Towards the design of simulators of medico-surgical gestures – An instrumental childbirth delivery simulator

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French American Innovation Day - FAID 2019 - March 7th 2019

Context of medical training

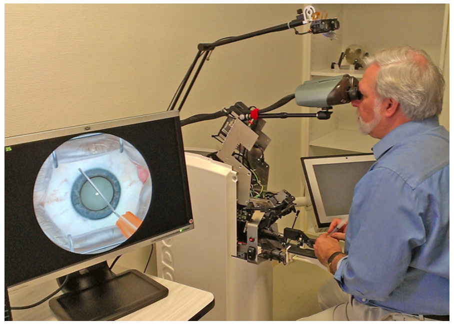
- Learning from the patient poses ethical problems due to risks linking to the training
- So currently, the medical training is based on the observation rather than practice
- But the dexterity of surgical instruments requires practice!

Question: How learning medical gestures efficiently without any risk for the patient?

Contribution of new technologies

One solution is to propose new learning simulators based on Virtual Reality, combining:

- A **numerical simulation** reproducing the behavior of organs during their interactions with each other and with medical instruments
- A **haptic device** reproducing the sensations perceived during the gesture
- A **didactic software** offering adapted scenarios for learning (notion of scores, progression, evaluation)



HelpMeSee - cataract

HRV - dental

Lap Mentor - laparoscopy

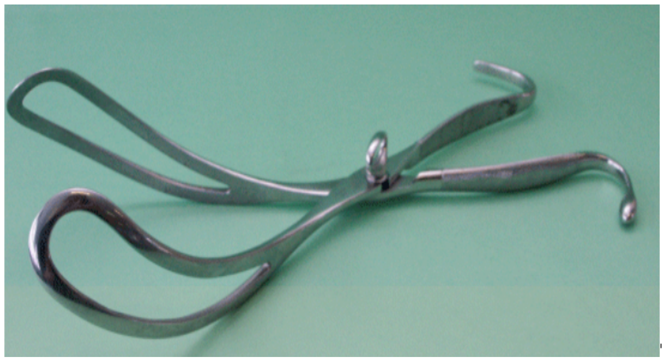
Comparable approach to simulators for airplane pilots

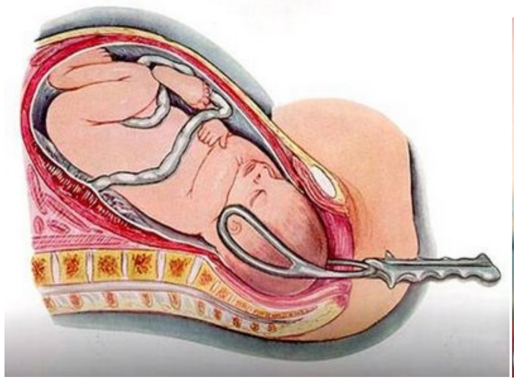
Interests of medical learning simulators based on Virtual Reality

- **Learning without risk for the patient:**
  - "Never the first time on the patient" – French High Authority of Health (HAS) - 2012 report
- **Multiplication and targeting of situations encountered**
  - Usual situations, rare situations
- Improvement of the knowledge of the gesture to be made
- Improvement of the reasoning to be done during the gesture
    - **to better understand / acquire / own it**
- **Acquiring the necessary dexterity** to handle the instruments before the first time on the patient

Context of medical training at gestures of childbirth

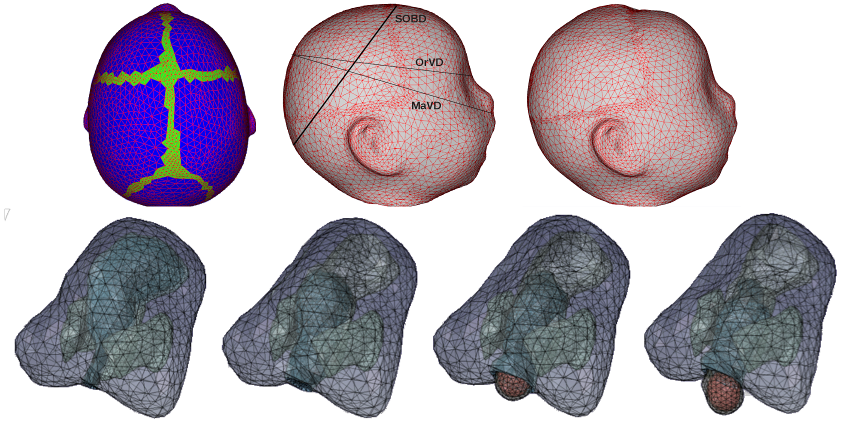
- **Acquire the right gestures for forceps extraction during childbirth**
  - Understanding of the gesture to be made
  - Do not damage the tissues of the parturient and the fetus
- **Dare to do this to limit caesareans**
- **Delicate context**
  - where the parturient is conscious, where the husband is present





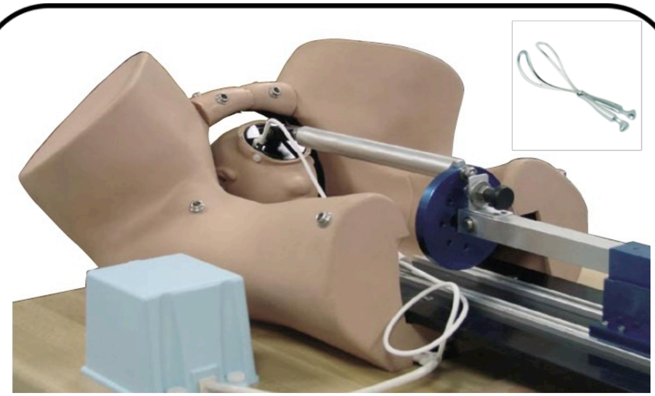
A childbirth simulator based on VR

[SAGA project (ANR-12-MONU-0006)]



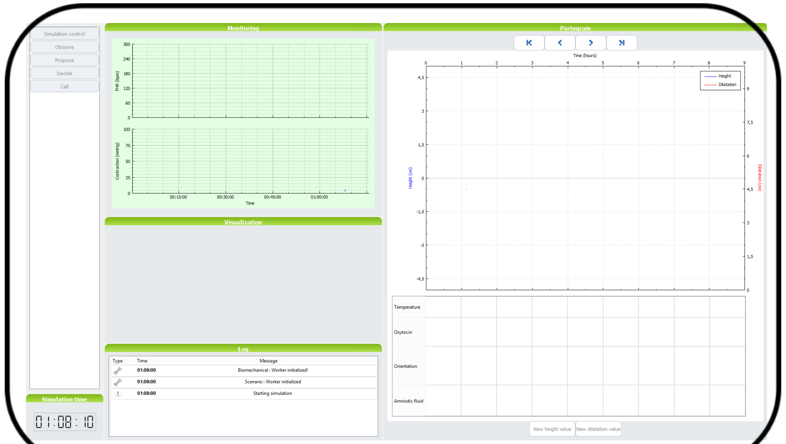
LIRIS, lab. TIMC-IMAG, CAOR ARMINES

A 3D simulation in real time



Lab. Ampère, CAOR ARMINES

Haptic device



All4Tech, HRV, LSE, Lyon Sud maternity, midwifery school of Grenoble (France)

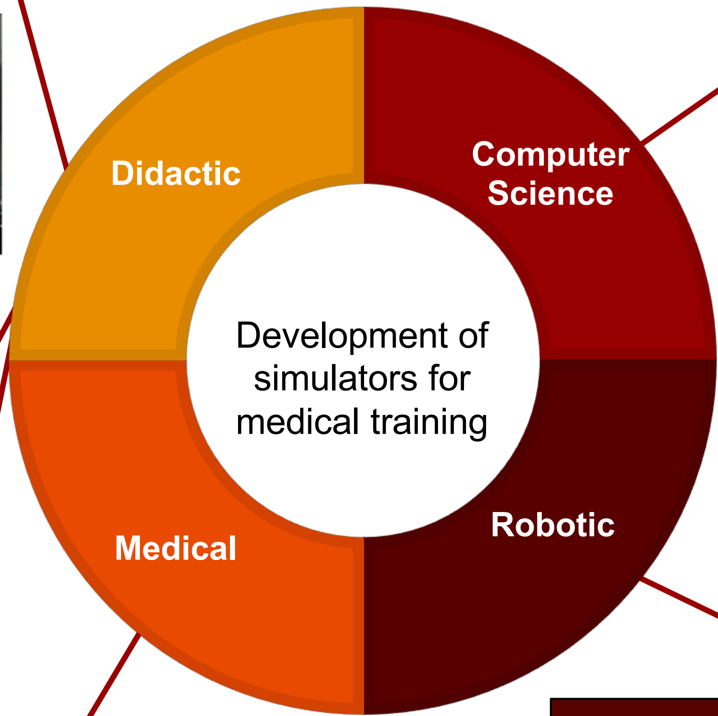
Didactic software

A necessary multidisciplinary approach

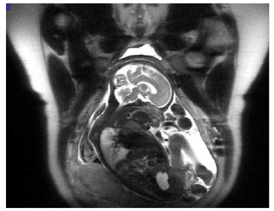
1- To analyze and understand the gesture and its learning to highlight the relevant components of the simulator

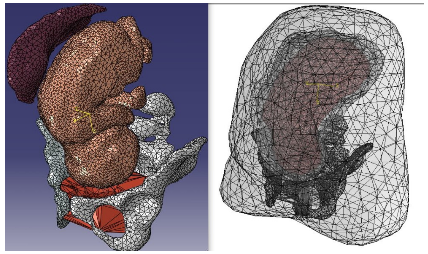
2- To develop relevant and progressive scenarios for learning

3 – To evaluate the contribution of the simulator for learning



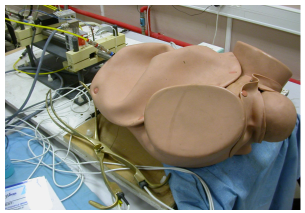
To develop a numerical simulation reproducing the behavior of the organs during the gesture in real time

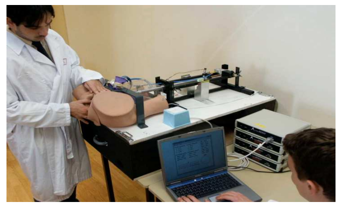




To validate the different parts of the simulator

To elaborate a haptic device restituting the real sensations of the gesture





Scientific issues

- **Simulate and visualize behavior of organs in real time**
  - Simplify the models (geometric / biomechanical) while ensuring an adequate realism for the training
  - Evaluate errors related to the approximation of the numerical model (comparison with the real is difficult)
- Propose an **adequate haptic device** rendering tactile sensations
  - Felt tested by obstetricians
- Ensure the **stability of the complete solution**
  - Numerical model, haptic interface, interaction between components

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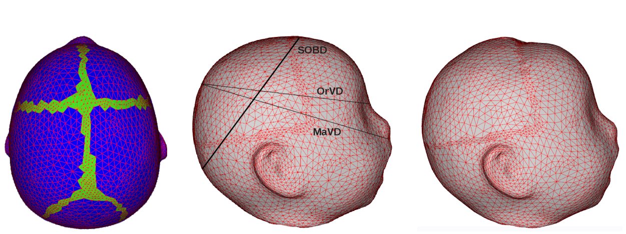
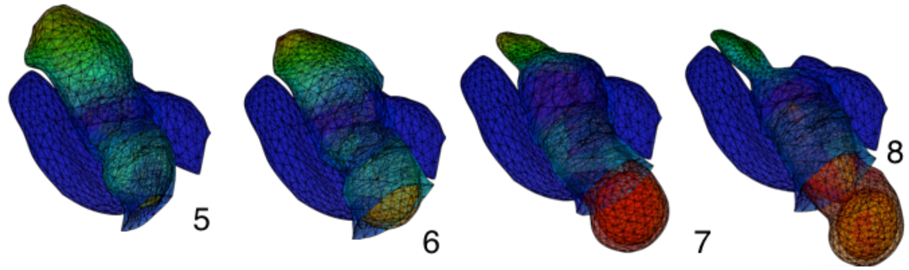
Goal of the numerical simulation

- To simulate the descent of the fetus during childbirth
- To simulate the deformation of the head due to uterine pressions / forceps



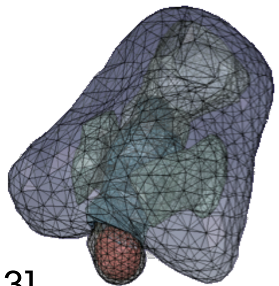
(a) (b) (c)

[Bailet 2013]

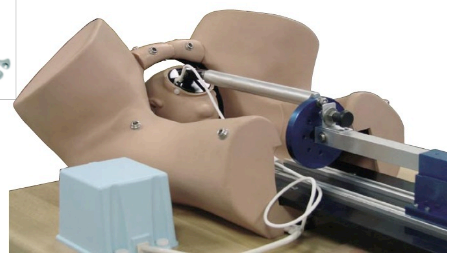


[Buttin 2013]

The goal is to communicate the forces applied on the head and its position to the haptic device… and reciprocally…

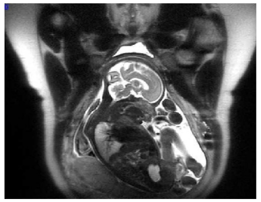


[Buttin 2013]



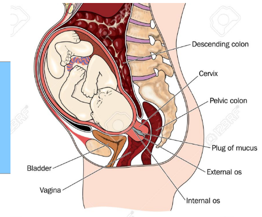
BirthSim, Ampère lab.

The pipeline for medical simulations



Medical images

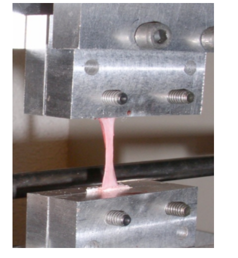
Anatomy

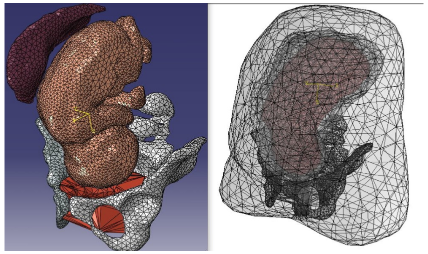


Organs

Segmentation

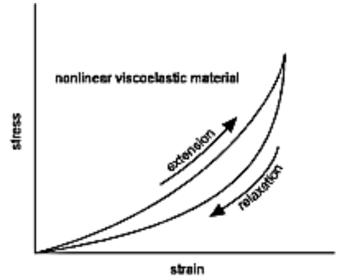
Expérimentations





Geometrical models
With high resolution

Constitutive laws and
mechanical properties



Partial Differential Equations

$$div([\sigma]) + f_{ext} = \rho\ddot{u}$$

ε= g(u)

σ = f(ε)

U

geom.

ε

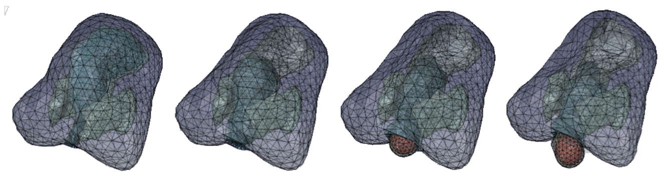
material

σ

Solving with the Finite
Element Method

$$[M]\ddot{U} + [D]\dot{U} + [K]U = F$$

Numerical simulations
high precision
high computational cost



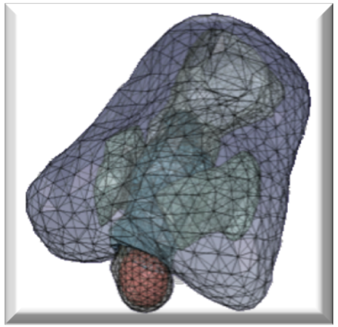
Challenges for training simulators

- We have:
  - **to be fast!** (and stable…) for interaction with haptic device
  - **to be enough accurate** to reproduce realist physical behavior

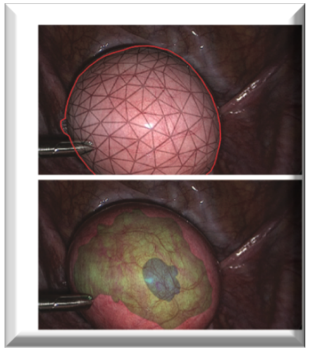
We have to find the adequate compromise between accuracy and execution time

A lot of simplications — *accuracy of biomechanical behavior* — Complex simulations

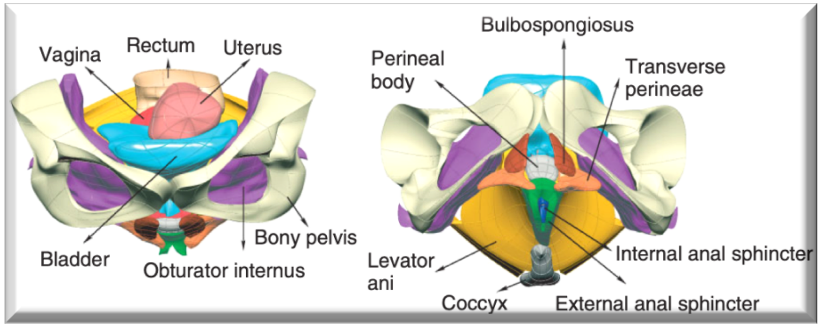
Training simulator | Planification of operations | Physiological acknowledgement



[Buttin 2013]



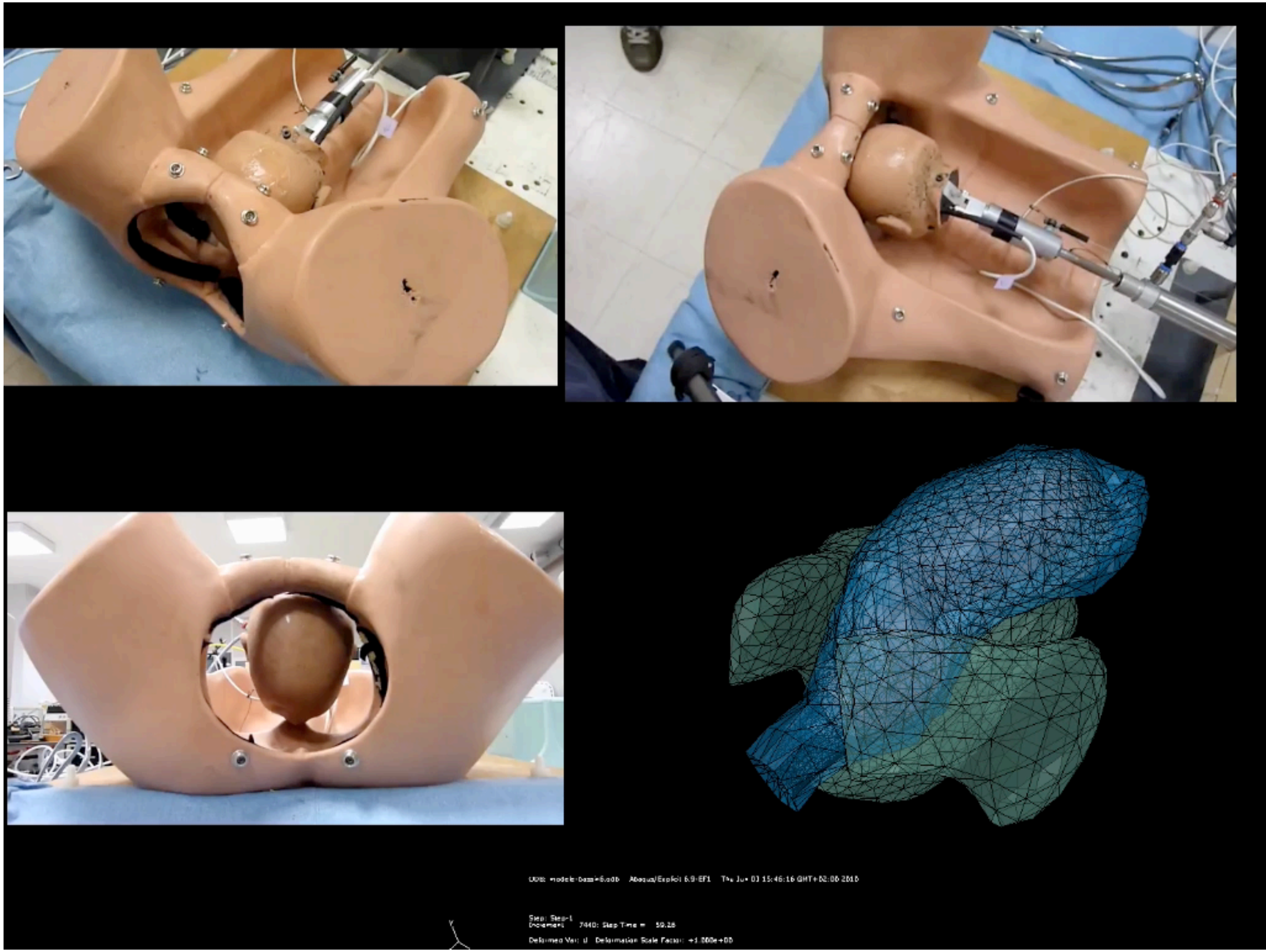
[Collins 2014]



[Li 2008]

Real time — *execution time* — Several hours of computation

The complete childbirth simulator



[SAGA project (ANR-12-MONU-0006)]

Difficulties and limits

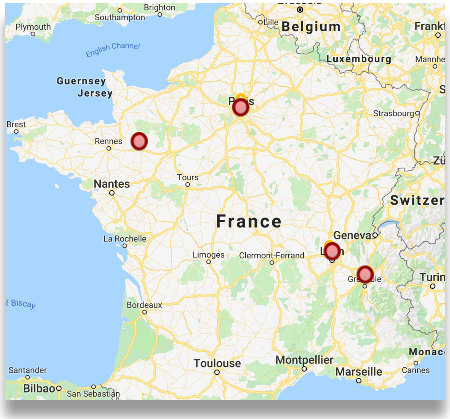
- The difficulty lies in the fact that one should not learn to do the intervention on the simulator / to use the simulator
- But the simulator must allow **to learn the "real gesture"**
- We must succeed in making sure that the simulator helps
  - to appropriate the gesture
  - to analyze the situations encountered
  - to acquire the dexterity of the gesture

"We have to learn how to operate a real patient and not to operate the simulator."

- **At shorter terms for medical simulators: "specific patient"**
  - Training before risky operations
  - Pre-operative diagnosis / prediction to assess risks
  - Help during the intervention

- **Case of the childbirth simulator**
  - Better understanding of the forces involved during childbirth
  - Limitation of the number of caesareans by daring to use forceps
  - Prediction of risky delivery in terms of damage for the parturient
  - Improvement of the medical care of prolapse

- **Expected interests of such simulators**
  - Acceleration of the learning process
  - Improvement of physiological knowledge
  - Implementation of new methods of gesture evaluation
  - Setting up new gestures

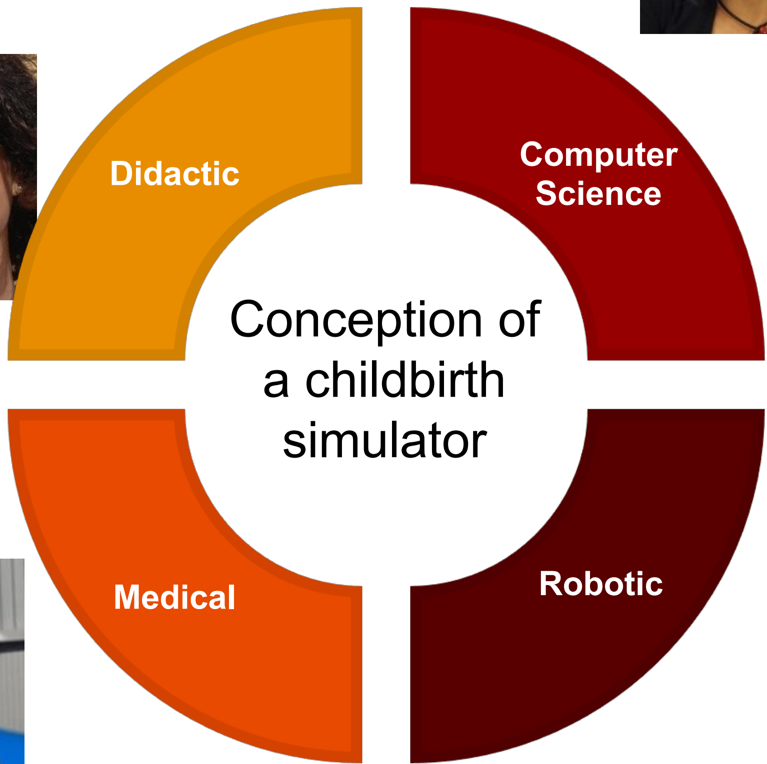


HRV

AGENCE NATIONALE DE LA RECHERCHE
ANR

LIRIS

LSE
LABORATOIRE DES SCIENCES DE L'ÉDUCATION



TIMC

ARMINES

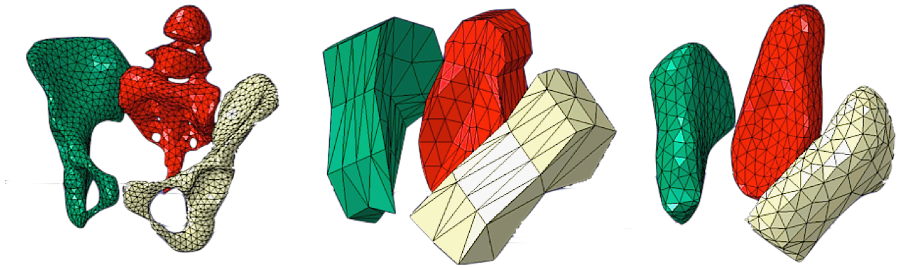
Hospices Civils de Lyon

Ampère

SAGA project's team

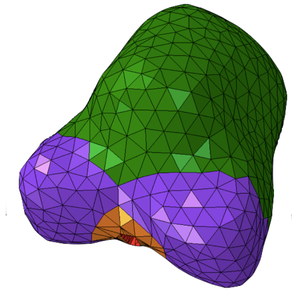
Our approach to obtain real time

- Simplication of the meshes (less nodes)



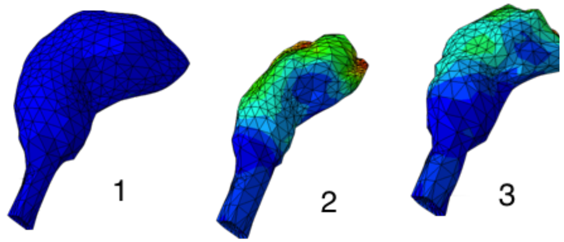
- Simplication of the constitutive law of organs

- **Pelvis**: Hooke - E = 23 Mpa, ν = 0.3, ρ = 1 000 kg/m3

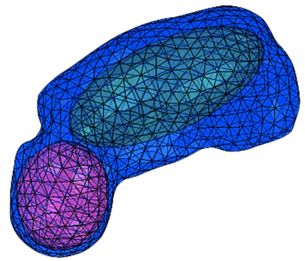


- **Abdomen**: Néo-Hooke - C10 = 5kPa, ρ = 2 500 kg/m3

- **Uterus**: Néo-Hooke - C10 = 30kPa, ρ = 950 kg/m3

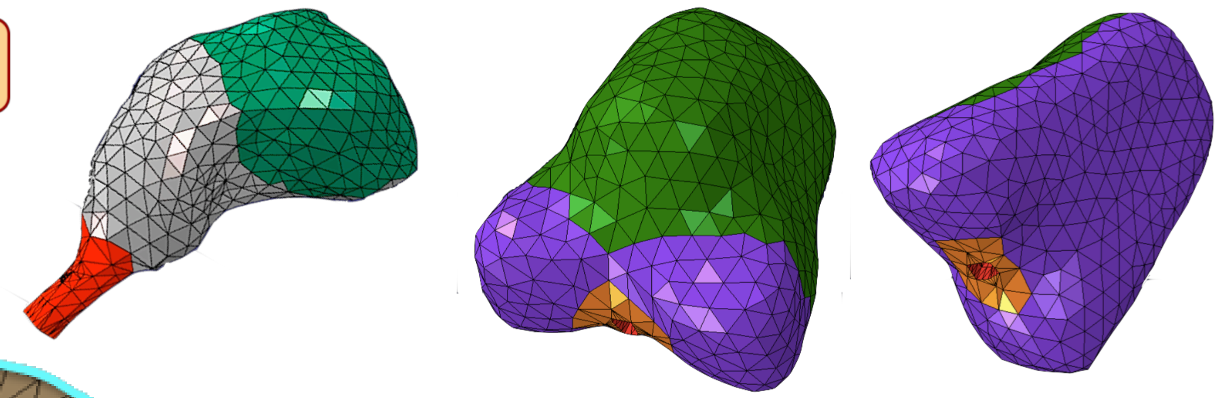


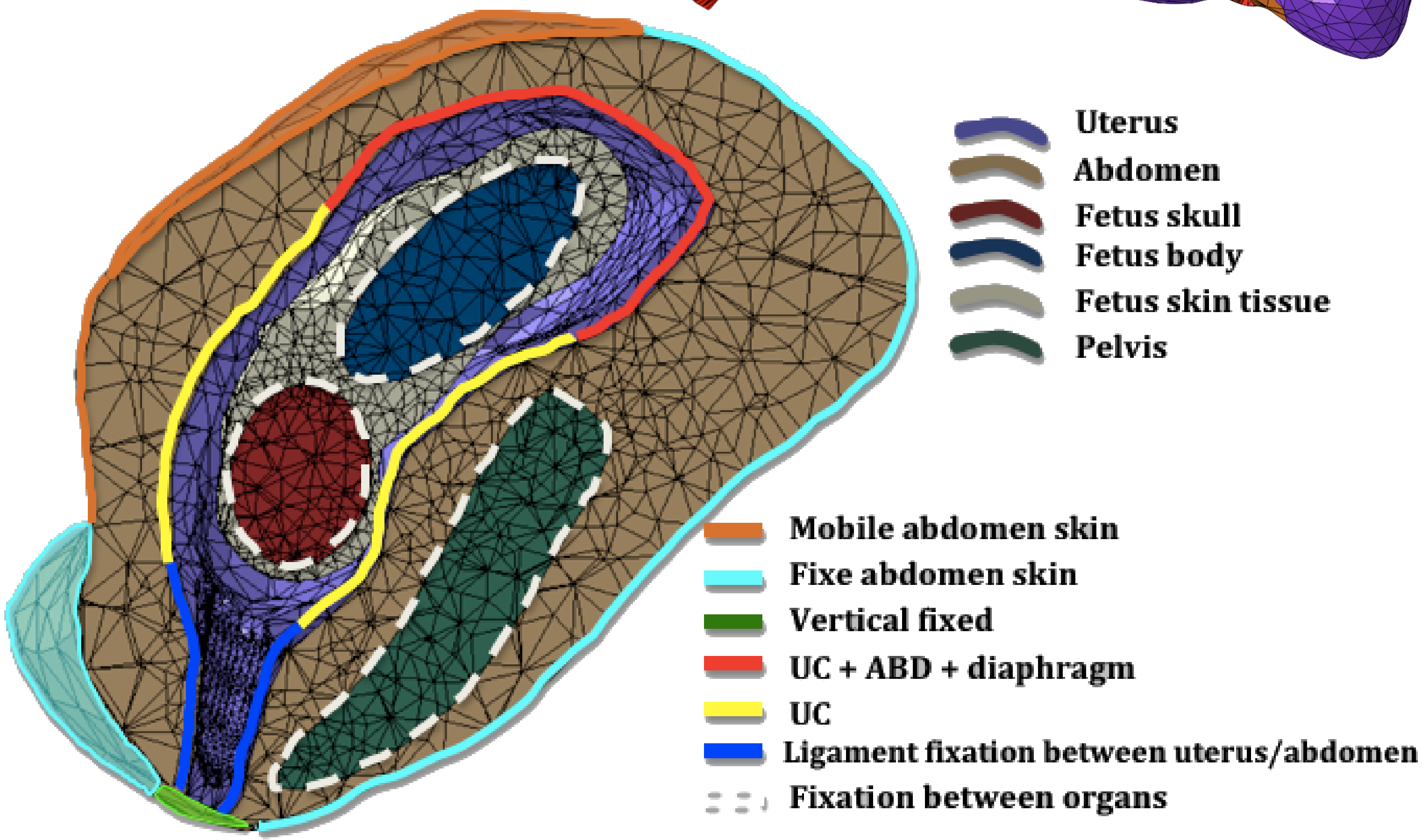
- **Fetus**: Néo-Hooke
  - Skin: C10 = 130 kPa, ρ = 400 kg/m3
  - Skull: C10 = 75 kPa, ρ = 950 kg/m3
  - Body: C10 = 70 kPa, ρ = 950 kg/m3



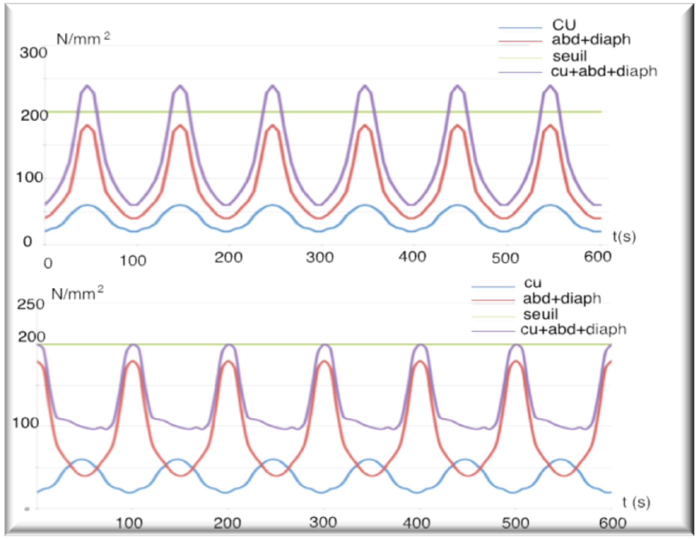
Our approach to obtain real time

- Put boundary conditions

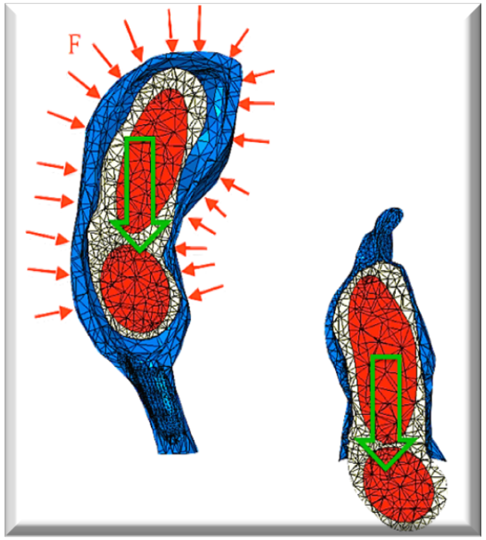




Simulation of fetal descent in real time



The descent of the fetus is involved by forces (abdominal, uterine contractions) applied on the uterus



[Buttin 2013]