Experimental evaluation of two haptic techniques for 3D interaction:
constriction polyhedron / magnetic attraction

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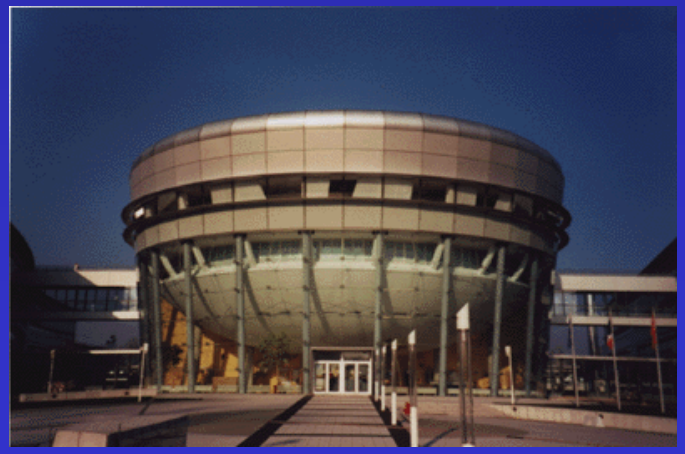
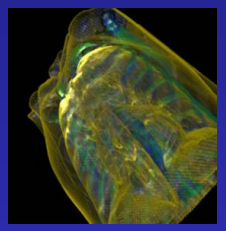
LSIIT Laboratory

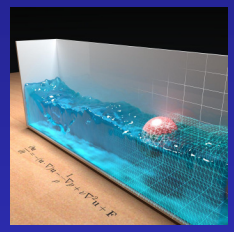
- LSIIT: Laboratoire des Sciences de l'Image, de l'Informatique et de la Télédétection (http://lsiit.u-strasbg.fr)
  - Joint laboratory: CNRS / Université de Strasbourg
  - Location: Strasbourg, France
  - 150 people
  - 75 faculty members
  - Since 1994



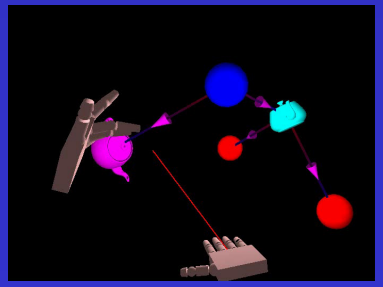
IGG Team: Computational Geometry & Computer Graphics

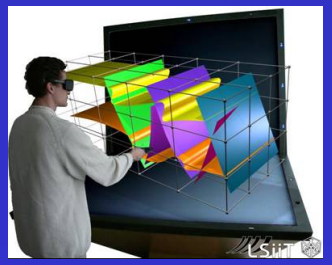
- 27 members (4 Pr., 9 Assist. Pr., 2 eng.)
- Many research topics around image synthesis & VR
  - Geometric modeling (surface & volume meshing)
  - Deformations
  - Simulation, animation
  - Scientific visualization
  - 3D interaction (virtual reality, haptic interfaces)
  - Proofs and constructions in geometry





spin menu



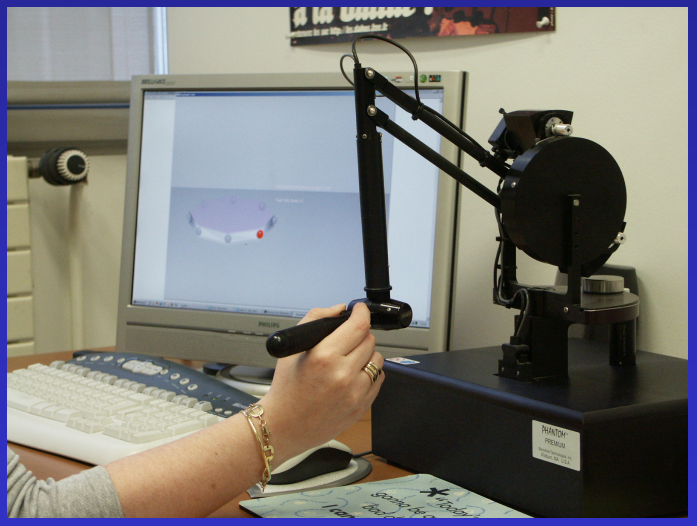


Study: Experimental evaluation of 2 haptic techniques for 3D interaction

- General objective of our work:
  - Enhance navigation and selection of randomly located targets within a 3D space, by using haptics
  - Haptic help in feeling depth
- Objective of this study:
  - First study on a 3D menu (set of targets located in the same plane)
- Preliminary comparative study of 2 haptic techniques:
  - Constriction polyhedron
  - Magnetic attraction
- Comparison with simple 3D interaction with no haptics

Experimental setting

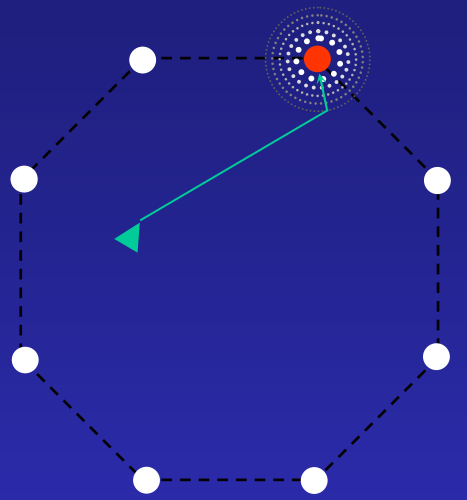
- Device:
  - Phantom Premium 1.5 (Sensable) with 6dof



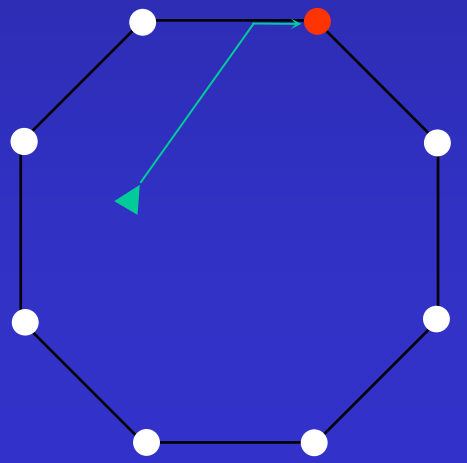
- Preliminary study → only 6 subjects

Description of the haptic menu

- Polyhedron shape (≈ "pie shaped")
- Each vertex:
  - small white ball which corresponds to a menu item
- Haptic plane:
  - User has a "tactile basis" where the pointer can lie on
- 2 propositions of haptic guidance to items:
  - Magnetic targets
  - Constriction polyhedron = borders of polyhedron are hard and slippery
- Modifiable parameters:
  - Diameter
  - Number of items (→ shape)
  - Strength of attraction (magnetic targets)
- Oblique 3D menu (not vertical)
  - Possibility to have several layers in the future



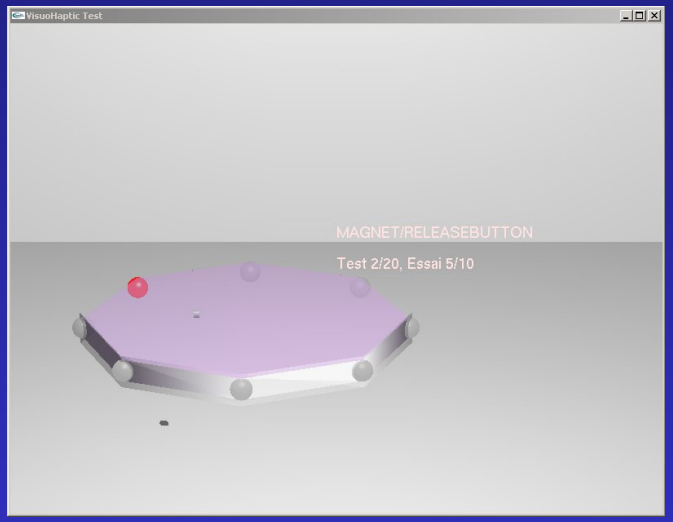
Magnetic targets



Constriction polyhedron (hardborders)

Description of task

- Select a randomly located item (red ball) in the menu → vertex



- Three conditions:
  - No haptics : attraction plane, no haptics on the targets
  - Magnet : attraction plane + magnetic attraction on the target
  - Hard borders (constriction polyhedron) : attraction plane + hard borders of the menu

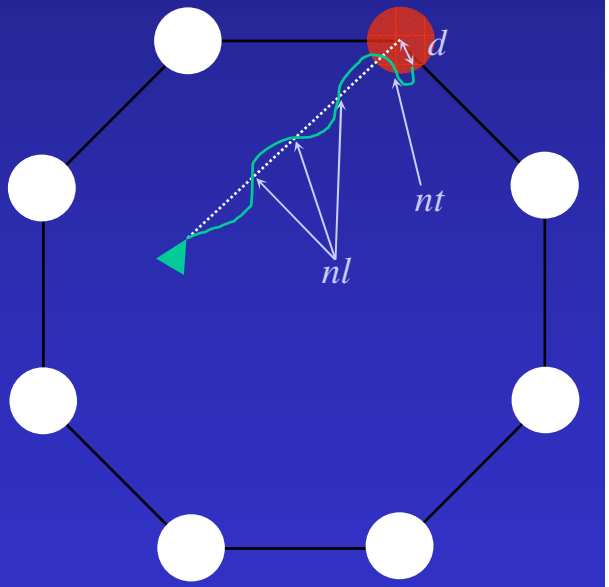
- Measurements (quantitative evaluation) + questionnaire (subjective evaluation)

Task progress

- Task progress:
  - Step 1: menu appears on demand (clic) centered on the pointer
  - Step 2: immediately a randomly selected item highlights (red ball)
  - Step 3: the subject positions the pointer on the item
  - Step 4: the subject validates the selection (clic, again)
  - Step 5: the menu disappears

Measurements

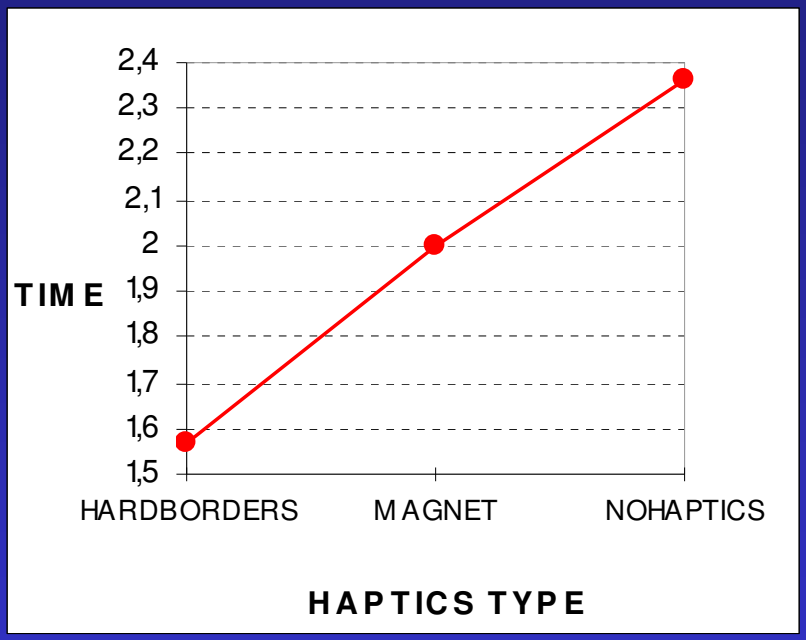
- From step 1 to step 5, we measure:
  - **Task completion time**: Time spent from the apparition of the menu to the validation of the selection
  - **Precision**: Distance between the pointer and the center of the target at the moment of the selection *(d)*
  - **Axis crossings**: Number of times the pointer has crossed the line connecting the center of the menu and the target *(nl)*
  - **Target crossings**: Number of times the pointer has crossed the target during the task *(nt)*



- For each measurement, we calculate probability p:
  - "p ≤ 0.05" = "less than 5% chance that the difference is due to coincidence" → significant difference

Experimental results

- Task completion times:



  - Significant effect of the type of haptics

    $F(2,537) = 62.051$ $p < 0.0001$

  - "*Hardborders*" technique significantly faster than "*magnet*"

    1.559 s. ↔ 2.003 s. gain of 22% $p < 0.0001$

  - "*Magnet*" significantly faster than "*nohaptics*"

    2.003 s. ↔ 2.361 s. gain of 15% $p = 0.001$

Experimental results

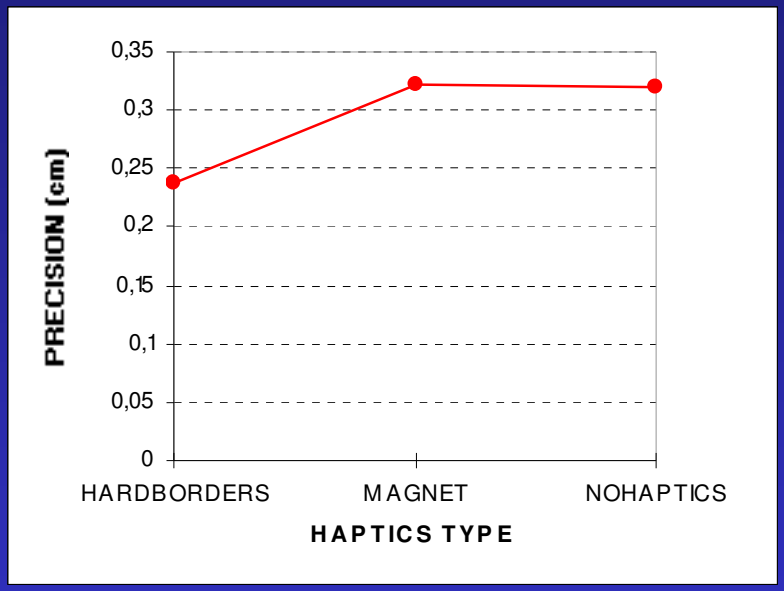
- Precision:

  - Significant effect of the type of haptics

    F(2,537) = 13.884 p < 0.0001

  - "*Hardborders*" technique significantly more precise than "*magnet*"

    0.228 cm ↔ 0.322 cm gain of 29% p <0.0001

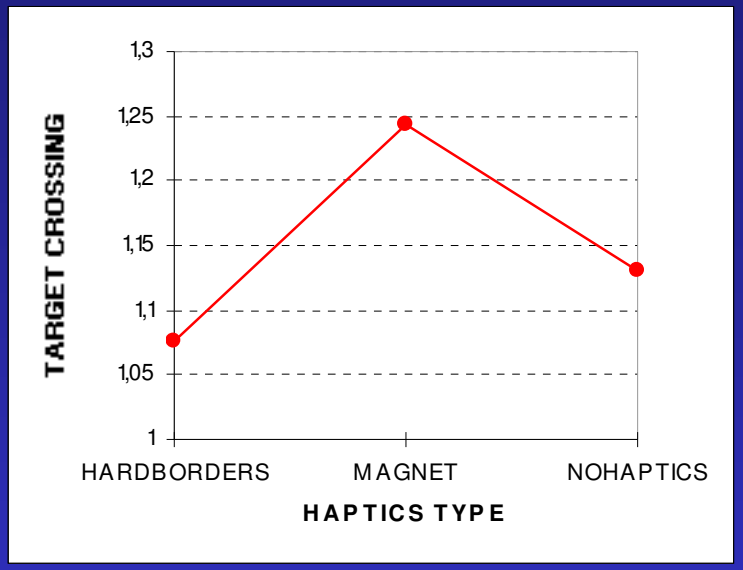


  - No statistically significant difference between "*nohaptics*" and "*magnet*"

    p = 0.956

Experimental results

- Target crossing:



  - Significant effect of the type of haptics

    $F(2,537) = 6.866$ $p = 0.001$

  - Target crossing number significantly higher with "*magnet*" than "*hardborders*"

    $1.243 \leftrightarrow 1.075$ $p < 0.0001$

  - No statistically significant difference between "*nohaptics*" and "*hardborder*"

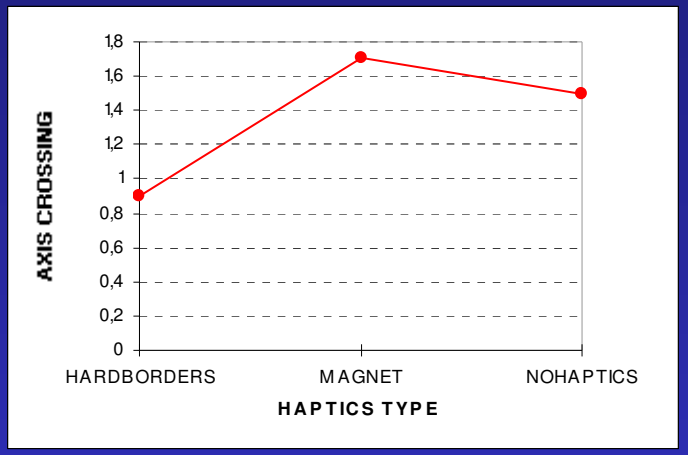
    $1.13 \leftrightarrow 1.075$ $p = 0.401$

  - No statistically significant difference between "*nohaptics*" and "*magnet*"

    $1.13 \leftrightarrow 1.243$ $p = 0.083$

Experimental results

- Axis crossing:



  - Significant effect of the type of haptics
    $F(2,537) = 10.7$ $p < 0.0001$
  - Axis crossing number significantly higher with "*magnet*" than "*hardborders*"
    $0.895 \leftrightarrow 1.709$ $p < 0.0001$
  - Statistically significant difference between "*nohaptics*" and "*hardborder*"
    $1.5 \leftrightarrow 0.895$ $p = 0.018$
  - No Statistically significant difference between "*nohaptics*" and "*magnet*"
    $1.5 \leftrightarrow 1.709$ $p = 0.407$

Discussion

- Results interpretation:
  - **Magnet:**

☺ short completion times

☹ no gain in precision

☹ a tendency to higher number of axis and target crossings

→ **loss of control of the user over the task**

(this hypothesis is supported by subjects commentaries)

  - **Hardborder:**

☺ shorter completion times

☺ gain in precision

☺ less axis and target crossings

→ **helps the user to complete the task while maintaining control over the behaviour of the pointer**

(this hypothesis is supported by subjects commentaries)

Questionnaire results

- Subjective evaluation: Effort

  - Significant effect of the type of haptics

    F(2,537) = 4.617 p = 0.013

  - "*Nohaptics*" vs "*hardborder*":

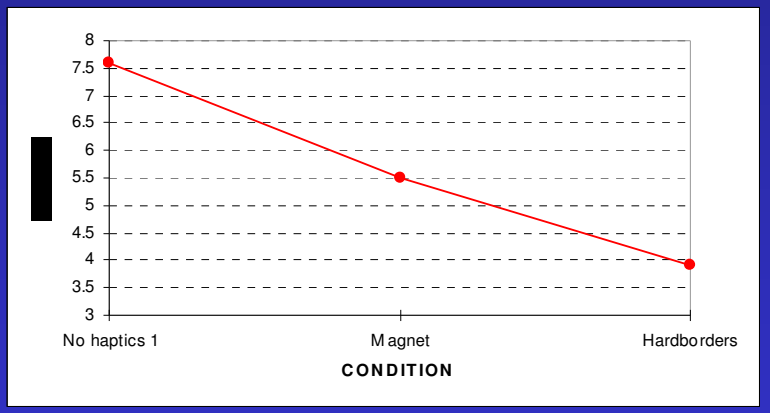
    7.6 ↔ 3.91 p = 0.005

  - "*Nohaptics*" vs "*magnet*":

    7.6 ↔ 5.51 p = 0.102

  - "*Magnet*" vs "*hardborder*":

    5.51 ↔ 3.91 p = 0.077



Questionnaire results

- Subjective evaluation: Performance
  - Significant effect of the type of haptics

    $F(2,537) = 11.986$, $p < 0.0001$
  - "*Nohaptics*" vs "*hardborder*":

    $10.4 \leftrightarrow 15.73$, $p = 0.005$
  - "*Nohaptics*" vs "*magnet*":

    $10.4 \leftrightarrow 13.71$, $p = 0.004$
  - "*Magnet*" vs "*hardborder*":

    $13.71 \leftrightarrow 15.73$, $p = 0.012$

Discussion

- Feeling of effort
  - Haptics in general help to reduce the subjective feeling of effort
  - Statistical tendency to feel less efforts with hardborders compared to magnet
- Feeling of performance
  - Haptics in general help to increase the subjective feeling of performance
  - Statistically significant difference between all conditions: hardborder leads to increased feeling of performance

Conclusion

- Preliminary study on a few subjects
  - Haptics are a good way to guide 3D interaction and selection
    - faster, easier than without haptic guidance
  - "*Hardborders*" technique wins:
    - better precision and performances
    - better feelings

- More complete study will follow with both methods, including:
  - Different values of parameters (diameter, number of items, strength of attraction, …)
  - Different modes of repulsion from borders (flat, incurved, "star borders"), with or without visualization of the haptic shape
  - Different ways to select (clicking, crossing the target)
  - Different levels of menu (submenus when choosing an item)
  - Different levels in main menu (layers)
  - More subjects

Future works

- Extension to navigation and selection of randomly located targets within a 3D space
  - Main (well known) problems:
    - Great number of objects
    - Occlusions between objects
    - Difficulty to perceive depth
- Haptic guidance to navigate within "convex 3D cells"
  - Haptically enhanced
  - Help overcoming problems

Thanks for your attention

- Questions ?