Generalized network modelling

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Outline

- **Overview**
  - Conventional network modelling
  - Direct simulations

- **Generalized network modelling**
  - Network extraction
  - Flow simulation

- **Future work**
Network extraction and modelling:

Network extraction

Flow simulation

Micro-CT image

pore-scale parameters:
shape, radius, length, volume, ...

Core-scale properties:
Kr, Pc, ....:

3 mm

(a)

(b)

(c)

(d)

(a)

(b)

(c)

(d)

Water-wet

Oil-wet

Water

Oil

Drainage

Imbibition
Conventional network modelling, draw backs

Different network extraction codes give significantly different results

What are the source of these uncertainties and how to eliminate them?

Oversimplification of the flow path (pore-space),
Uncertainties in the conventional approach are introduced due to unnecessary intermediate parameters:

- Assignment of the boundary between pores/throat volumes
- A shape factor doesn’t uniquely specify the prism shape

As a result, conductances and volumes may not be assigned correctly to capillary radii and hence causing uncertainty in the flow modelling predictions.
Drainage simulations followed by water-injection simulations on micro-CT images can produce reliable results, but is computationally expensive.

**Direct Simulations advantage:** good predictions
Direct simulations drawback: computationally expensive

Studying pore-events:
100,000 cells, simulation time ~ 1 Day

Simulations on micro-CT images:
1000,000 cells, simulation time ~ 1 week on 24 processors
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Theory behind network extraction

- Theory: there is a one-to-one relationship between any 3D geometry and its medial axis → no information loss → no additional uncertainty due to oversimplification of the pore space

Generalized pore network can be viewed as a coarse medial-surface representation of the pore space

Picture from: [http://www.agg.ethz.ch/research/medial_axis](http://www.agg.ethz.ch/research/medial_axis)
Generalized network modelling:
upscaling of pore/throat Pc-Sw-Kr relationship

- Intermediate steps for assignment of volume (saturation) and conductivity to pores/throats/corners are eliminated

- **The necessary parameters are extracted directly from the micro-CT image as tabulated functions.**

**Generalized network model:**

- MS-P theory is used to relate **Pc to Volume (Sw)** for each pore/throat
  - The necessary parameters: **pore/throat radius and corner angles.** → extracted directly from the micro-CT image
  - Direct simulation is used to compute the pore/throat conductivities
  - Effect of contact angle and other fluid properties is added during flow simulation.
Network extraction -> pore space parametrization

An illustration of the network extraction workflow: (a) the pore space is segmented into pore bodies and (b) subsequently into half-throats and corners where the generalised element parameters are extracted.
Rationale behind the discretization choice:

There is a one-to-one (although history dependent) relationship for capillary radius versus interface location for each half throat, allowing the interface location to be recorded and tracked as a single scalar variable.
Network extraction Validation, test-case

Pore-space, converted into micro-CT (voxelated) format, on which Navier-Stokes equations are solved:

Cross-section:

Pressure field:
Network-extraction work flow

Step 1. Compute ball radii

Radius = distance of each voxel from nearest solid wall
Step 2.
2.1. Extract ball hierarchy (medial surface),
2.2. find local maxima of the radius and
2.3 Assign a pore index to each of the local maxima
Step 3.0. Find pore-to-pore connections (throats)
Step 3.1. Identify and label individual corners on the throat medial axis
Step 3.1. Map corner labels to the original image and analyse direct simulation results for each corner at Level 0.
Step 3.2. Throat centres are deleted from corners to analyse direct simulations at Level 1.
Network-extraction work flow

Step 3.3. More balls from throat centres are deleted from corners to analyse direct simulations at Level 2.
Generalized network extraction

A primitive visualization of the extracted network as interpreted in the flow simulator
Comparison - conventional network extraction

Conventional network extraction, Only throat corners are visualised

Corner conductivities are calculated using correlations, from the shape of the corner
Corner conductivities are calculated from tabulated functions extracted from direct single-phase flow simulations.

Generalised network simulation results - validation in progress.
Network extraction demonstration – Berea sandstone

Element Indices

✔ High resolution

➔ Important for detecting and analysing corners accurately
Berea sandstone, generalized network

Generalised network
In the flow simulator
Berea sandstone, conventional network

Conventional network
In the flow simulator
Preliminary results – Berea sandstone

- Oak (1990)
- Fulcher et al. (1985)
- Krevor et al. (2012)
- Akbarabadi and Piri (2013)
- Our Simulations
- NetModel - 500cube

The graph shows the relationship between Sw (water saturation) and Kr (relative permeability) for different models and simulations. The data points from various sources are plotted to compare their results.

- Fulcher et al. (1985)
- Oak (1990)
- Akbarabadi and Piri (2013)
- Amaefule and Handy (1982)
- USS, Amaefule and Handy
- Our Simulations
- NetModel - 500cube
Network extraction – a close look

Voxel radius
Network extraction – a close look

Medial surface - ball hierarchy
Network extraction – a close look

Local maxima of radius on the media surface → pores
Network extraction – a close look

Pores mapped on the original image for throat identification
Network extraction – a close look

Throat medial axis added to the medial surface
Network extraction – a close look

Corners marked on the throat medial axis
Network extraction – a close look

A visualization of the half-throats
Network extraction – a close look

A closer look to the corners of a sample pore
Network extraction – a close look

A closer look to the corners of another pore

Half-throat # 1
Half-throat   # 2
Network extraction – a close look

Half-throat  # 4
Network extraction – a close look

Network representation during the flow simulation
Network extraction – a close look

Higher filtering $\rightarrow$ coarser network
Network extraction – a close look

Lower filtering → additional small pores
Conclusion and future work

Generalised network modelling *combines the superior efficiency of network models with the accuracy of the direct simulations.*

Write-up and validation using direct simulation and multiphase micro-CT imaging is undergoing - a pore-by-pore comparison shall be conducted.

Viscous forces are taken into account in the filling process during flow simulations.

Corner connectivity-tracking provides richer predictions.
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Thank you for your attention
Spare slides