University of Stuttgart
Institute for Modelling and Simulation
of Biomechanical Systems

Introduction to User Materials in Abaqus FEA

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IRTG STR regular meeting

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Stuttgart, Germany

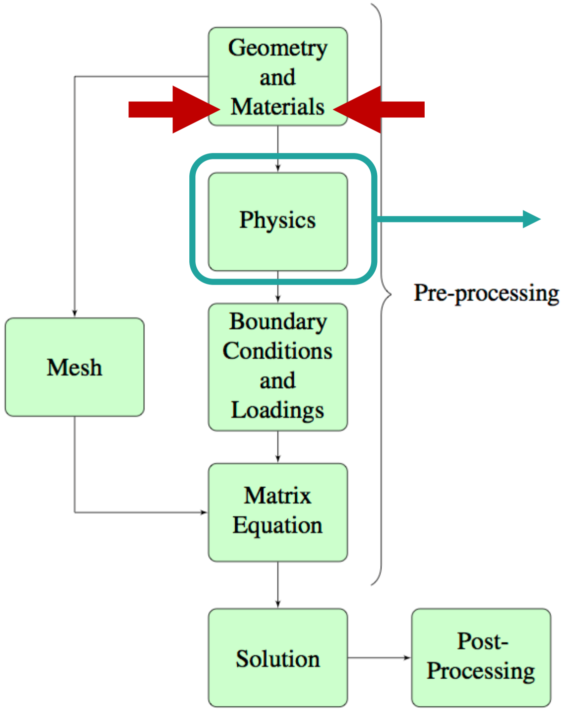
DFG Deutsche Forschungsgemeinschaft

Soft Tissue Robotics

CBM

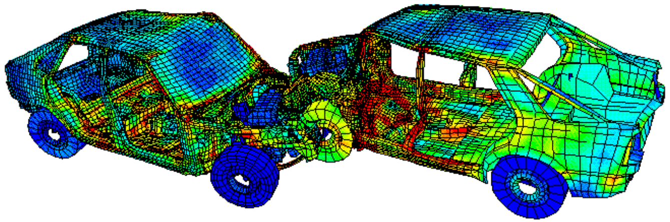
Introduction

Finite Element Analysis



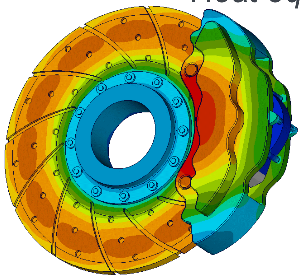
http://www.iue.tuwien.ac.at/phd/rovitto/node72.html

Structural mechanics *Momentum balance*



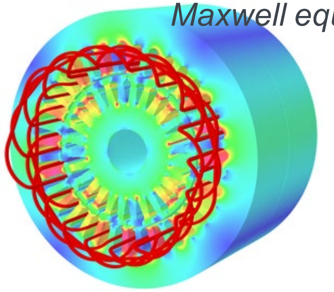
http://www.tam.northwestern.edu/tb/D26/

Heat-transfer *Heat equation (Fourier)*



https://www.theseus-fe.com/simulation-software/heat-transfer-analysis

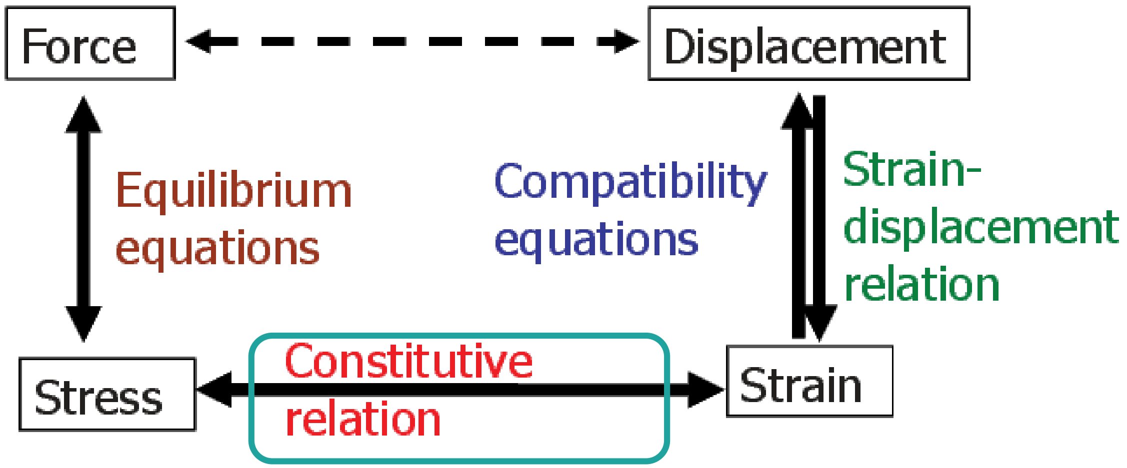
Electromagnetic *Maxwell equations*



https://www.3ds.com/products-services/simulia/products/opera/

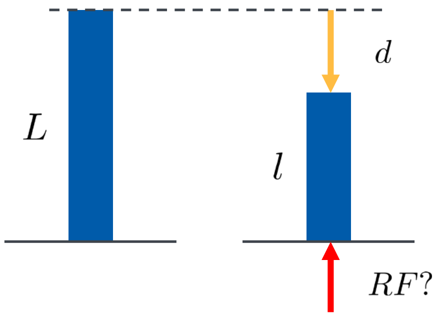
Introduction

Material Modelling



https://nptel.ac.in/courses/105106049/

1D Example



$$\epsilon = \frac{l-L}{L} = \frac{d}{L}$$

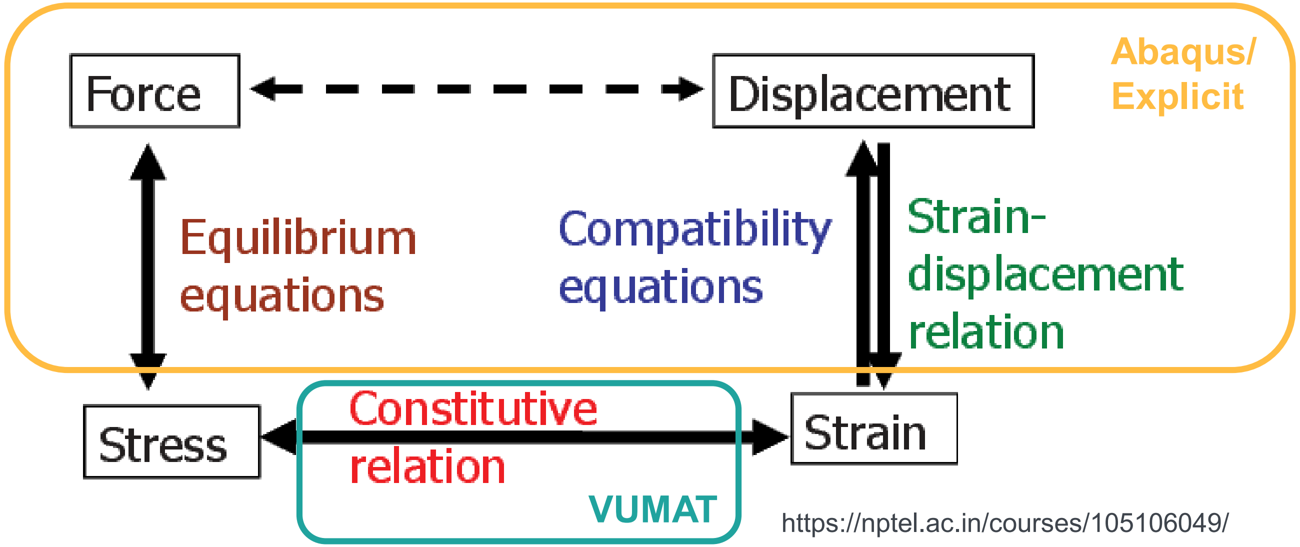
$$\sigma = \boxed{E} \times \epsilon$$

$$F = \sigma \times A = RF$$

Introduction

User Materials in Abaqus (Explicit)

- Abaqus/implicit uses information at current and previous time $G\Big(Y(t), Y(t+\Delta t)\Big) = 0$
- Abaqus/explicit uses information only from previous time $Y(t+\Delta t) = F(Y(t))$

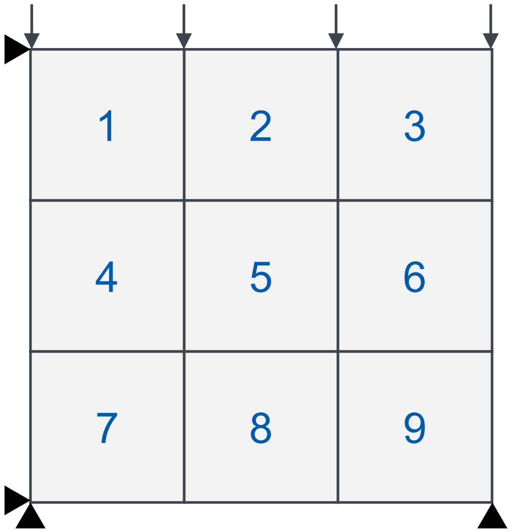


https://nptel.ac.in/courses/105106049/

VUMAT

Basic Structure

$$t_0, t_1, \ldots, t_i, t_{i+1}, \ldots, t_n$$



Per element; call VUMAT:

$$\Delta\boldsymbol{\epsilon}_i$$
$$\boldsymbol{\sigma}_i$$
$$\mathbf{c}$$

VUMAT

$$\boldsymbol{\sigma}_{i+1} = \mathbf{C}\,\epsilon_{i+1}$$

$$\ldots$$

$$\epsilon_{i+1} = \epsilon_i + \Delta\epsilon$$
$$\sigma_{i+1} = c_1 \times \epsilon_{i+1}$$
$$\sigma_{i+1} = c_1 \times (\epsilon_i + \Delta\epsilon)$$
$$\sigma_{i+1} = \sigma_i + c_1 \times \Delta\epsilon$$

$$\boldsymbol{\sigma}_{i+1}$$

VUMAT

Welcome to the real world

```
stretchNew(nblock)
stressOld(nblock,ndir+nshr)
props(nprops)
totalTime,...
```

VUMAT

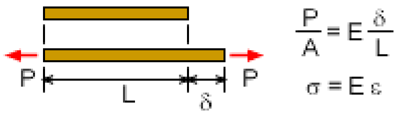
```
      subroutine vumat(
C Read only (unmodifiable)variables -
     1  nblock, ndir, nshr, nstatev, nfieldv, nprops, lanneal,
     2  stepTime, totalTime, dt, ...,
     4  tempOld, stretchOld, defgradOld, fieldOld,
     5  stressOld, ...,
C Write only (modifiable) variables -
     7  stressNew, stateNew, enerInternNew, enerInelasNew )
C
      include 'vaba_param.inc'
C
      dimension props(nprops), density(nblock), coordMp(nblock,*),
     1  charLength(nblock), strainInc(nblock,ndir+nshr),
     2  relSpinInc(nblock,nshr), tempOld(nblock),
     3  stretchOld(nblock,ndir+nshr),
     4  ...
     2  enerInternNew(nblock), enerInelasNew(nblock),

      do 100 km = 1,nblock
        user coding
  100 continue

      return
      end
```

```
stressNew(nblock,ndir+nshr)
```

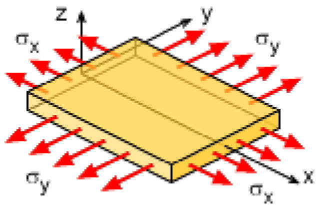
VUMAT

A worked example – three-dimensional isotropic, linear elasticity

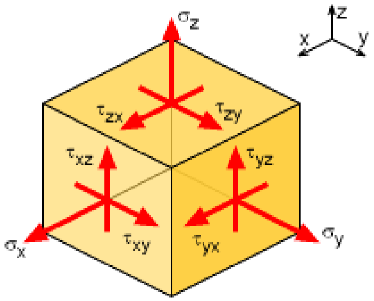
- Generalise 1D elasticity to 3D
- Implement in FORTRAN according to VUMAT requirements
- Validate against in-built Abaqus linear elasticity



1-D Hooke's Law

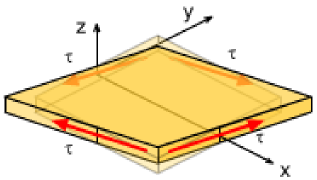


Stress in Two Directions



Stress Directions in 3D

($\tau_{xy} = \tau_{yx}$, $\tau_{yz} = \tau_{zy}$, $\tau_{xz} = \tau_{zx}$)



Pure Shear Stress in a 2D plane

https://www.ecourses.ou.edu/cgi-bin/eBook.cgi?doc=&topic=me&chap_sec=01.4&page=theory

$$\sigma_{ij} = C_{ijkl}\epsilon_{kl}$$

$$C_{ijkl} = \lambda\delta_{ij}\delta_{kl} + \mu(\delta_{ik}\delta_{jl} + \delta_{il}\delta_{jk})$$

$$\sigma_{ij} = \lambda\delta_{ij}\epsilon_{kk} + 2\mu(\epsilon_{ij})$$

$$\mu = \frac{E}{2(1+\nu)}$$

$$\lambda = \frac{E\nu}{(1+\nu)(1-2\nu)}$$

VUMAT

A worked example – three-dimensional isotropic, linear elasticity

```
      do i = 1,nblock
c             sigma_11 component
              stressNew(i,1)=
c             sigma_22 component
              stressNew(i,2)=
c             sigma_33 component
              stressNew(i,3)=
c             sigma_12 component (shear stress)
              stressNew(i,4)=
c             sigma_13 component (shear stress)
              stressNew(i,5)=
c             sigma_23 component (shear stress)
              stressNew(i,6)=
      end do
```

$$\sigma_{ij} = \lambda \delta_{ij} \epsilon_{kk} + 2\mu(\epsilon_{ij})$$

$$\sigma_{11} = \lambda(\epsilon_{11} + \epsilon_{22} + \epsilon_{33}) + 2\mu\epsilon_{11}$$

$$\sigma_{11}^{i+1} = \sigma_{11}^{i} + \lambda(\Delta\epsilon_{11} + \Delta\epsilon_{22} + \Delta\epsilon_{33}) + 2\mu\Delta\epsilon_{11}$$

current configuration

→ Linear or non-linear analyses: (1) material (2) geometric (3) boundary conditions

reference configuration


400
HAPPINESS
1400
VUMAT IN FORTRAN
ImageChef.com

Stable time increment

$$\Delta t \leq \frac{2}{\omega_{max}}$$

$$\Delta t \approx \frac{L_{min}}{c_d}$$

$$c_d = \sqrt{\frac{\hat{\lambda} + 2\hat{\mu}}{\rho}} \; ,$$