SOFA: a modular yet efficient physical simulation architecture

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Outline

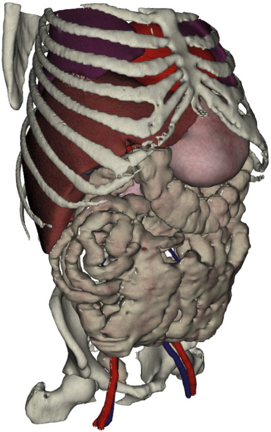
Motivation

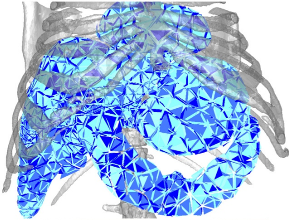
Modularity

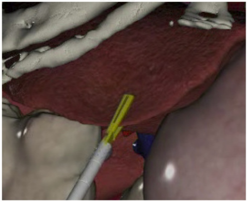
Software development

Conclusion

The complexity of physical simulations







Material, internal forces, contraints, contact detection and modeling, ODE solution, visualization, interaction, etc.

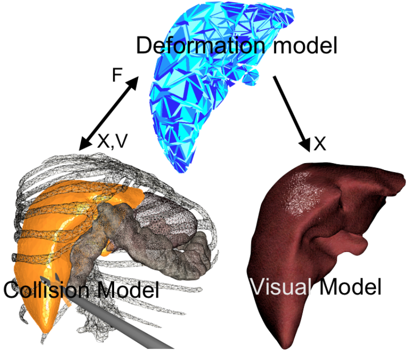
Simulation platforms

- Current platforms (ODE, Havok, PhysX, etc.) provide :
  - limited number of material types
  - limited number of geometry types
  - no control on collision detection algorithms
  - no control on interaction modeling
  - few (if any) control of the numerical models and methods.
  - no control on the main loop
- We need much more !
  - models, algorithms, scheduling, visualization, etc.

Outline

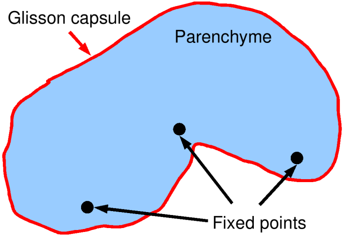
A generic approach

- Behavior model : all internal laws
- Others : interaction with the world
- Mappings : relations between the models (uni- or bi-directional)



Animation of a simple body

- a liver



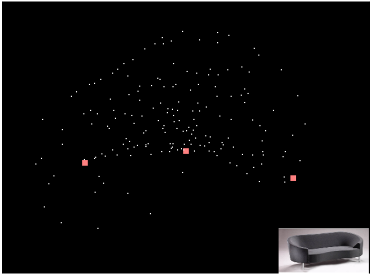
- inside : soft material
- surface : stiffer material

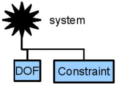
A specialized program :

```
f  =  M*g
f  += F1(x,v)
f  += F2(x,v)
a  =  f/M
a  =  C(a)
v  += a * dt
x  += v * dt
display(x)
```

Component-based simulation object

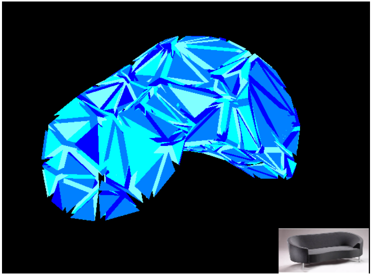
- state vectors (DOF) :
  x, v, a, f
- constraints : fixed points
  other : oscillator, collision plane, etc.

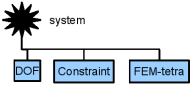




Component-based simulation object

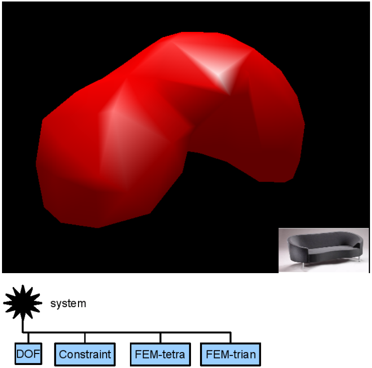
- state vectors (DOF) :
  x, v, a, f
- constraints : fixed points
- force field : tetrahedron FEM
  other : triangle FEM, springs, Lennard-Jones, SPH, etc.





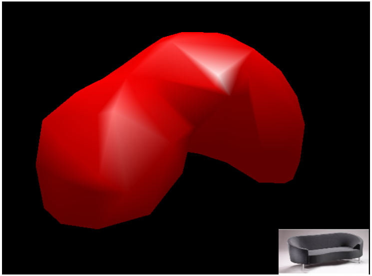
Component-based simulation object

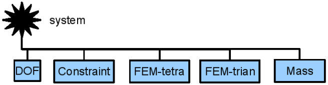
- state vectors (DOF) : x, v, a, f
- constraints : fixed points
- force field : tetrahedron FEM
- force field : triangle FEM



Component-based simulation object

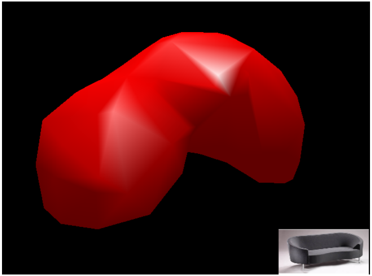
- state vectors (DOF) : x, v, a, f
- constraints : fixed points
- force field : tetrahedron FEM
- force field : triangle FEM
- mass : uniform
  other : diagonal, sparse symmetric matrix

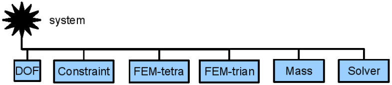




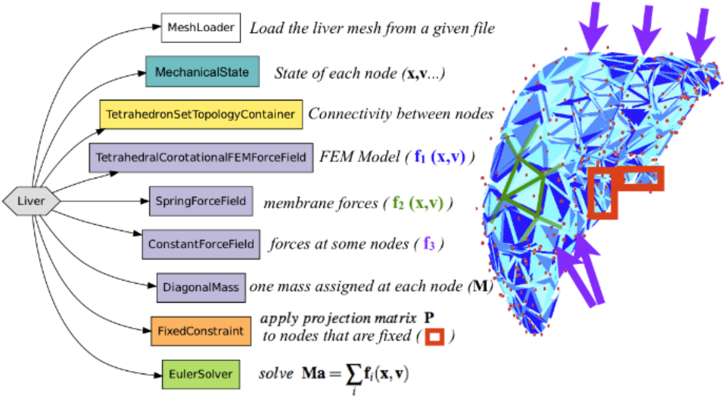
Component-based simulation object

- state vectors (DOF) : x, v, a, f
- constraints : fixed points
- force field : tetrahedron FEM
- force field : triangle FEM
- mass : uniform
- ODE solver : explicit Euler
  other : Runge-Kutta, implicite Euler, static solution, etc.



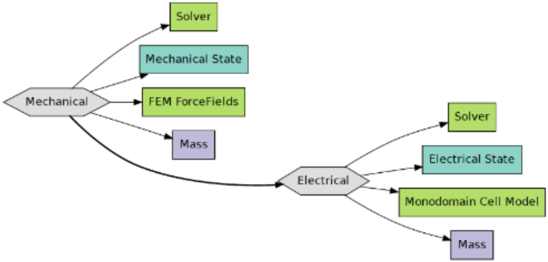


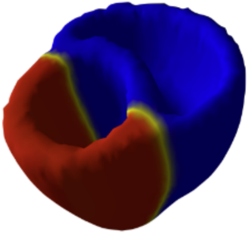
Actual decomposition



Multiphysics

Non-mechanical solvers can be coupled with the simulation





Operations

- The ODE solver sends visitors to apply operations
- The visitors traverse the scene and apply virtual methods to the components
- The methods read and write state vectors (identified by symbolic constants) in the DOF component
- Example : accumulate force
  - A `ResetForceVisitor` recursively traverses the nodes of the scene (only one node here)
    - All the `DOF` objects apply their `resetForce()` method
  - An `AccumulateForceVisitor` recursively traverses the nodes of the scene
    - All the `ForceField` objects apply their `addForce( Forces, const Positions, const Velocities )` method
  - the final value of f is weight + tetra fem force + trian fem force

Outline

Implementation

- C++ libraries
- Linux, Windows, Mac
- 800,000 lines of code
- 138,000 downloads

Contributors

80 contributors to the code. Three full-time engineers.

- Cimit (Boston)/Graphix (Lille)
- Evasion/Imagine (Grenoble)
- Epidaure/Asclepios (Sophia-Antipolis)
- Shacra (Strasbourg)
- MOAIS (Grenoble), Sed Sophia, ...
- Companies : Digital Trainers, Bellcurves, InSimo, ...

Features

- deformable solids : FEM, cables, frame-based,...
- mass-springs, rigid, SPH
- soft, stiff, hard constraints
- iterative and direct solvers
- collision detection and response
- multiphysics

Outline

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Conclusion - Features

High modularity :

- Abstract components : DOF, Force, Constraint, Solver, Topology, Mass, CollisionModel, VisualModel, etc.
- Multimodel simulations using mappings
- Explicit and implicit solvers, Lagrange multipliers

Efficiency :

- global vectors and matrices are avoided
- parallel implementations

Implementation :

- currently $450,000$ C++ lines
- Linux, MacOs, Windows

Ongoing work

- models and algorithms : better numerical solvers, cutting, haptics, Eulerian fluids...
- asynchronous simulation/rendering/haptic feedback
- multiphysics (electrical/mechanical)
- parallelism for everyone
- more documentation

www.sofa-framework.org