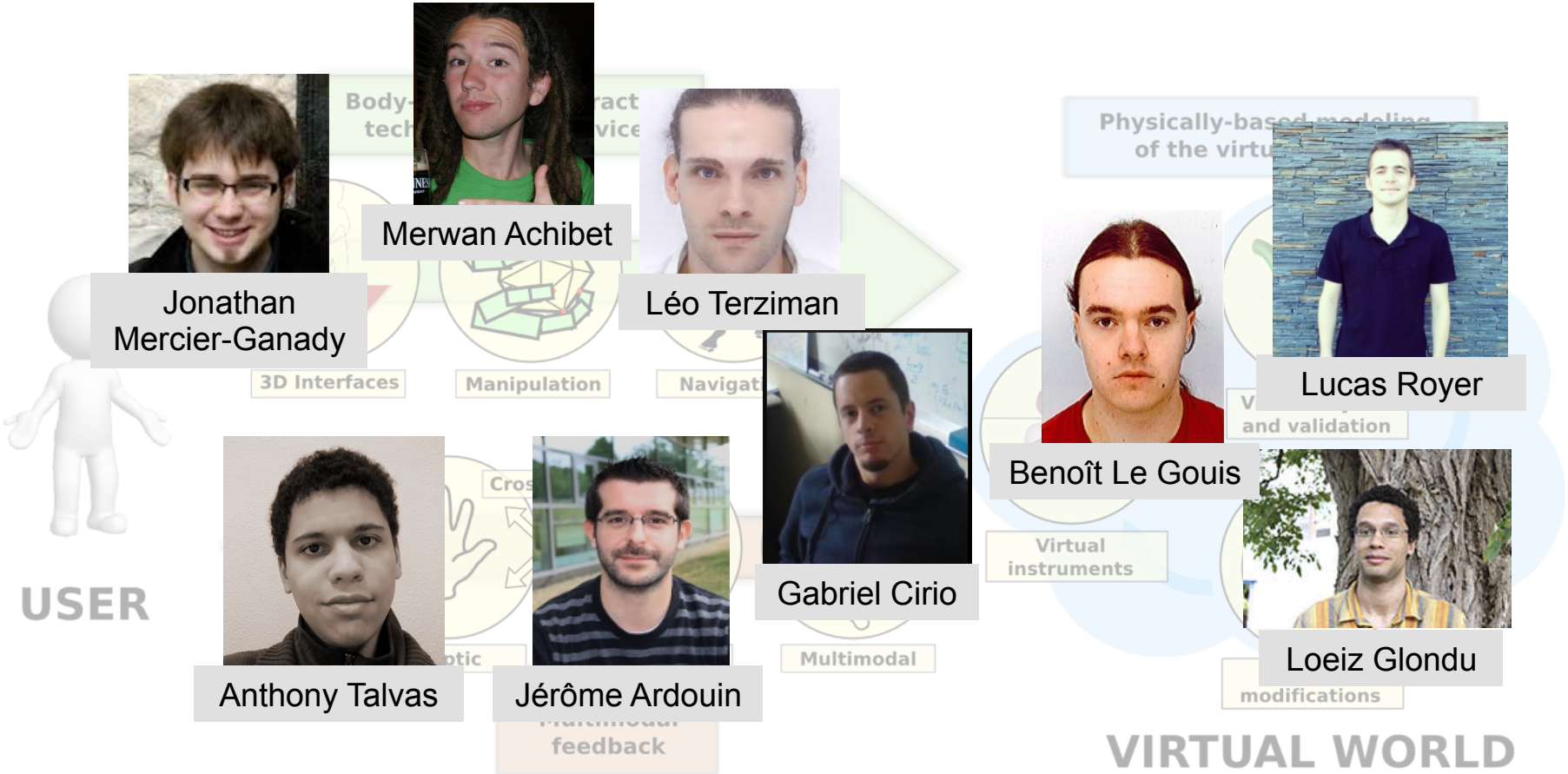


- Perspectives:
  - Design of interaction techniques for complex tasks
  - Multi-tasks interaction metaphors

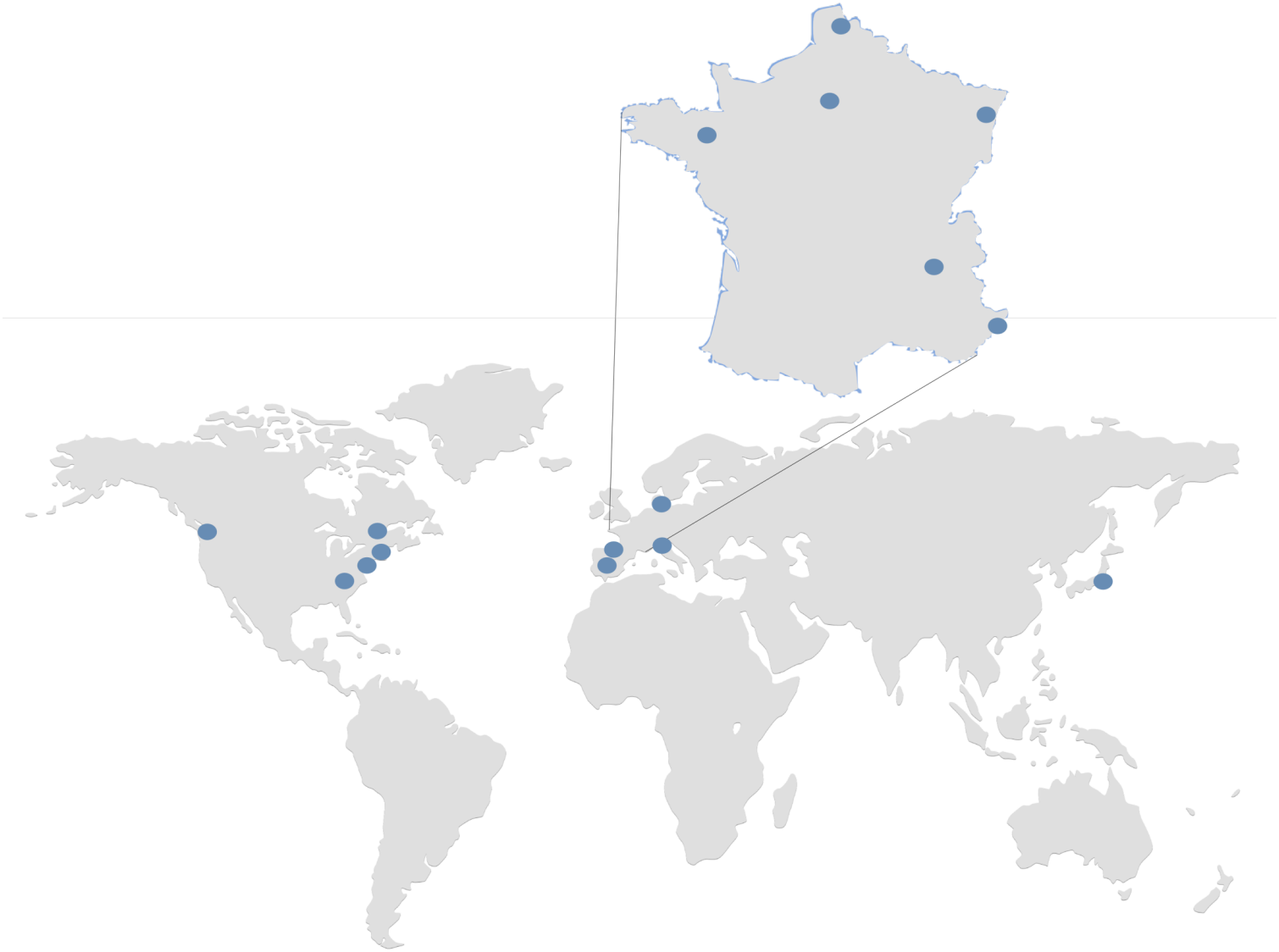
Long-term perspectives

- Perceptually-adaptive physically-based simulations
  - Parameter identification and inverse dynamics
  - Multi-scale approach with user's perception
- From multimodal to user-specific feedback
  - Natural gestures and haptic rendering
  - From multimodal to perception-based approaches
- Physicality of 3D interactions with virtual environments
  - Rising the body as a core interface
  - Towards dynamic metaphors for virtual tasks

Thanks to my PhD students



… and thanks to all my colleagues



Thank you for your attention