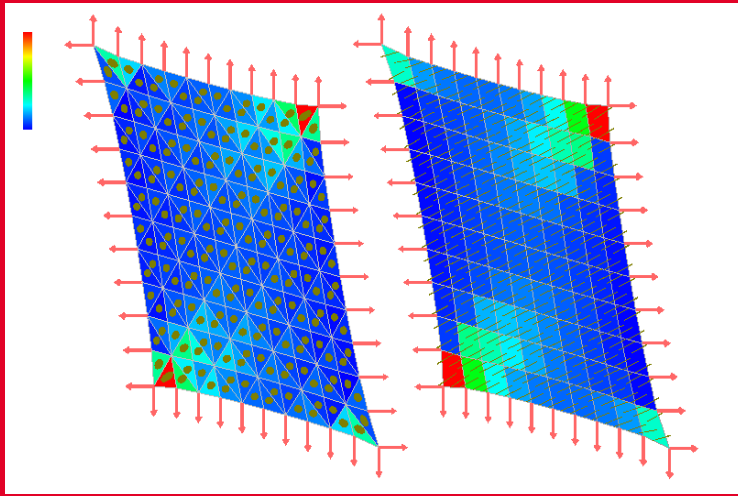


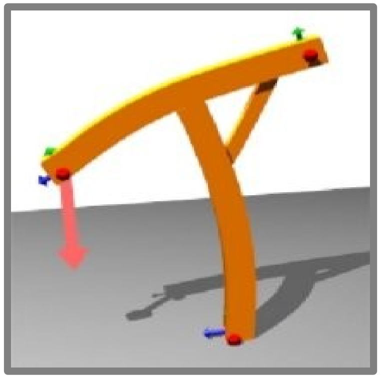
Flexible Plugin

Benjamin Gilles, François Faure, Maxime Tournier, Matthieu Nesme

Training Days, Montpellier

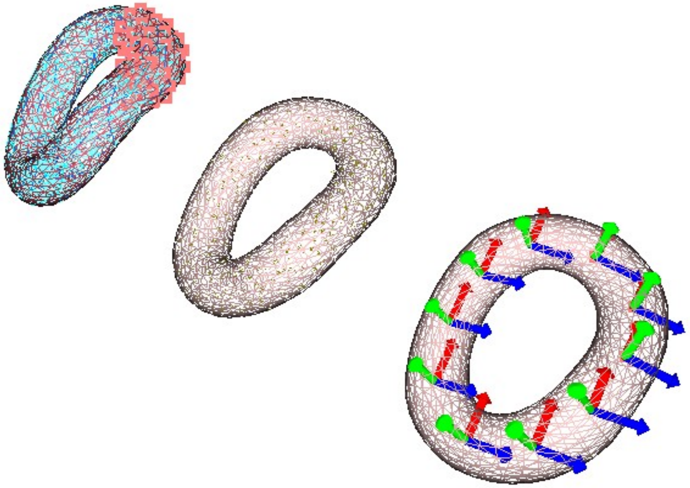
22 OCTOBRE 2013

Objectives



Deformable solid simulation

- Modularity
- Unification of mesh-based and mesh-free methods
- Code reusability
- Method comparison

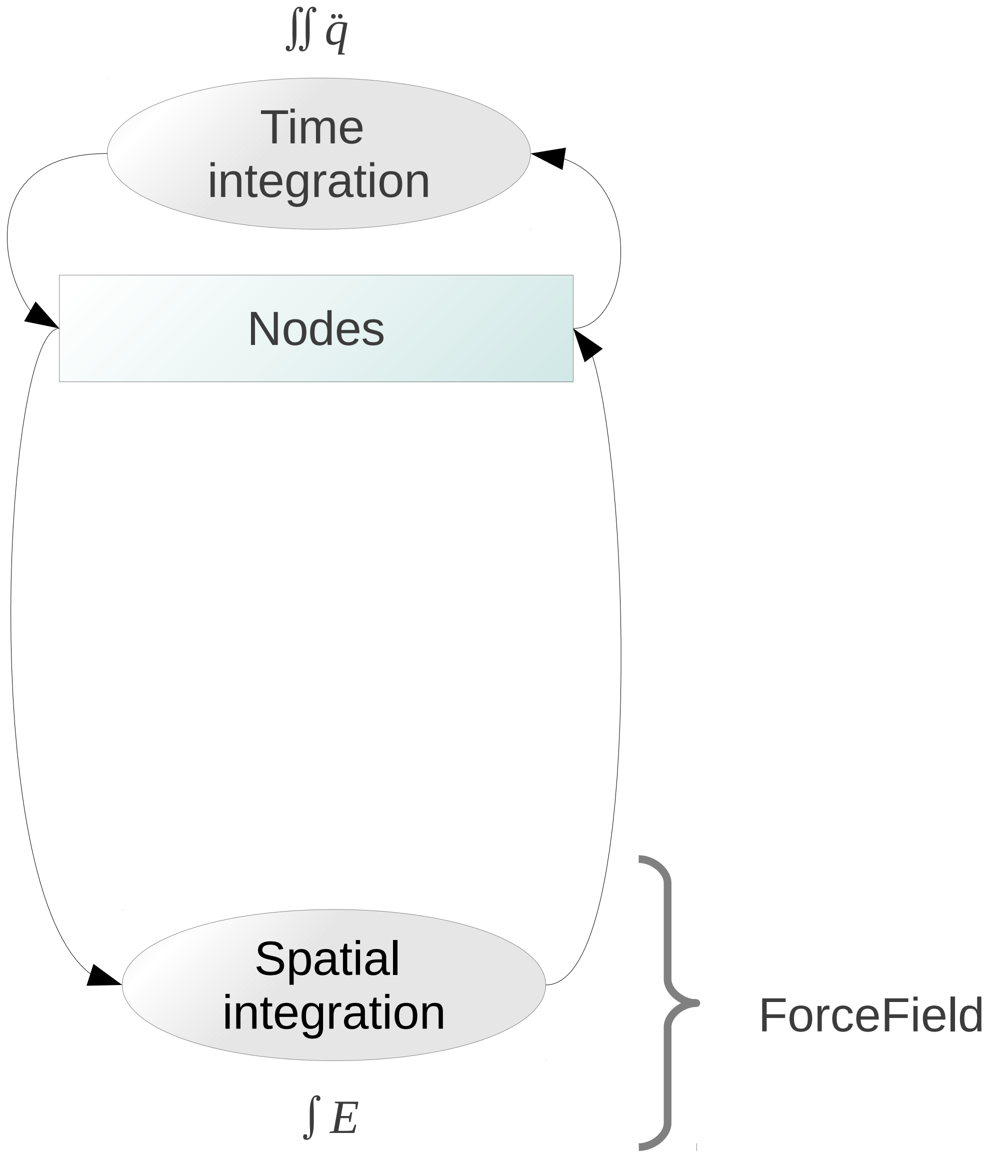


1

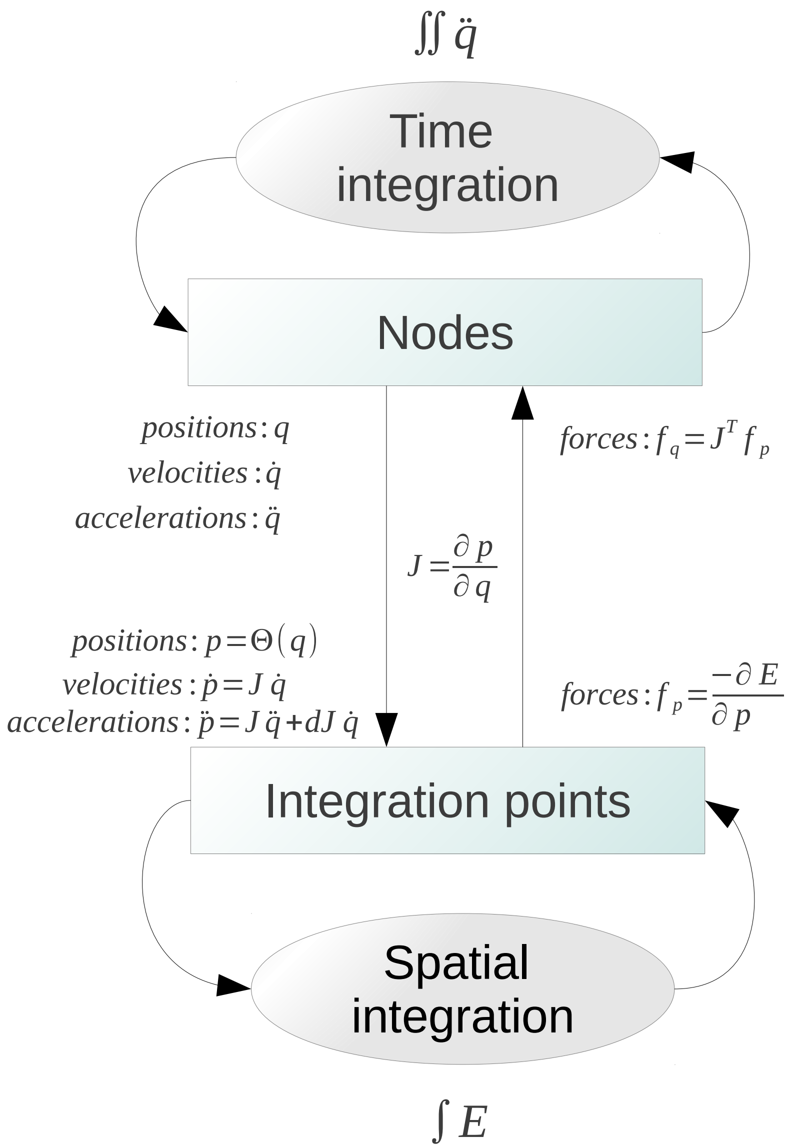
PRINCIPLES

Modular vision of solid mechanics

Regular vision of solid mechanics

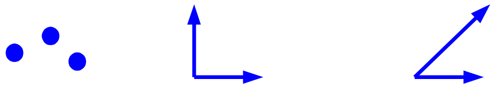


Modular vision of solid mechanics

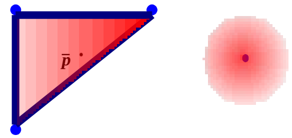


Solve equations of motion
e.g. : static, explicit, implicit..

Independent degrees of freedom
e.g. : Points, rigid frames, affine frames, angles...



Interpolation method using shape function
e.g. : barycentric, moving least squares, skinning..



Mapped quantities
e.g. : strain, displacement..

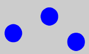
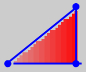
Energy, constitutive law
e.g. : kinetic, elastic, external..

Quadrature method
e.g. : midpoint, Gauss, elastons..

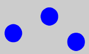
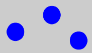
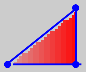
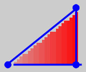
Modular vision of solid mechanics

	Linear FEM St Venant Kirchoff	Linear FEM Corotational	Meshless Neo-Hookean	Frame-based Neo-Hookean
Independant DOFs				
Interpolation				
Shape function				
Strain				
Constitutive law				
Quadrature method				

Modular vision of solid mechanics

	Linear FEM **St Venant Kirchoff**	**Linear FEM** **Corotational**	**Meshless** **Neo-Hookean**	**Frame-based** **Neo-Hookean**
Independant DOFs	Points 			
Interpolation	Linear			
Shape function	Barycentric 			
Strain	Green-Lagrange			
Constitutive law	Hooke			
Quadrature method	midpoint			

Modular vision of solid mechanics

	Linear FEM **St Venant Kirchoff**	**Linear FEM** **Corotational**	**Meshless** **Neo-Hookean**	**Frame-based** **Neo-Hookean**
Independant DOFs	Points 	Points 		
Interpolation	Linear	Linear		
Shape function	Barycentric 	Barycentric 		
Strain	Green-Lagrange	Corotational		
Constitutive law	Hooke	Hooke		
Quadrature method	midpoint	midpoint		

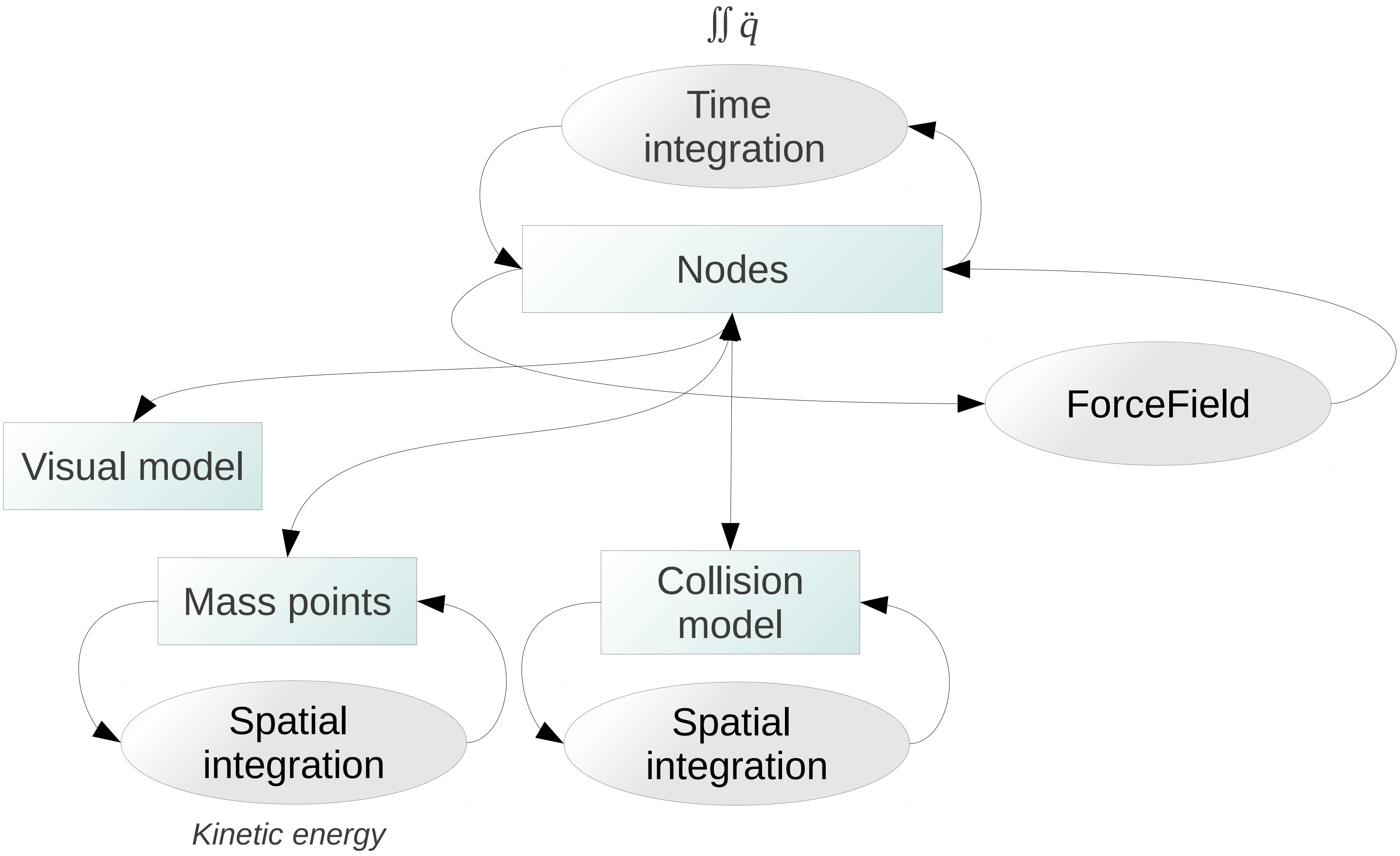
Modular vision of solid mechanics

	Linear FEM **St Venant Kirchoff**	**Linear FEM** **Corotational**	**Meshless** **Neo-Hookean**	**Frame-based** **Neo-Hookean**
Independant DOFs	Points	Points	Points	
Interpolation	Linear	Linear	Moving Least Square	
Shape function	Barycentric	Barycentric	Radial	
Strain	Green-Lagrange	Corotational	Invariants	
Constitutive law	Hooke	Hooke	Neo-Hookean	
Quadrature method	midpoint	midpoint	midpoint	

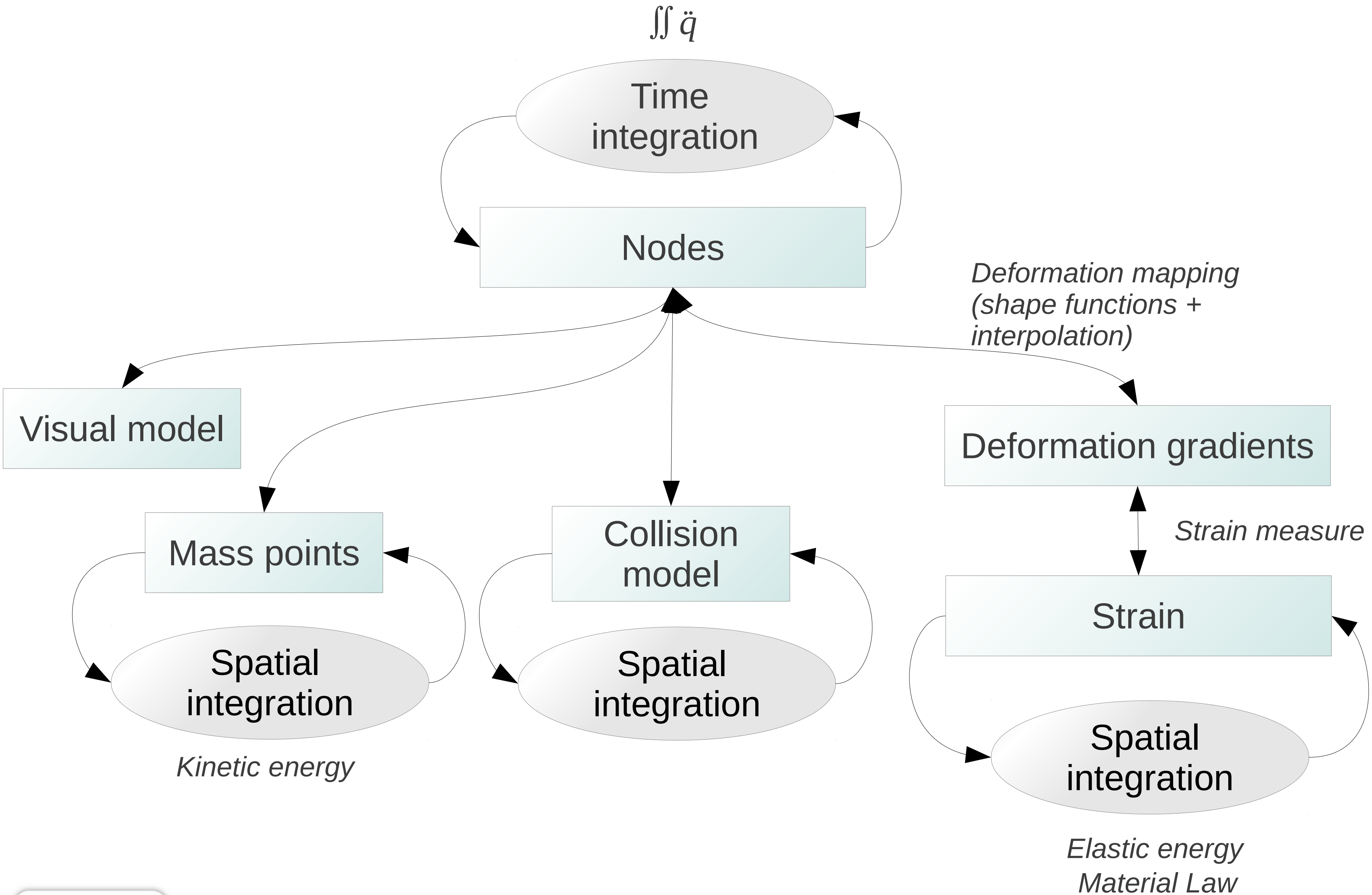
Modular vision of solid mechanics

	Linear FEM **St Venant Kirchoff**	**Linear FEM** **Corotational**	**Meshless** **Neo-Hookean**	**Frame-based** **Neo-Hookean**
Independant DOFs	Points	Points	Points	Affine Frames
Interpolation	Linear	Linear	Moving Least Square	Linear
Shape function	Barycentric	Barycentric	Radial	Voronoï-based
Strain	Green-Lagrange	Corotational	Invariants	Principal Stretches
Constitutive law	Hooke	Hooke	Neo-Hookean	Neo-Hookean
Quadrature method	midpoint	midpoint	midpoint	midpoint

Regular vision of solid mechanics



Modular vision of solid mechanics



Basic Demos

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Implemented Components

DOF Types

- Nodes
  - Particles (2d, 3d)
  - Rigid, Affine, Quadratic Frames
- Deformation Gradients
  - 1d, 2d, 3d
  - Up to 2nd order (F + dF)
- Strain
  - Regular tensor (2x2, 3x1, 3x2, 3x3)
  - Principal Stretches
  - Up to 3rd order
- (Deviatoric) Invariants of the Cauchy Green deformation tensor

- To do:

  - Higher order invariants

  - Angles

DOF Types - Notation

Type **S**patialDimension **M**aterialDimension **O**rder

- Deformation gradient **F**
- Strain
  - Tensor **E**
  - Principal Stretches **U**
  - Invariants **I**
- Examples
  - A deformation gradient in 3d space for 2d material, order 1 (triangle FEM)

    → **F321**
  - A strain tensor in 2d space for 1d material, order 1 (2d spring)

    → **E211**

Shape Functions

- Barycentric based on topology
- Shepard and Hat functions based on Euclidean distances
- Voronoï based on geodesic distances in images [Faure11]

- To do :
  - High order elements
  - Diffusion distances

Deformation Mapping

- Linear mapping
  - Vec2,Vec3 → Vec3, F (1d,2d,3d)
  - Rigid, Affine, Quadratic Frames → Vec3, F, dF
- Moving Least Squares
  - Vec3 → Vec3, F
  - Rigid, Affine, Quadratic Frames → Vec3, F, dF
- Extension, Volume mappings
  - Vec3 → d, v

Strain Mapping

- Green-Lagrange Strain
  - F33→E33, F32→E32, F31→E31
- Corotational Strain (invertible QR, polar, invertible SVD)
  - F33→E33, F32→E32, F31→E31, F22→E22
- Principal Stretches (invertible)
  - F33→E33, F32→E32
- Invariants
  - F33→I33
- Plasticity (relative strain) E → E [Muller04,Irving04]
- To do:
  - Check geometric stiffness for corotational / invariants!!
  - Complete 2d mappings

Quadrature

- Topology-based sampling and weighting
  - Gauss-Legendre quadrature (order 0 and 1)

- Image-based
  - Uniform sampling → mid-point integration
  - Sampling driven by weight linearity → elastons [Martin10]

- To do:
  - Implementation for higher order elements
  - Other rules (Newton Cotes, Gauss Kronrod, ...)

Materials

- Hooke (isotropic+viscosity, transverse, anisotropic)
- Neo-Hookean (+stabilization [Teran12])
- Mooney-Rivlin
- Ogden
- Volume Preservation

- Inhomogeneous properties defined in images

- To do:
    - More materials

Misc

- ImageDensityMass
  - A « clean » mass computed from a density image
  - Particles, Affine & Quadratic Frames
  - To do:
    - Rigid Frame

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Conclusion

Avantages

- Modularity
  - Code reusability
  - Easier implementation (focus on one part)
  - Share progress on specific area

- Method Comparison

Drawbacks

- More Memory
  - Every DOFs at each stage (deformation gradient, strain)
- Some optimisations are not trivial
  - Corotational Hexa FEM
- To do:
  - Meta-ForceField internally using Flexible Components DOF per DOF

Future Works

- Extend to methods not based on the continuum mechanics
  - Shape matching

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Coupling with other plugins

Coupling with other plugins

- Image
  - Sampling and interpolation weights for meshless methods
  - Definition of heterogeneous material properties
  - Visualisation
- SofaPython
  - Visualisation
  - Control of material properties (e.g. plasticity and anisotropy of plant cells)
- Compliant
  - Assembly & solvers friendly

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MORE DEMOS

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NOM DU CHAPITRE

Sous-titre facultatif

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Sous-titre facultatif

Thank you

Flexible Plugin