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Nb: I had to remove slides containing input from our industrial partners. Sorry.

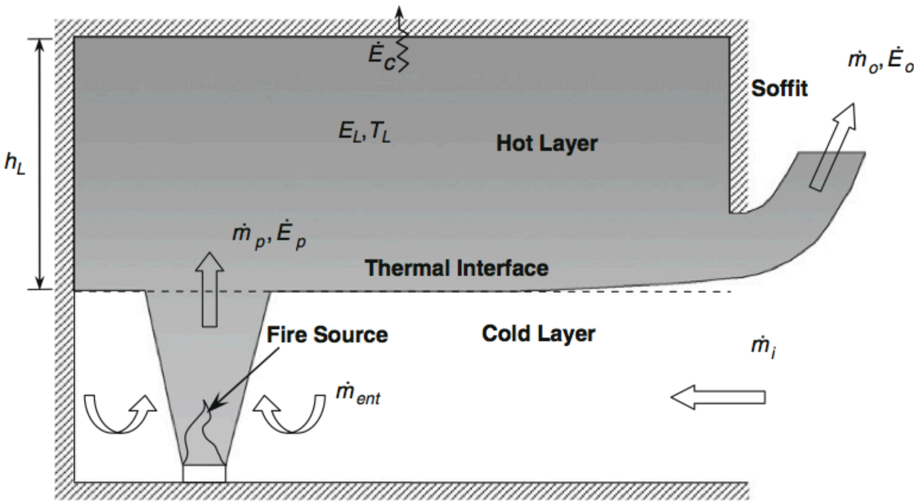
JÜLICH FORSCHUNGSZENTRUM

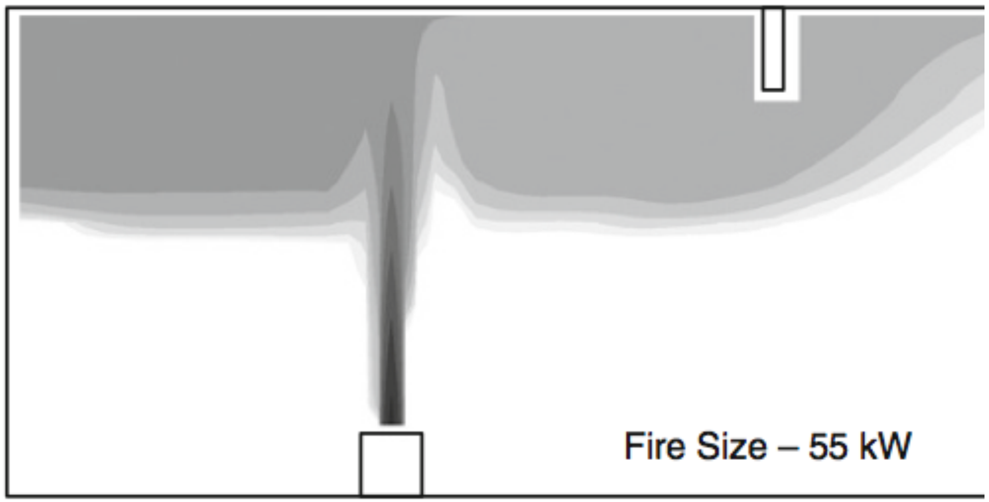
Fire Simulations in Civil Engineering

07.05.2013 | Lukas Arnold

Fire Simulations in Civil Engineering

- Complex buildings do not fit into rigid fire safety regulations
- Fire safety can be shown by adequate numerical simulations
- Two approaches for numerical simulations
  - Zone models
  - Field models – computational fluid dynamics





Figures adopted from Yeoh&Yuen (2009)

Fire – pyrolysis, combustion & radiation

- Fire simulations are a combination of multiple models:
  - Turbulent multi-species fluid dynamics
  - Pyrolysis
  - Combustion
  - Radiation & heat transfer
  - Soot creation and transport

- CFD regimes
  - Weakly compressible
  - High Reynolds numbers (turbulence modelling: mainly LES)

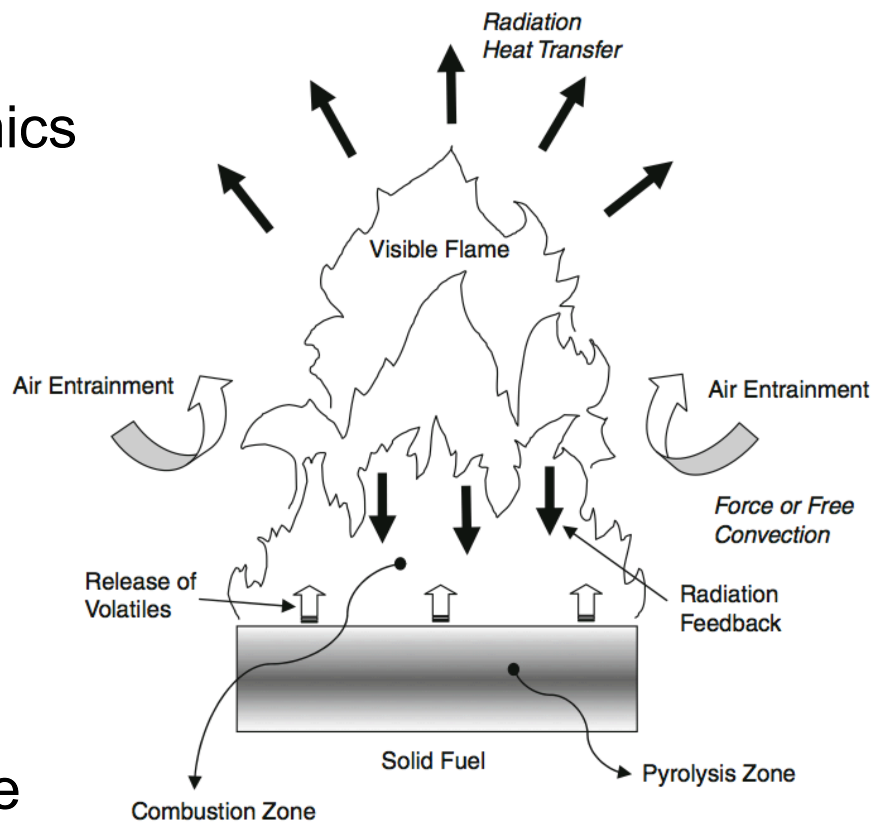


Figure adopted from Yeoh&Yuen (2009)

Mitglied der Helmholtz-Gemeinschaft

FDS – fire dynamics simulator

- Developed by NIST, USA – open source, freely available
- Fortran code with focus on engineering, not computer science
- Very large user community, only few developers

- Finite difference, second order, Cartesian grids
- Includes all major models, easy to use

- OpenMP parallelization developed and maintained by one person, who just finished his PhD and moved to industry
- MPI parallelization: see second bullet
  - No automatic domain decomposition, no load balancing
  - Pressure solver is problematic (kind of Schwarz method, FFT)

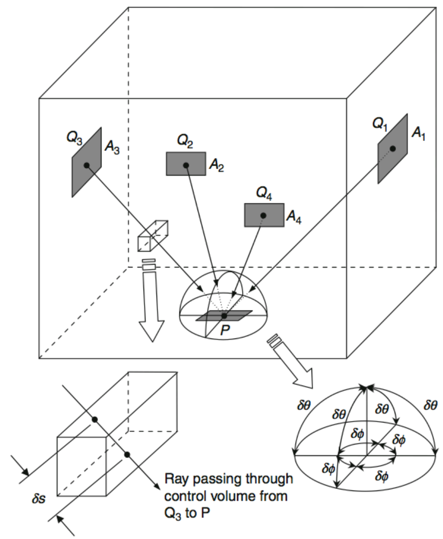
Main equations

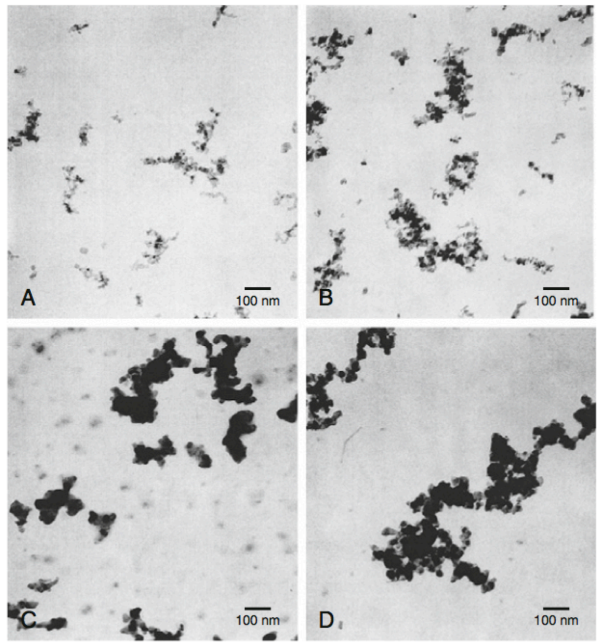
- Pressure decomposition
  $$p(\mathbf{x},t) = \overline{p}_m(z,t) + \tilde{p}(\mathbf{x},t)$$
- Equation of motion
  $$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u}\right) + \nabla p = \rho\mathbf{g} + \mathbf{f}_b + \nabla\cdot\tau_{ij}$$
- Heat flux
  $$\dot{\mathbf{q}}'' = -k\nabla T - \sum_\alpha h_{s,\alpha}\,\rho\, D_\alpha \nabla Z_\alpha + \dot{\mathbf{q}}_\mathrm{r}''$$
- Energy equation
  $$\frac{\partial}{\partial t}(\rho h_s) + \nabla\cdot(\rho h_\mathrm{s}\mathbf{u}) = \frac{\mathrm{D}\overline{p}}{\mathrm{D}t} + \dot{q}''' - \dot{q}_\mathrm{b}''' - \nabla\cdot\dot{\mathbf{q}}''$$
- Divergence equation
  $$\nabla\cdot\mathbf{u} = \frac{1}{\rho h_\mathrm{s}}\left[\frac{\mathrm{D}}{\mathrm{D}t}(\overline{p} - \rho h_\mathrm{s}) + \dot{q}''' + \dot{q}_\mathrm{r}''' - \dot{q}_\mathrm{b}''' - \nabla\cdot\dot{\mathbf{q}}''\right]$$
- Continuity equation
  $$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\mathbf{u}) = \dot{m}_\mathrm{b}'''$$

Radiation transport & soot

- Radiation is crucial in fire simulations
  - For pyrolysis
  - For heat trasfer to solid walls
  - Cooling of hot smoke
- FDS uses discrete angle radiation model (order of 100 rays)

- Soot is a major player in radiation transport
- Simple soot creation (prediscribed) and transport model (additional species) implemented in FDS

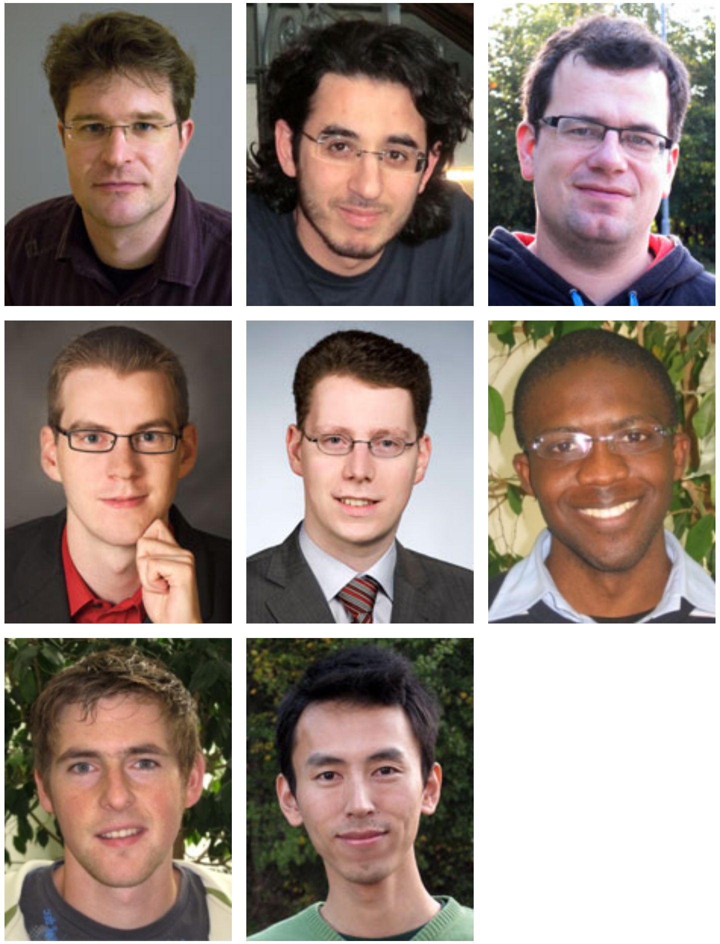




Figures adopted from Yeoh&Yuen (2009)

Members

FZJ



FZJ / BUW

BUW

Fire Simulations

Andreas Meunders
Fire Safety Engineer (M.Sc.)
PhD student at BUW

Kevin Drzycimski
Technomathematics
PhD student at FZJ

Lukas Arnold
Physics, Computational Science
senior researcher at FZJ

Close cooperation with University Wuppertal:

- Lectures for Engineers and Computer Simulations in Sciences
- Joint Master and PhD students

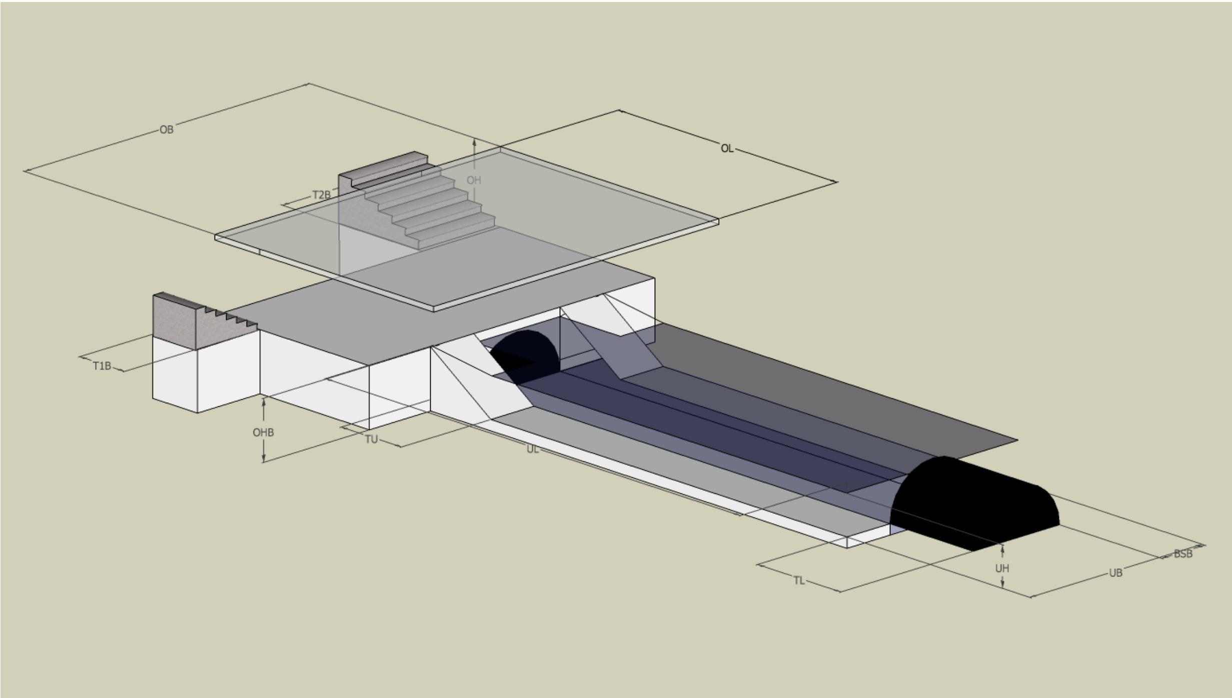
Motivation: underground stations

- Selected fire disasters
  - Kings Cross, London (1987), fire under stairs in station
  - Deutsche Oper, Berlin (2000), the only exit blocked by burning train
  - Daegu, South Korea (2003), arson attack with hundreds fatalities
  - Berlin (2011), small fire with massive smoke emission

- In most cases, toxic gases are the major thread in underground fires

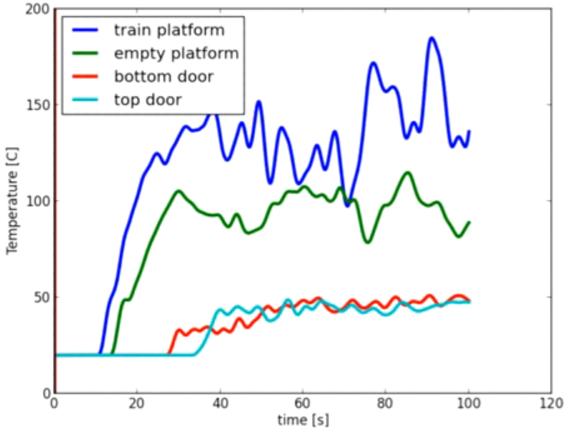
Daegu, South Korea (2003)

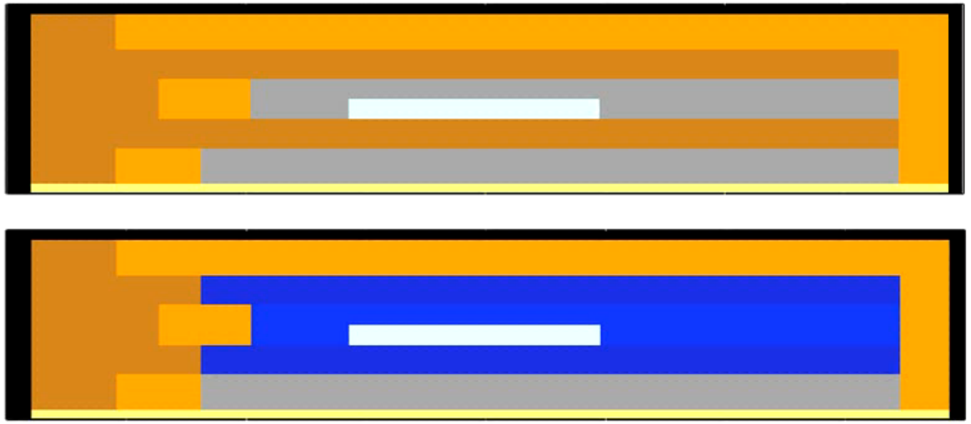
Application Scenario: Metro Stations

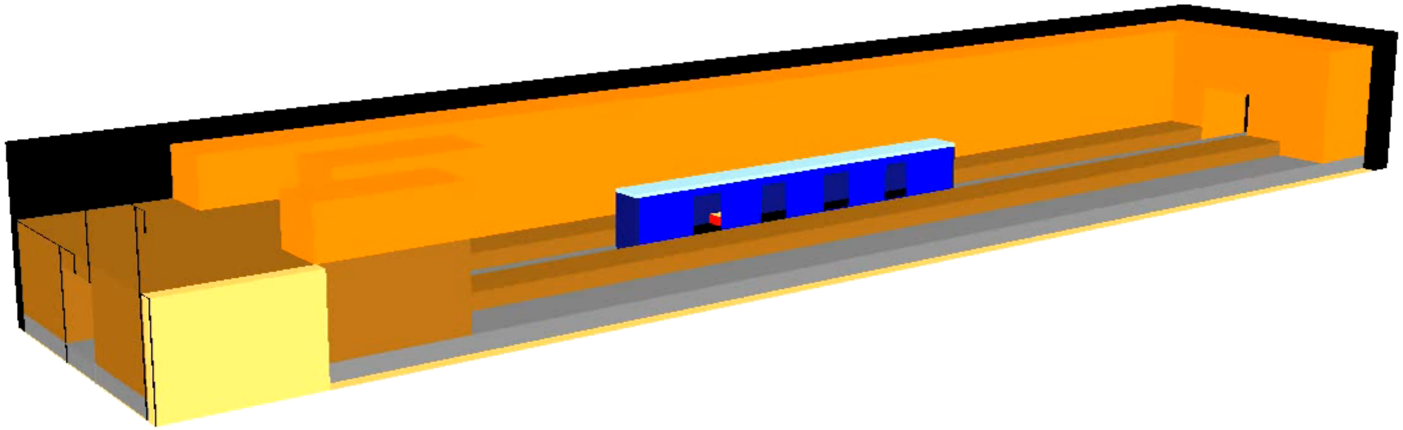


- complex and compact geometries
- no active smoke or fire control
- no combustion → design fires

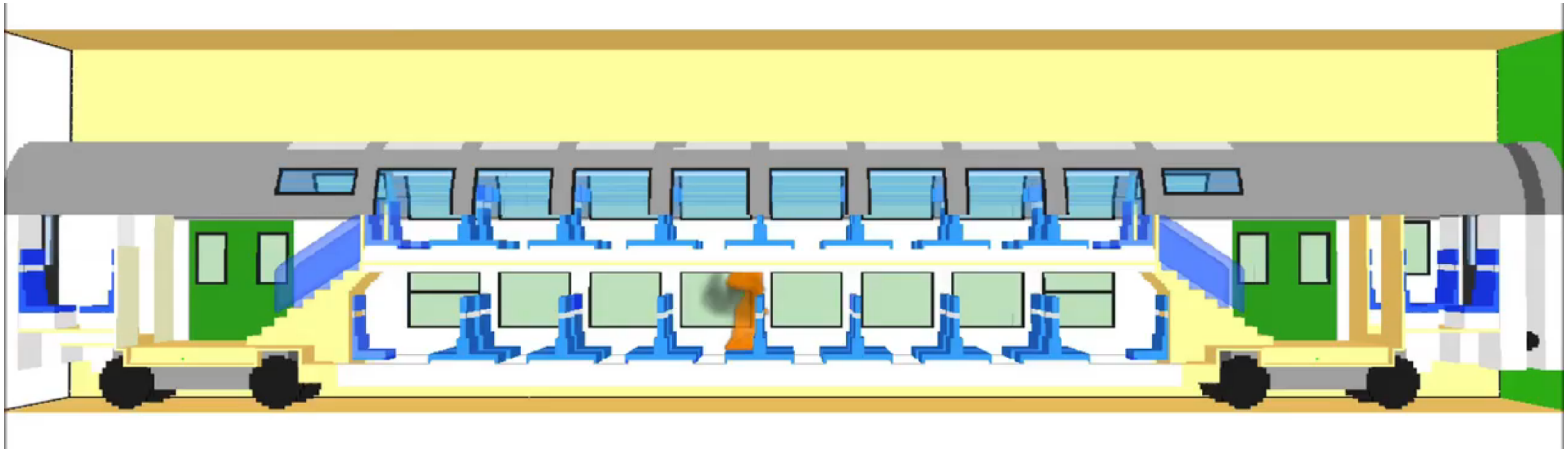
Application Scenario: Metro Station





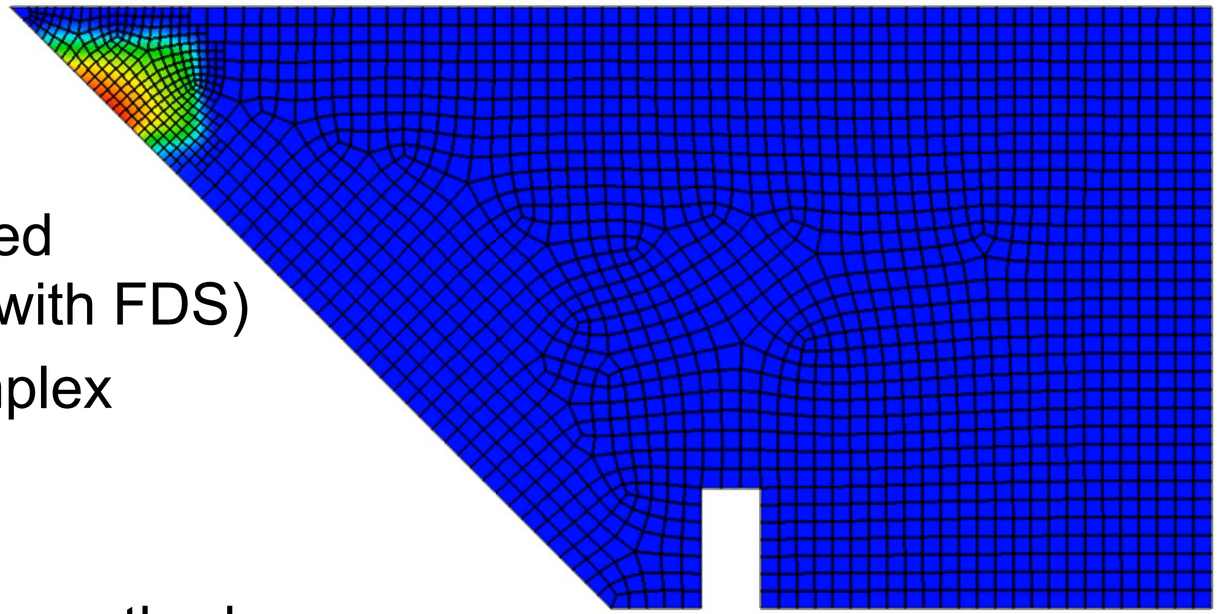


Application scenario: fire in moving trains



- Evaluation of ventilation systems
- Creation of design fires
- In cooperation with Corinna Trettin (BUW)
- Simulations run on juropa, up to 128 cores

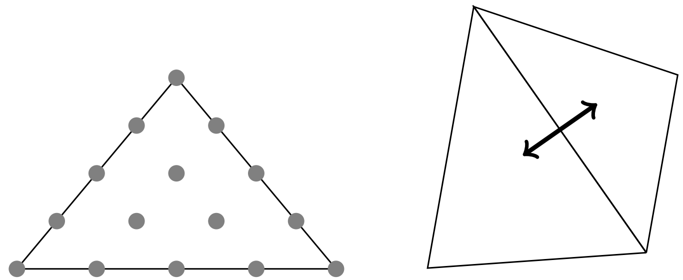
New numerics for fire engineering



- Support for unstructured meshes (not possible with FDS)
- Adaptive grids for complex building structures

- Discontinuous Galerkin method with p-adaptivity
- High scalability (goal >1k MPI processes)

- Current work based on the deal.ii library



FEM inside an element   FVM between elements

ORPHEUS – Main idea

- ORPHEUS: **O**ptimierung der **R**auchableitung und **P**ersonenführung in U-Bahn-**H**öfen: **E**xperimente **u**nd **S**imulationen

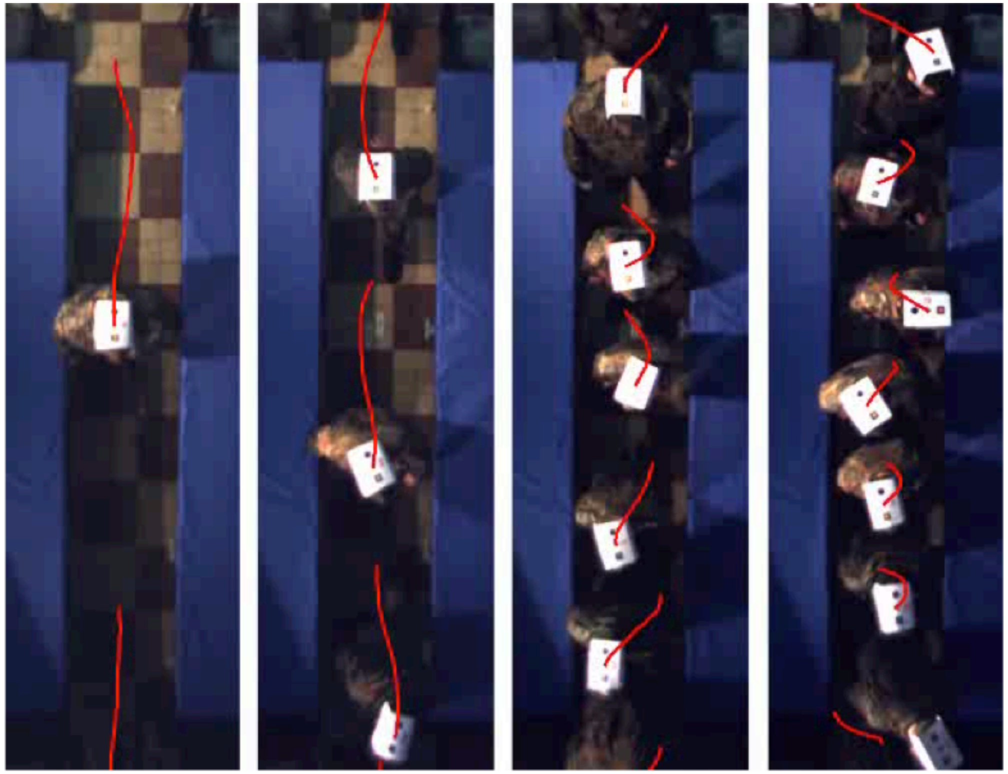
- Current project proposal with 12 partners from academia and industry
- Main idea: optimise smoke management in underground stations

- Three main topics:
  - Capture current state (real fire experiments, CFD validation)
  - Smoke management systems (sensors, ventilation, CFD and small scale models)
  - Emergency management (communication structures, real-time smoke propagation prognosis)

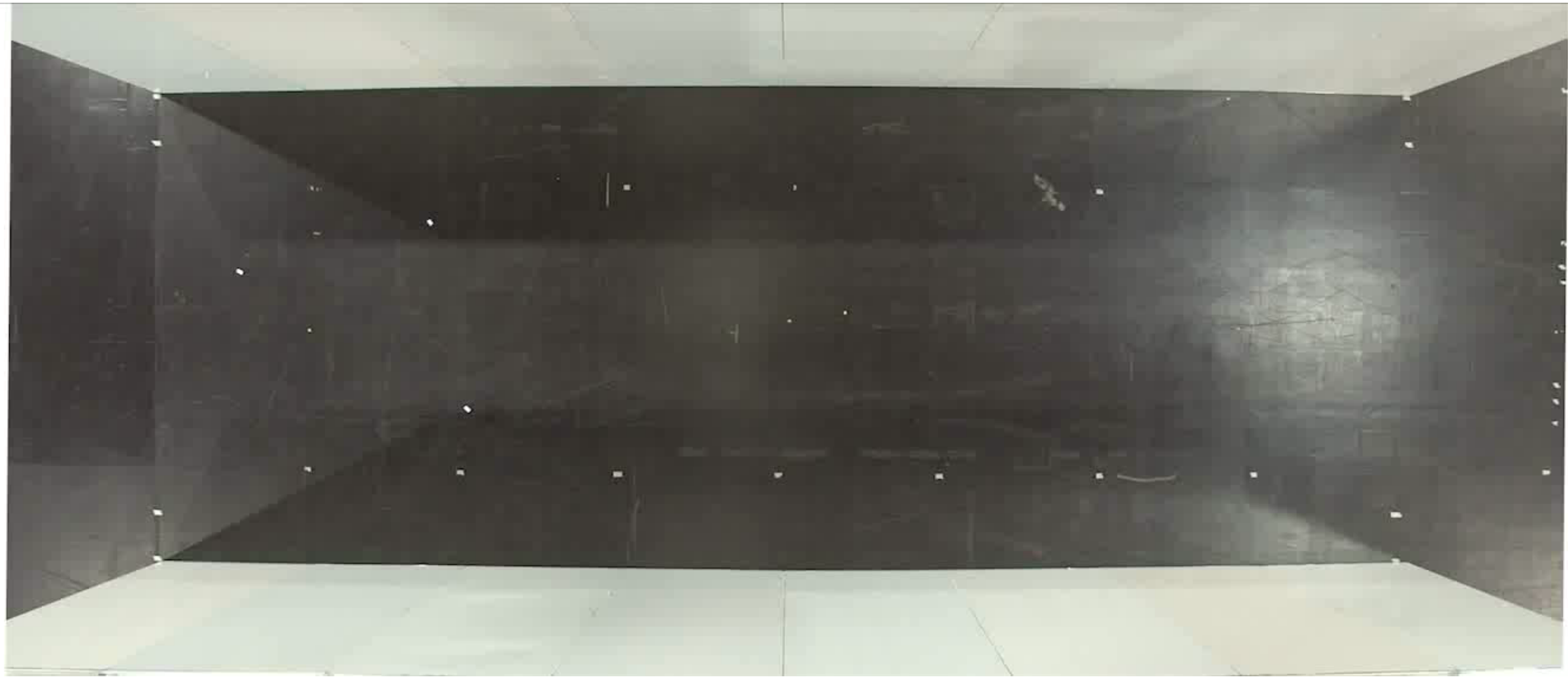
Pedestrian Dynamics

- Scientific Topics
  - elemental modelling
  - route finding
  - position tracking
  - laboratory experiments

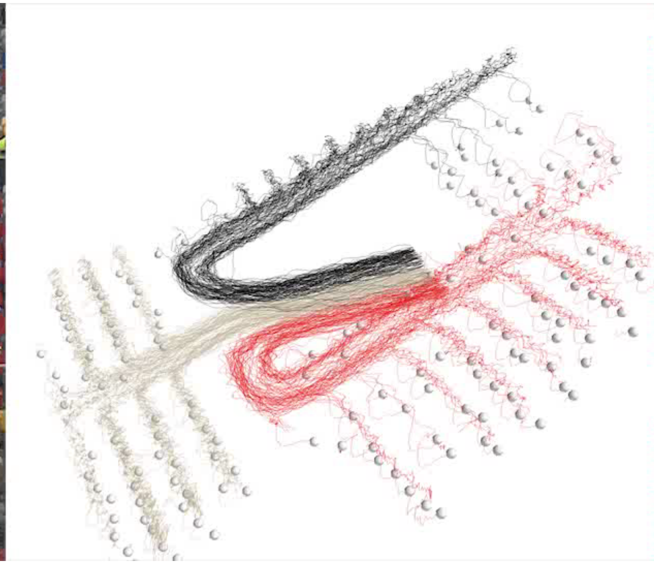
- Projects
  - HERMES (BMBF)
  - BaSiGo (BMBF)

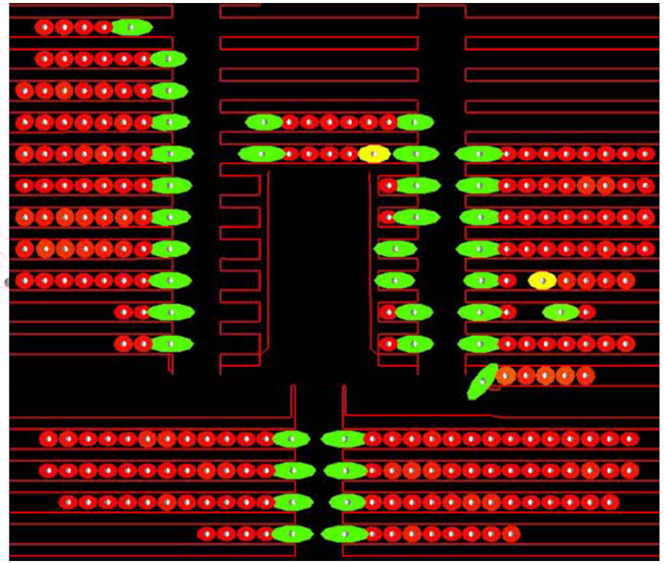


Laboratory Experiments



Experiments in Complex Geometries





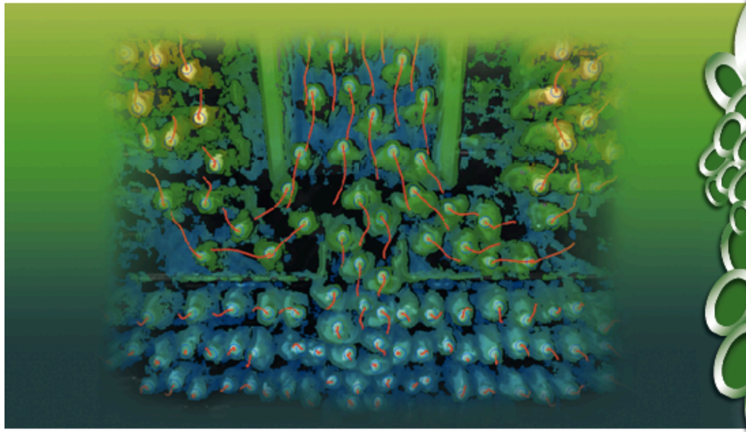
Traffic and Granular Flow (TGF) 2013

Scientific areas:

- Highway and urban vehicular traffic
- Granular flow and dynamics of granular materials (jamming, force networks, dense and intermittent flows, friction, ...)
- Pedestrian and evacuation dynamics
- Collective motion in biological systems (swarm dynamics, molecular motors, social insects, ...)
- Complex networks and their dynamics (transportation networks, Internet, epidemics, social networks, ...)
- Intelligent traffic systems (ITS)

Conference on Traffic and Granular Flow 2013

25 – 27 September 2013 | Jülich, Germany



The Conference on Traffic and Granular Flow brings together international researchers from different fields ranging from physics to computer science and engineering to discuss the **latest developments in traffic-related systems.**
The conference covers, but is not limited to, the following areas:

- Highway and urban vehicular traffic
- Granular flow and dynamics of granular materials (jamming, force networks, friction, ...)
- Pedestrian and evacuation dynamics
- Collective motion in biological systems (swarm dynamics, molecular motors, social insects, ...)
- Complex networks and their dynamics (transportation network, Internet, epidemics, social network, ...)
- Intelligent traffic systems

For its 10th edition, TGF celebratory conference will return to the location of the very first conference held in 1995 at **Forschungszentrum Jülich in Germany**.

Organization: Maik Boltes, Mohcine Chraibi, Andreas Schadschneider, Armin Seyfried

Deadline for abstract submission: 15 March 2013
Notification of acceptance: 15 May 2013

www.tgf13.de

Summary

- Fire simulations are complex (to setup and interpret) due to the combination of multiple (complex) physical and chemical processes
- Current software (i.e. FDS) lacks of state of the art flow solver, adaptive techniques and the (needed) HPC capabilities