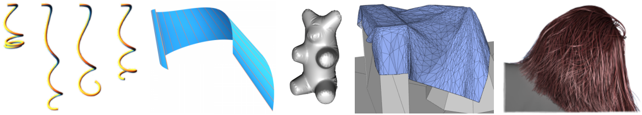
Class on numerical mechanics:

From Lagrangian mechanics to simulation tools for computer graphics



Florence Bertails-Descoubes [1], Thibaut Métivet [2], Mélina Skouras [3]

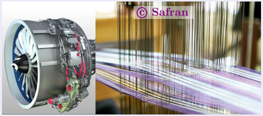
2025, September 23 - Ensimag

[1] florence.descoubes@inria.fr
[2] thibaut.metivet@inria.fr
[3] melina.skouras@inria.fr

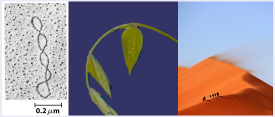
Motivation

Increasing need for effective mechanical simulators

Movie industry



Virtual prototyping

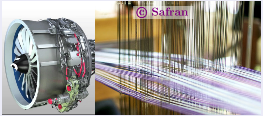


Natural sciences

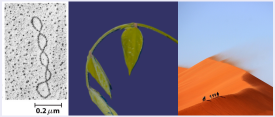
Motivation

Increasing need for effective mechanical simulators

Movie industry

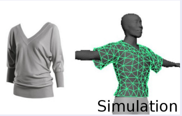


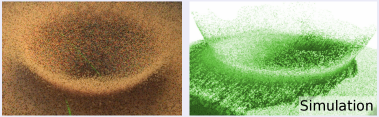
Virtual prototyping



Natural sciences

Requires the numerical modeling of objects with complex shapes and motion

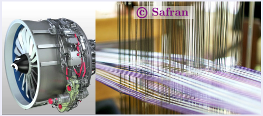




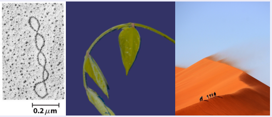
Motivation

Increasing need for effective mechanical simulators

Movie industry

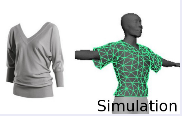


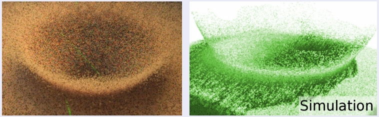
Virtual prototyping



Natural sciences

Requires the numerical modeling of objects with complex shapes and motion



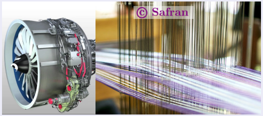


$\rightarrow$ Challenges: nonlinear and even nonsmooth regimes

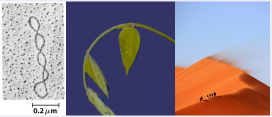
Motivation

Increasing need for effective mechanical simulators

Movie industry

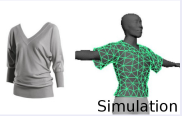


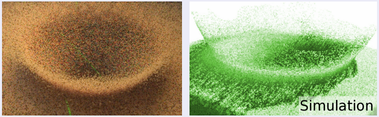
Virtual prototyping



Natural sciences

Requires the numerical modeling of objects with complex shapes and motion





→ Challenges: nonlinear and even nonsmooth regimes

Goal: design dedicated numerical models

Realism + robustness + efficiency + user control


μ = 0.3

Objectives of the course

Objectives of the course

Discover important concepts and techniques behind simulation

- acquire some fundamentals of numerical mechanics
  at least for (articulated) rigid bodies
- get a sense of good practices for numerical modeling
- have the right pointers to go further by yourself...
  and at some point create your own impressive simulations!

Objectives of the course

Discover important concepts and techniques behind simulation

- acquire some fundamentals of numerical mechanics
  at least for (articulated) rigid bodies
- get a sense of good practices for numerical modeling
- have the right pointers to go further by yourself...
  and at some point create your own impressive simulations!

How we have built this course

- The kind of course we would have liked to have ourselves before our PhD!
- Not a review of recent research papers, but really a course on fundamentals
- A balanced mix between mechanics and numerics
- A balanced mix between theory and practice
- A selection of useful references to go beyond this course

Objectives of the course

Discover important concepts and techniques behind simulation

- acquire some fundamentals of numerical mechanics
  at least for (articulated) rigid bodies
- get a sense of good practices for numerical modeling
- have the right pointers to go further by yourself...
  and at some point create your own impressive simulations!

How we have built this course

- The kind of course we would have liked to have ourselves before our PhD!
- Not a review of recent research papers, but really a course on fundamentals
- A balanced mix between mechanics and numerics
- A balanced mix between theory and practice
- A selection of useful references to go beyond this course

Sixth time we deliver (partly) this course, third time (with substantial modifications, still) in this form and for Ensimag
$\rightarrow$ feel free to give us feedback!!

Content of the course

Mechanics + Mathematical tools & Numerics

Content of the course

Mechanics + Mathematical tools & Numerics

- Topic 1: Lagrangian mechanics and finite differences
- Topic 2: 2D and 3D rigid bodies and integration on SO(3) groups
- Topic 3: Kinematic constraints and optimisation with bilateral constraints
- Topic 4: Rigid contact modelling and optimisation with unilateral constraints
- Topic 5: Rigid frictional contact and optimisation with conical constraints

Content of the course

Mechanics + Mathematical tools & Numerics

- Topic 1: Lagrangian mechanics and finite differences
- Topic 2: 2D and 3D rigid bodies and integration on SO(3) groups
- Topic 3: Kinematic constraints and optimisation with bilateral constraints
- Topic 4: Rigid contact modelling and optimisation with unilateral constraints
- Topic 5: Rigid frictional contact and optimisation with conical constraints

Teaching team

- Lecturers: Florence Bertails-Descoubes, Thibaut Métivet and Mélina Skouras (Inria researchers)
  at Elan team: https://team.inria.fr/elan/
  and Anima team: https://team.inria.fr/anima/

Organisation

Schedule

- 36 hours in total, weekly, starting from now and ending on January 13 (exam)
- Break: during Toussaint holidays (no class on October 28)
- Probably one change for the October 21 class (will be announced)

Organisation

Schedule

- 36 hours in total, weekly, starting from now and ending on January 13 (exam)
- Break: during Toussaint holidays (no class on October 28)
- Probably one change for the October 21 class (will be announced)

First slot

Alternately, lecture on mechanics or math. tools & numerics + exercises

Organisation

Schedule

- 36 hours in total, weekly, starting from now and ending on January 13 (exam)
- Break: during Toussaint holidays (no class on October 28)
- Probably one change for the October 21 class (will be announced)

First slot

Alternately, lecture on mechanics or math. tools & numerics + exercises

Second slot

In general, practice on machine (**python**)

- First practicals: guided
- Other practicals: work on a **personal project**

Evaluation

A personal code project

- Goal: choose, implement and study one simulation scenario **of your choice**

  by applying and deepening one or several techniques learnt during classes

  Requested: the scenario should include 2D (or 3D) rigid bodies, bilateral constraints, contact and friction
- Should be done by pairs of students
- Recommended programmation language: **python**
- Advice: choose your simulation scenario carefully
  - Not too simple, not too ambitious
  - Set incremental milestones over time
  - Split the work equally in the team

Evaluation

In practice

- **Oral defence** on January 13 (last course)
- Around 20 minutes per team in total (15 min pres + 5 min Q&A)
- Evaluation criteria:
  - **Requested:** Inclusion of these 4 key elements: 2D **rigid bodies**, **bilateral constraints**, **contact** and **friction** (3D is a bonus)
  - **Originality** and **difficulty** of the chosen scenario
  - **Success** of the implementation, related to the difficulty of the chosen scenario
  - **Depth of analysis** of results (even in case of a failure), **mastery** of the topic
  - Project **organisation** and **team management**
  - **Quality** of the oral presentation and answers to questions

Let's start!