

# Discrete element modeling of damage and fracture processes

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## Scientific collaboration with TOYOTA R&D

- Technological evolution of socio-economic systems
- Discrete Element Modeling of fracture process
- Future perspectives

# Motivations for Collaboration

## ■ Physics of complex systems

Collective behaviour of many-particle systems

Scaling, behaviour, phase transitions and critical phenomena

Non-equilibrium phase transitions, theory of networks, ...

## Extensions to sociological and economical systems

## ■ Computational materials science and technology

Discrete nature of materials, micro-cracking and fracture

Mechanical performance of High-Tech materials

Smart composites

## Realistic models and computer simulations

# What the academic side benefits?

- Interesting research problems from “real life”
- Experience in
  - Project oriented thinking and research
  - Industrial applications of latest basic research results
- Innovative research

# Fields of collaborations

## Diffusion of Innovations in Socio-Economic Systems

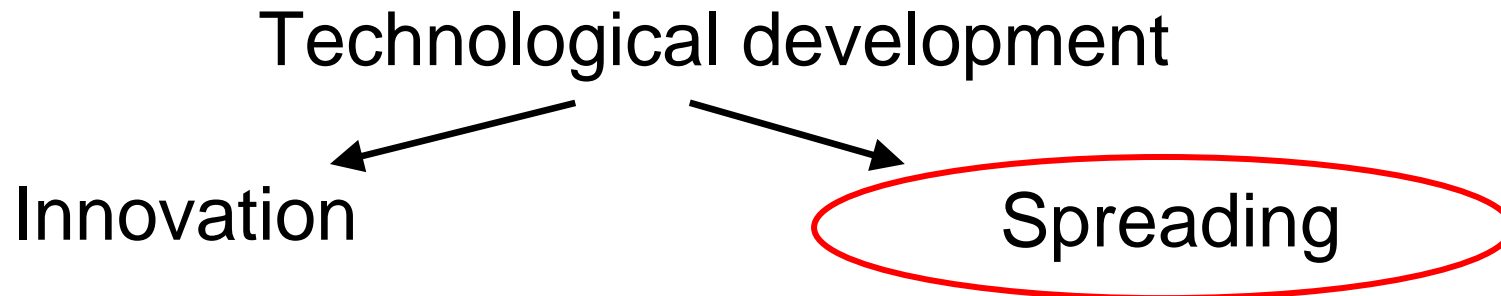
- agent-based modelling strategy
- from individuals to technological progress

## Discrete element modelling of bone fracture

- fracture of the bone of leg in car accidents
- realistic microscopic approach

Complement traditional engineering approaches

# Technological development



Can quality win over quantity?

What are the conditions of proliferation?

Effect of the behavior and social contacts of individuals on spreading?



# Brief overview

Large number of interacting agents

*Agent:*  $-0 \leq \tau \leq 1$  technological level  
-  $S = \{-1 | +1\}$  two providers

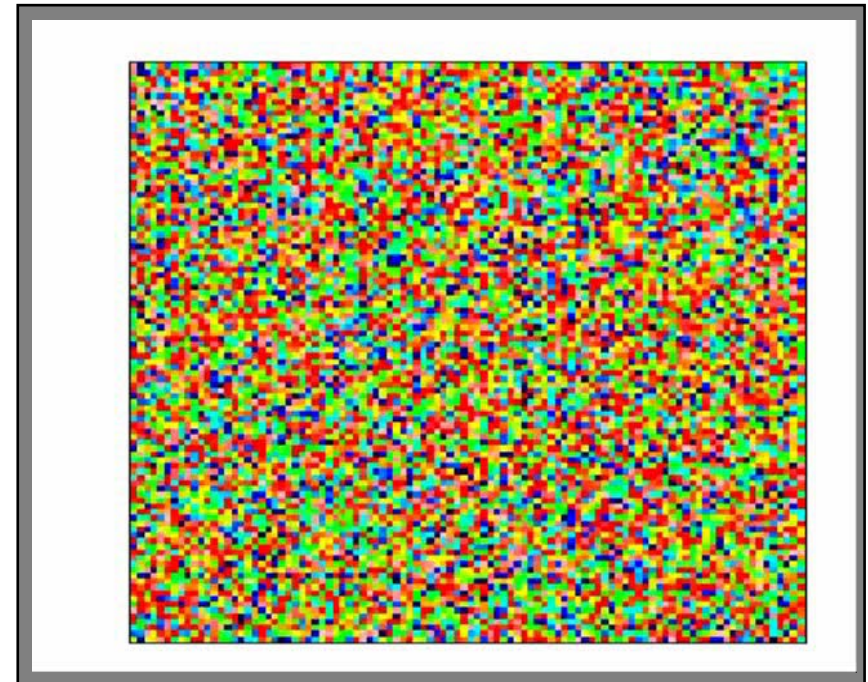
Cost function:  $C(\tau, \Delta)$

Agents purchase products

Driving force: Decrease costs!

Mechanism: rejection-adaptation

Control parameter: advantages  
of more advanced



# Technological development: Results

## Technological progress

- ➔ Clustering of agents with similar technologies
- ➔ Social contacts play an important role
- ➔ A complex system of local communities

## Presence of providers

- ➔ Makes the system more sensitive to advantages
- ➔ Helps technological evolution

# Materials strength

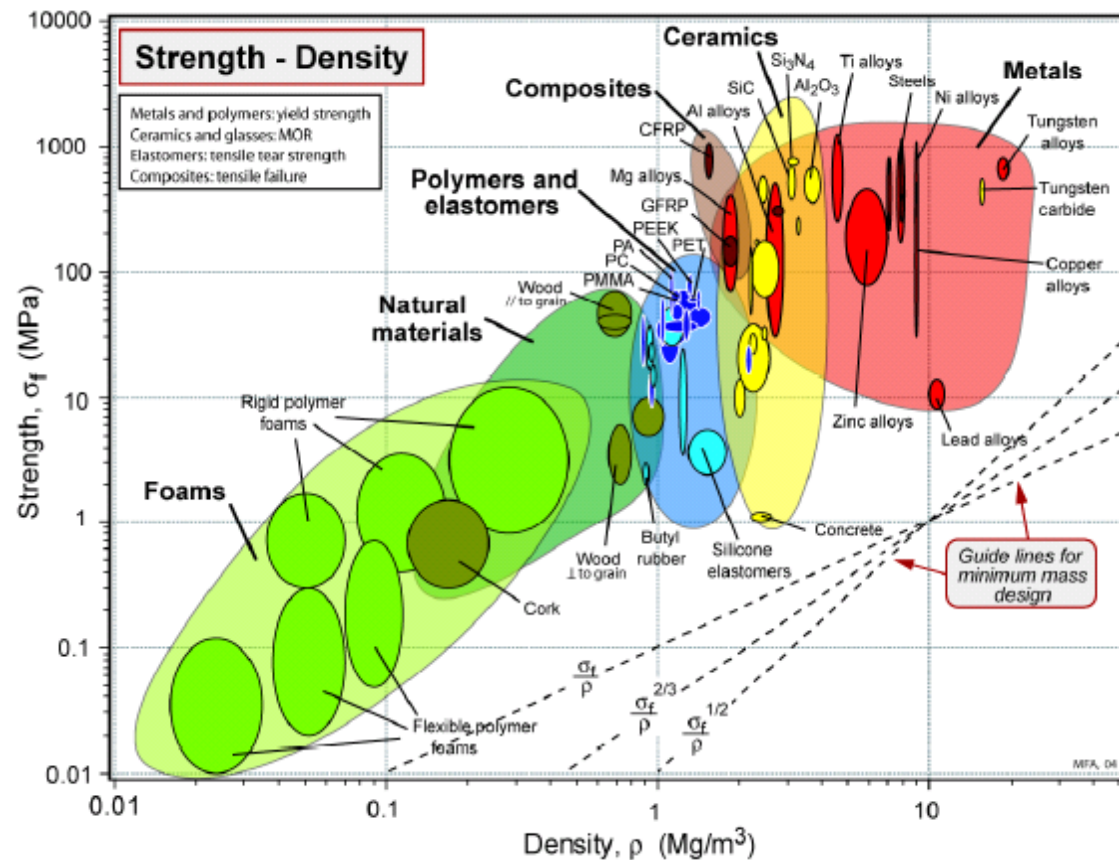
Materials look very different

Materials properties vary by many orders of magnitude

Composition/chemistry  
**Microstructure**

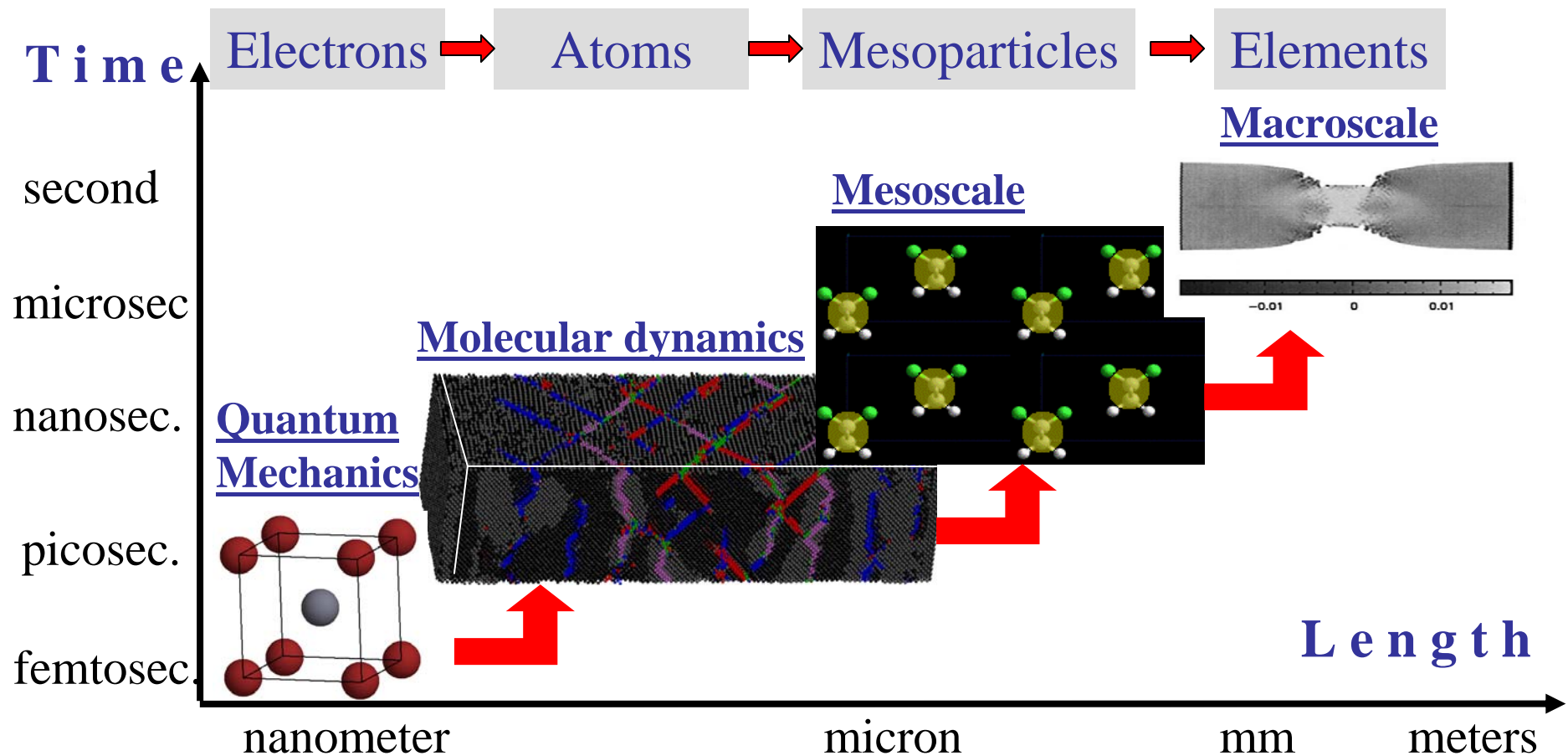


A variety of mechanisms govern materials behavior



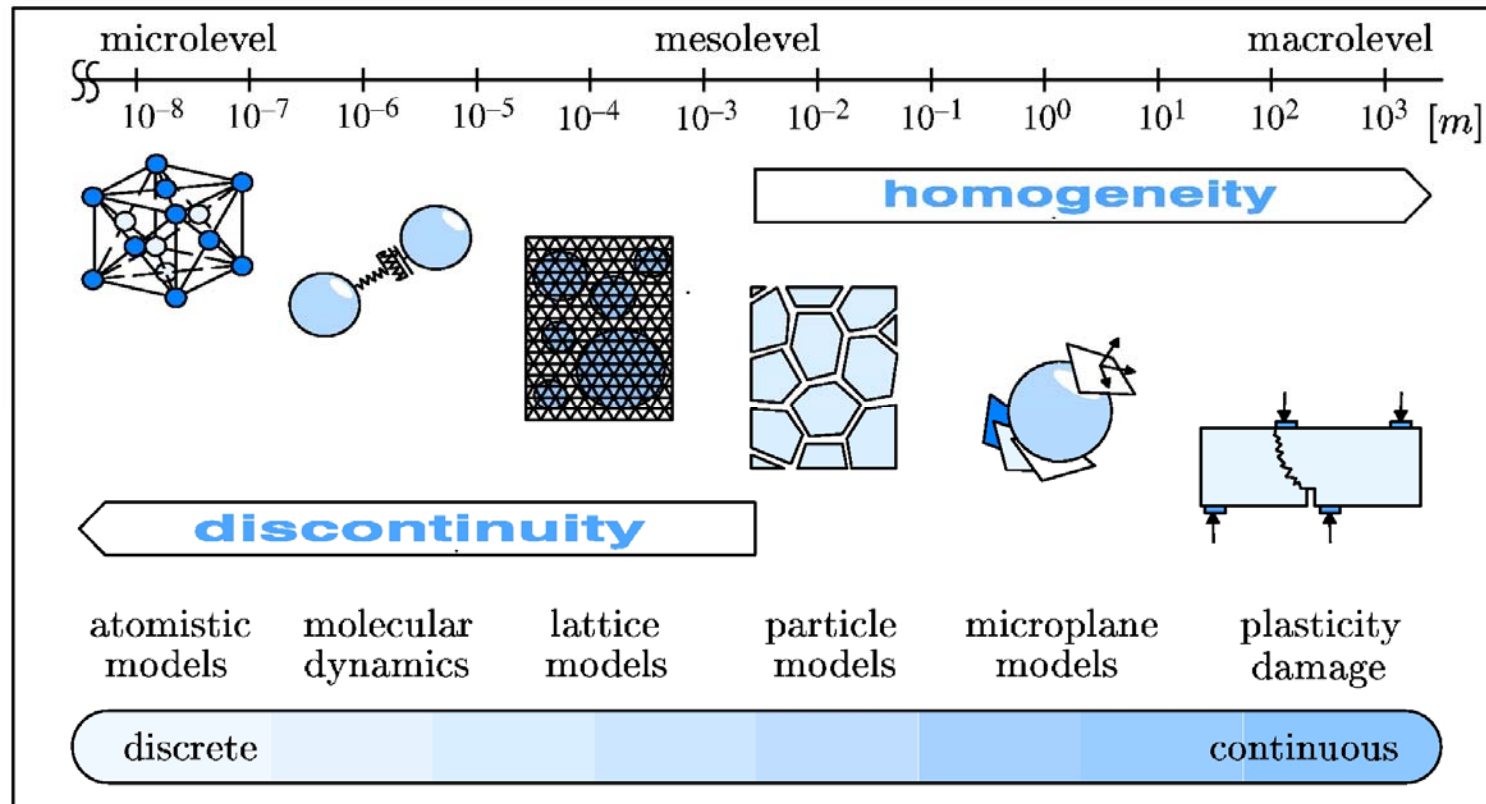
*Materials Selection in Mechanical Design (3rd edition)*  
by MF Ashby, Butterworth Heinemann, 2005

# Multi-scale materials modeling



Help to design new materials or devices with improved performance

# Length scales and models



Discrete element models

Finite element method

# Theoretical approaches

## Finite element method

- Formal discretization, numerical solution of partial differential equations
- Macroscopic constitutive laws
- Cannot capture: inhomogeneous physical properties large number of interacting cracks

## Discrete element models

- Physical discretization: interacting particles
- Realistic description of disorder
- Computer simulations

Combined  
Finite-Discrete  
Element

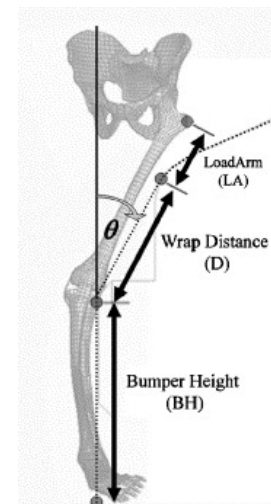
# Bone fracture in car accidents

Vehicle-pedestrian impact

Typical injury



Laboratory test

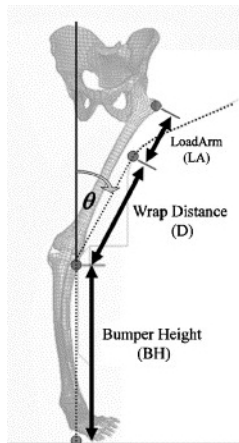


Upper and lower leg fractures

Need for a detailed understanding

# Bio-Mechanics

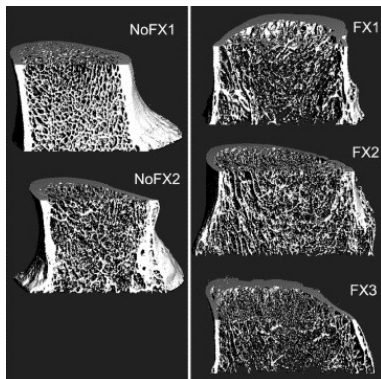
## Loading condition



- Three-point bending
- Dynamic loading

Computer modeling

## Material properties

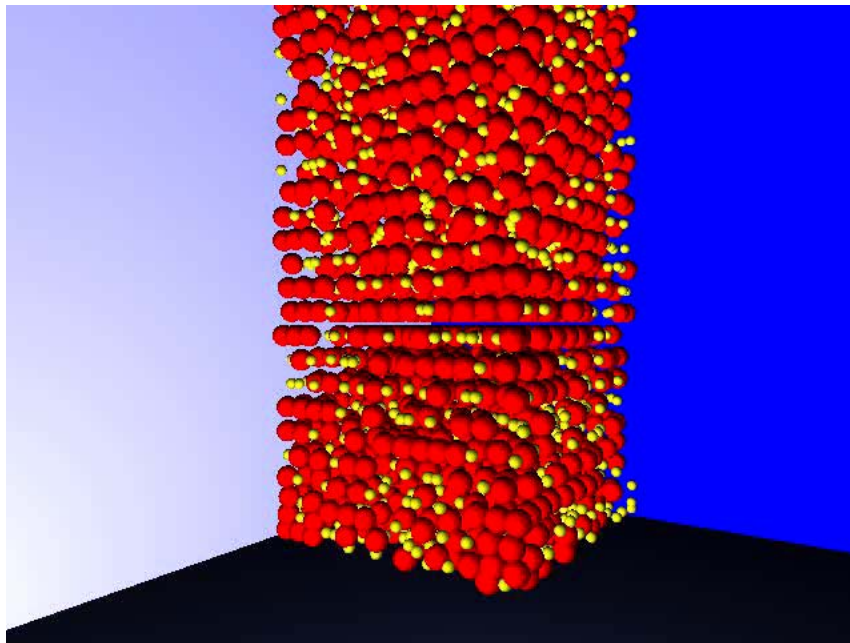


- Highly disordered
- Porous structure
- Fluid content
- Non-linear response

# DEM for bone fracture

Building the micro-structure of the model bone

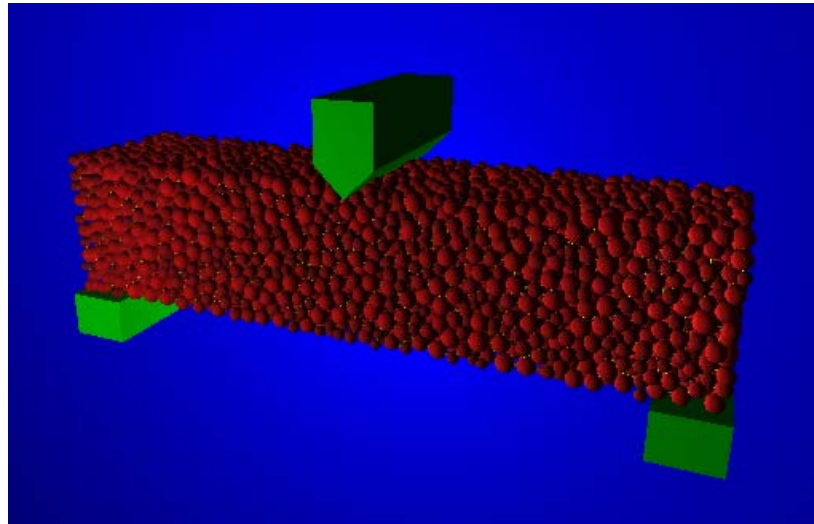
## Random particle packing



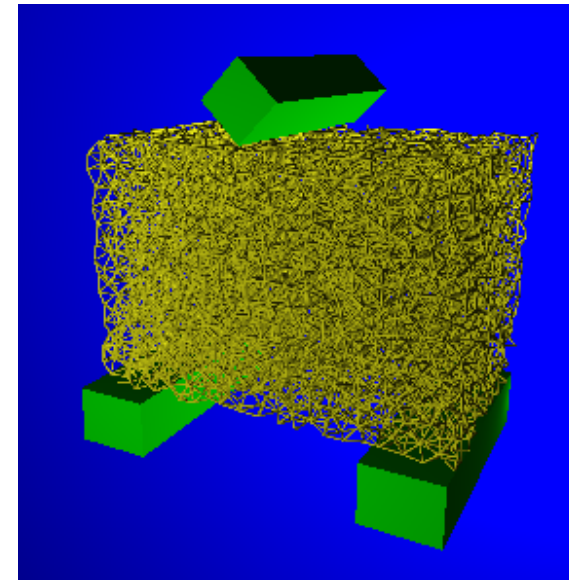
- Particles on a regular cubic lattice
- Confined in a container
- Polydispersity: random particle sizes
- Sedimentation under gravity
- Beam elements in 3D

# DEM for bone fracture

Sample geometry



Final structure for loading



- ➡ Porosity: Random dilution
- ➡ Correlations: Simulated annealing

- ➡ Two ends clamped
- ➡ Hit in the middle

# Future perspectives

## ➡ Studying diffusion of technologies

- agent-based modelling strategy
- relevant for vehicle industry

## ➡ Bone fracture under dynamic loading

- constructing the 3D simulation code
- verification of model parameters
- realistic calculations