UNIVERSITÀ DEGLI STUDI
DI GENOVA

Haptic simulation for surgical training

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Robotics Engineering Course – Literature Review

Motivation

? Why haptics

Most medical procedures involve the use of **tactile sense** to feel and manipulate tissues and body parts.

To acquire the right motor skills, students must repeat the same operation multiple times.

Various teaching options have been tested, such as: animals, mannequins, Virtual Reality with **haptics.**

Pros: multiple sensory channels involved in training, can reproduce various scenarios, repeatability, no ethical problems.

Virtual environment models

Create the skin patch simulation: behavior model, collision model and visual model.

SOFA

Haptic control

Implement a single or bimanual haptic control with the **Geomatic Touch**.

Medical task simulation

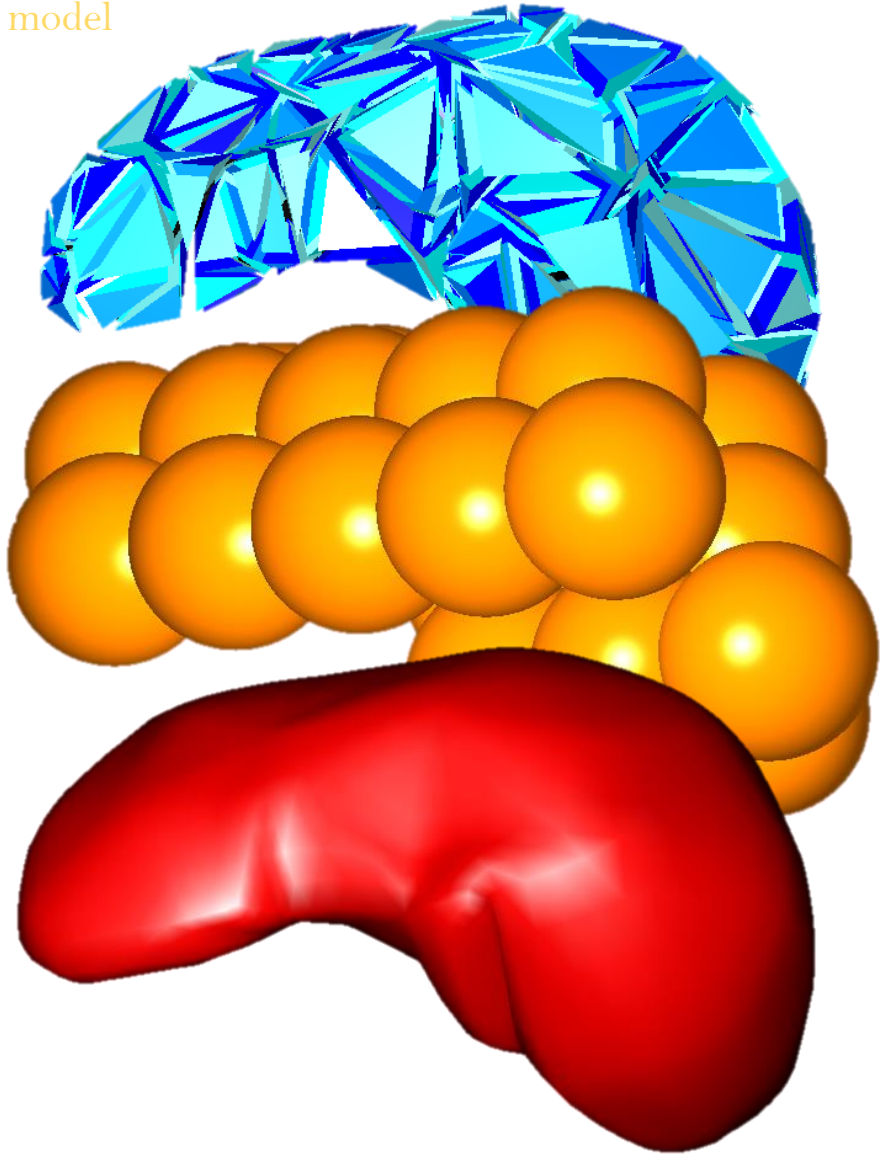
Develop multiple tasks for medical training: needle insertion, suturing procedure, skin incision, hernia palpation, …

Testing phase

Testing phase (pilot testing) and analysis of results.

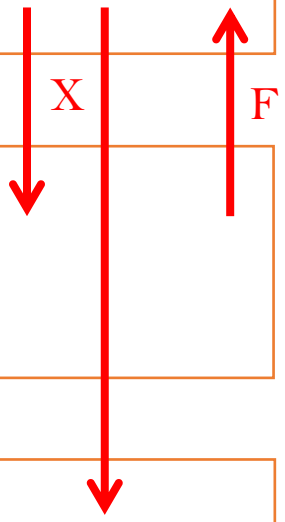
Virtual Environment Models

Behavior model
Collision model
Visual model



SOFA

Behaviour model:
F = ma



Collision model:
Three phases pipeline

Visual model:
Graphical rendering

Behavior model
Collision model
Visual model

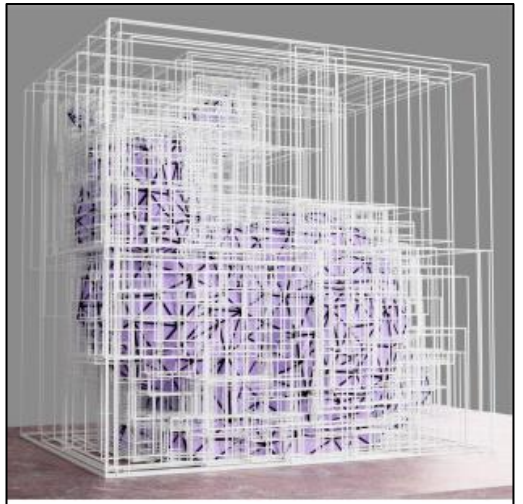
- Describes internal mechanical behavior.
- The object is modelled with a dynamic system of particles (**Discretization of space)** whose positions and velocities are calculated by integrating $F = ma$ at each time interval dt (**Discretization of time**).
- Need to define:
  - the mass and its distribution
  - how to build the system $a = F\,m^{-1}$
  - how to solve such system.

Mesh

- Bounding volumes hierarchy: wrap all nodes in bounding volumes then group the nodes in small sets enclosed within larger bounding volumes in a recursive way. Result: tree structure with a single bounding volume at the top of the tree

- Collision is checked in 3 steps:
  - broad phase
  - narrow phase
  - response

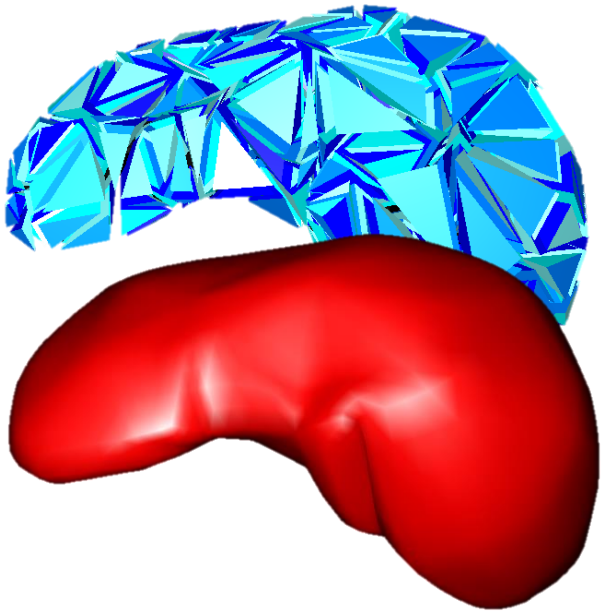
Bounding Volumes



Resulting BVH

Behavior model
Collision model
Visual model

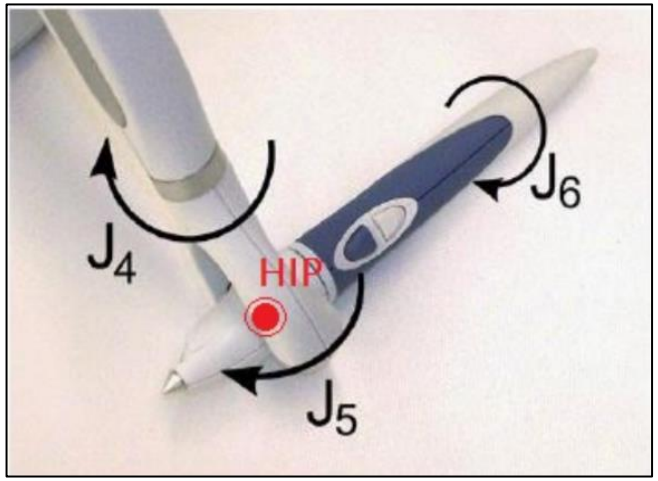
- Important for **suspension of disbelief**
- Small meshes (trade off between rendering and computational power)



Haptic feedback

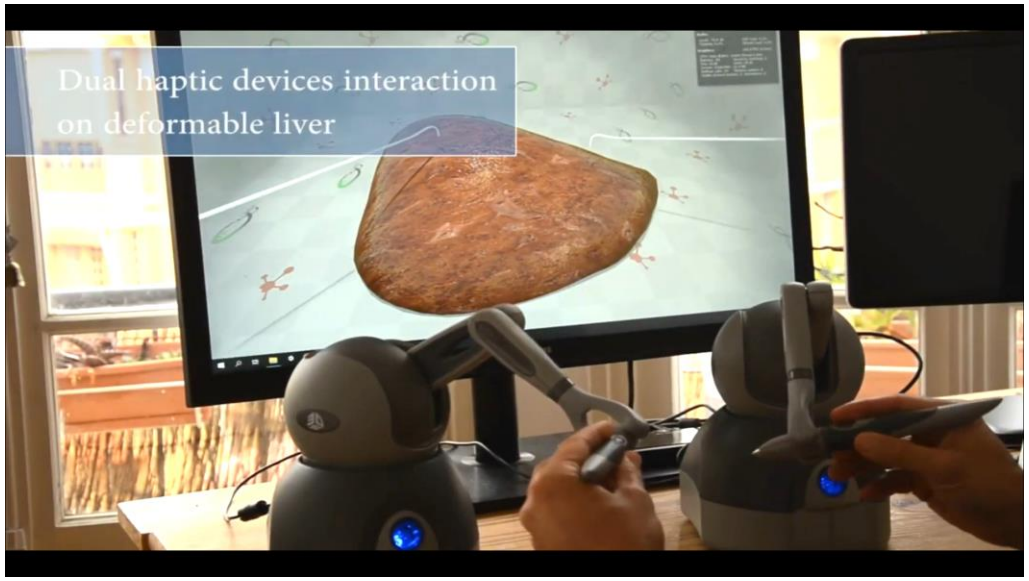
- Add the tactile feedback:
  - Geomatic Touch device

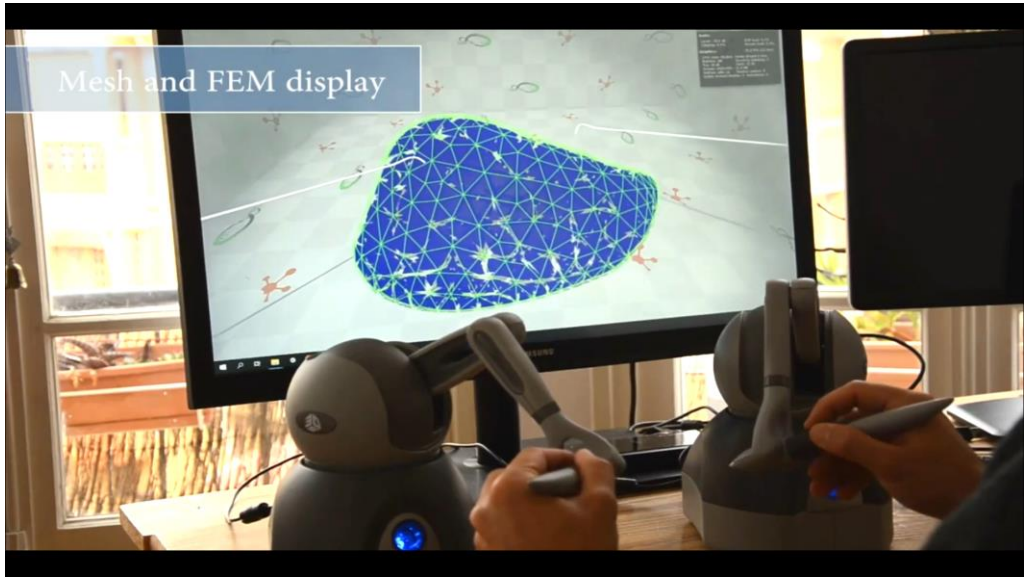
ACTUATED JOINTS – position of the HIP



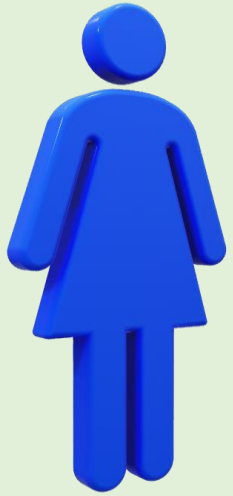
PASSIVE JOINTS – orientation of the stylus

- Add the tactile feedback:
  - Geomagic driver
  - OpenHaptics libraries
  - SOFA Geomagic plugin



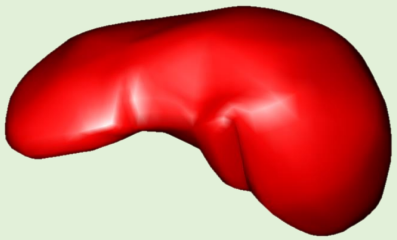


HUMAN USER



HAPTIC DEVICE

VIRTUAL ENVIRONMENT



Manipulation

Sensing

Joint sensors

q

Forward Kinematic Equations

$x = f(q)$
$\dot{x} = J(q)\dot{q}$

Haptic control

Perception

Actuation

Actuators

$\tau = J^T F$

Kinematics

F

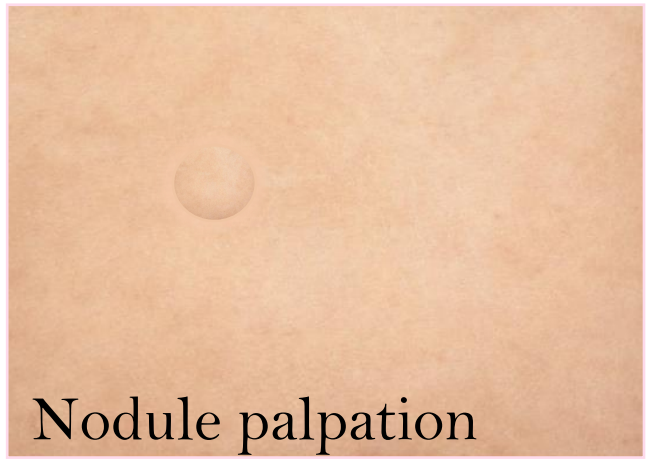
Haptic feedback

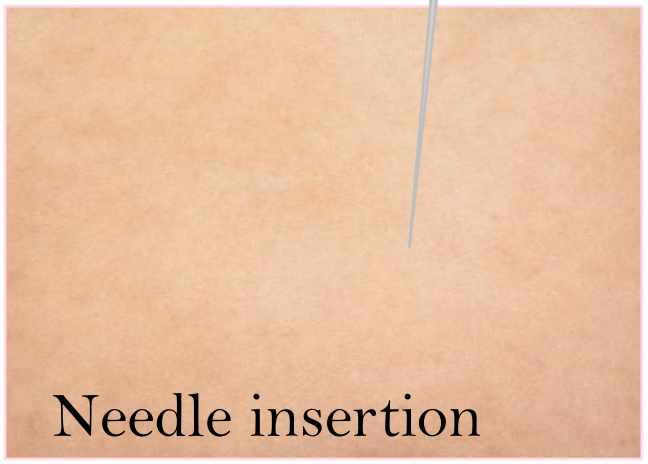
Bimanual control

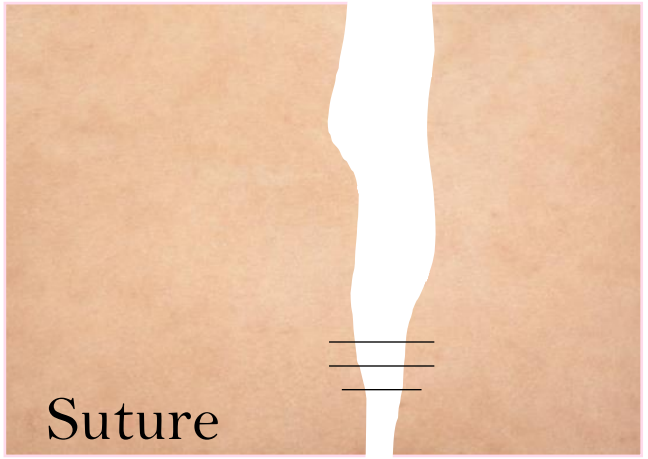
- Possibility to work with two devices and feel the force feedback on both of them.
- Good for some tasks (suture for example) in which two hands are needed.
- In some cases the second device is used to change the orientation of the camera view

Medical task simulation

Needle insertion
Hernia palpation
Incision
Suture







Resistive force:

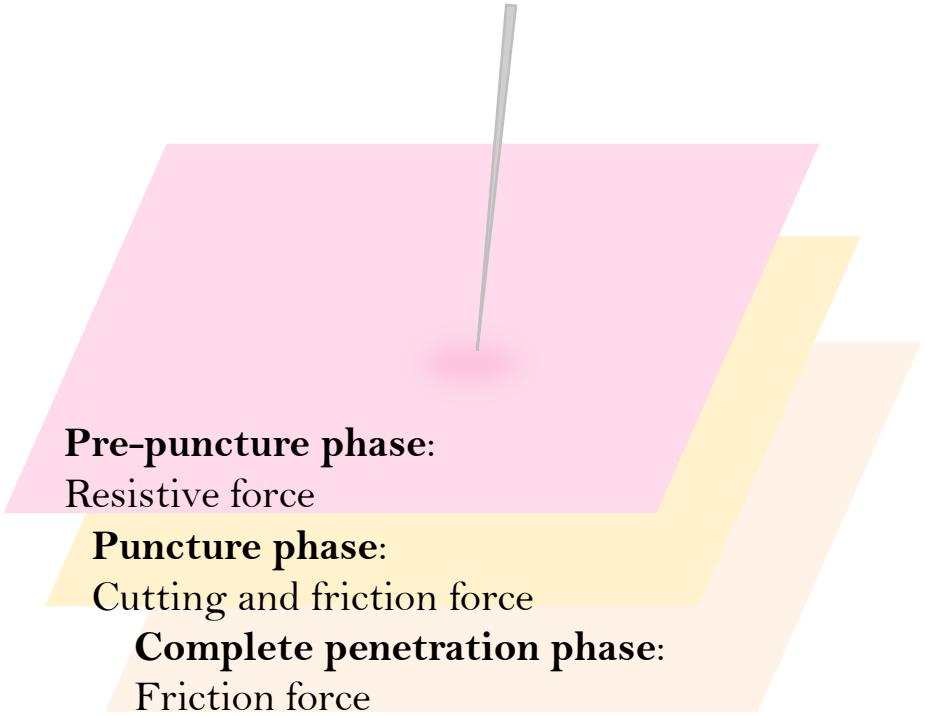
- **Okamura et Al. (2004), Jayasudha et Al. (2019), Moreau et Al. (2020):** second order polynomial to recreate a non linear effect.

Friction force:

- **Okamura et Al. (2004):** modified Karnopp model that includes dynamic, static and viscuous friction.
- **Asadian et Al. (2011):** dynamic model based on the microscopic representation of irregular contact surfaces and elastic bristles.

Cutting force:

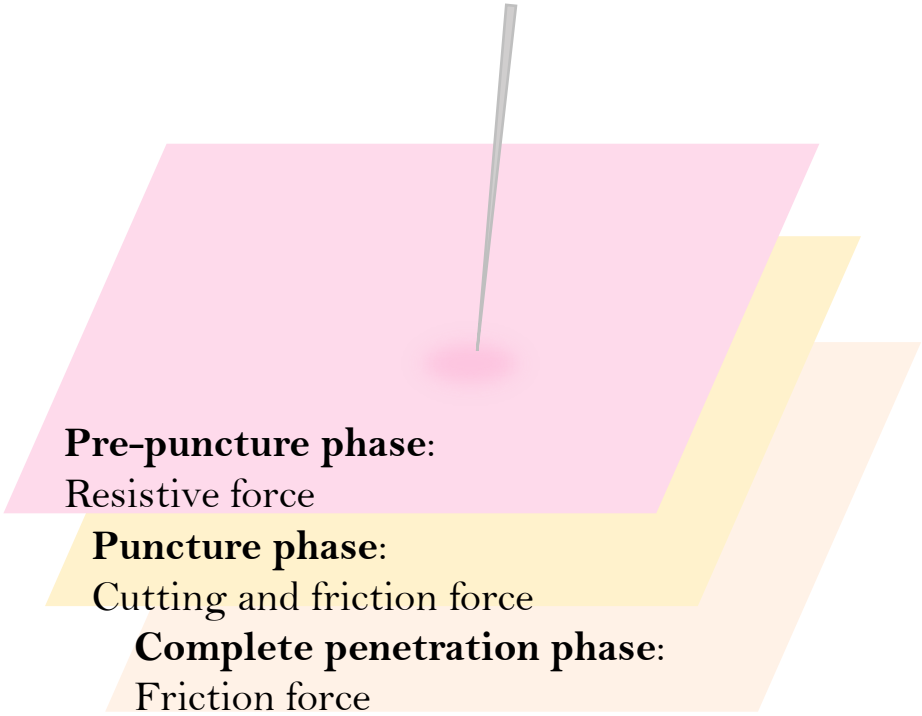
- **Yang et Al. (2014), Moreau et Al. (2020):** total force – frictional force.



Simulation approaches:

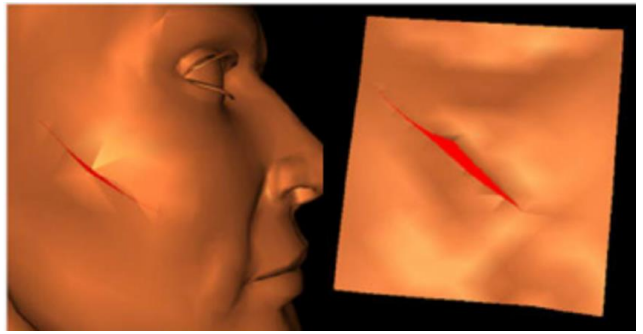
- **Choi et Al. (2010)**: after a threshold distance inside the skin, the skin is considered punctured. The resistive force is linearly proportional to the needle's penetration. During penetration, an anchoring spring constrains the needle segment to the centroid of the tissue element.
- **Moreau et Al. (2020):** tracking-wall approach: virtual wall that follows the needle's position. Once the needle stops its progression, the wall is smoothly updated to the needle's last position.

Problem with Geomagic: low resolution.



- Authors usually either adapt haptic devices with pads to provide real sensations, or provide proper sensations of tumors by scanning current tumor pads.
- **Ullrich and Kuhlen (2012)**: They performed dragging of the tissue and studied the forces that are generated. They use a bimanual station of Geomagic Touch. They modify the end effector of one to provide a lightweight palpation pad to enable the use of two fingers (minimum number of fingers used during palpation).
- *Meeting with surgeons*: need for a different feedback on each finger, impossible to do with Geomagic. However, a pad for two fingers could work for some tasks.

- **Zhang (2004)**: Skin (MSS) with tetrahedral surface mesh and additional meshes built in runtime for depth. Methods for cutting: pierce-in, slide-in: cut-into, cut-through. Two different primitives after cut through has ended.
- **Zerbato (2010)**: Moves calculations to the GPU. Skin (MSS) based on matrix that stores: positions, force and mass (update lasts 3ms). Methods for interaction: probing, grabbing, cutting. Collision for cut: disable spring contribution.
- **Gutierrez (2010)**: works with SOFA and one Geomagic Touch. XFEM / FEM model remapping. When collision is true: check for collision in the nearby tetrahedra. Internal mesh is created by connecting intersected points on the tetrahedra that have been cut.



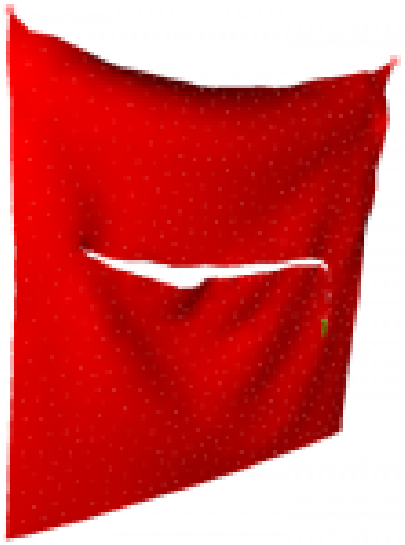
Needle insertion
Hernia palpation
Incision
Suture

Pros:

- Interesting task to simulate
- Used in many medical tasks

Cons:

- Possibly difficult to implement on SOFA: need to modify the model runtime (SofaCarving plugin), save the model and repropose it to Geomagic (computationally demanding: SofaCUDA could help). It already exists a way to cut in 2D on Sofa, but offline.



Needle insertion
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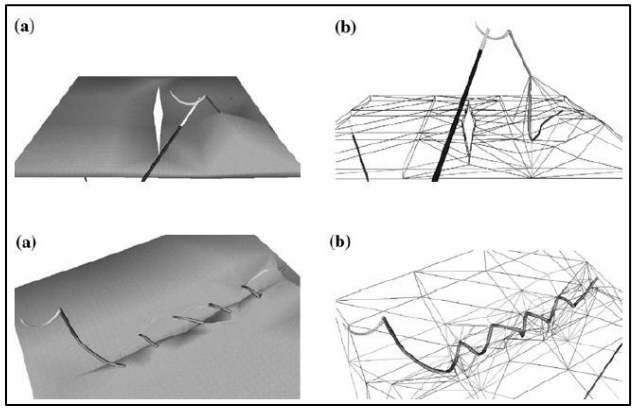
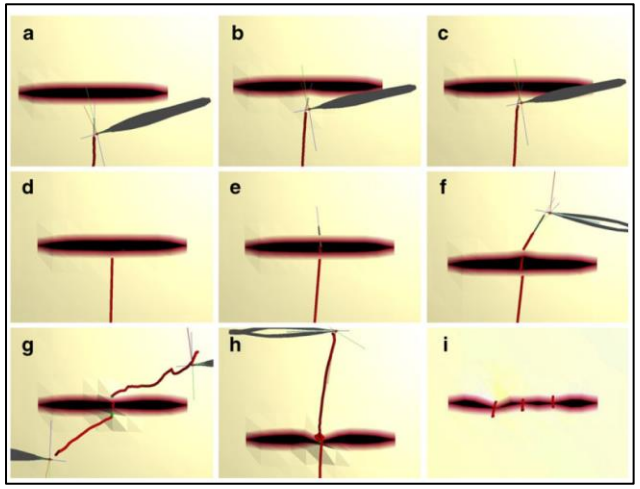
Suture

- **LeDuc et Al (2003)**: Skin model based on MSS. Suture idea: join thread to skin with springs
- **Payandeh et Al (2010)**: Skin model based on MSS, collision detection based on a BVH of boxes. Suture idea: skin moves with suture if friction with suture is greater than spring force on node. Otherwise, it slides along suture. Addition: ripping of tissue for realism. They use a bimanual station of Geomagic Touch.
- **Choi et Al (2010)**: Skin model based on MSS. Suture idea: check distance needle-skin and orientation of needle. When penetration has occurred: constrain needle with anchoring spring, same for thread. They use a bimanual station of Geomagic Touch.
- **Sung et Al (2020)**: They simulate five different suture procedures.





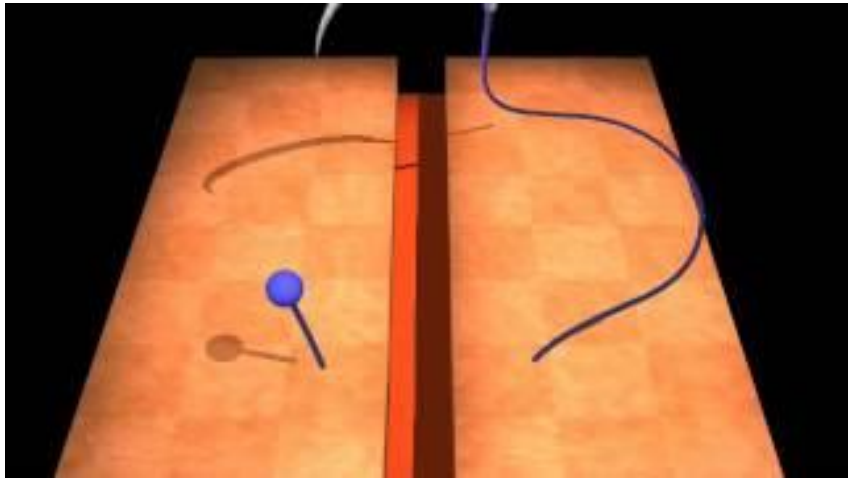
Needle insertion
Hernia palpation
Incision
Suture

Pros:

- Interesting task to simulate
- Phantoms are very used for their 6DoF (torsion important to pierce skin)
- Breakable into steps, which is good both for teaching and for simulating.

Cons:

- Possibly difficult to implement on SOFA: some other plugins may help



- *Meeting with surgeons*: need for a bimanual control.

Summary

- Problems in perceiving skin layers correctly

Needle insertion

- Problems in giving different feedbacks on each finger

Hernia palpation

- Some difficulties but apparently doable ☺

Incision

- Some difficulties but apparently doable ☺

Suture

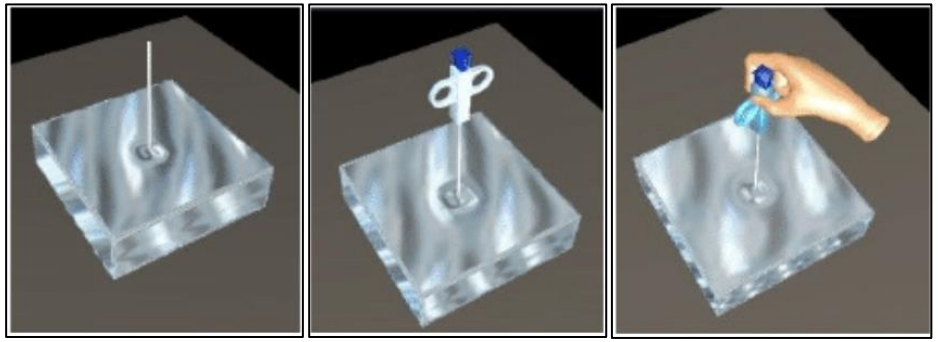
Testing phase

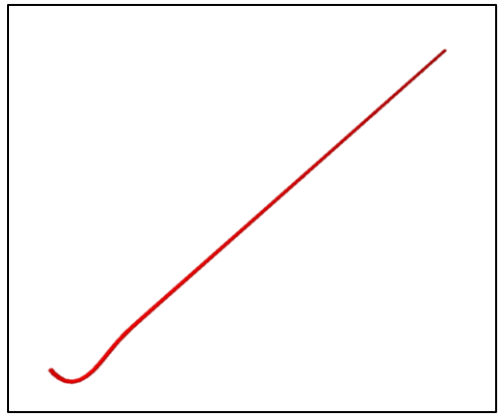
The tests
Miscellanea

- Prepare a simulation for testing puroposes
- Perform tests
- Provided data has statistical relevance, analyze results

- Important for **suspension of disbelief.**
- Literature review: **Benyahia et Al (2015):**
  - 45° angle for the simulation camera
  - shadows showing the haptic device
  - needle/neelde+holder/ needle+holder+hand?
- GUI
- Audio/text
- VR headset

- *Meeting with surgeons*: no phantom omni view, but also no hook.





Thank you for your attention!

Hope you will be available for the testing phase ;)