An open-source solution for interactive physics simulation

Room 3 - 09.00 - 12.30

Reims 2022

SOFA

Simulation
Open
Framework
Architecture

An open-source solution for collaborations, prototyping and innovation in simulation

Monday, 25th April 2022 (Reims - France)

Overview of the 3h30

- Introduction on biomechanical simulation with SOFA
  - What is SOFA?
  - A development project
  - Its international community
- Understanding SOFA at a glance
  - Main principles
  - Life cycle
- User tutorial: hands-on!
  - Download SOFA
  - Building a simulation step by step in XML
  - The power of Python

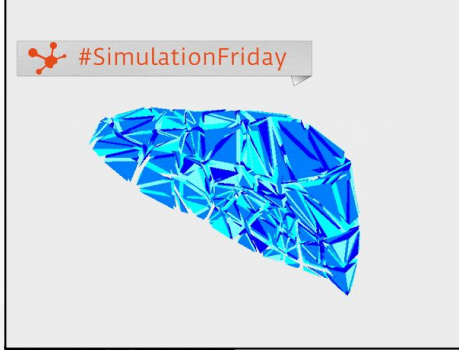
SOFA

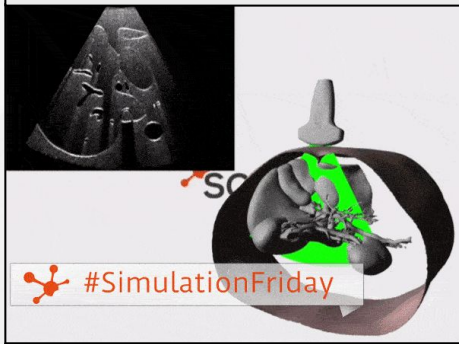
What is SOFA?

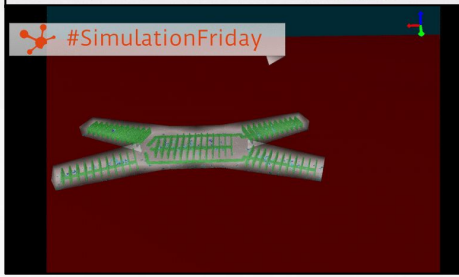
SOFA

A framework for physics simulation

- Implements mathematical models & algorithms describing the physics around us
  - Soft and rigid body dynamics (mostly)
  - Heat transfer
  - Fluid mechanics
- Various fields being investigated
  - Medical simulation
  - Robotics and control → soft-robotics
  - Animation
  - Biology







SOFA

SOFA principles: scene graph

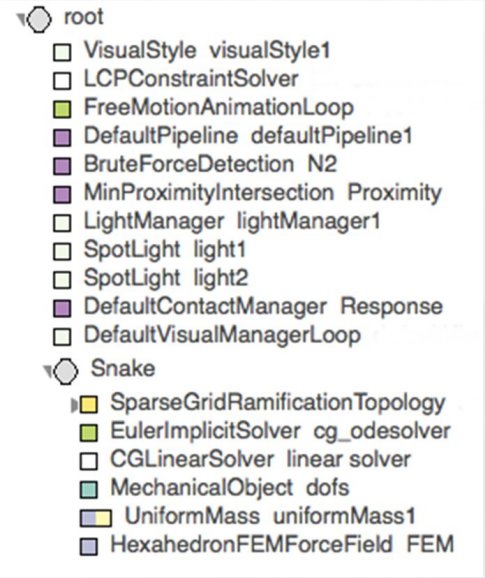
- Simulation described as a graph

  (Direct Acyclic Graph, i.e. generalized hierarchy)

  - Composed of nodes
  - Nodes contain **Components**
  - Components have parameters: **Data**

- Data can be linked together (*input=@dofs.value*)

- Described using XML or Python



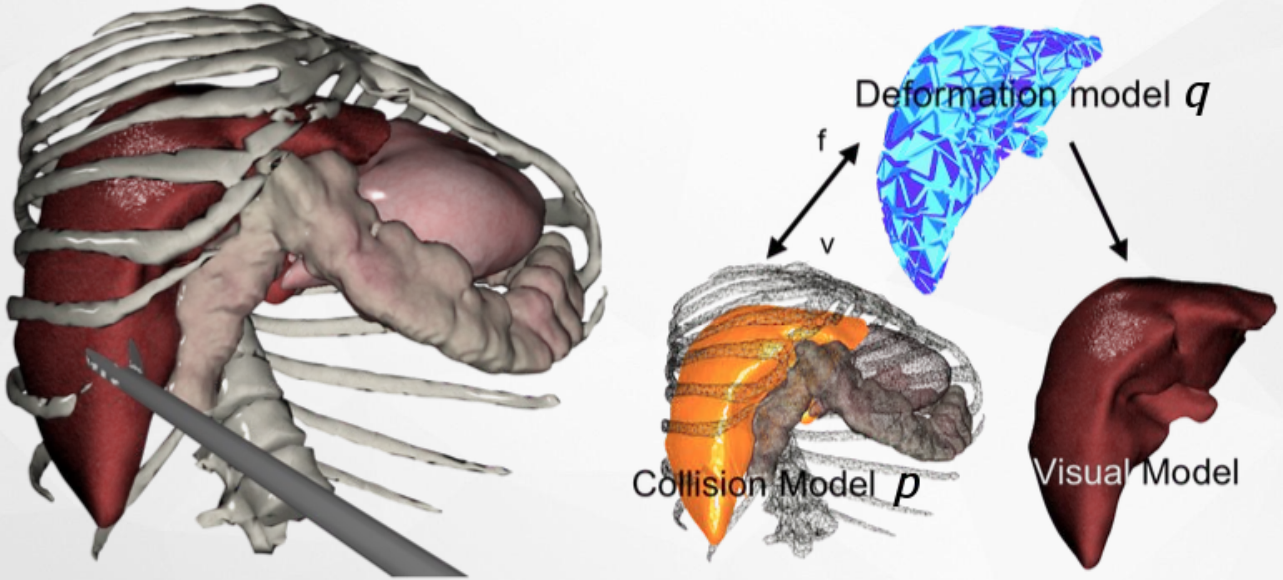
SOFA principles: multi-model representation

- Matching mechanism : correspondence between models
- Each object can have several models in SOFA
  - Mechanical model
  - Collision model
  - Visual model
- Each model can rely on a different representation/topology

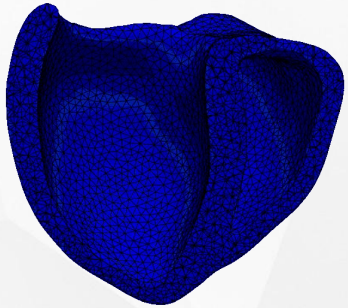
SOFA

SOFA principles: multi-model representation

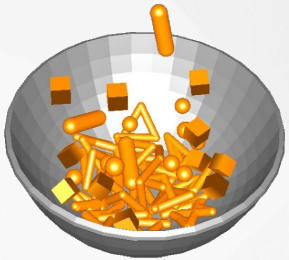
- Matching mechanism : correspondence between models



Usual physics features



- Loading topologies
  - Discretization in space with elements (FEM)
  - Different topologies can be used for physical, visual and collision models
- Collision detection and response : CollisionPipeline
- Integration schemes and linear solvers
- Mechanical models
  - Linear elasticity, plasticity
  - Hyperelasticity
  - Damping



SOFA

The SOFA concept

- Scene graph
  - Ease design and prototyping of simulation
- Multi-model representation
  - Define the optimal tradeoff between accuracy and efficiency
  - Along with multithreading / GPU computing
- Interactive
  - User interactions to take into account
  - Enclose SOFA in optimization loops
  - Dynamic simulation updates

SOFA

A development project

SOFA

Structure of the open-source project

- SOFA: core project
  - C++ based, coming with python bindings
  - LGPL License
    - Download and use it
    - Modify it
    - Make products from SOFA!

- External repositories
  - Implementing additional features
  - Free-to-define license: open source or closed source? YOU choose!

SOFA

Code production of SOFA

- GitHub processes
  - Contribution process (fork and pull-requests)
  - Peer-review process
  - Continuous integration for robustness (unit, feature and regression tests)
  - Stable releases every 6 month (including 360+ pull-requests!)
- Definition of the roadmap: technical governance
  - Bi-annual technical committee (STC)
  - Weekly development meetings

SOFA

Documentation & support

- User online documentation → sofa-framework.org/community/doc
- API documentation for devs → sofa-framework.org/api
- Open forum → github.com/sofa-framework/sofa/discussions
- Open chat → gitter.im/sofa-framework/sofa

SOFA

Its international community

SOFA

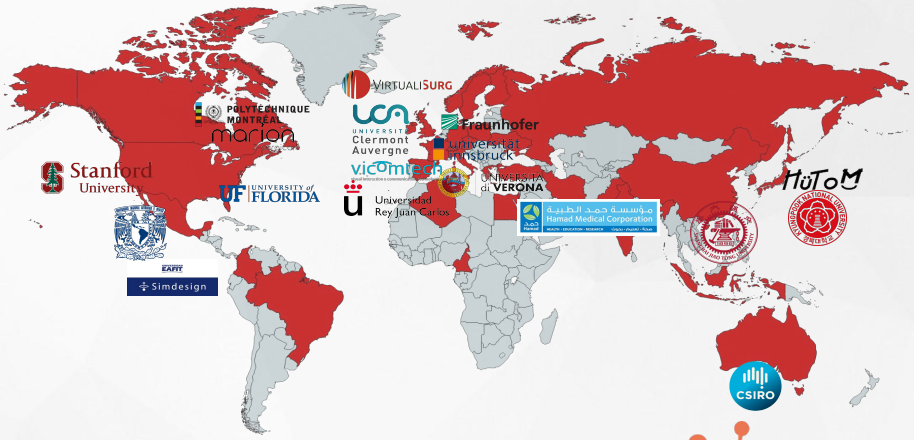
Community

- Developed from more than 16 years with +1000 worldwide users
- Worldwide network
  - dissemination & communication of your production
  - collaborations (bilateral, EU etc.)
  - hiring or finding the ideal job
- Today
  - Worldwide universities 80%
  - New international startups 10%
  - International companies 8%
  - Independent developers 2%

SOFA

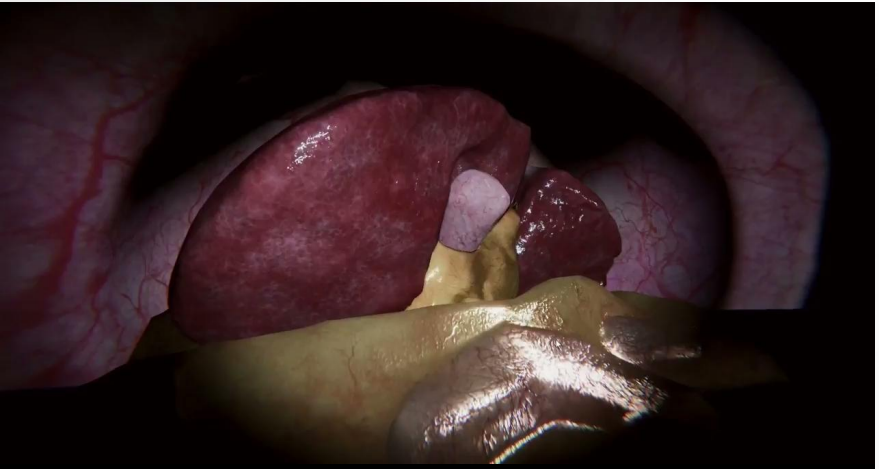
Community

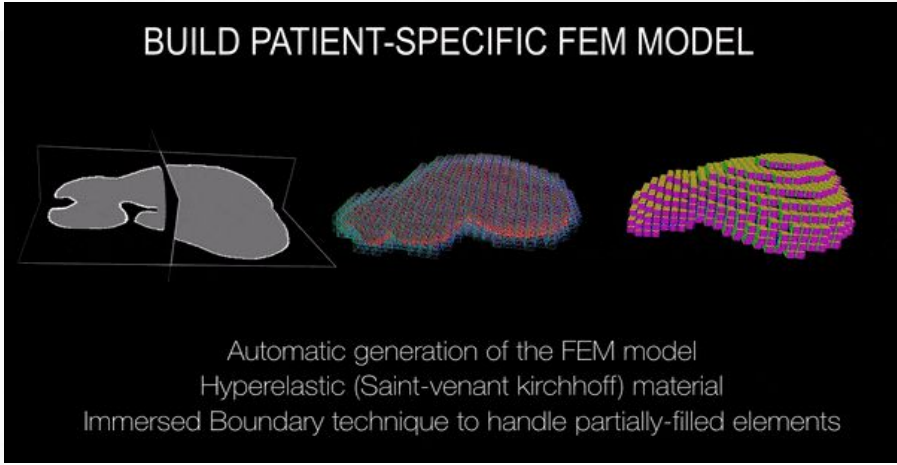
- Developed from more than 16 years with +1000 worldwide users
- Startups: 7 companies created for the last decade
- SOFA Week
  - Annual community event
  - Gathering ~200 participants
  - Topics

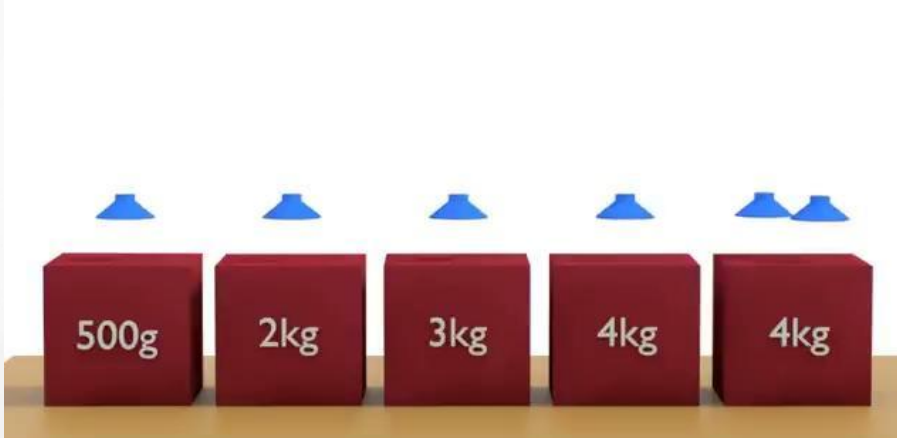


SOFA

Recent achievements with SOFA







An open-source consortium

- Gathers partners willing to share the costs of
  - Coordination of the developments
  - Maintenance and industrialization
  - Animation and support to the community
  - Structure the ecosystem
- Acting as a third-party and non-profit organization
- Hosted at Inria

SOFA

An open-source consortium

- **Strategic partners**, steering the strategy of the project

- **Technical members**, defining the roadmap based on contributions

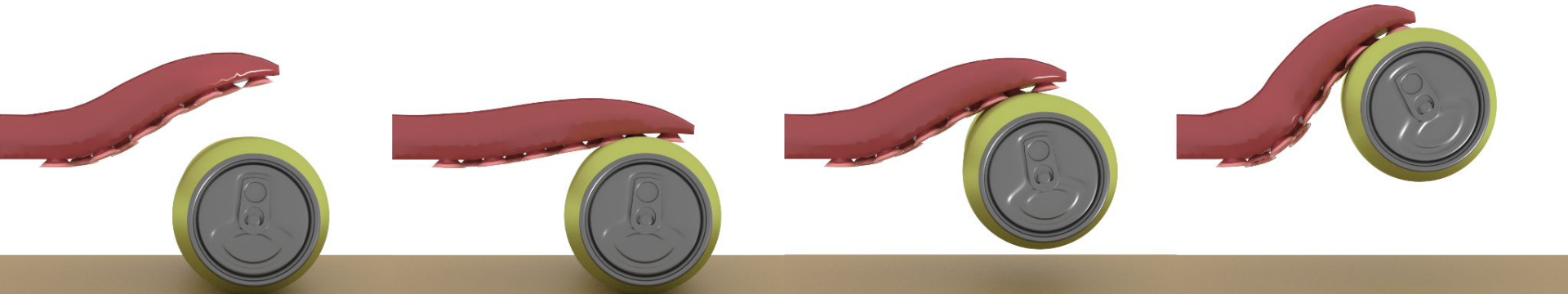
- Donors

Be part of the community

- Discover SOFA, enter the community and benefit from it!
- Join us at our 2022 events
- Any question?

Web www.sofa-framework.org

Contact consortium@sofa-framework.org



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SOFA

Main principles

SOFA

Scene Graph

- Simulation described as a graph

  (Direct Acyclic Graph, i.e. generalized hierarchy)
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- Data can be linked together (*input=@dofs.value*)
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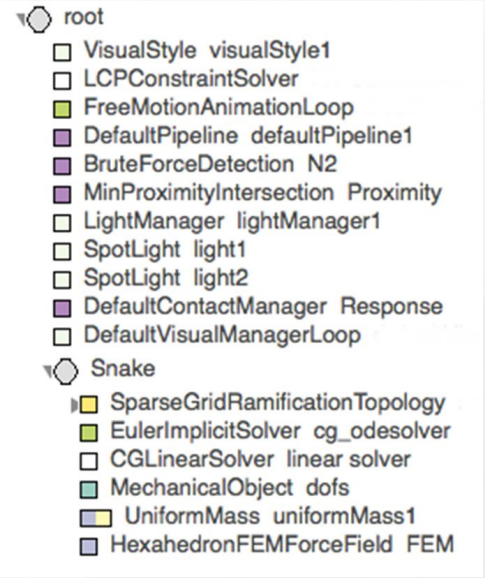

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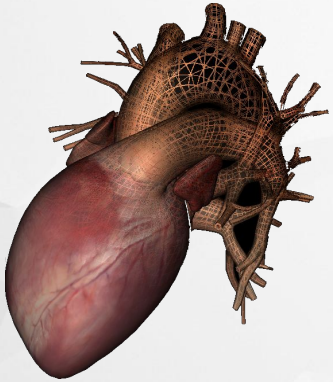
Scene Graph



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Scene Graph (XML format)

```
<Node name="root" dt="0.01" gravity="0 0 -9.81">

    <Node name="Liver">
        <EulerImplicitSolver name="EulerImplicit_scheme" />
        <CGLinearSolver name="CG" iterations="200" tolerance="1e-09"/>
        <MechanicalObject template="Vec3d" name="myLiverDOF" position="..." />
        <MeshMatrixMass totalmass="1" />
        <TetrahedronFEMForceField name="LinearElasticity" youngModulus="1e7" />
    </Node>


    <Node name="Heart">
        <EulerImplicitSolver name="EulerImplicit_scheme" />
        <CGLinearSolver name="CG" iterations="200" tolerance="1e-09"/>
        <MechanicalObject template="Vec3d" name="myHeartDOF" position="..." />
        <MeshMatrixMass totalmass="2" />
    </Node>

</Node>
```

1. Scene Graph (Python format)

```
import Sofa
import SofaRuntime

def createScene(rootNode):
     rootNode.dt=0.01
     rootNode.gravity="0 0 0"

     liverNode = rootNode.addChild("Liver")
     liverNode.addObject(EulerImplicitSolver)
     liverNode.addObject('CGLinearSolver', iterations="200", tolerance="1e-09"...)
     liverNode.addObject('MechanicalObject',  template="Vec3d", name="myLiverDOF", position="...")
     liverNode.addObject('MeshMatrixMass', name="mass", totalMass="1" )
     liverNode.addObject('TetrahedronFEMForceField', name="LinearElasticity", youngModulus="1e7")

     heartNode = rootNode.addChild("Heart")
     heartNode.addObject(EulerImplicitSolver)
     heartNode.addObject('CGLinearSolver', iterations="200", tolerance="1e-09"...)
     heartNode.addObject('MechanicalObject',  template="Vec3d", name="myHeartDOF", position="...")
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```

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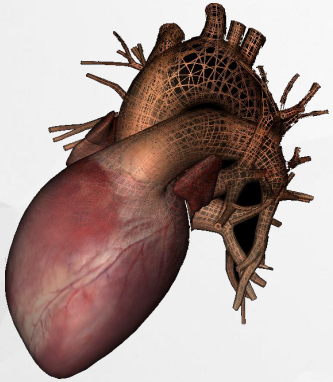
     liverNode.addObject('MeshMatrixMass', name="mass", totalMass="1" )
     liverNode.addObject('TetrahedronFEMForceField', name="LinearElasticity", youngModulus="1e7")

     heartNode = rootNode.addChild("Heart")
     heartNode.addObject(EulerImplicitSolver)
     heartNode.addObject('CGLinearSolver', iterations="200", tolerance="1e-09"...)
     heartNode.addObject('MechanicalObject',  template="Vec1d", name="myTemperatureDOF")
     heartNode.addObject('MeshMatrixMass', name="conductivity", totalMass="1" )
     heartNode.addObject('TetrahedronDiffusionFEMForceField', name="DiffusionEffect")
```

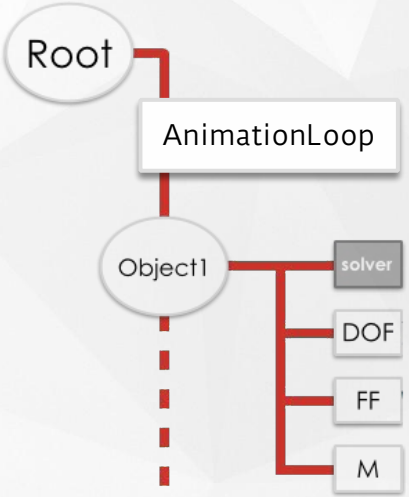
Scene Graph



SOFA Consortium

AnimationLoop and Visitor

- Compulsory in a simulation
- Rules and orders all simulation steps
- At each time step, it triggers Visitors to solve the system



- Visitors browse the graph : graph traversal
- Each specific visitor triggers specific functions in components (ex: *accumulateForce* → *addForce()*)

Mapping

- Matching mechanism : correspondence between models

- Each object can have several models in SOFA
  - Physical model
  - Collision detection model
  - Rendering model (or visual model)

- Each model can rely on a different representation/topology

An open-source project

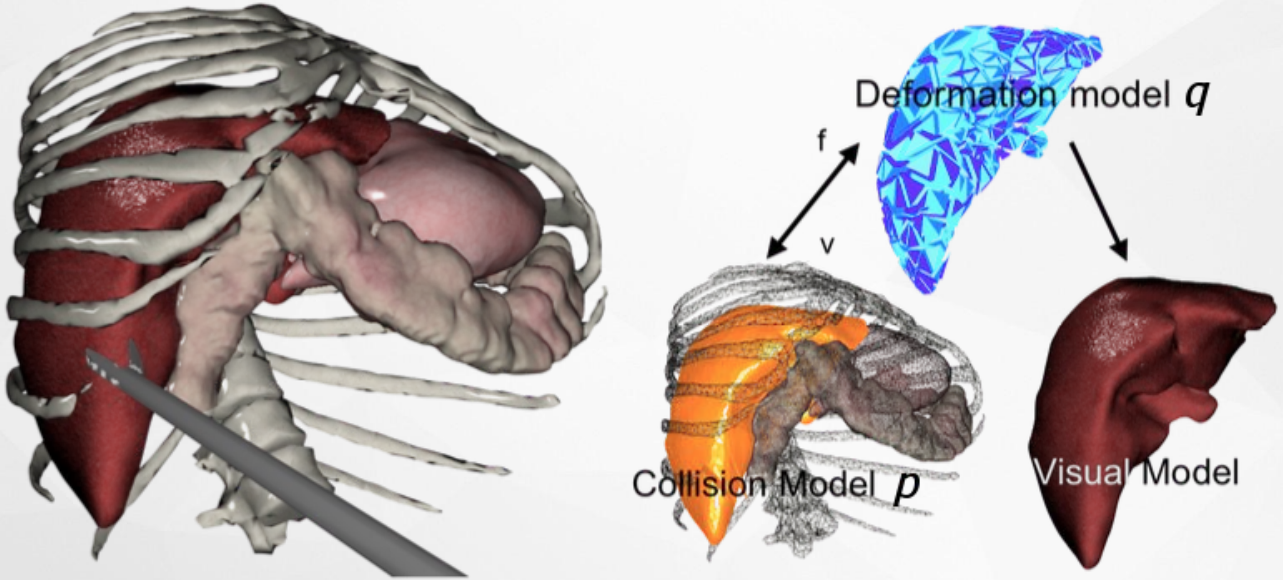
- Arose from research back in 2006 at 
- Need of a collaborative framework for physics simulation
- Project definition

Being the open-source reference for interactive and real-time applications

SOFA

Mapping

- Matching mechanism : correspondence between models



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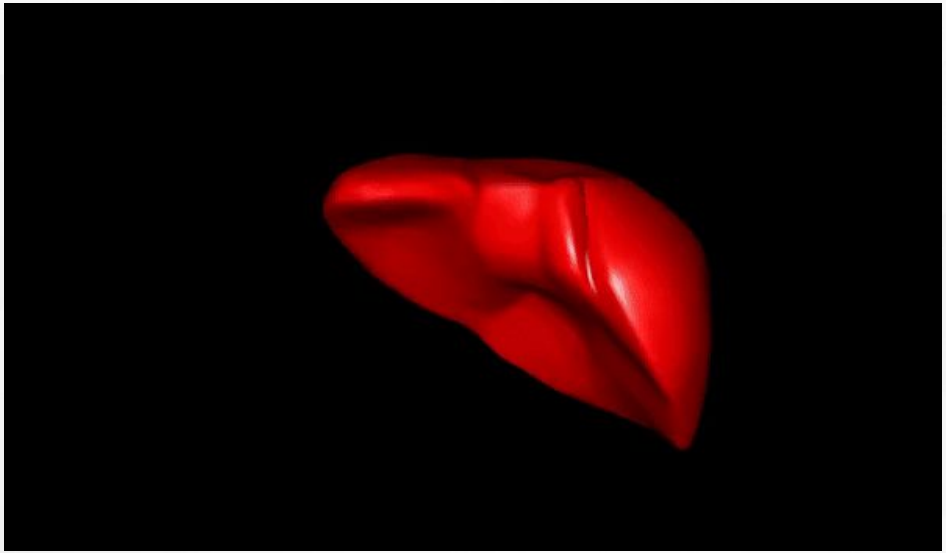
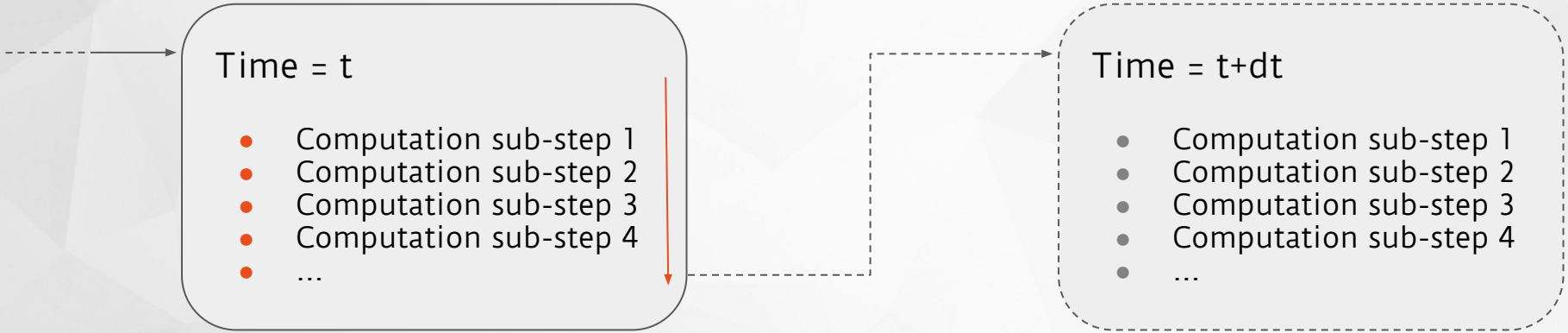


Lifecycle Overview

Lifecycle of one simulation step

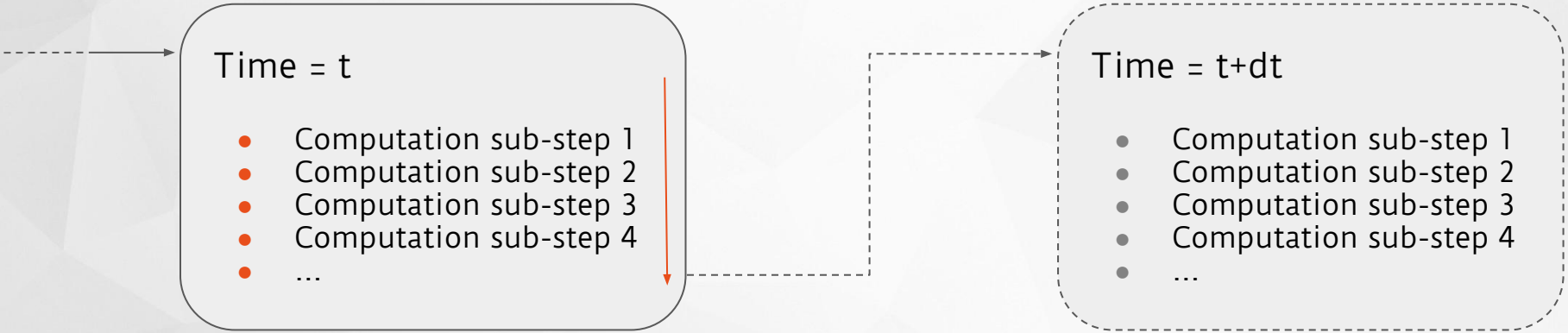
- Which component defines the sub-steps of one time step?



Lifecycle of one simulation step

- Which component defines the sub-steps of one time step?

AnimationLoop



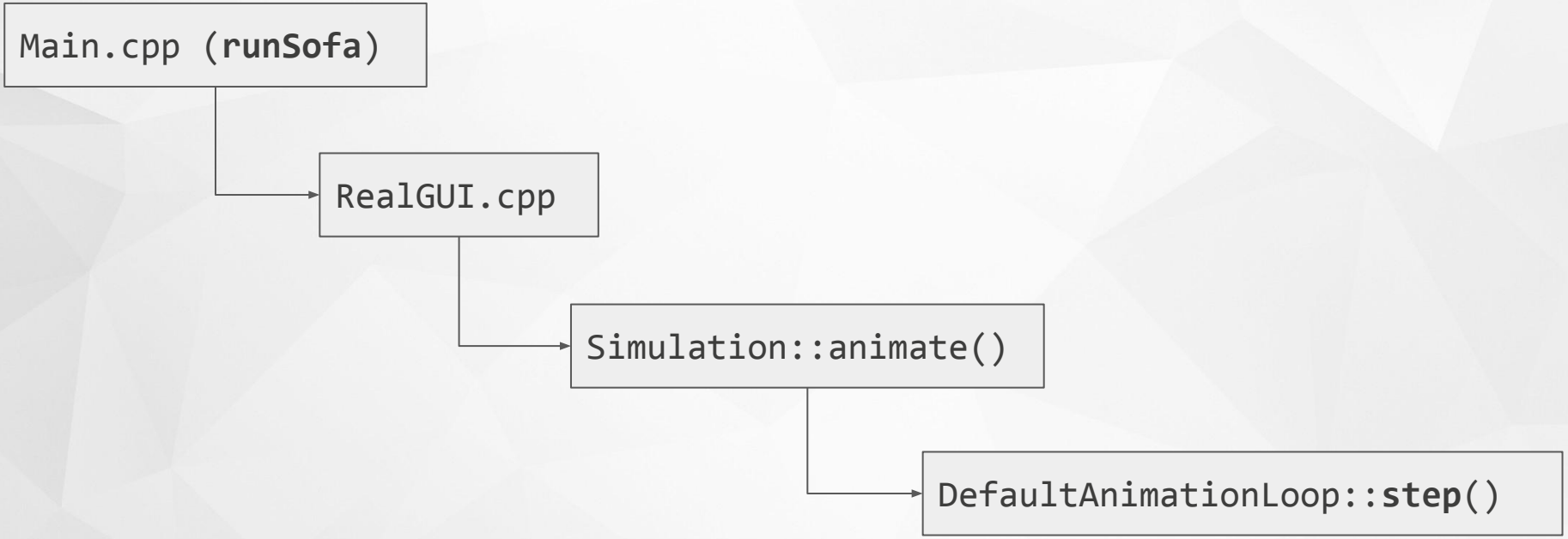
Lifecycle of one simulation step

- Which component defines the sub-steps of one time step?

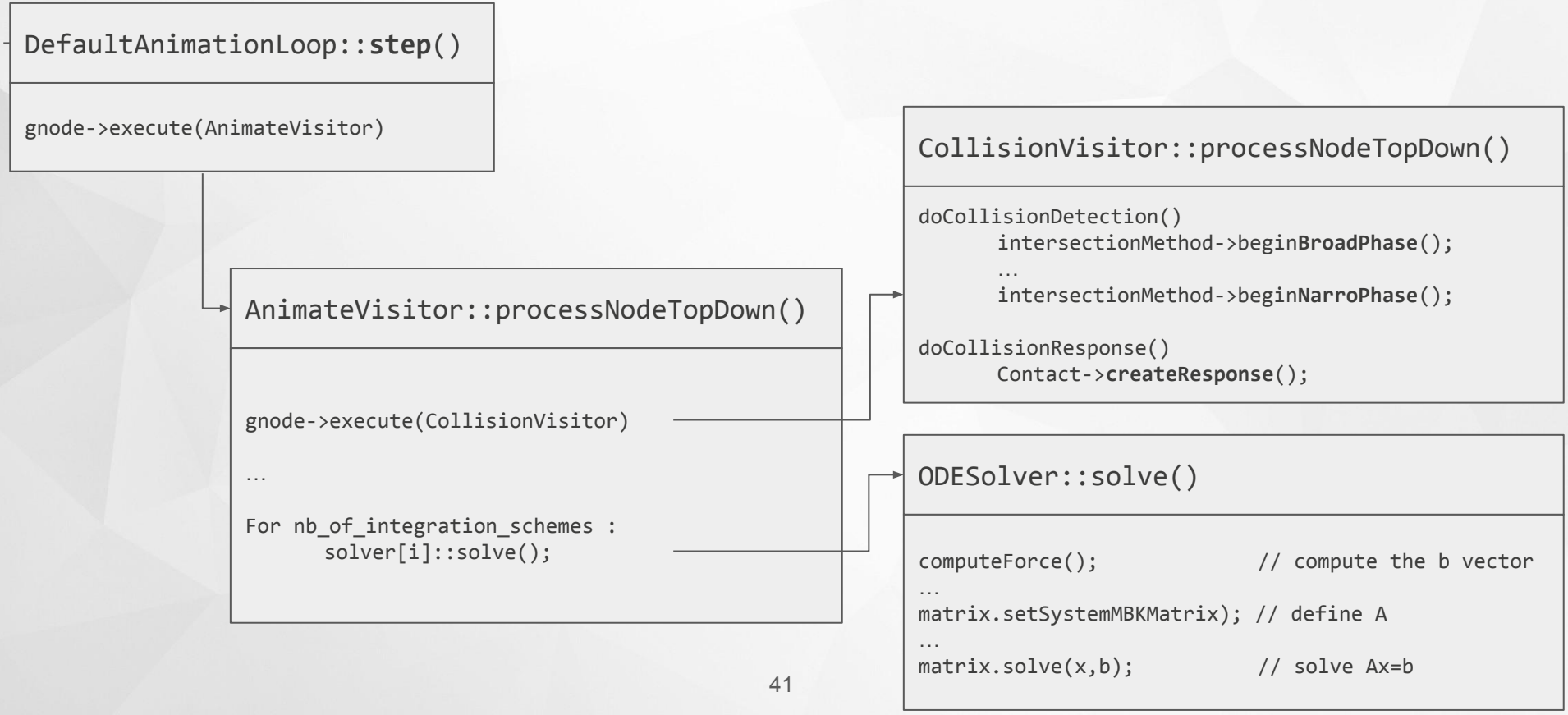
AnimationLoop

- Two implementations
  - DefaultAnimationLoop
  - FreeMotionAnimationLoop (constraint problems solved using Lagrange multipliers)

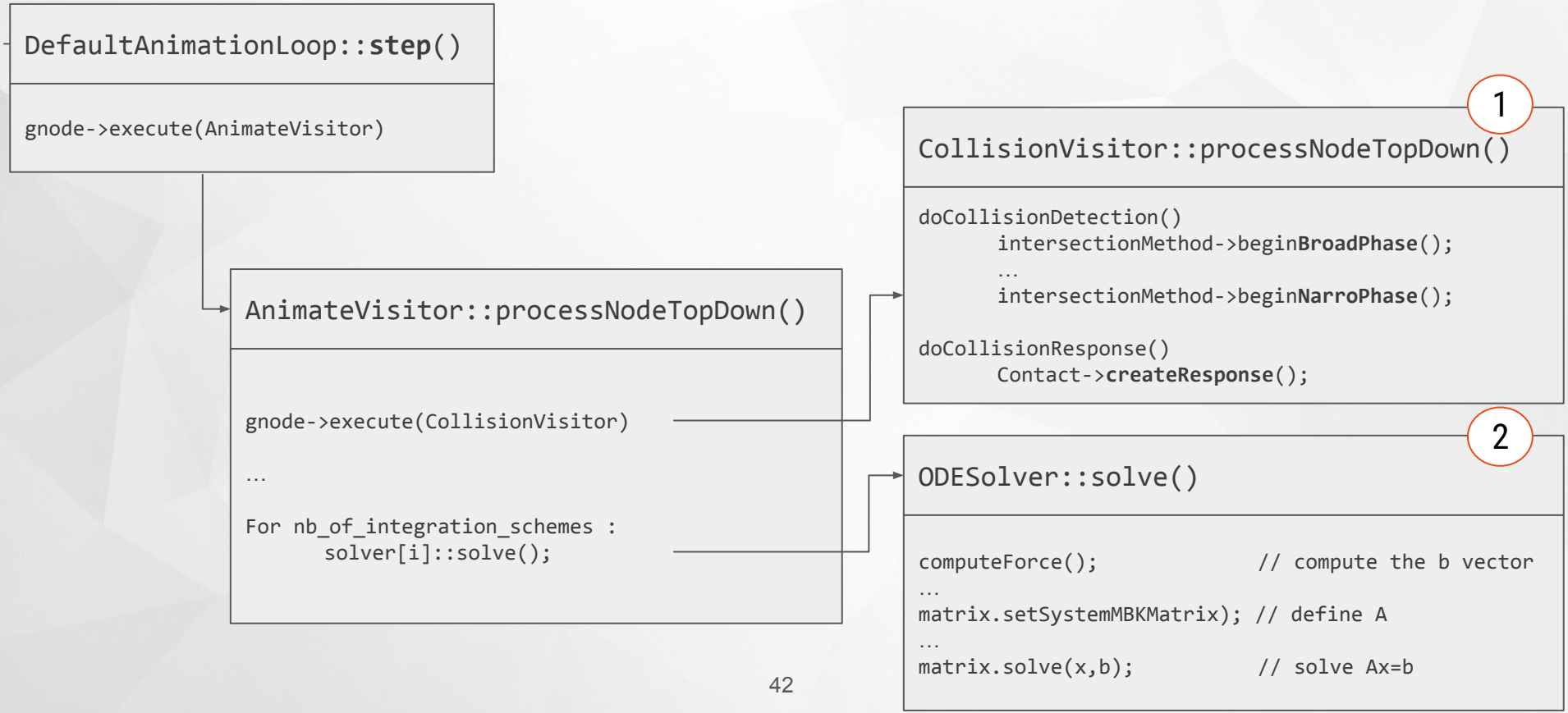
Lifecycle: DefaultAnimationLoop



Lifecycle: DefaultAnimationLoop



Lifecycle: DefaultAnimationLoop



Let’s start with SOFA: User Tutorial

SOFA

Download SOFA

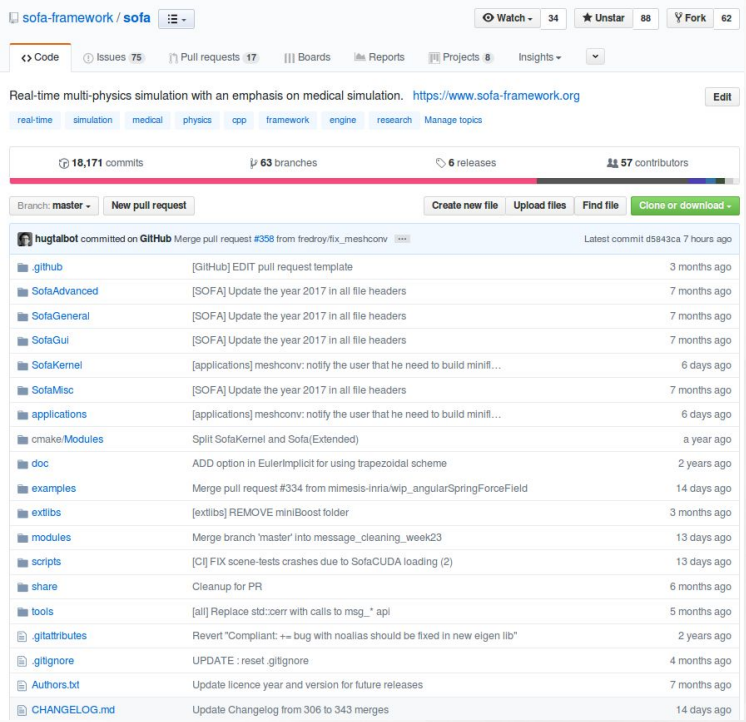
- Two ways!
- Download the binaries
- Download + compile the sources
  - Configure with Cmake
  - Build (using make or others)
- Online documentation

Versioning of sources

- Relying on Git versioning system
- Hosted on GitHub

  https://github.com/sofa-framework/sofa/

- Start with GitHub
  - Create your fork
  - For your development project, work in branches
  - Keep your master branch up-to-date regularly



SOFA Consortium

SOFA architecture

- C++ classes
- Contains all physical models, algorithms and simulation mechanisms
- Structure

  - SOFA core modules (abstract classes = API)
  - Sofa.Components/ ...
  - examples/Components/ ...
  - applications/plugins/

Compilation

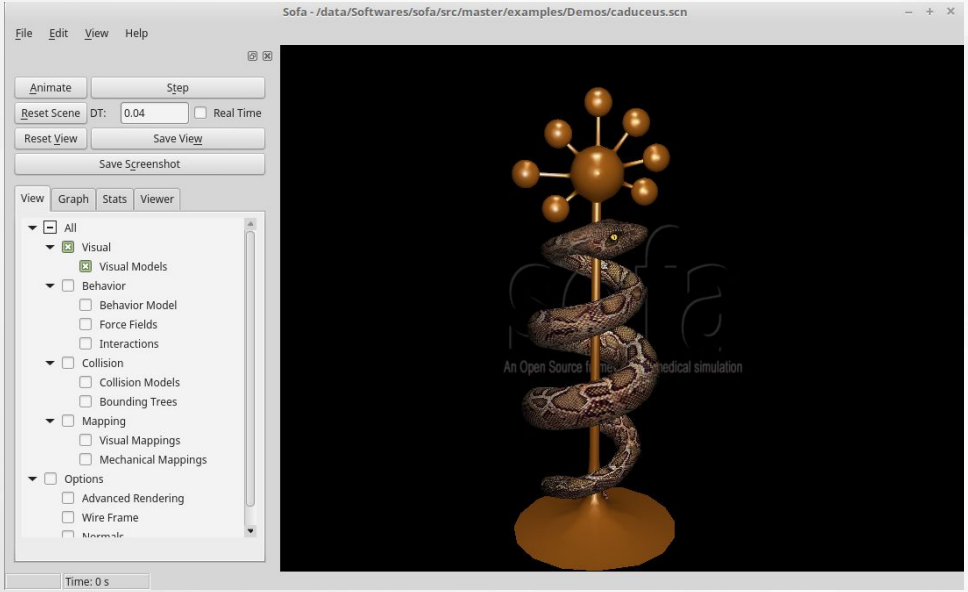
sofa-framework.org/download

- Compile SOFA
  - Checkout the sources
  - Configure with Cmake
  - Build (using make, ninja or others)
- Documentation

Note that stable binary version of SOFA is available: **v21.12**

GUI runSofa

- Build-in Graphical User Interface (GUI) is available
- When running the SOFA executable *./runSofa*



SOFA Consortium

Materials

- Download scenes
  (but do not launch the simulation and spoil yourself!)

www.sofa-framework.org/download-materials

Targeted simulation !

Thank you!

- Welcome in the community!
- Time to get started → sofa-framework.org/community/get-involved
- Get support from the community
- Join us at our 2022 events