# Use of HPC to Predict Porous Media Properties and Flow in Hydrocarbon Reservoirs


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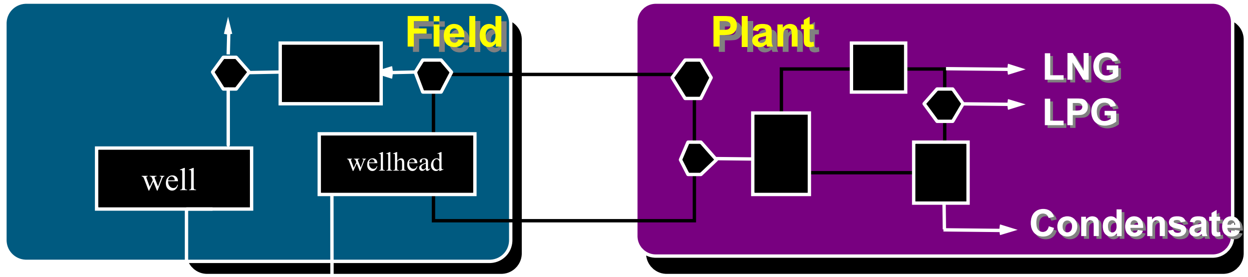
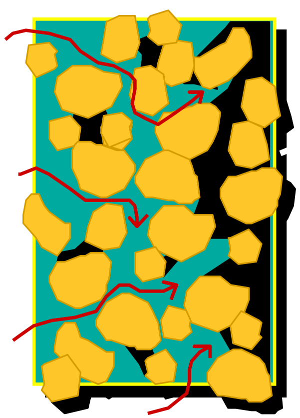
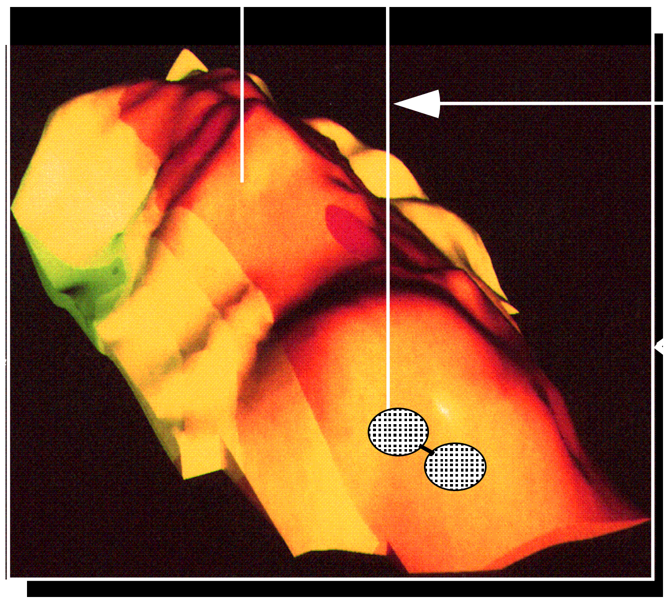
# Integrated Reservoir Simulation

Integrated Surface Facilities



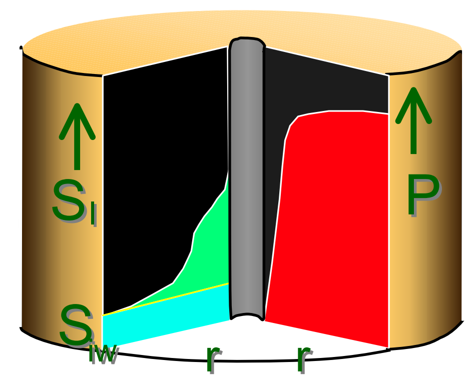

Fundamentals of Rock Physics and Fluid Flow





Reservoir Simulation

Data Input for Wellbore Corrosion Models




Deliverability of Gas Condensate Reservoirs

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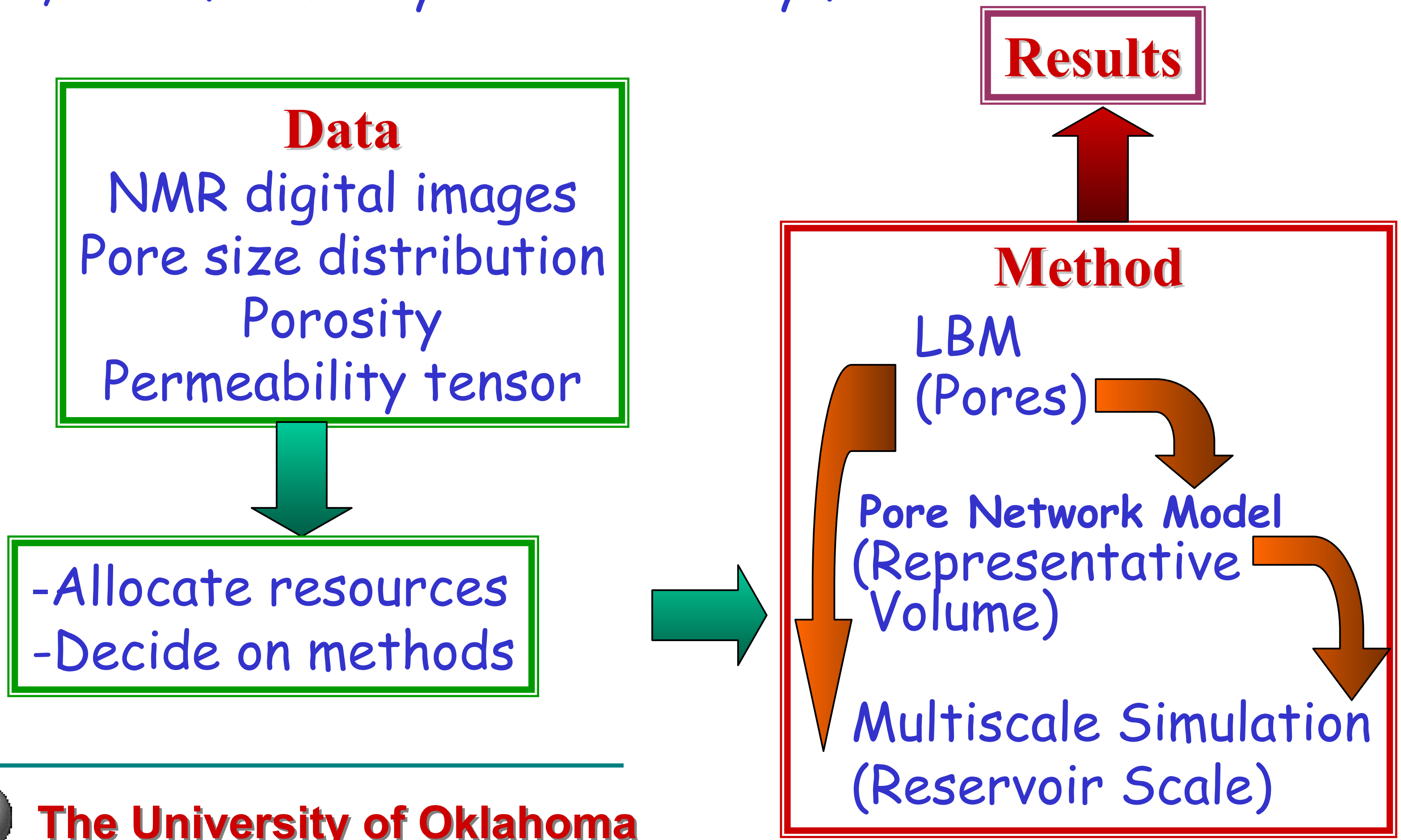
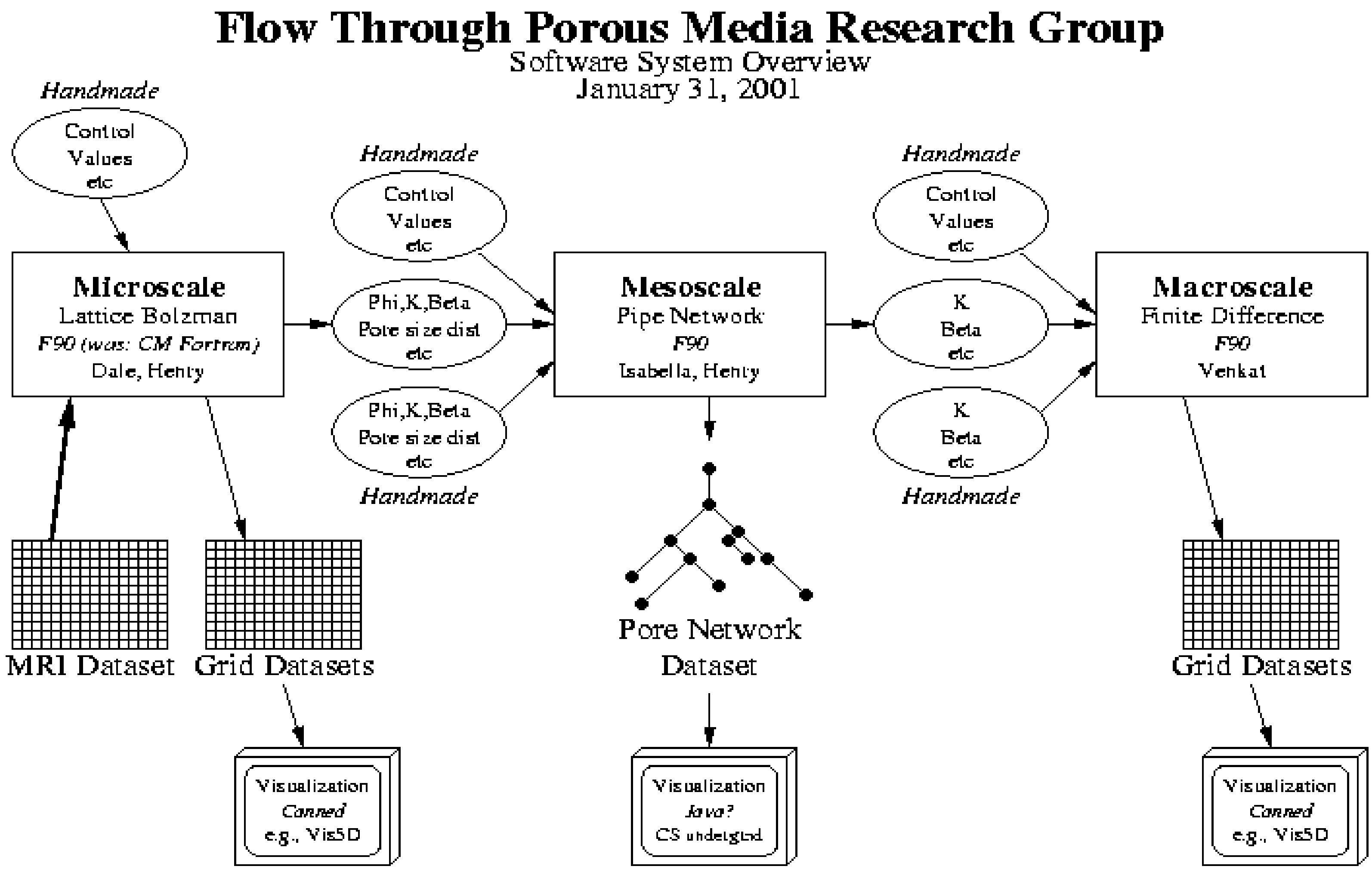
# Hierarchical Multiscale Simulator Technology (HiMuST)

Develop an integrated, multiscale Problem Solving Environment consisting of software components that simulate, using a hierarchy of scales, the 3D flow through anisotropic porous media, both for Darcy and non-Darcy flow.



# Hierarchical Multiscale Simulator Technology (HiMuST)

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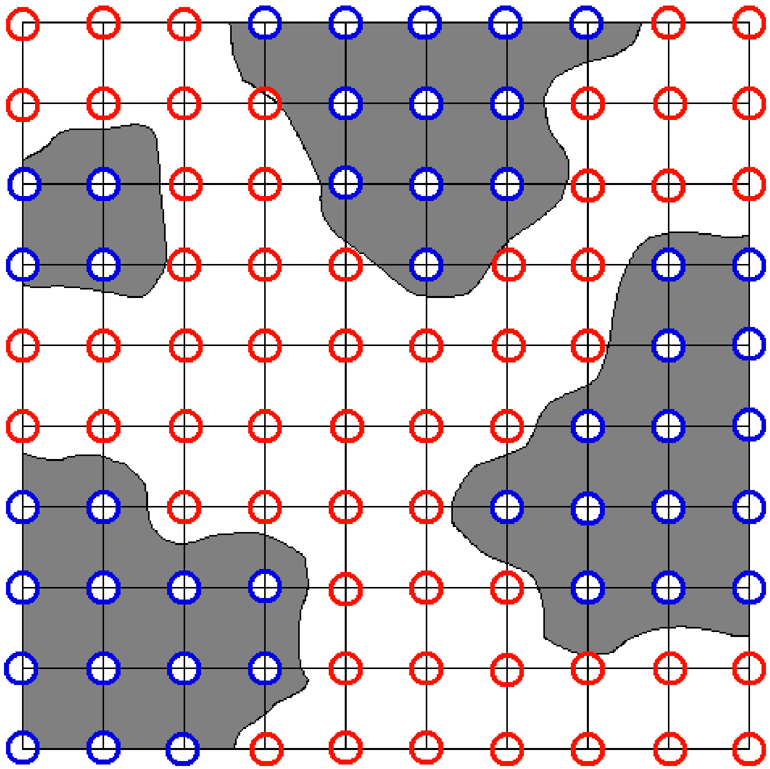
# Level 1: Pore scale simulation

**Advantages of the Lattice Boltzmann Method**

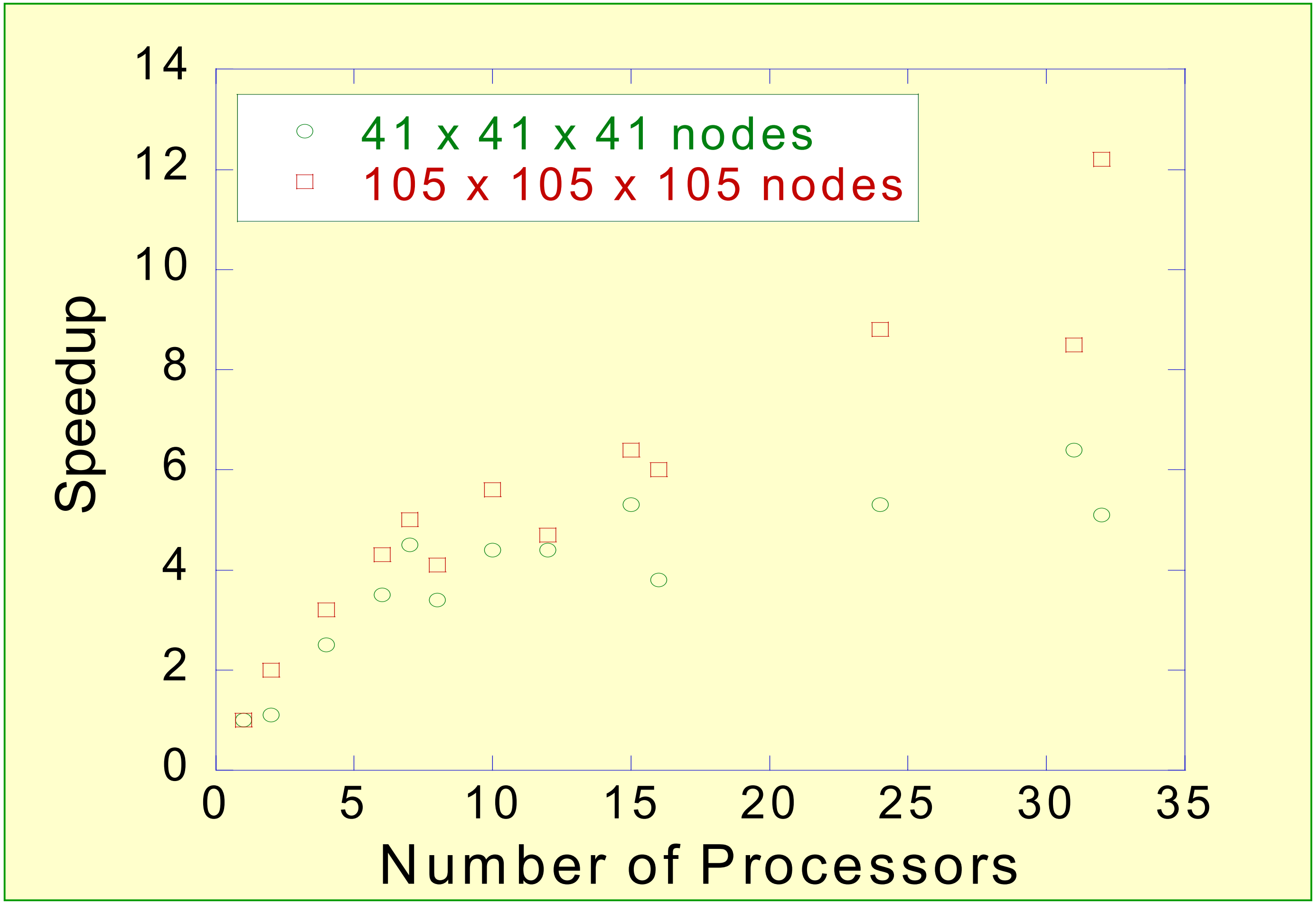
- It is based on first principles.
- It is substantially parallelizable.
- It can handle irregular boundaries.
- It is equivalent to 2nd order accurate Navier-Stokes solver (Chen et al., 1992)



**Discretization**

- The porous medium is divided into a 3D network of nodes.
- Each node inside the solid material is set as a "wall" node and is unavailable for flow.

# Autoparallelization Speedup




$41^3$: 863s on 1 proc

$105^3$: 30358s on 1 proc

SGI Origin 2000 (@NCSA), MIPSpro compiler.

# Current Parallelization Effort

**Done:**

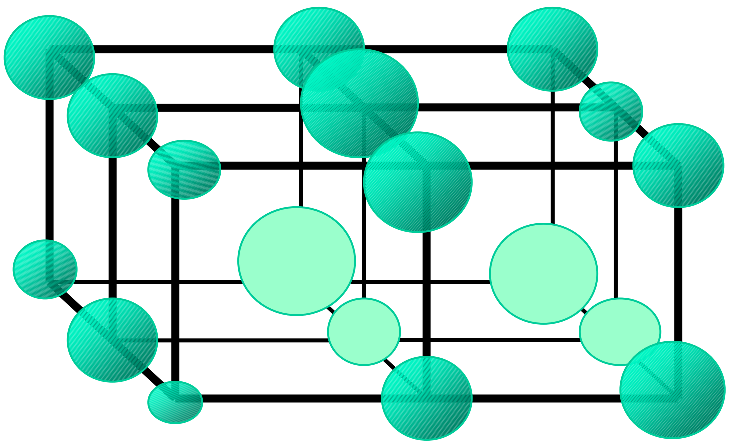
- Code has been translated to standard Fortran90 code.
- Optimization of computational efficiency of the program.
  - Reordering of arrays (e.g. A(k,j,i) instead of A(i,j,k)) to improve data locality (23% increase in execution speed)
  - Change to array notation and nested loops (e.g. avoid A=B, where A,B are arrays) to improve data locality (330% increase in execution speed !! )
- Simulation of single phase flow through unconsolidated media.

**To Do:**

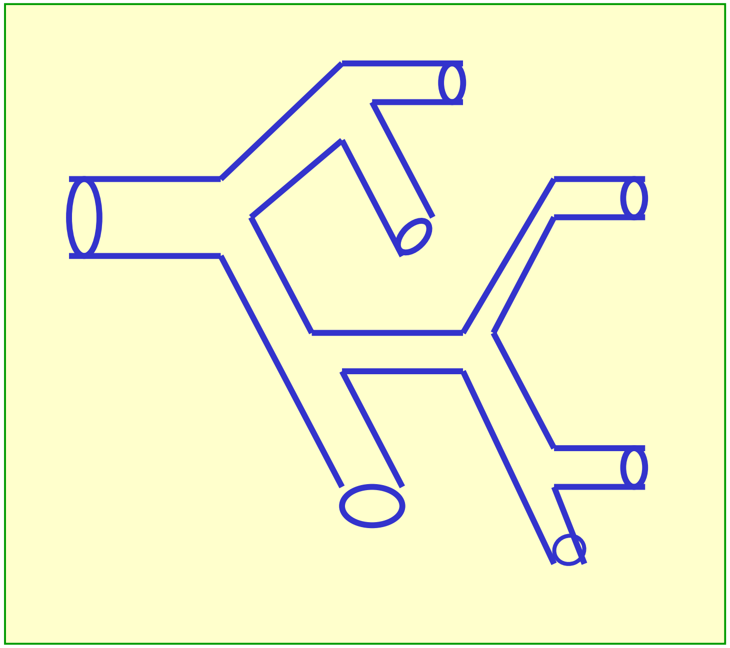
- Simulate two-phase flow through realistic porous material (X-ray tomography images).
- Use Message Passing Interface to improve parallel performance

# Level 2: Pore Network Representation

Pores and throats
Array geometry
(e.g., Dias & Payatakes; Mohanty et al)



Collection of Pipes
(e.g., Haring & Greenkorn)



# Pore Network Modeling

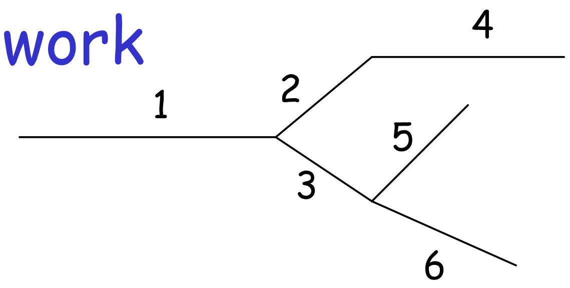
## The Code

- Network geometry module
    - Two versions:
        - 2D with two geometries (Fortran 90)
        - 2D and 3D with fully random configuration (C++)
        - Capability to use experimentally observed pore size distributions
    - Common output format for network geometry

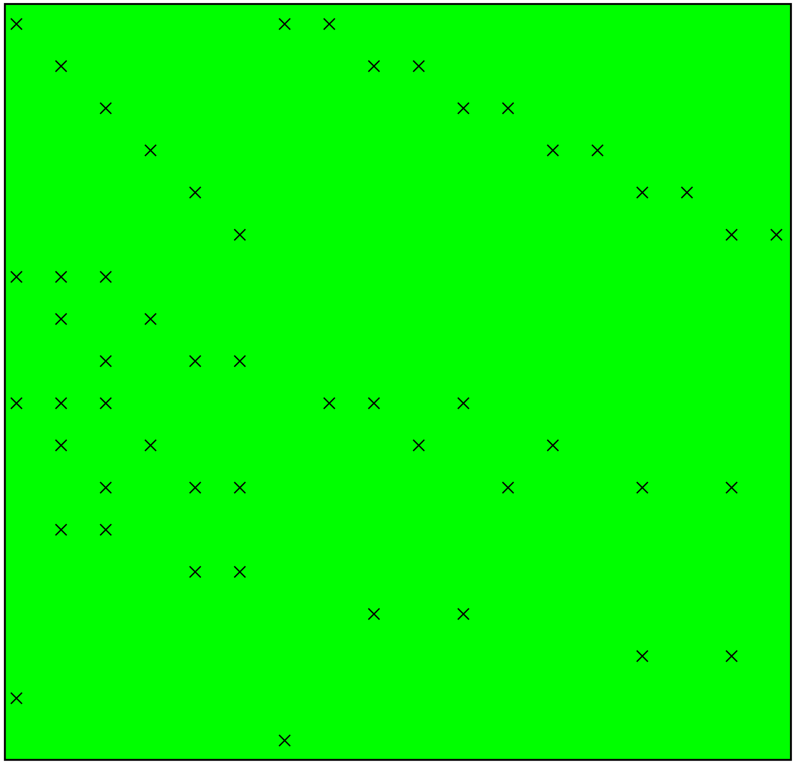
- Flow module
    - Network geometry read interface
    - Single phase, incompressible, maximum C=3
    - Momentum, mass and energy balances
    - Non-linear system of equations (order of 3N)
    - Newton's method with direct solvers
    - Solving for velocity and pressure drop
    - Goal: obtain permeability and Forchheimer coefficient

# Original Flow Matrix Structure

Example Pipe Network



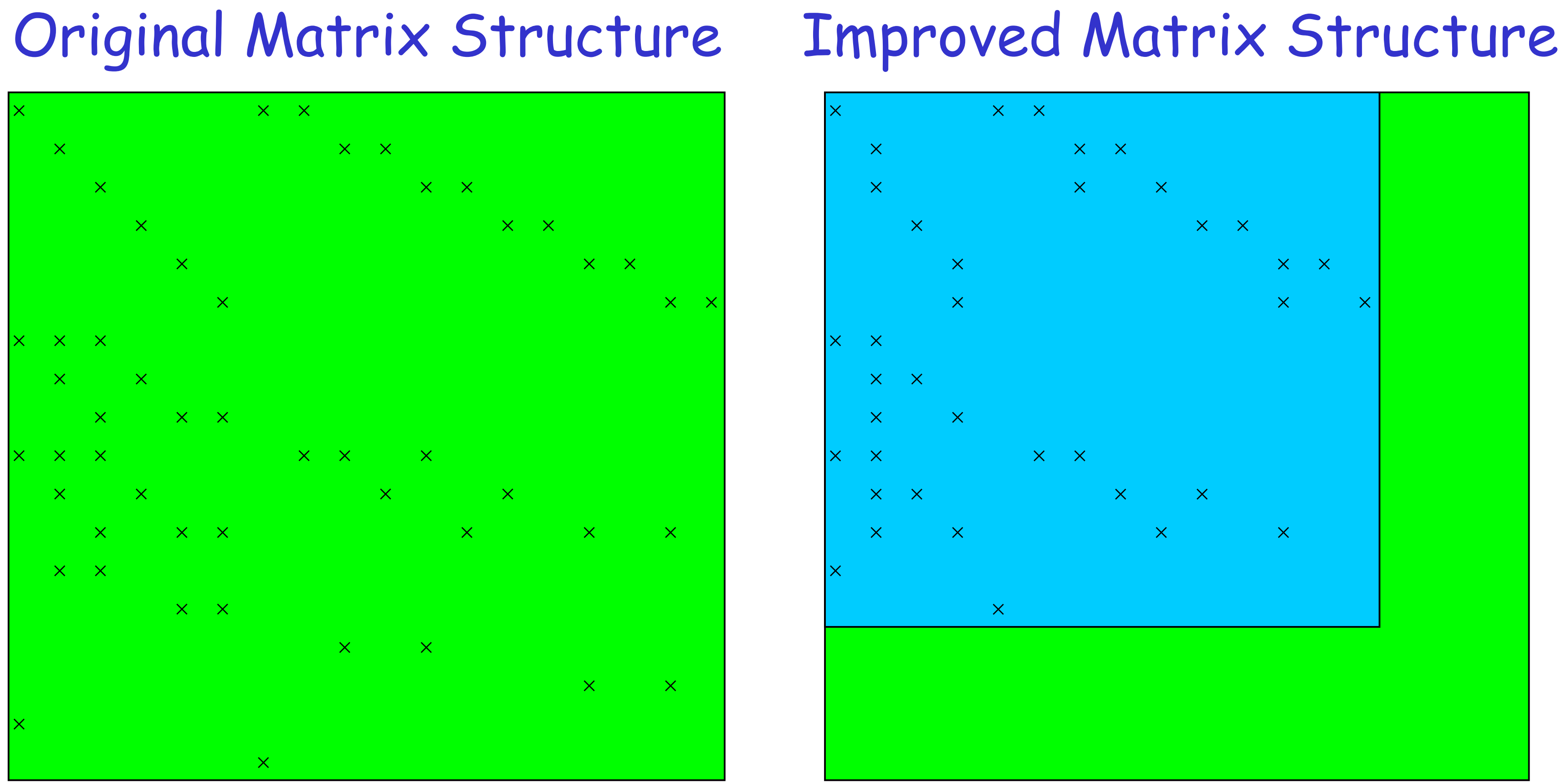

Matrix Structure
(Newton's Method)



Problem: system of equations is ***very*** hard to solve!

- Failed:
  - LAPACK
  - PETSc
  - QMRPack
- Succeeded:
  - IMSL (sometimes)

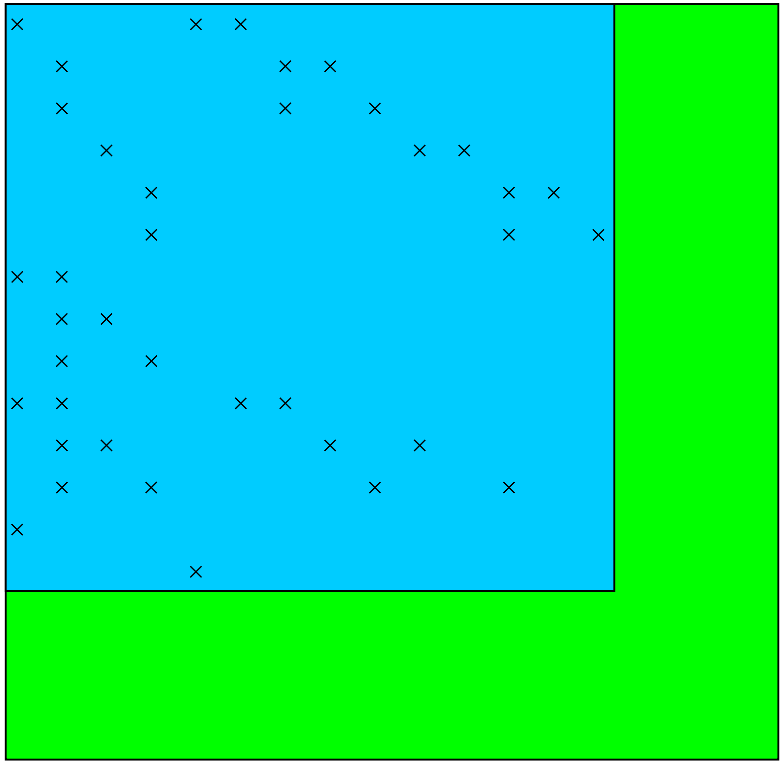
# Improved Flow Matrix Structure



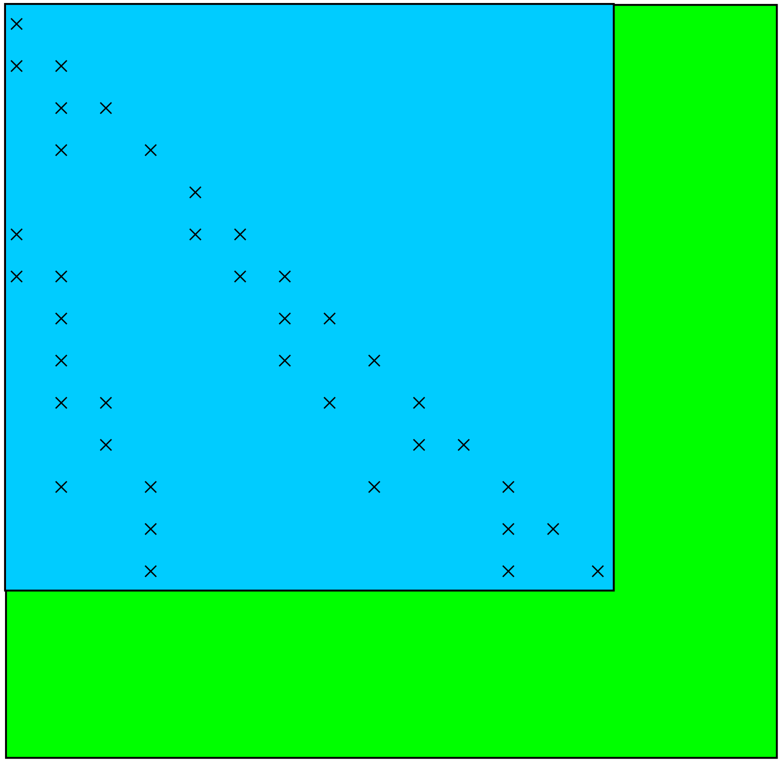

The new matrix structure is smaller, but that's not what makes it interesting . . . .

# Permuted Flow Matrix Structure

Improved Matrix Structure



After Permuting Rows



The permuted matrix is lower triangular!

Properties: 1 – 4 nonzero entries per row # of rows < $3 * N_{pr}$

Therefore: can solve in $O(N_{pr})$ via substitution!

# Level 3: Macroscopic scale

## Anisotropic Non-Darcy Integrated Reservoir Simulator
## ANDIRS

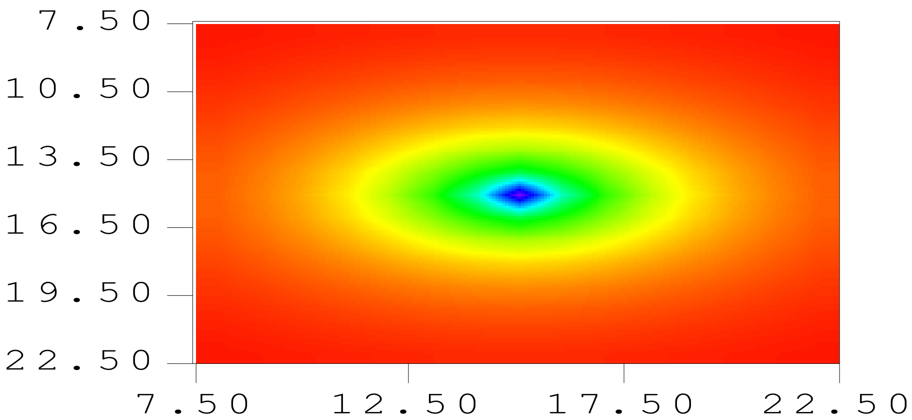
**Done:**

- Code has been written in standard Fortran90.
- Implicit methods.
- 2D simulation with anisotropic permeability.
- Validation of 2D results

**To Do:**

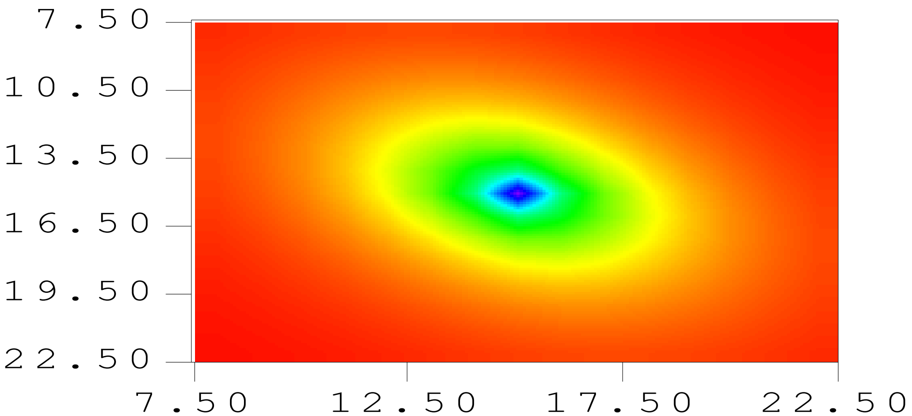
- Further improve the numerical scheme
  - Use iterative solvers
- Incorporate well equations
- Incorporate anisotropic, non-Darcy flow cases

# ANDIRS – Implicit methods, Anisitropy




Kxx=120mD, Kyy=80mD
Kxy=Kyx=0

Kxx=100mD, Kyy=100mD
Kyx=Kxy=20mD




Single – spot pattern, 20 days, Lx=Ly=100m, $\phi$=25%

# Summary

- Scope: Develop multiscale, hierarchical simulator.
- Each software component (scale) is stand-alone.
- Prediction of porous media properties with a computational approach based on measurable properties, such as pore size distribution and porosity.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