Falltests von Flüssigkeitsgefüllten Behältern mit Berücksichtigung von Fluid-Struktur Interaktion

28. Oktober 2010

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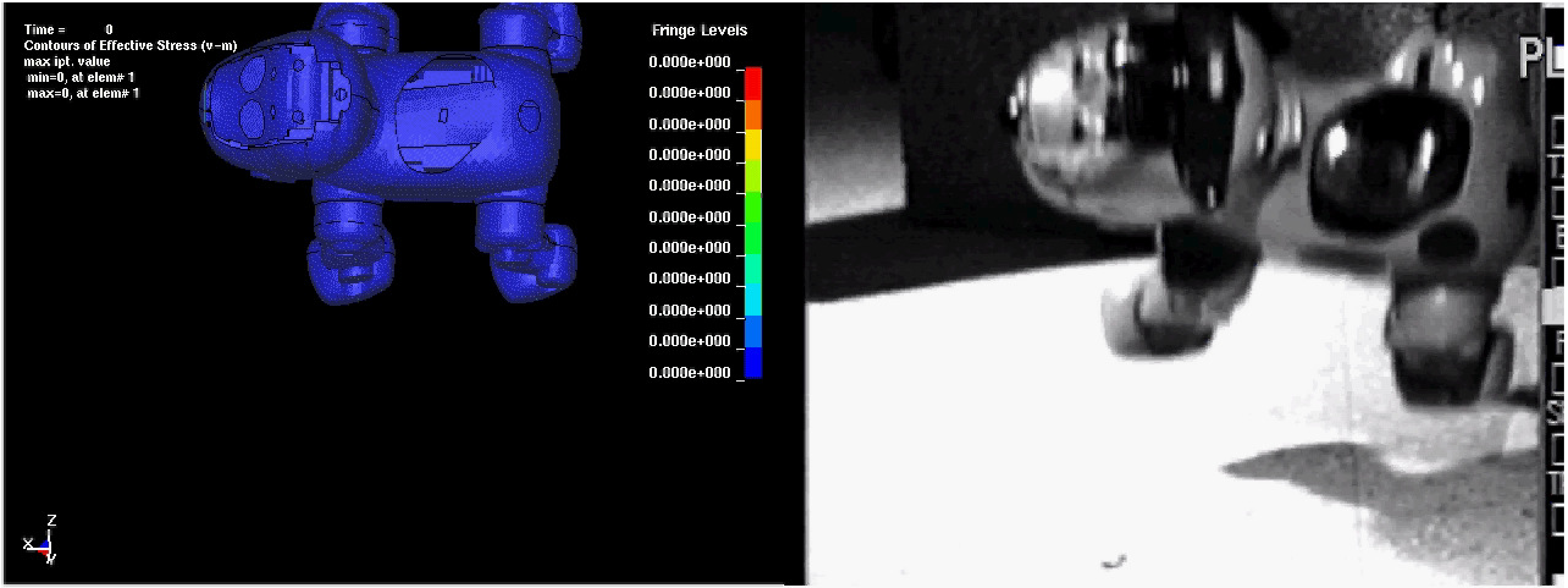
Overview

- Motivation
- Basis of Lagrangian, Eulerian and ALE Methodology
- Possible Applications
- Ingredients for FSI Coupling
- Summary
- Industrial Application

1 Motivation



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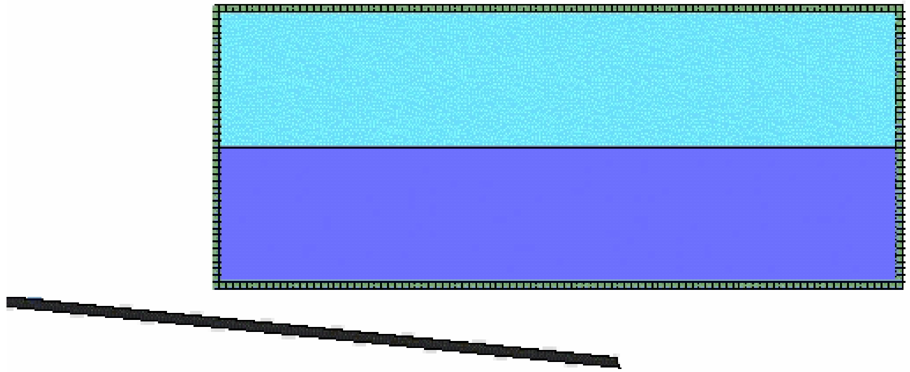

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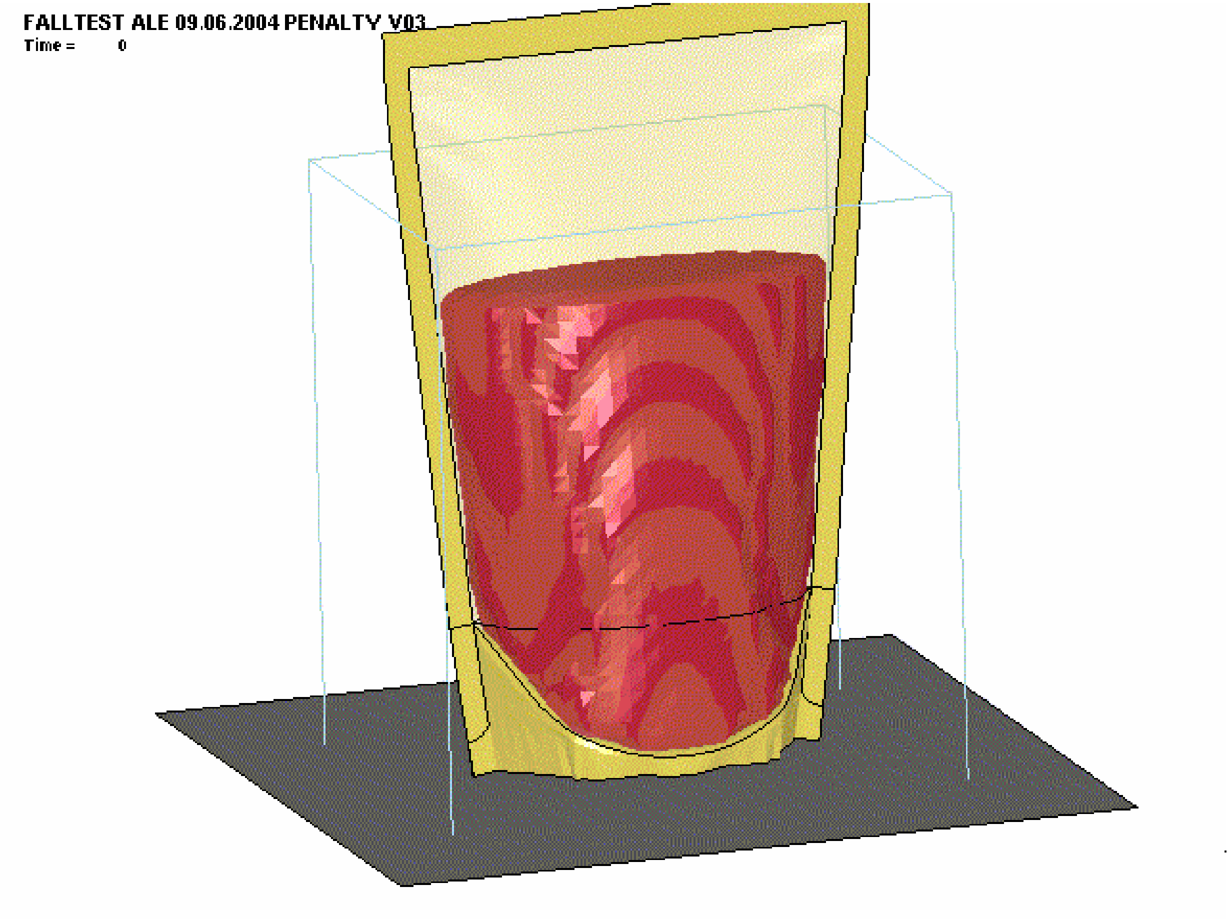
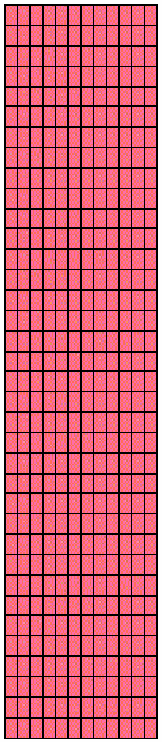


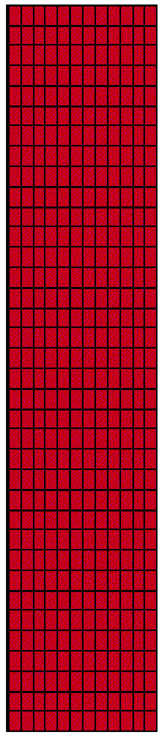
1 Motivation

Limits in classical structural mechanics

Problem:
- Large deformations/distortions
- Performance of elements degrades

Solution
- Adaptivity (re-meshing/re-zoning)
- ALE-mesh smoothing

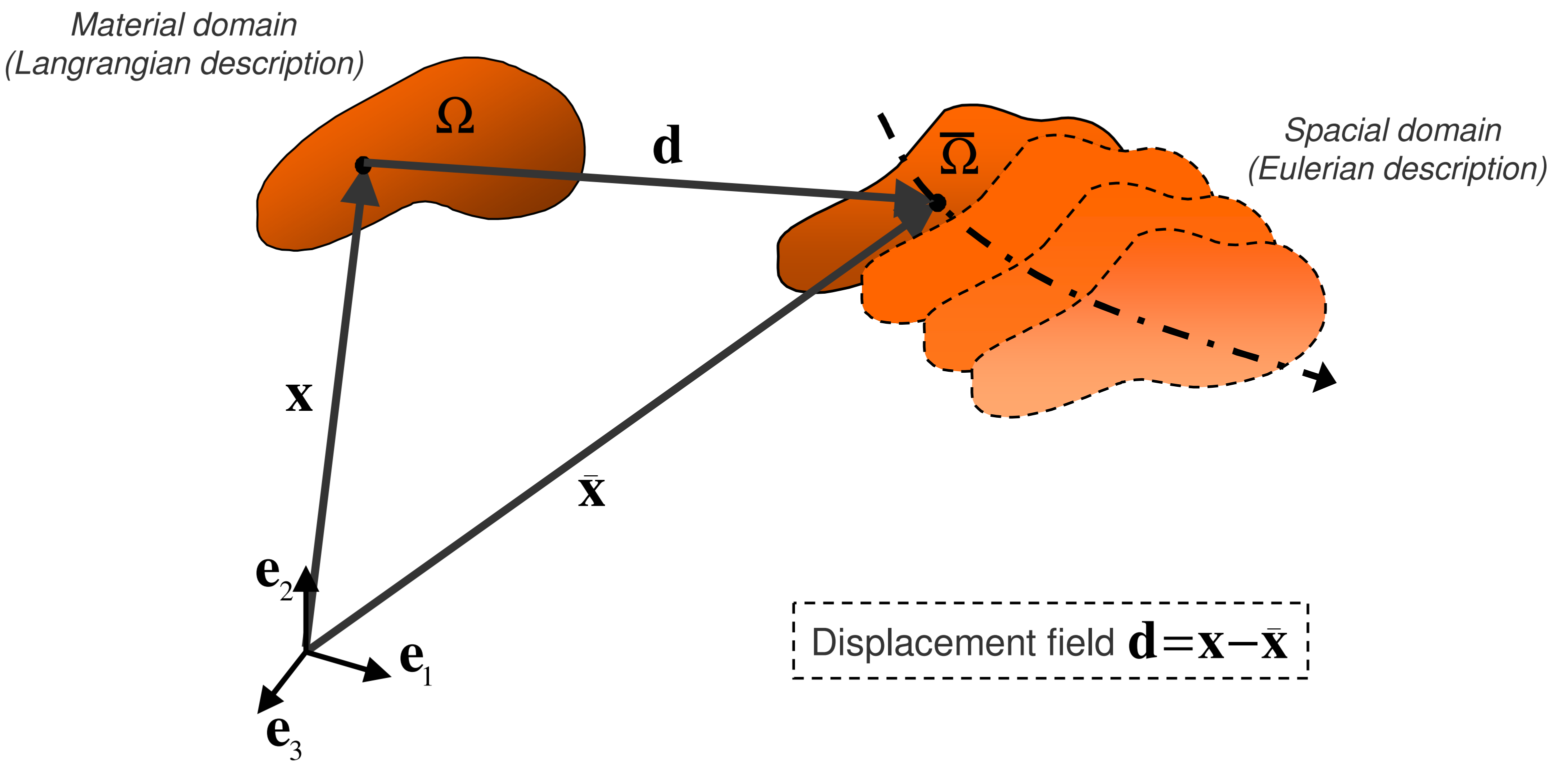




Example by Lars Olovsson

2 Basics

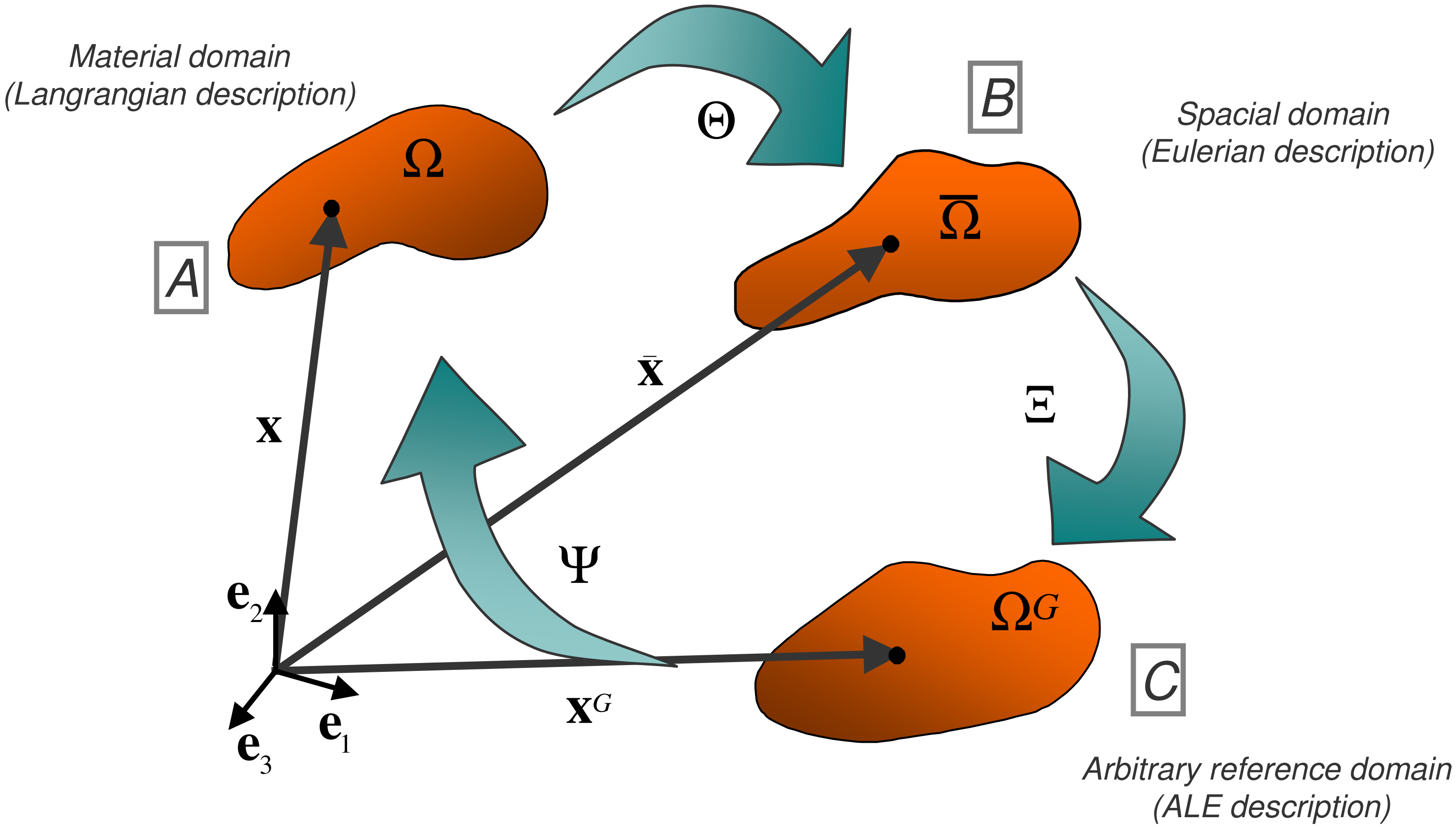
Standard continuum potatoes



Displacement field $\mathbf{d}=\mathbf{x}-\bar{\mathbf{x}}$

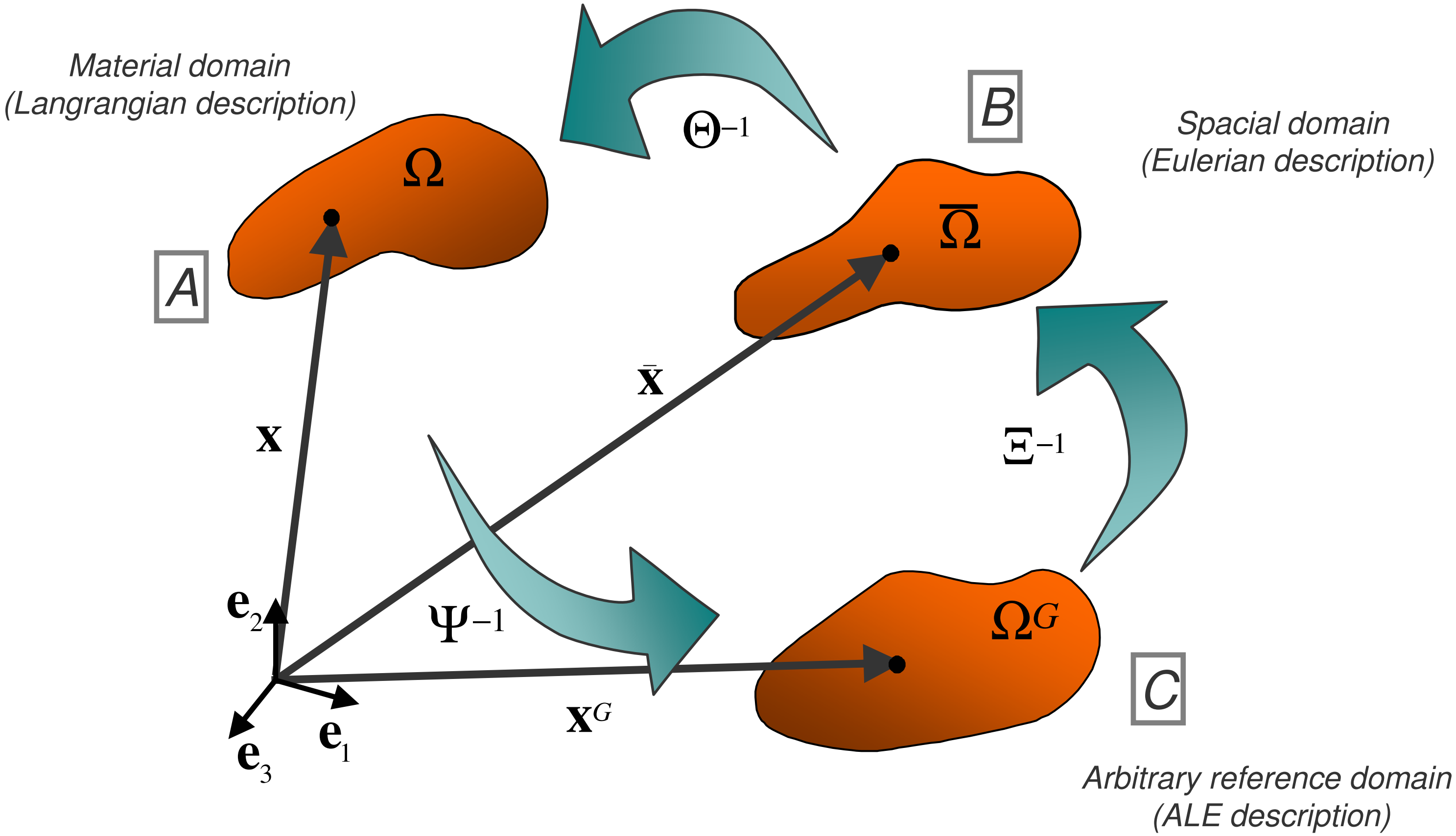
2 Basics

"Advanced" continuum potatoes



2 Basics

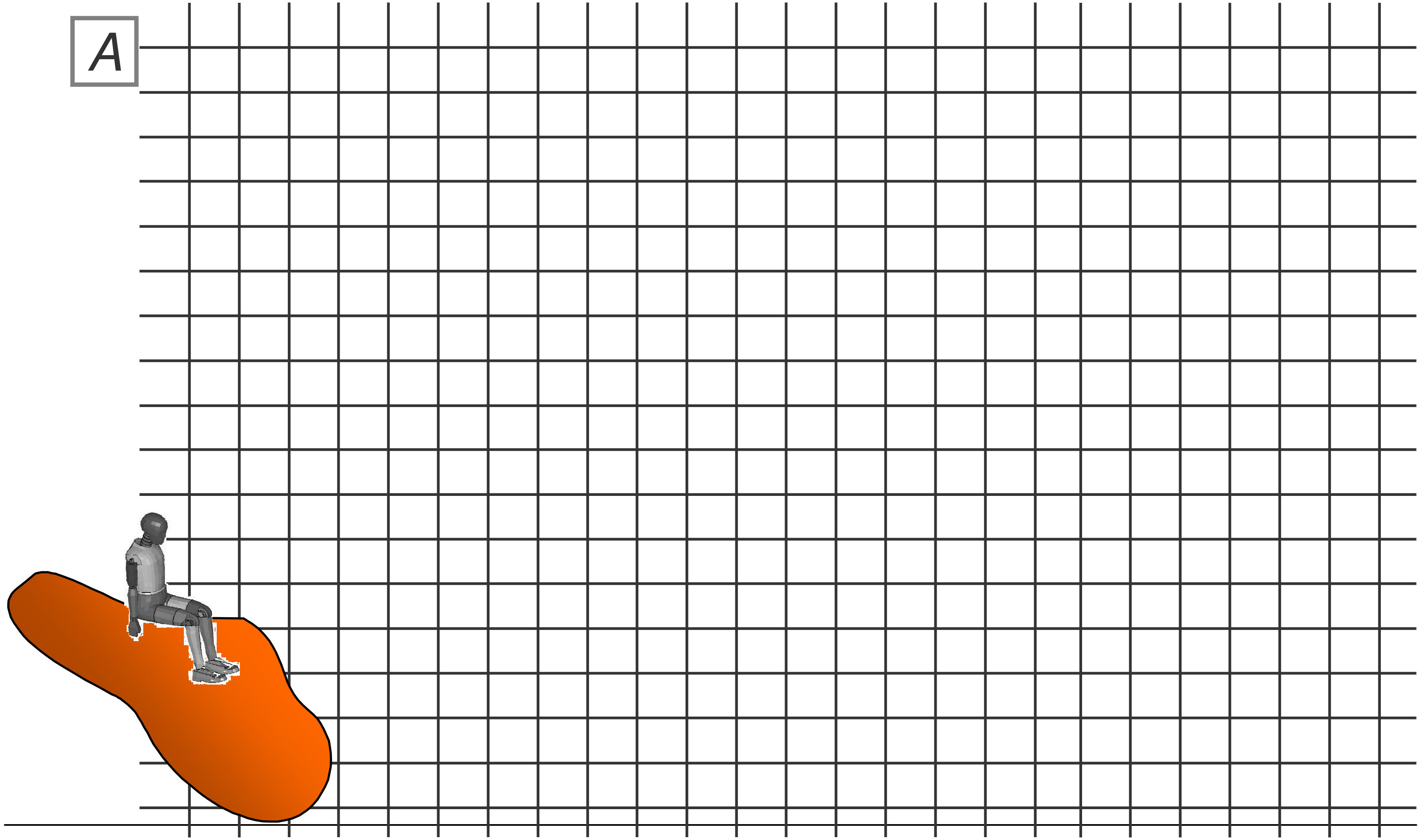
"Advanced" continuum potatoes



2 Basics

The moving potato: Lagrangian

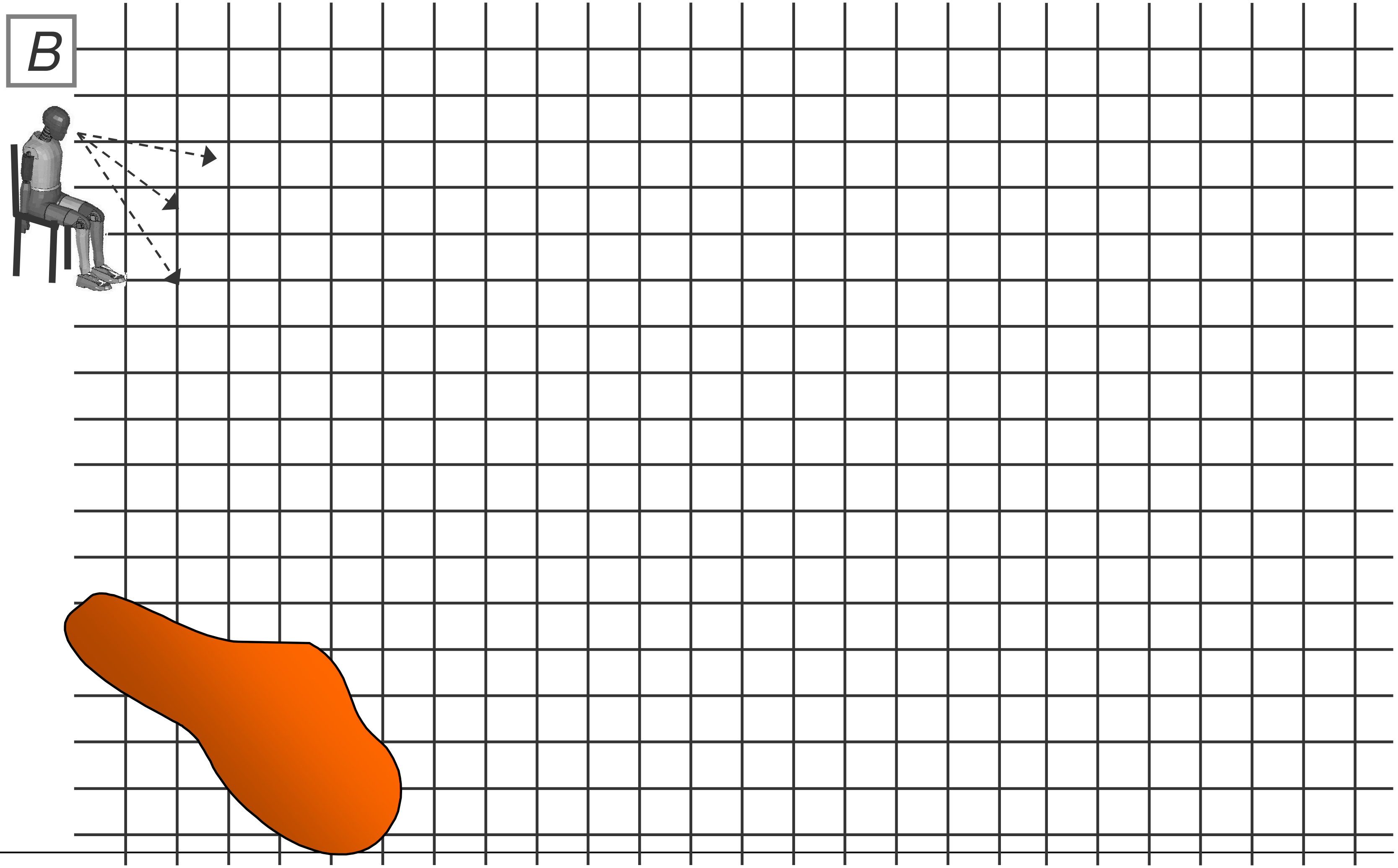
… introduced by Euler and named after Lagrange!



2 Basics

The moving potato: Eulerian

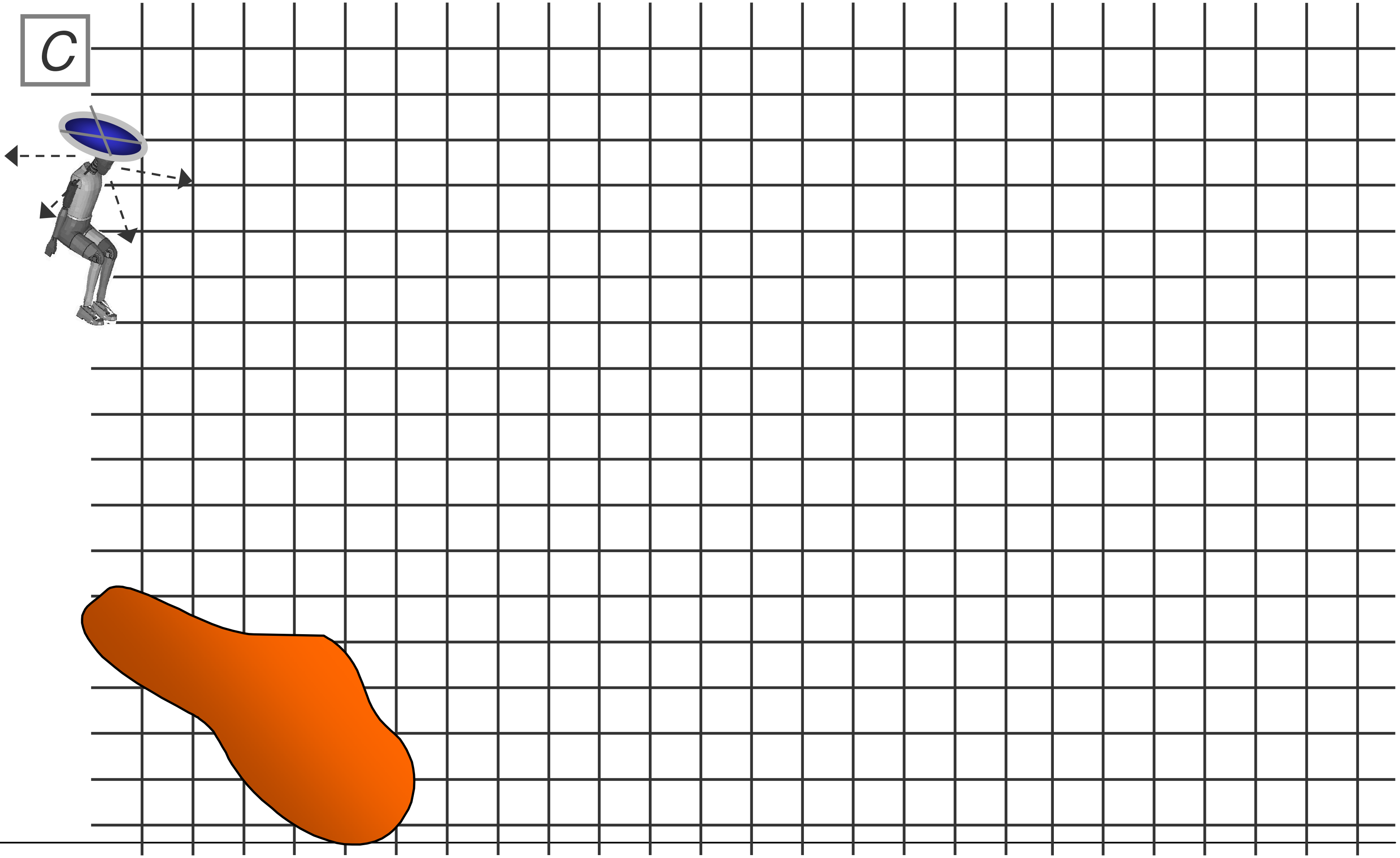
… introduced by Bernoulli/D'Alambert and named after Euler!



2 Basics

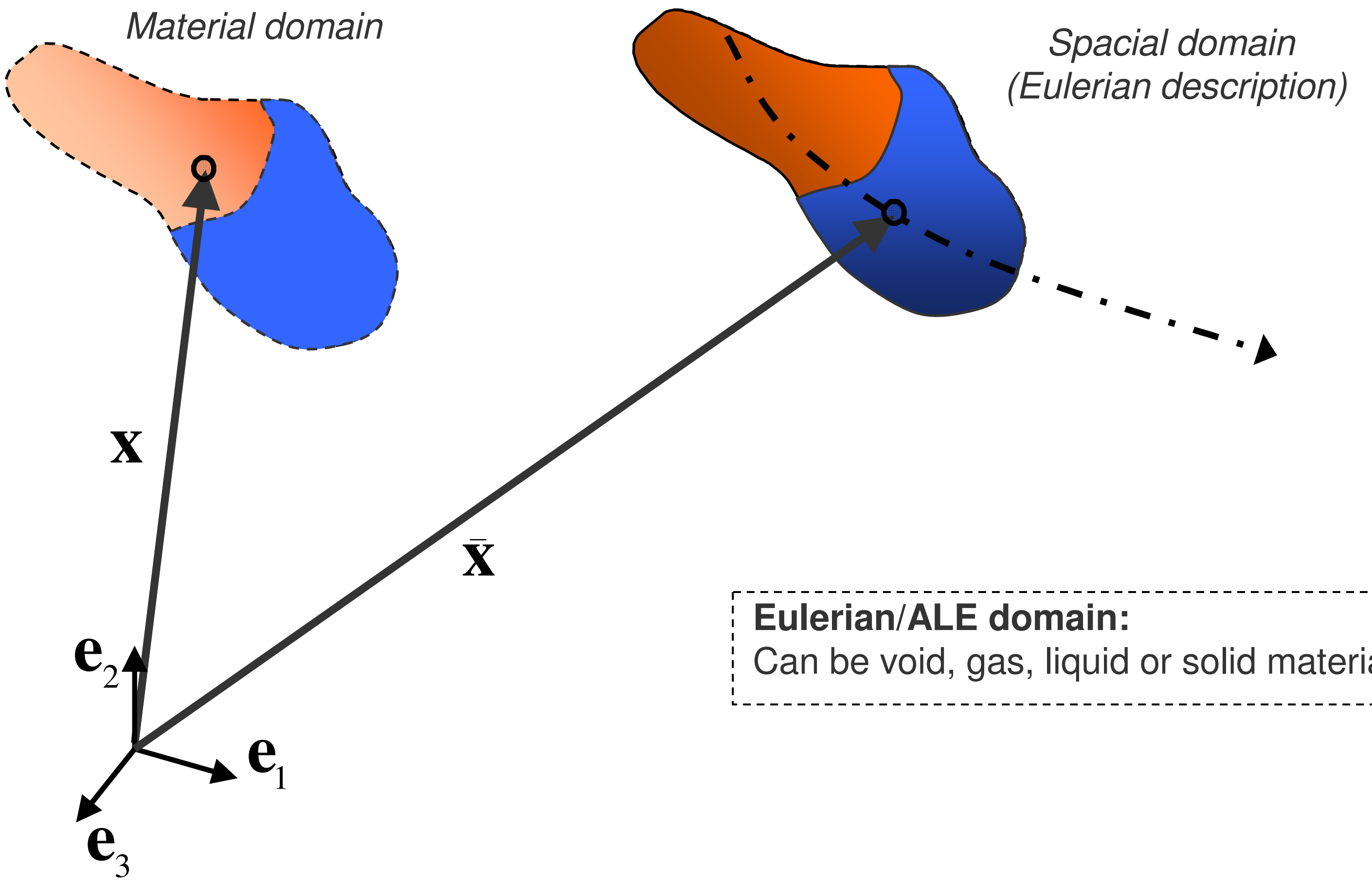
The moving potato: Arbitrary reference system

… Lagrangian-Eulerian



2 Basics

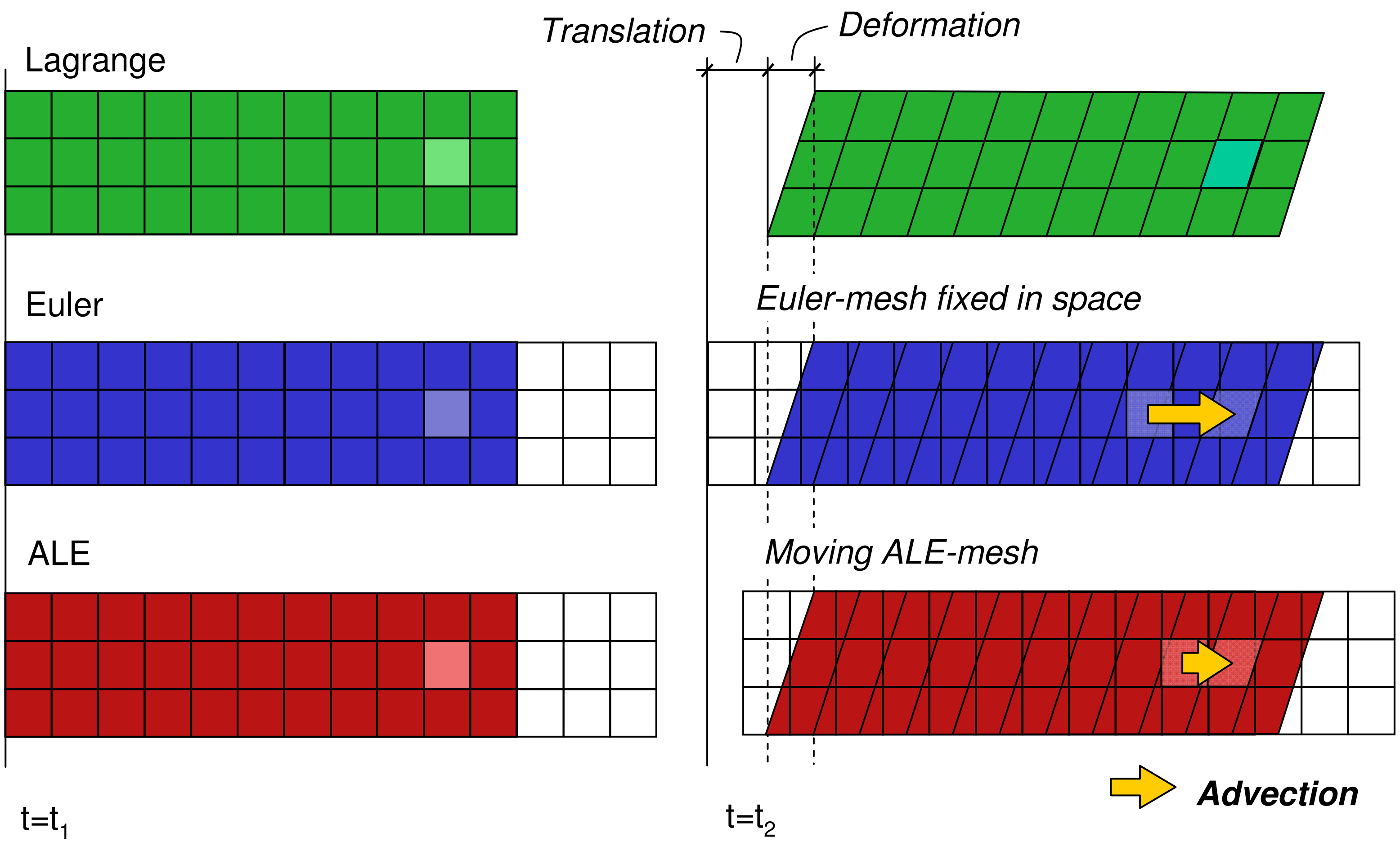
More than one material…



Eulerian/ALE domain:
Can be void, gas, liquid or solid material !

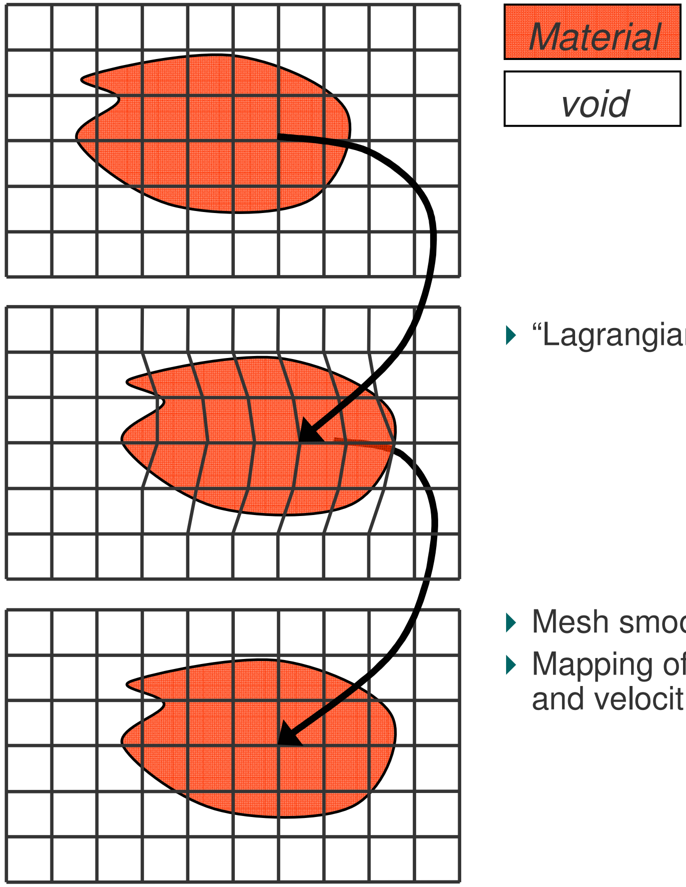
2 Basics

Necessity of advection



2 Basics

Sketching advection



- “Lagrangian step”
- Mesh smoothing
- Mapping of history variables and velocities!

Smoothing
- Simple average method
- Equipotential smoothing

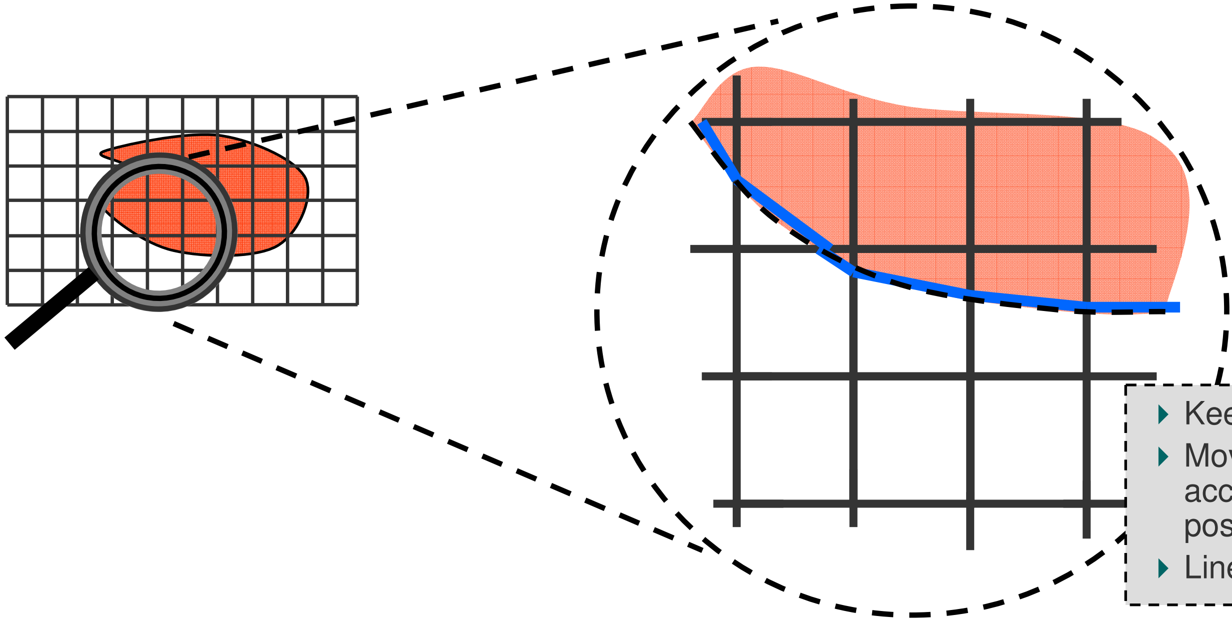
Advection
- Donor cell scheme (1st order accurate)
- Van Leer scheme (2nd order accurate)

Comment on time step and accuracy
- The mass flow velocity influences the time step!
- A material particle is not allowed to move more than through half an element during one time step:

$$\Delta t_{cr} \approx \min_{nel}\left[\frac{\Delta x^e}{c}, \frac{2\Delta x^e}{v^e}\right]$$

2 Basics

Interface reconstruction



- Keep material together
- Move material fractions according to velocities (also for post-processing)
- Linear interface

Composite stress tensor

- The internal forces are based on the composite stress tensor
- A pressure iteration algorithm assumes the same hydrostatic pressure in all materials

$$\sigma^* = \sum_{k=1}^{nmat} \eta_k \sigma_k \quad \wedge \sum_{k=1}^{nmat} \eta_k = 1$$

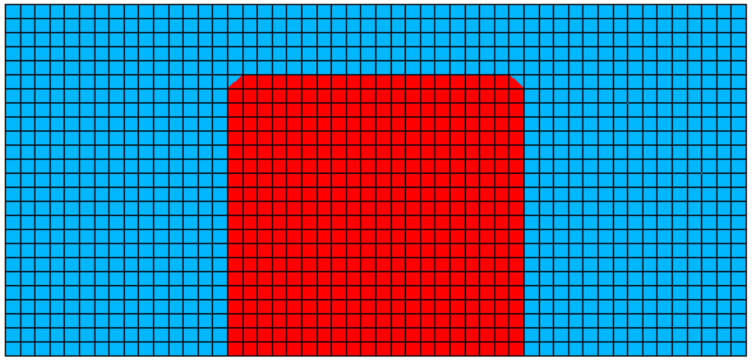
2 Basics

Summary of ingredients

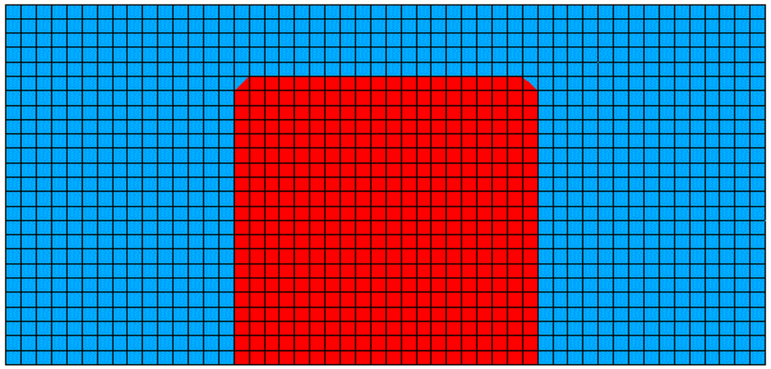
Example by Lars Olovsson

- Any material can flow through a defined domain
- Currently the maximum number of materials is 8
- The domain may be fixed in space (Eulerian) or may move arbitrarily (ALE)
- Interfaces between different materials will be traced and reconstructed
- Stresses will be iterated on element level

Multi-Material Euler



Multi-Material ALE



3 Possible applications

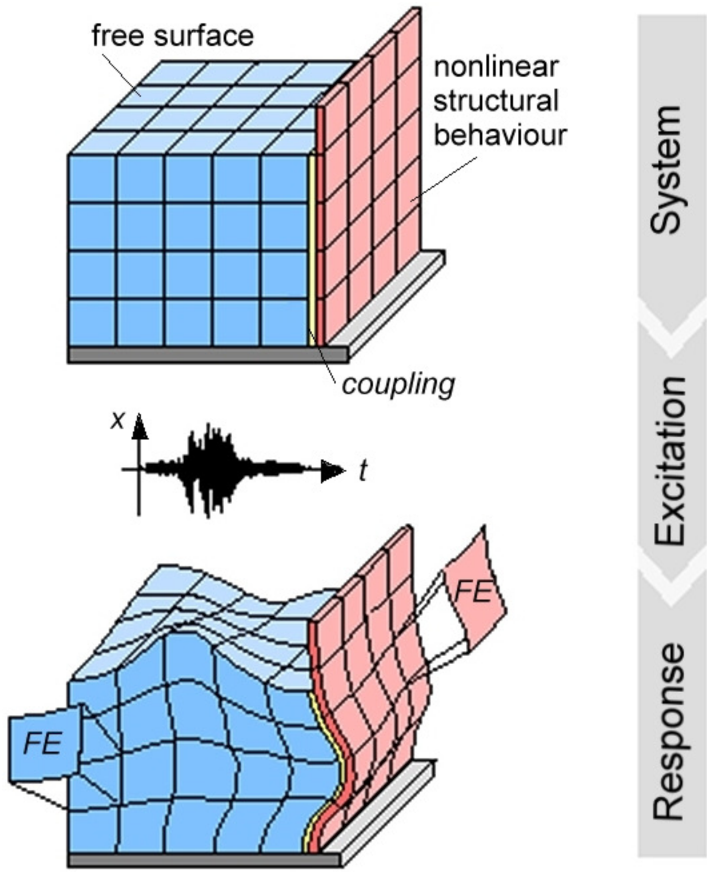
What can be done with this?

- It is advantageous to model
  - gases
  - fluids
  - massive/bulky solid materials (w large deformations)

  by Eulerian/ALE-methods

- Often these parts are contained in or are constrained by other parts. In many cases it might also be advantageous to model these structures Lagrangian.

➔ Interaction between Eulerian/ALE- and Lagrangian parts (FSI)



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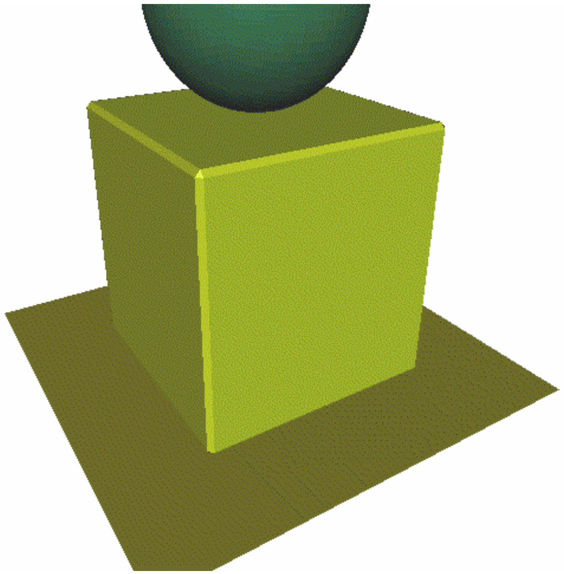

Bulk forming

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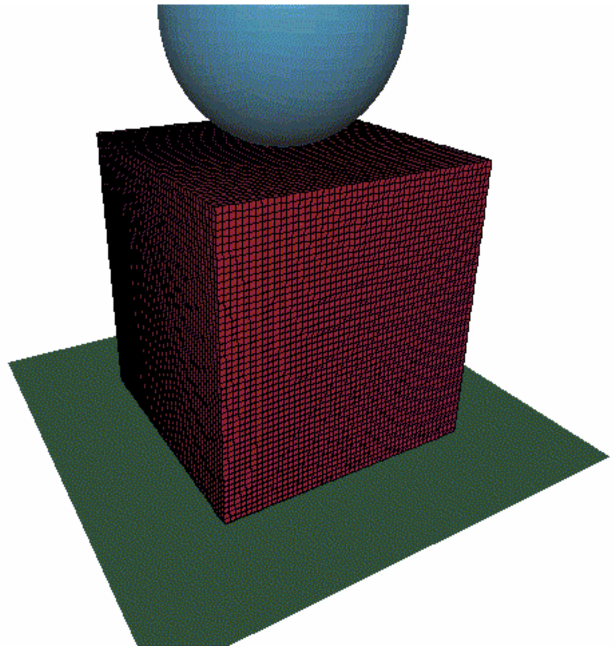

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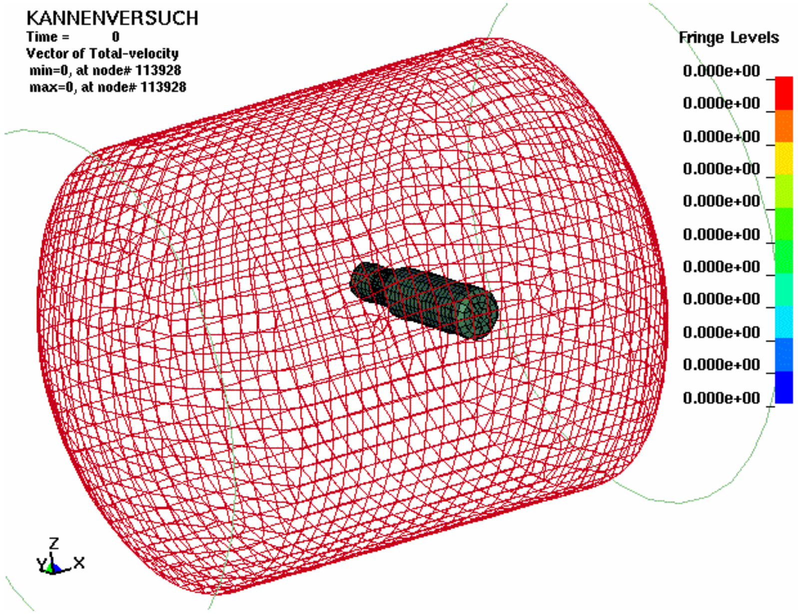

Gas flow

3 Possible applications

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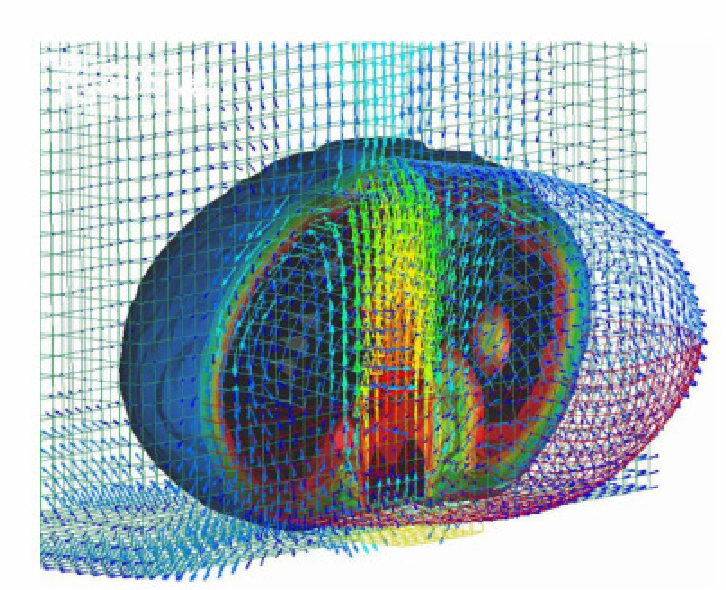


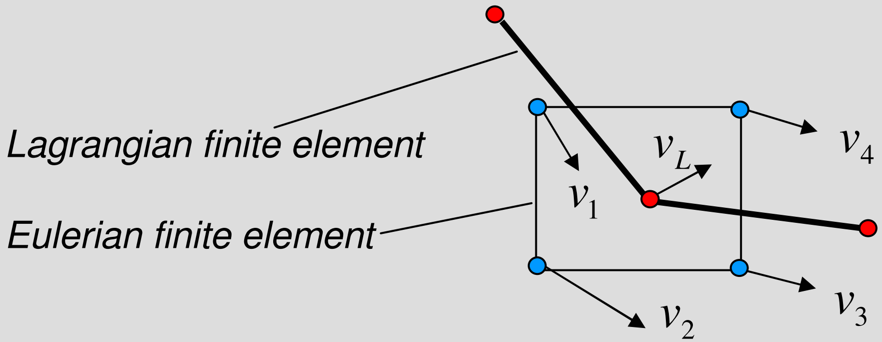
- Airbags -

4 More ingredients

Coupling Lagrangian and ALE: Constraint or penalty method?

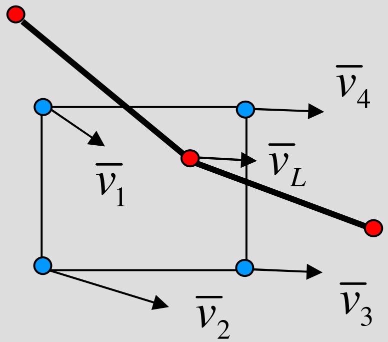
- **Constraint based method:**
  Preserves momentum but does not conserves energy

- **Penalty based method:**
  Conserves energy but may be unstable



$$\sum N_i v_i \neq v_L$$

$$I = \sum m_i v_i + m_L v_L$$



$$\sum N_i \overline{v}_i \neq \overline{v}_L$$

$$\overline{I} = \sum m_i \overline{v}_i + m_L \overline{v}_L$$

$$\overline{I} = I$$

➔ *Nodal velocities are forced to follow each other*

4 More ingredients

Coupling Lagrangian and ALE: Constraint or penalty method?

- **Constraint based method:**
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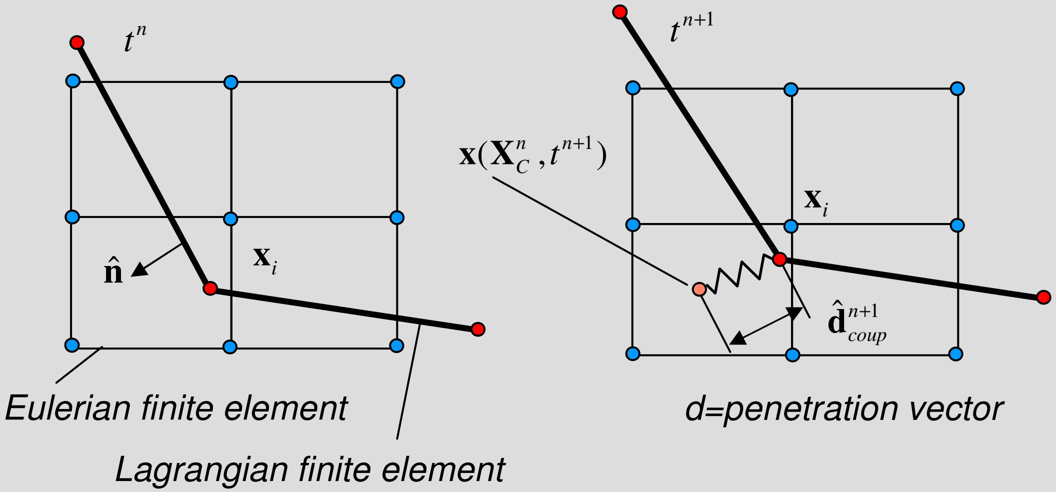
$$\mathbf{F}_{coup} = \left[k\, \mathbf{d}_{coup} \cdot \hat{\mathbf{n}} \right] \hat{\mathbf{n}}$$

$$k = \alpha \frac{m^*}{\Delta t^2}$$

$$m^* = \min \left[m_{coup}, \sum_{j=1}^{8} N_{E,j}\, m_{E,j} \right]$$



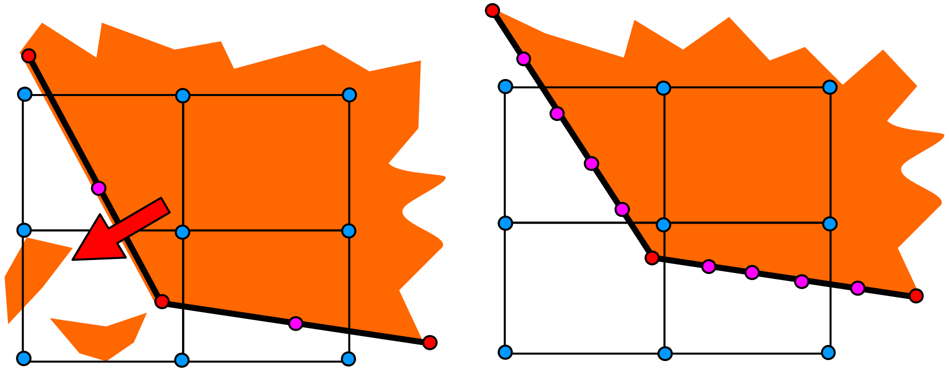
➔ *Coupling force is proportional to **d** , pressure vs. penetration curves can be defined*

4 More ingredients

Leakage, blockage and porosity

- Leakage

*In order to prevent leakage (**unwanted/undefined** loss of material through Lagrange boundaries) a number of sophisticated algorithms are available.*



Increase number of coupling points if leakage is a problem

4 More ingredients

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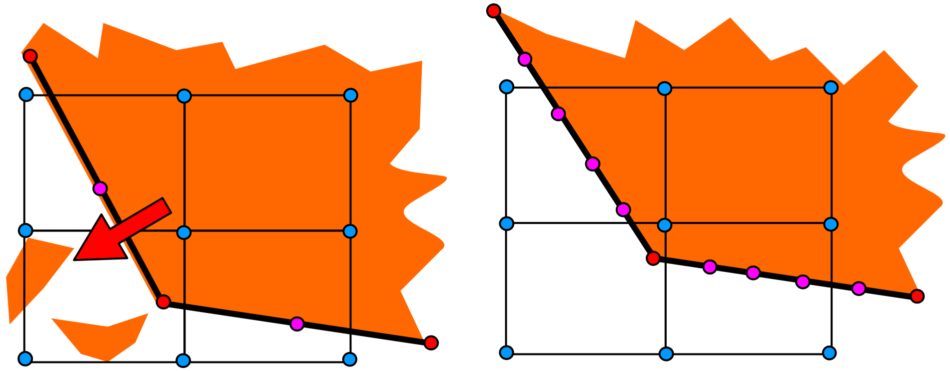
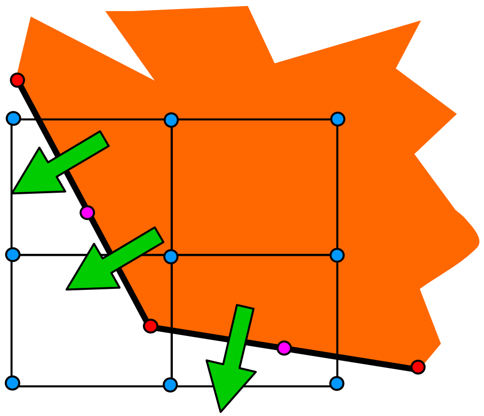


Increase number of coupling points • if leakage is a problem

- Porosity

*Porosity can be **defined**, based on a relative pressure vs. relative porous fluid velocity relation.*



Defined flow (loss of material) through fabric

4 More ingredients

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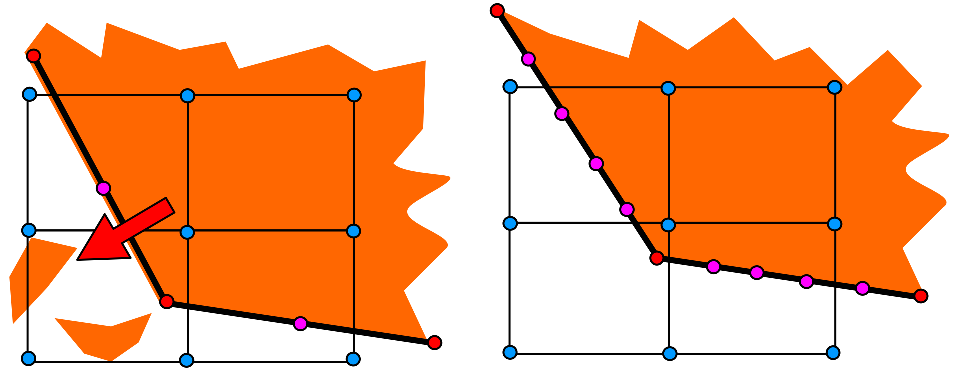


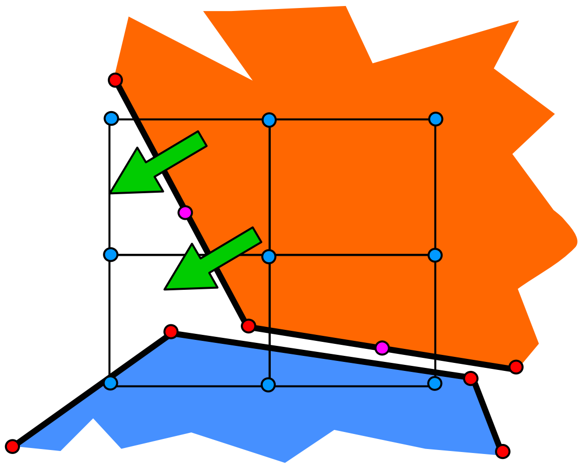
Increase number of coupling points • if leakage is a problem

- Porosity

  *Porosity can be **defined**, based on a relative pressure vs. relative porous fluid velocity relation.*

- Blockage

  Blockage for airbags – as already available for CV airbags – is now also available for ALE-formulation



Defined flow (loss of material) through fabric

Defined blocking, thus no flow through fabric

5 Summary

- Eulerian/ALE:
  - *Very attractive technology for the simulation of gases, liquids and large deformations in solids*
  - *Stable and reliable implementation*
- In combination with Lagrangian coupling new fields of application:
  - *Special bulk forming problems*
  - *Tank sloshing*
  - *Drop tests of liquid filled objects*
  - *Bird strike*
  - *Flow in pipes*
  - *OoP Airbag simulations*
  - *…. and other FSI problems!*
- Give it a try!