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Next Generation Reservoir Simulation – New Capabilities For New Challenges

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ExxonMobil Upstream Research Co.

Society of Petroleum Engineers
Distinguished Lecturer Program
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Presentation Outline

- Objective
- Next Generation Simulation Drivers
- Unstructured Grids
  - What is it?
  - Application to Geologic Features
  - Application to Engineering Features
- Integrated Surface/Subsurface Modeling
  - Simple Example
  - Field Example
- Parallel Reservoir Simulation
  - Field Examples
- Concluding Remarks

Next Generation Reservoir Simulation

Another Next Generation Talk?

Objectives:

Discuss New Simulation Technologies That Are Commercially Robust And Readily Available

- **Unstructured Gridding**
- **Integrated Facilities/Multi-field Simulation**
- **Parallel Reservoir Simulation**

Show Application And Benefits Of These Technologies

Are You Using All Reservoir Simulation Technologies You Can?

Next Generation Reservoir Simulation Drivers

Opportunity and Characteristics

Previous generation of reservoir simulators has a technology vintage of late 1980s/early 1990s.

Significant advances in reservoir simulation technology and technical computing capability in the interim.

Exploits Advances in Technical Computing

- Desktop 3D Visualization
- Object-Oriented Design/C++
- Parallel Desktops

New Challenges

Explosive Growth of Geological Modeling

- Near Doubling of Application Usage From 2006 to 2009
- New Demands on Simulation Accuracy and Speed

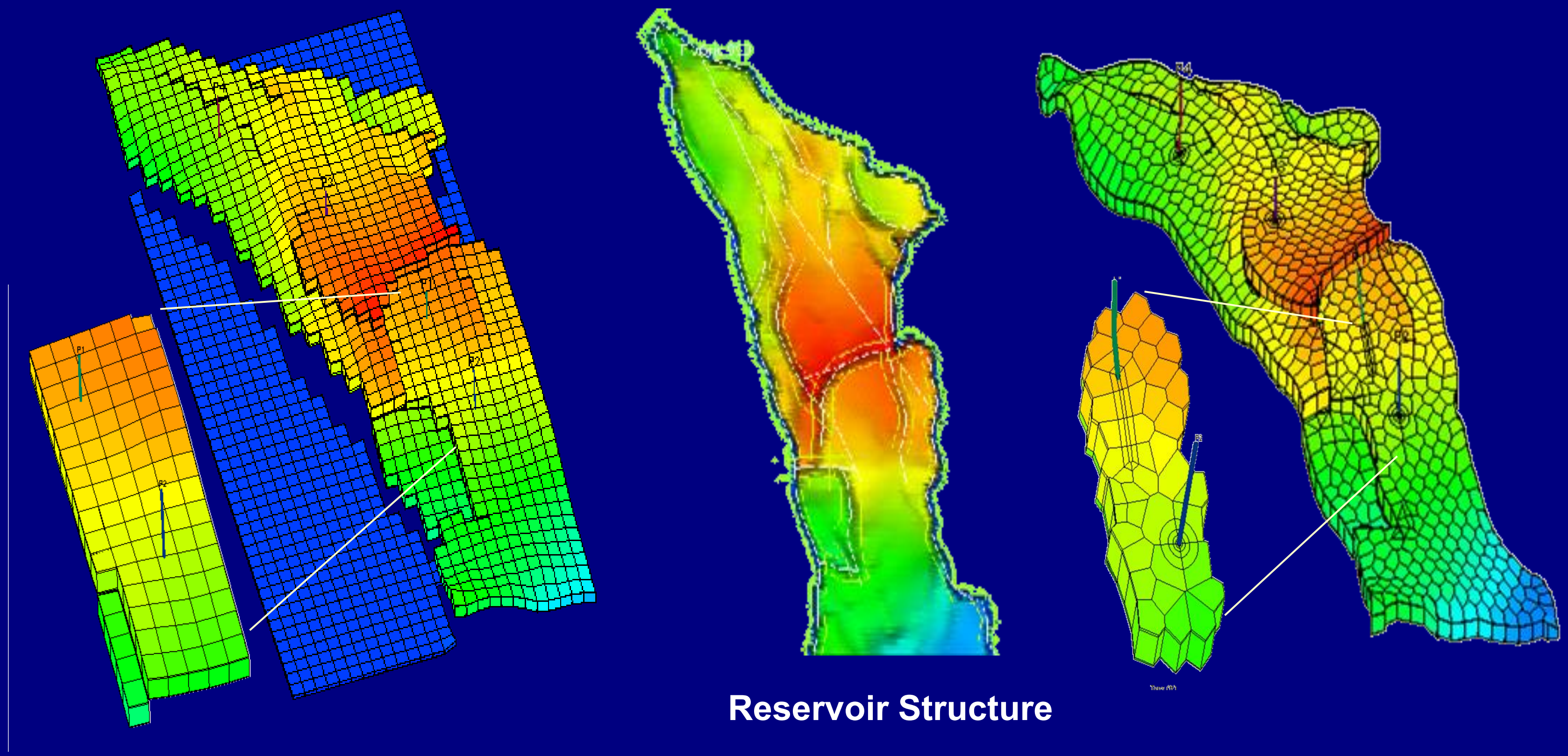
Stronger Focus on Complex Assets

- Thermal, IOR
- Tight Gas, Shale Gas, CBM

Reservoir Simulation Using Unstructured Grids

Usual Practice
Use simulators that approximate geology with structured grids

Better Practice
Use next generation simulators that honors geology with unstructured grids

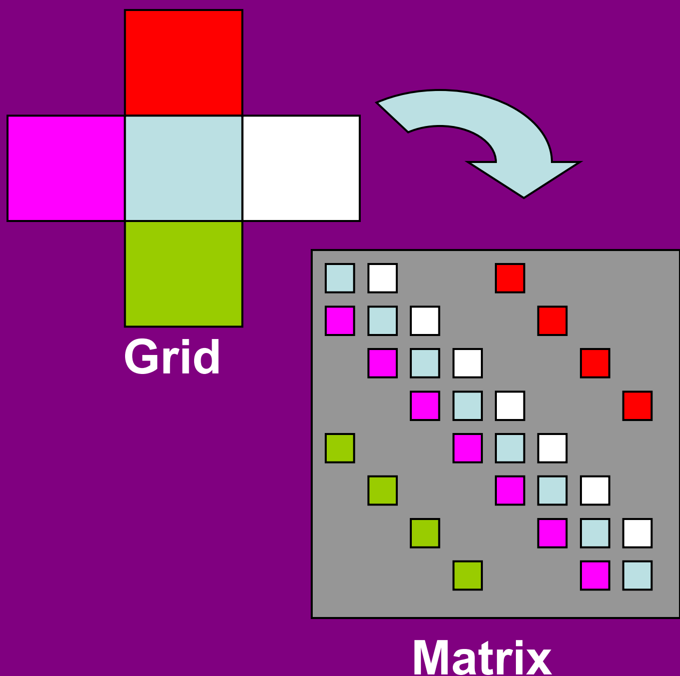


Reservoir Structure

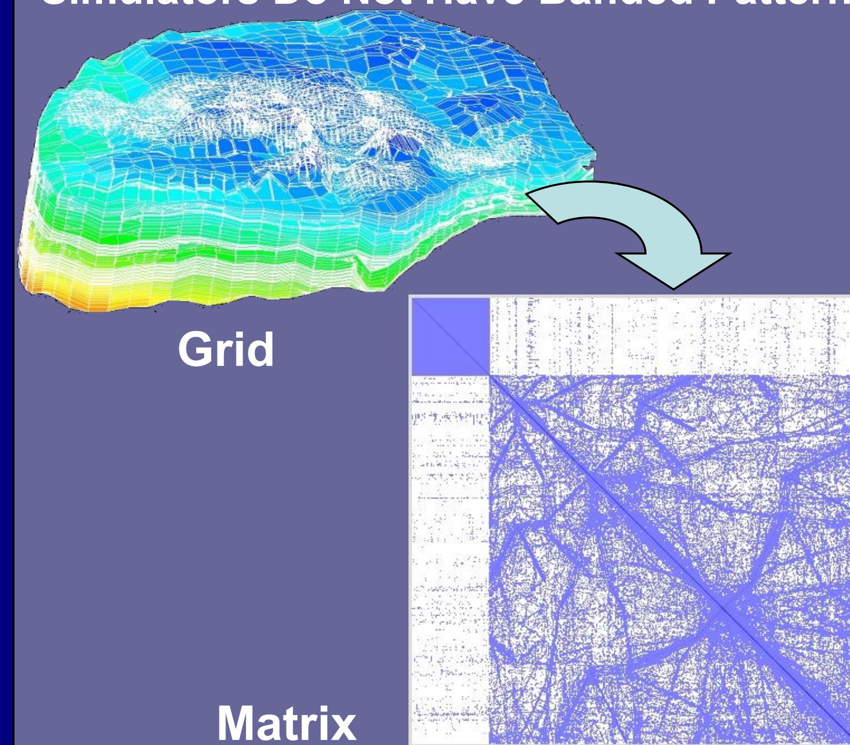
Linear Solvers for Unstructured Matrices

New Solution Techniques Required

Matrices From Conventional Reservoir Simulators Have Banded Pattern Due to Rectilinear Grid



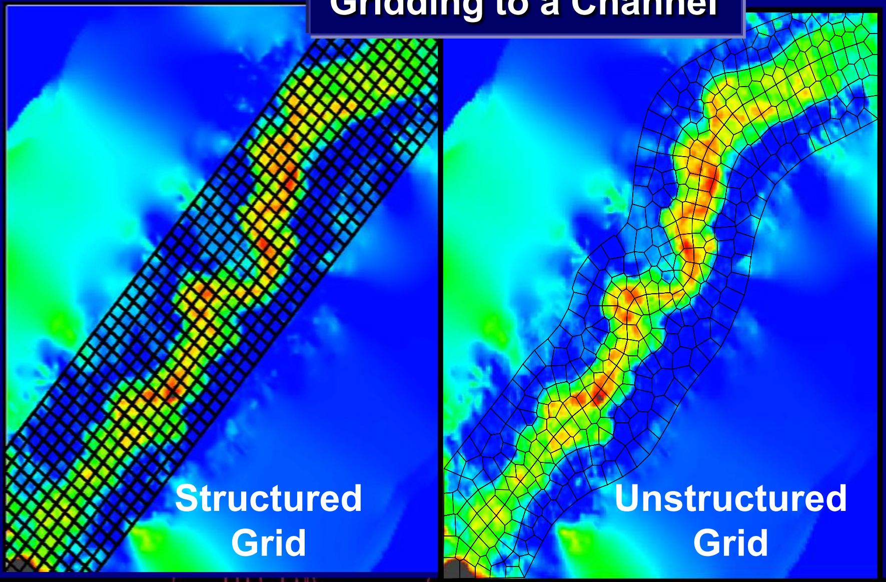
Matrices From Unstructured Reservoir Simulators Do Not Have Banded Pattern

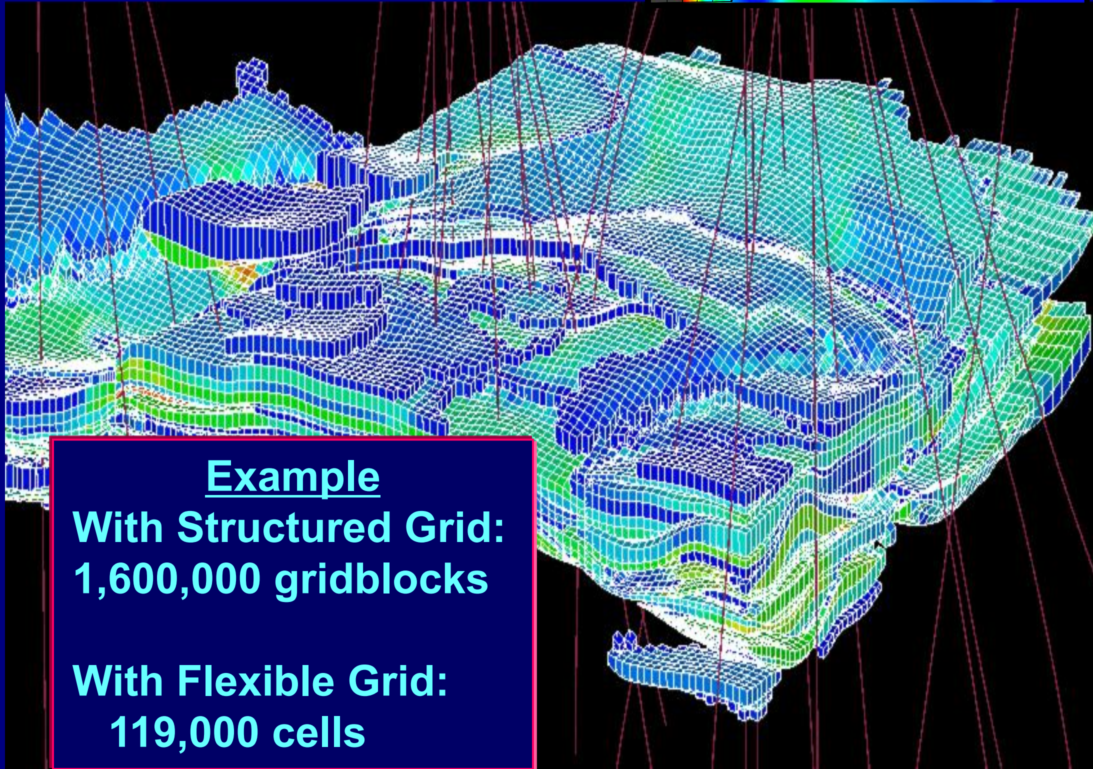


Benefits of Unstructured Grids

- Greatly Improves Ability to Honor:
  - Geologic Features (Complex Faults, Channels, Pinchouts, Fluid Contacts)
  - Engineering Detail (Wells, “Sweet-spot” Development)
- Eliminates “non-essential” Grids, Putting Detail Where Needed

Gridding to a Channel



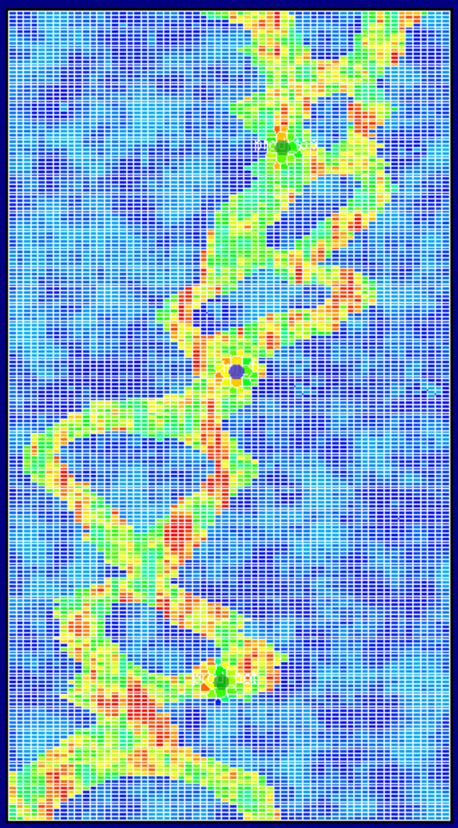


Unstructured Grids – Model Example

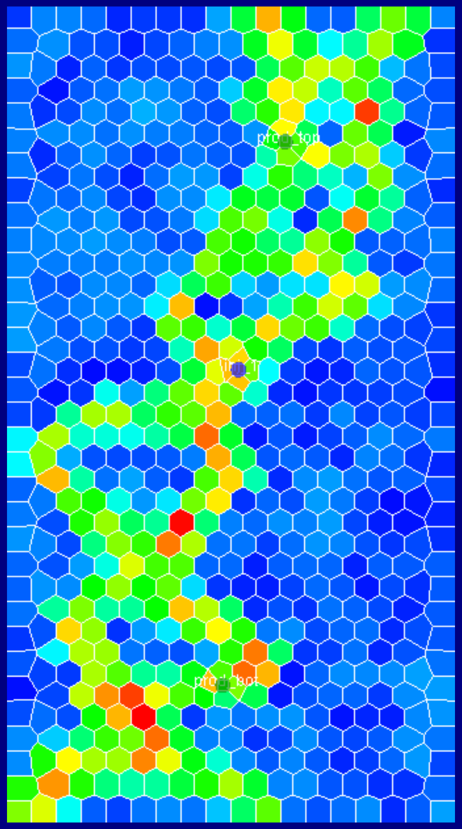
Preserving Correlated Heterogeneity

Highly correlated heterogeneity often has dominant effects on fluid transport and need to be captured explicitly.

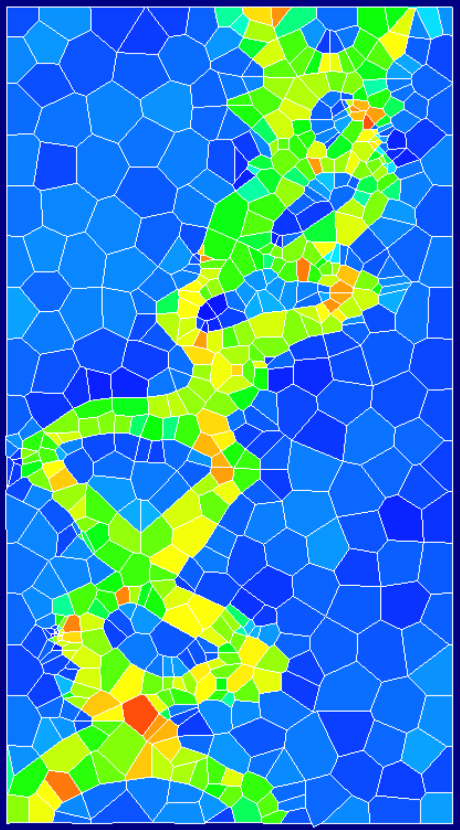
SIAM GS09 Branets et al.



Fine Grid
39327 Cells



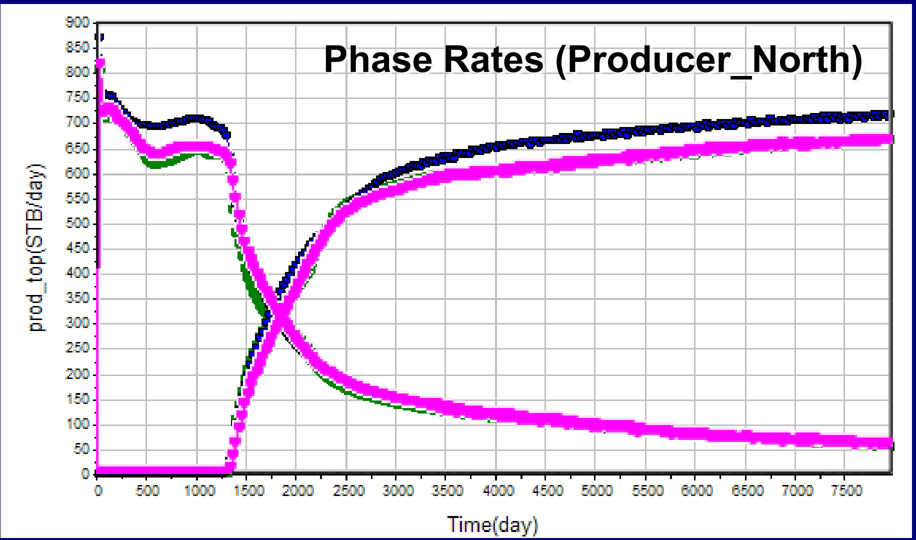
Hex Grid
1950 Cells

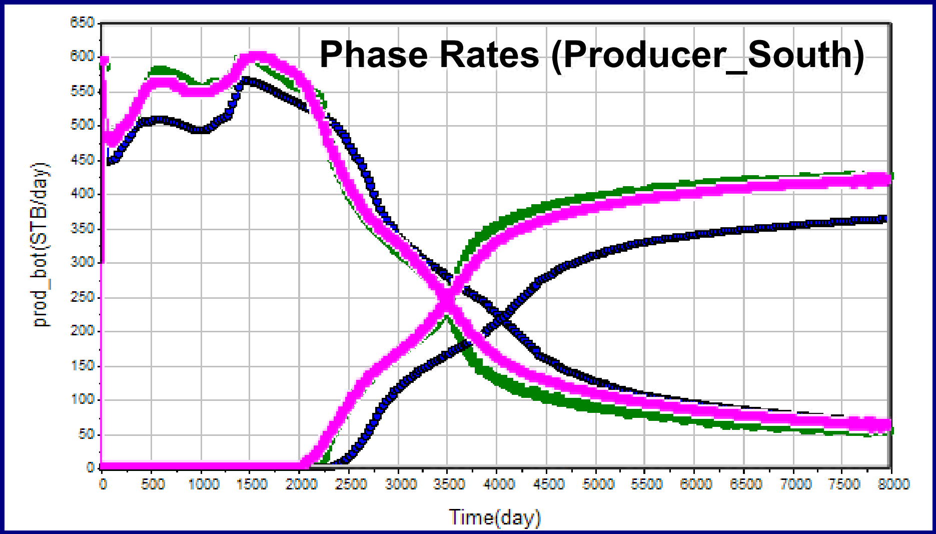


Adaptive Grid
1932 Cells

Unstructured Grids – Model Example

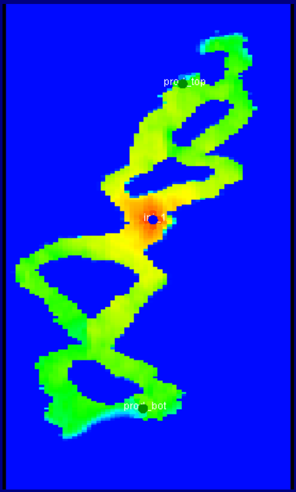
Preserving Correlated Heterogeneity (cont.)



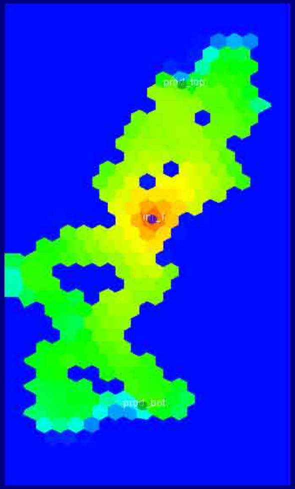


Fine Grid Hex Grid Adaptive Grid

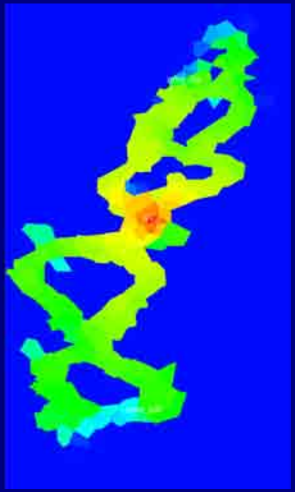
Fine Grid



Uniform Hex



Adaptive Grid



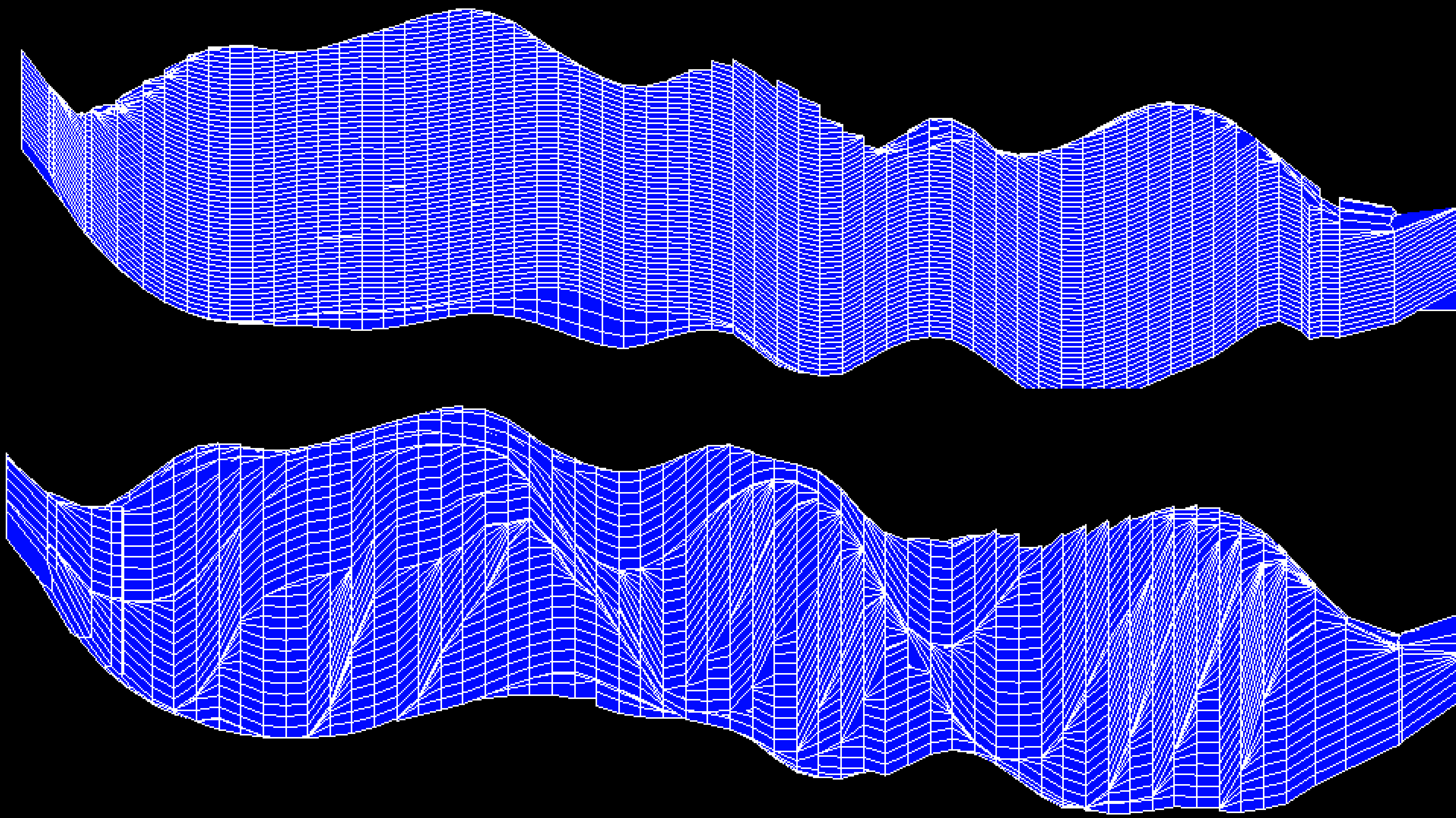
S_w at Breakthrough

Unstructured Grids – Model Example

Gridding To Internal Geologic Structures

Constant Porosity and Permeability with $K_v : K_h = 0.01$

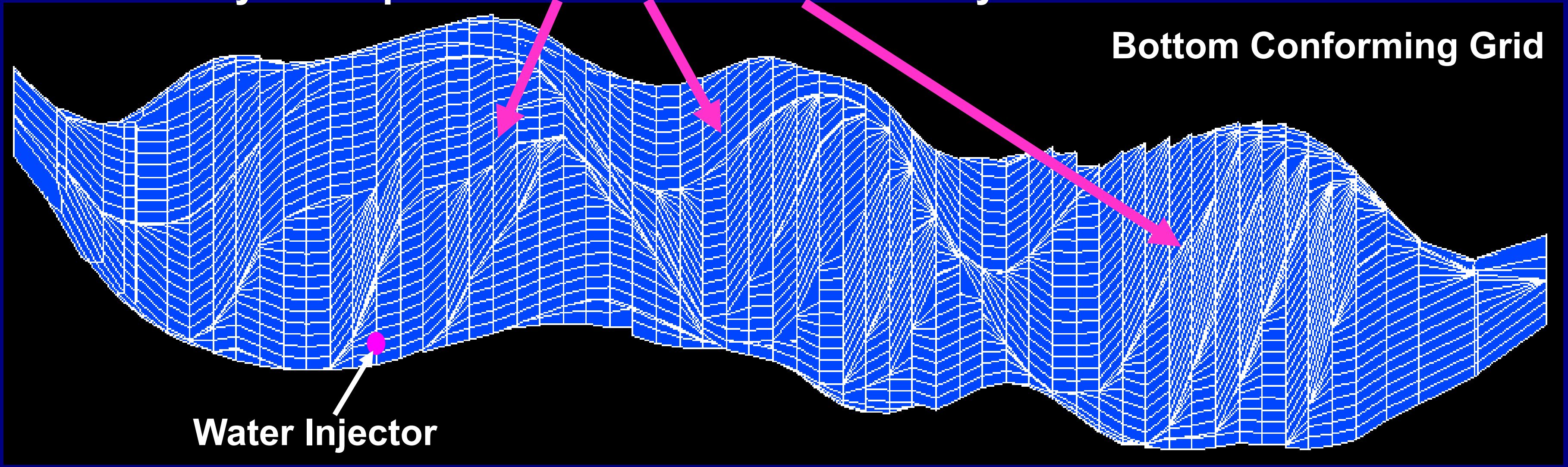
Proportional Grid



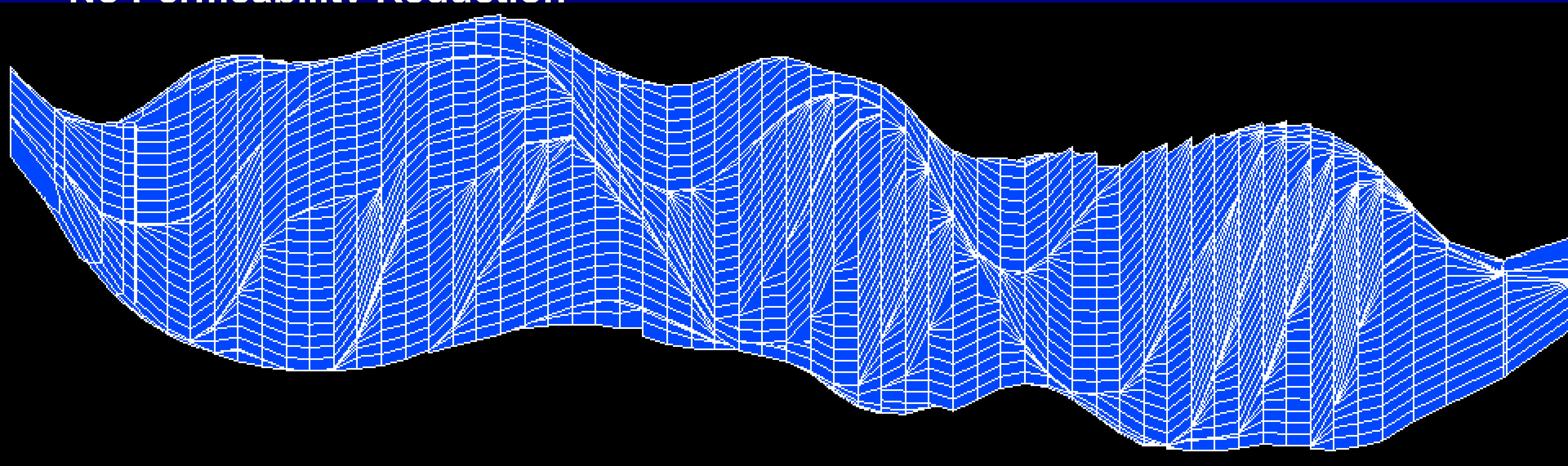
Unstructured Grids – Model Example

Gridding To Internal Geologic Structures

Permeability at Sequence Boundaries Reduced by 0.01



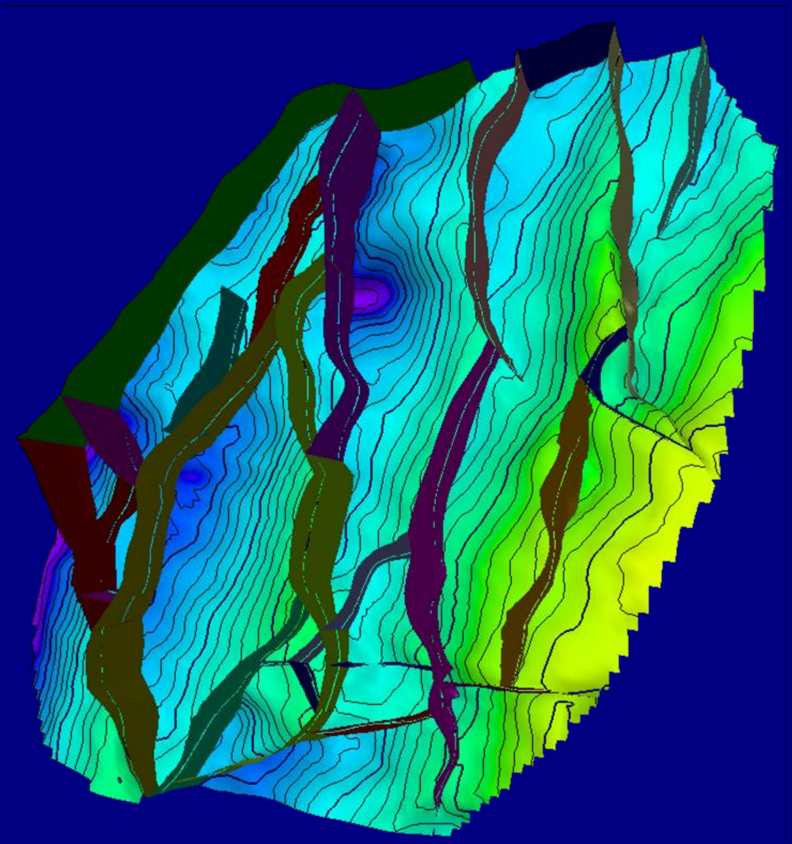
No Permeability Reduction



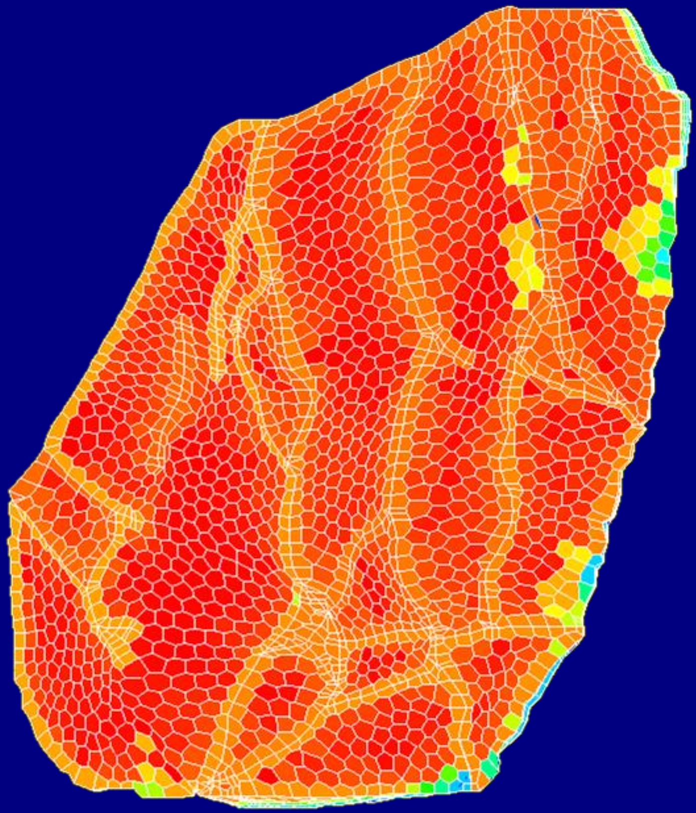
Unstructured Grids – Field Application Example

Complex Deviated Faults

- Honoring Irregular Boundaries
- Flexible Cell Size in Local Area



Geologic Model Structural Framework

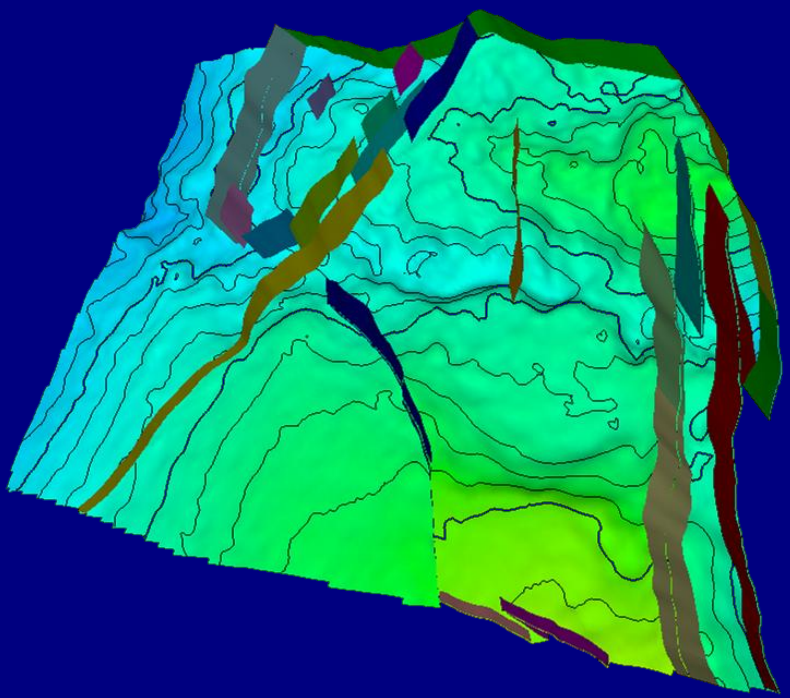


Unstructured Simulation Grid

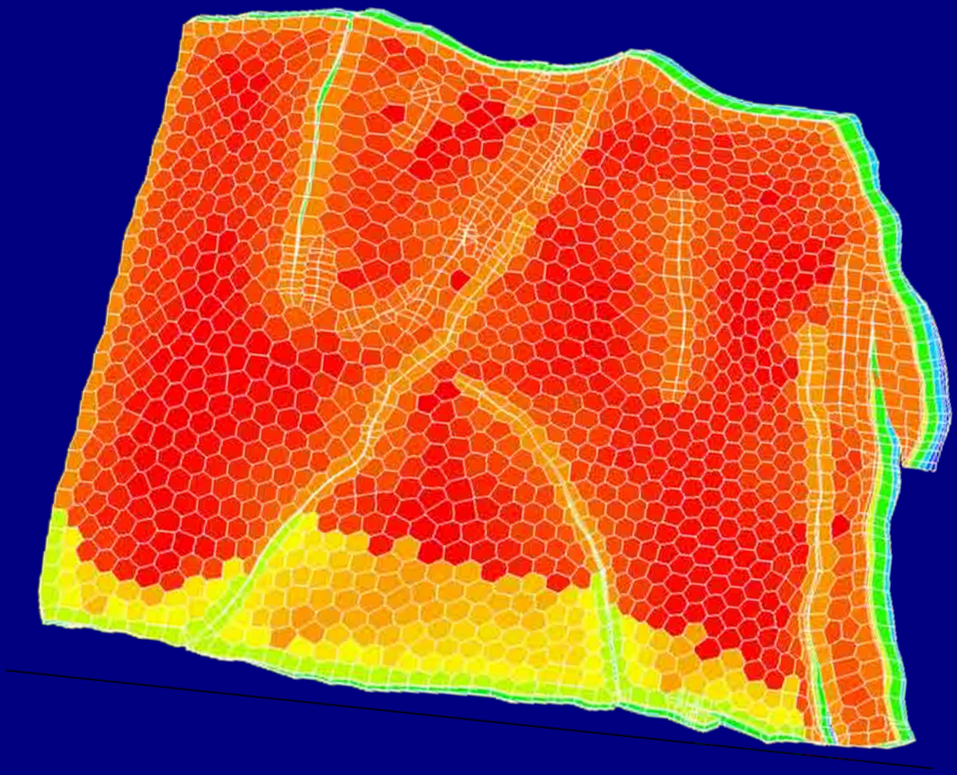
Unstructured Grids – Field Application Example

Multiple Small Faults

- Honoring Irregular Boundaries
- Flexible Cell Size in Local Area

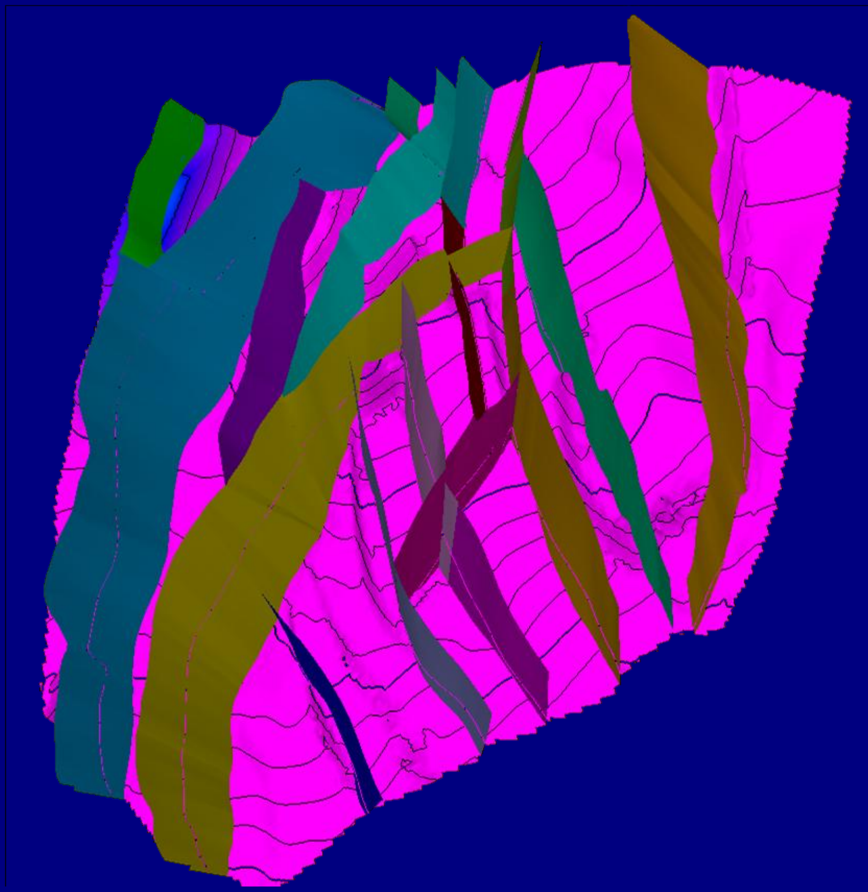


Geologic Model Structural Framework

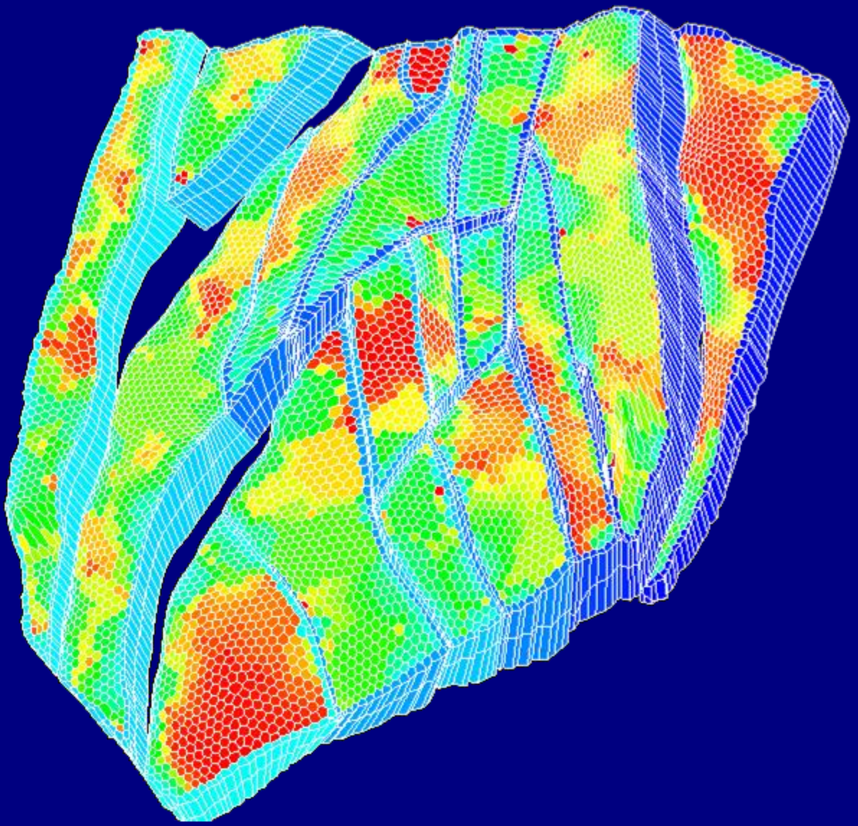


Unstructured Simulation Grid

Unstructured Grids – Field Application Examples

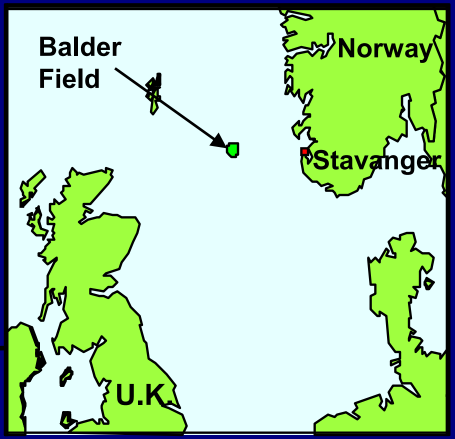


Geologic Model Structural Framework

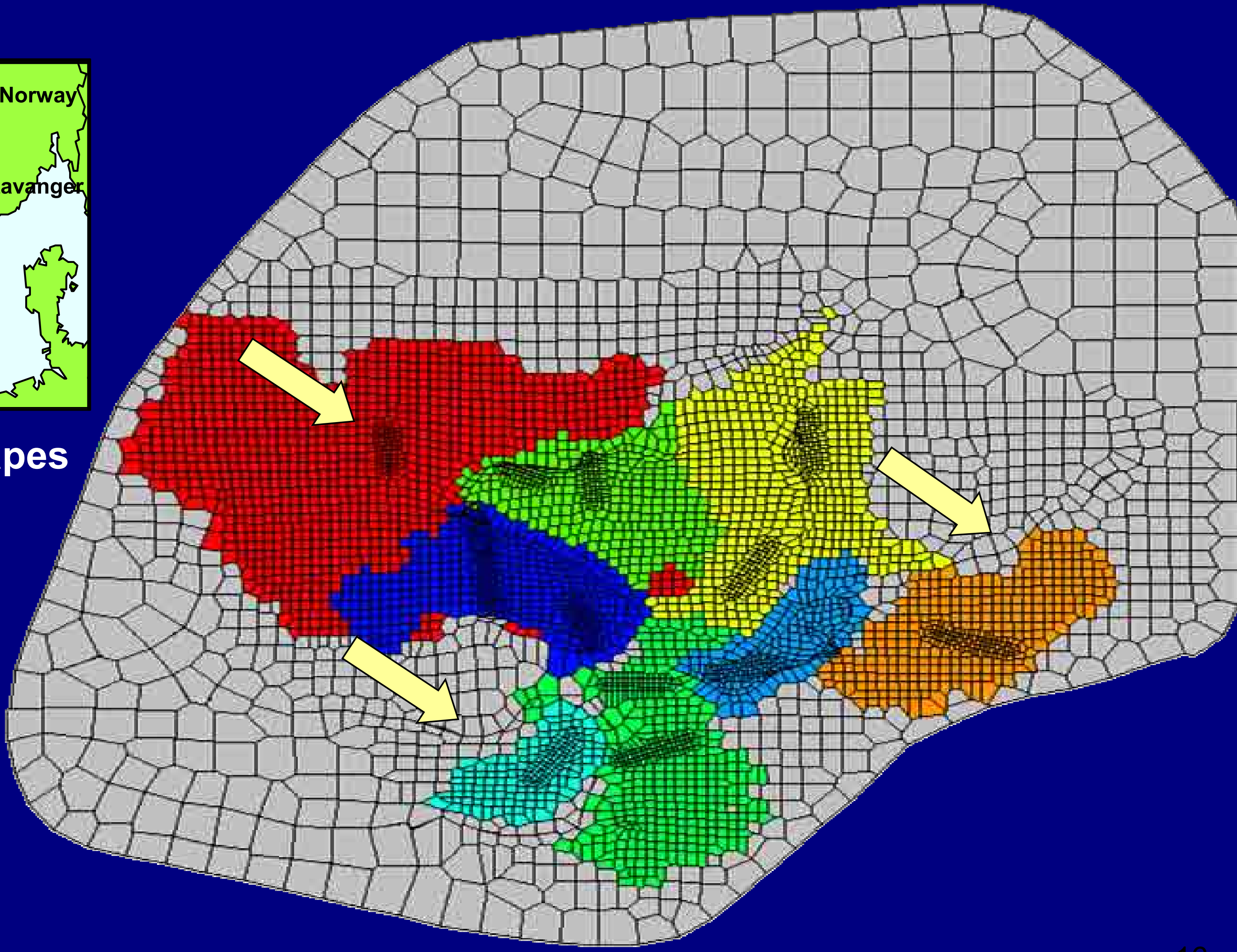


Unstructured Simulation Grid

Unstructured Grids – Field Application Example

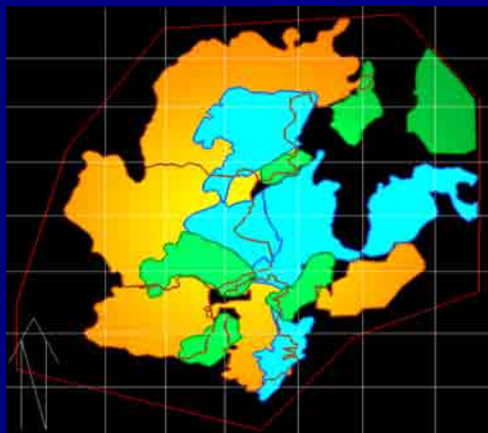


- Arbitrary Shapes
- Nonlinear Fault Traces
- Multi-level Grid Refinements
- Horizontal Wells

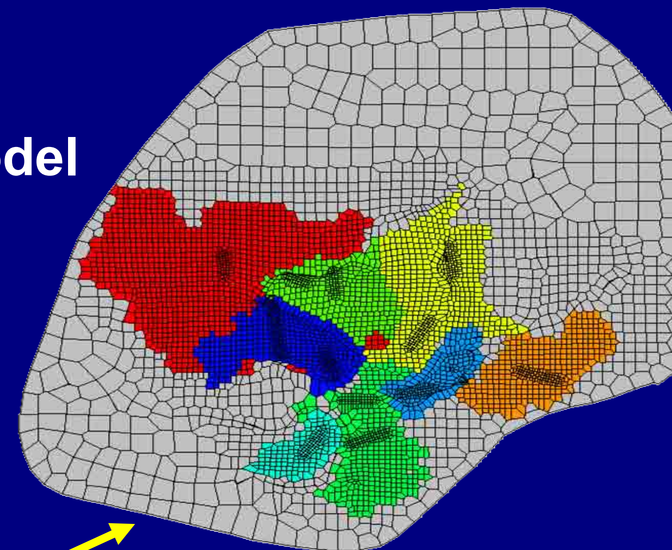


Unstructured Grids – Field Application Example

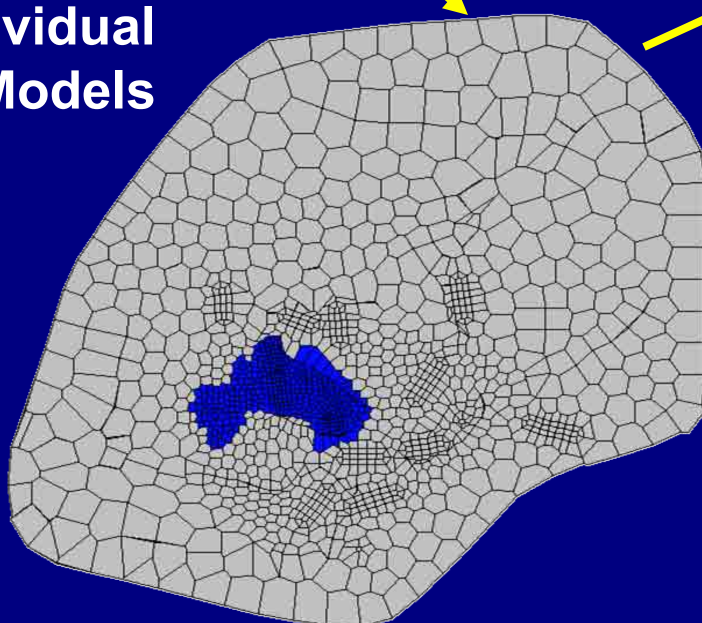
Geological Model

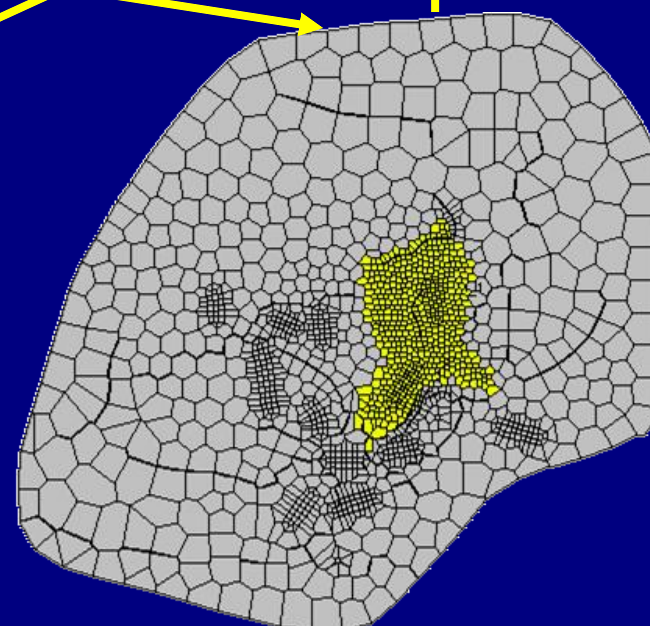


Full-Field Model

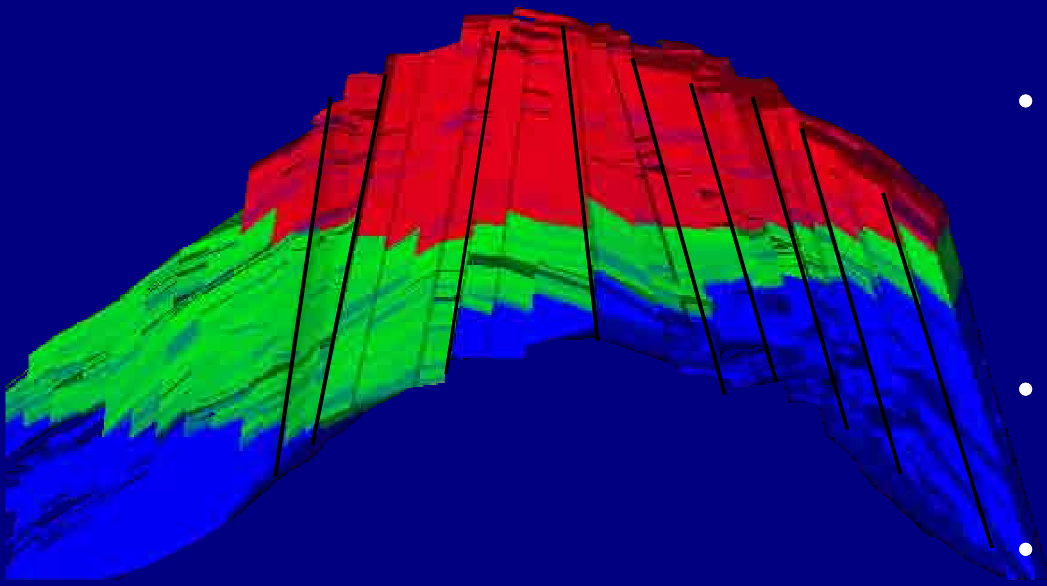


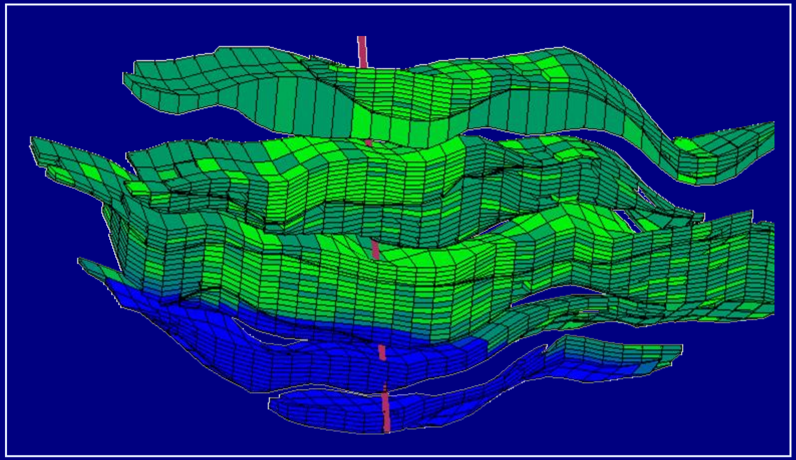
Multiple Fine-Grid Individual Mound Models





Unstructured Grids – Deep Water Application



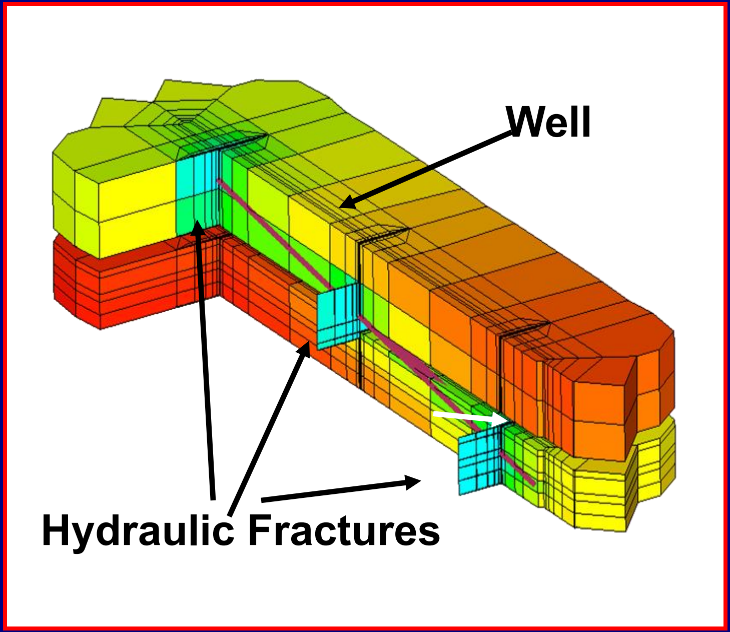


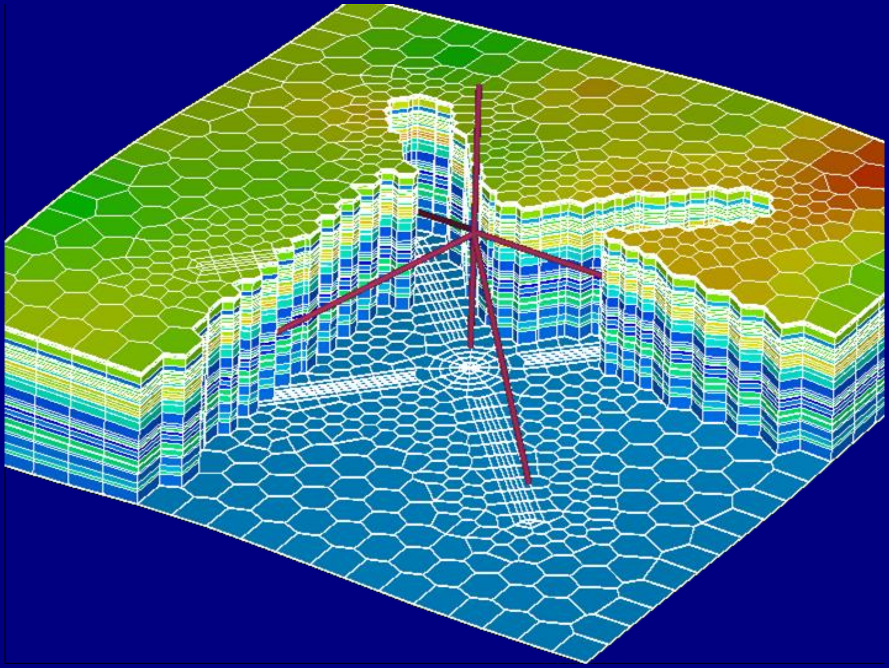
- Unstructured Gridding Allows High-resolution Representation of Complex Structure/Sloping Faults
- Improved Modeling of Complex Stratigraphy
- More Accurate Connectivity, Better Well Placement
- Equivalent Resolution in Previous Generation Simulator would be unattainable

Unstructured Gridding of Complex Wells and Fluids

Unstructured Gridding Enables Significantly Enhanced Near Well Detail

- **Detailed Well Topology**





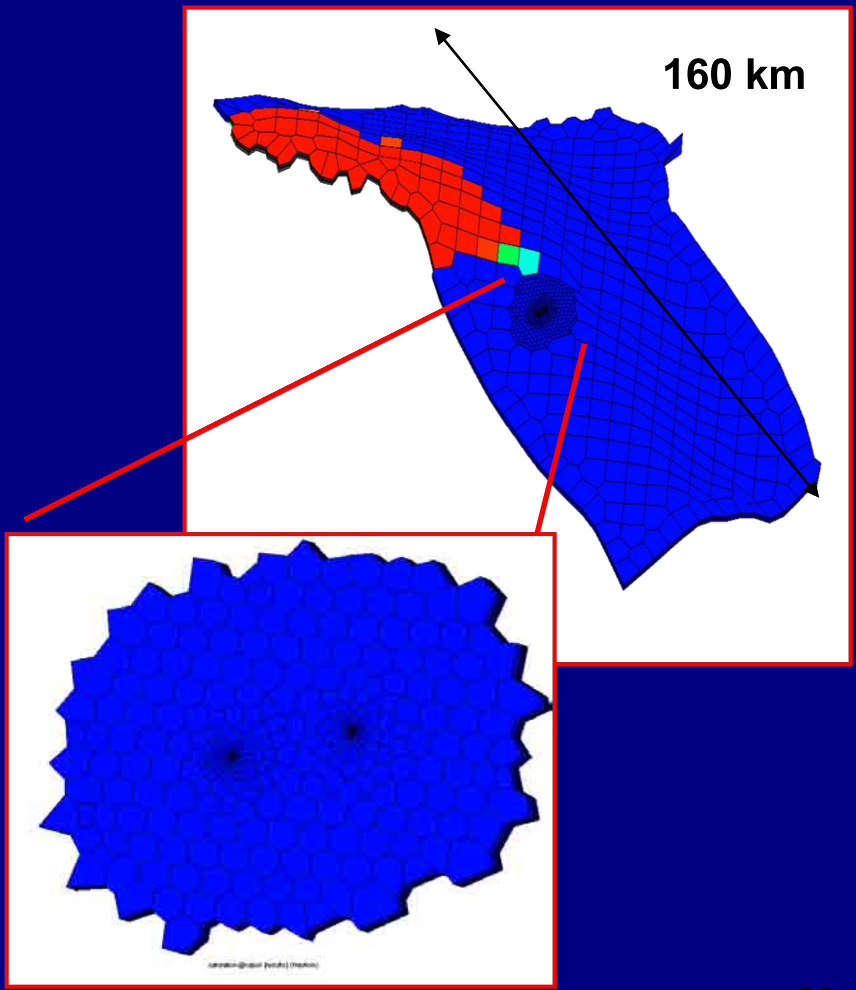
Multi-Lateral Well Model

Unstructured Gridding of Complex Wells and Fluids

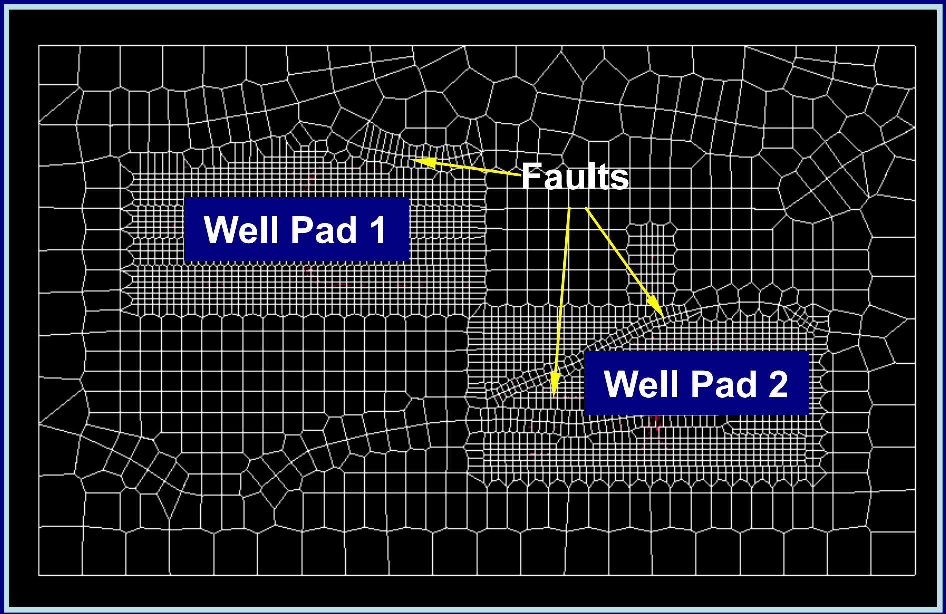
Unstructured Gridding Enables Significantly Enhanced Near Well Detail

- Detailed Well Topology
- Drainage Region Resolution

Areal Grid Refinement of 5 km to 10 m



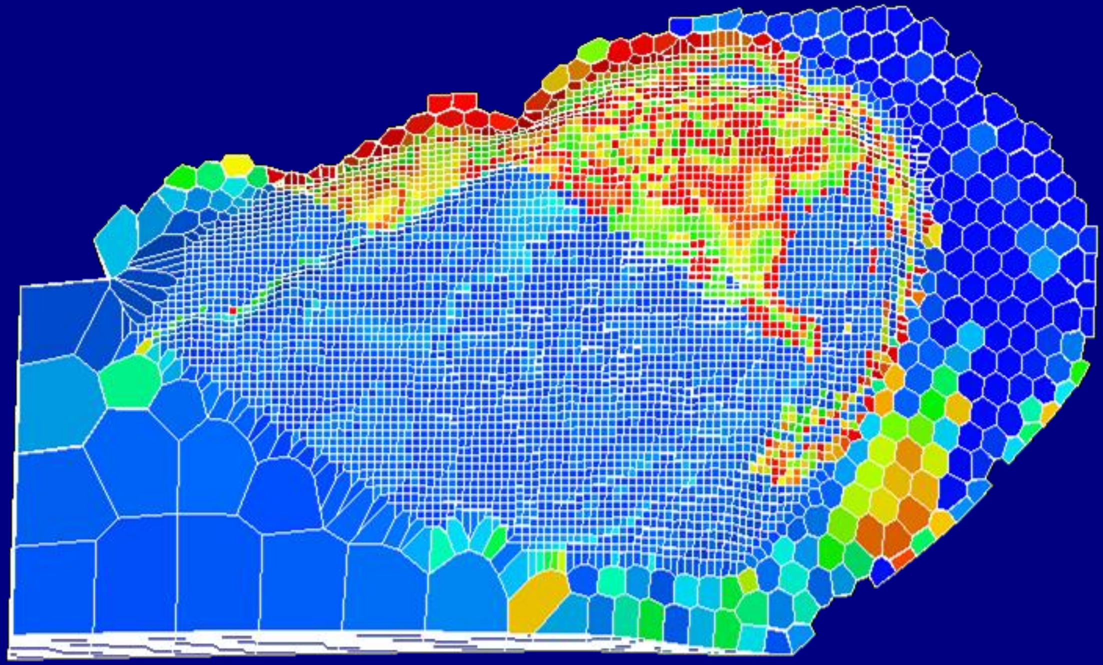
Seamless and Efficient Local Grids



Unstructured Gridding of Complex Wells and Fluids

Unstructured Gridding Enables Significantly Enhanced Near Well Detail

- Detailed Well Topology
- Drainage Region Resolution
- Gridding to Aquifers

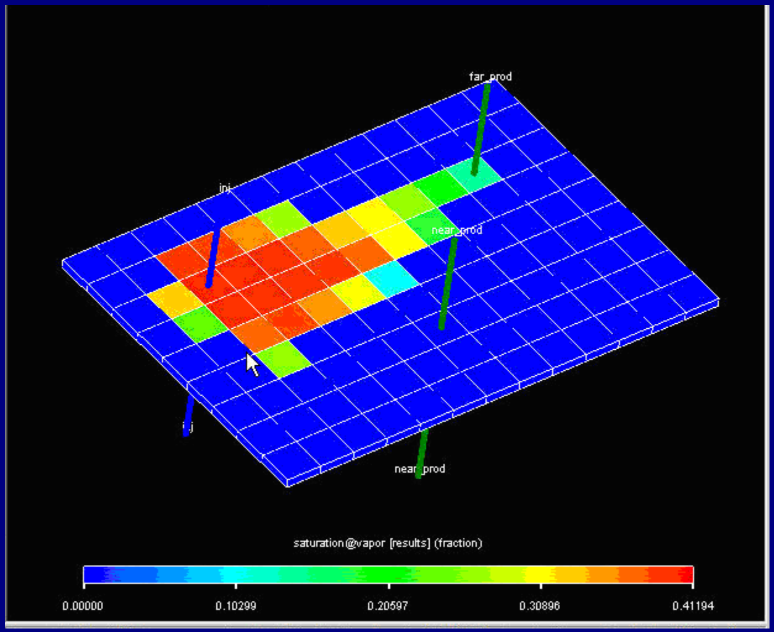


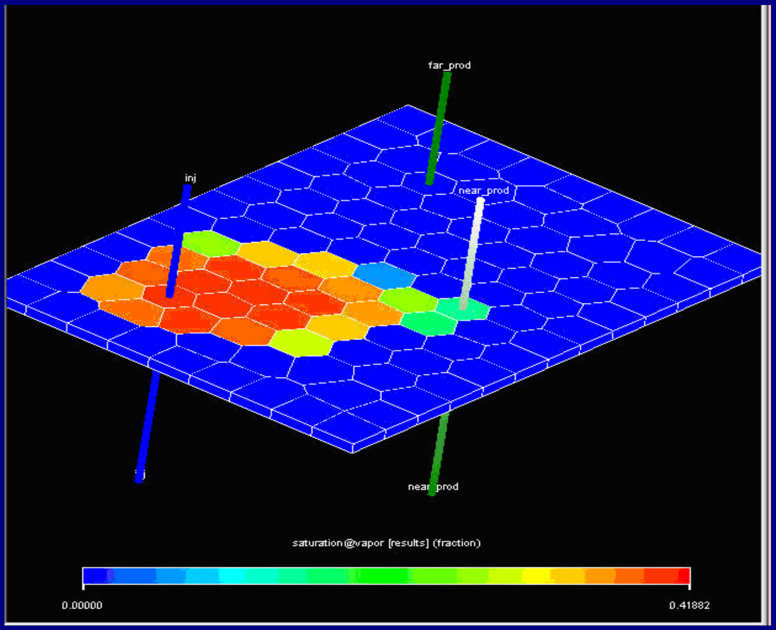
Gridding to Oil/Water Contact

Next Generation Reservoir Simulation - Examples

Unstructured Grids

Controlling Grid Orientation in Thermal Simulation





Integrated Modeling of Reservoirs, Wells, and Facilities

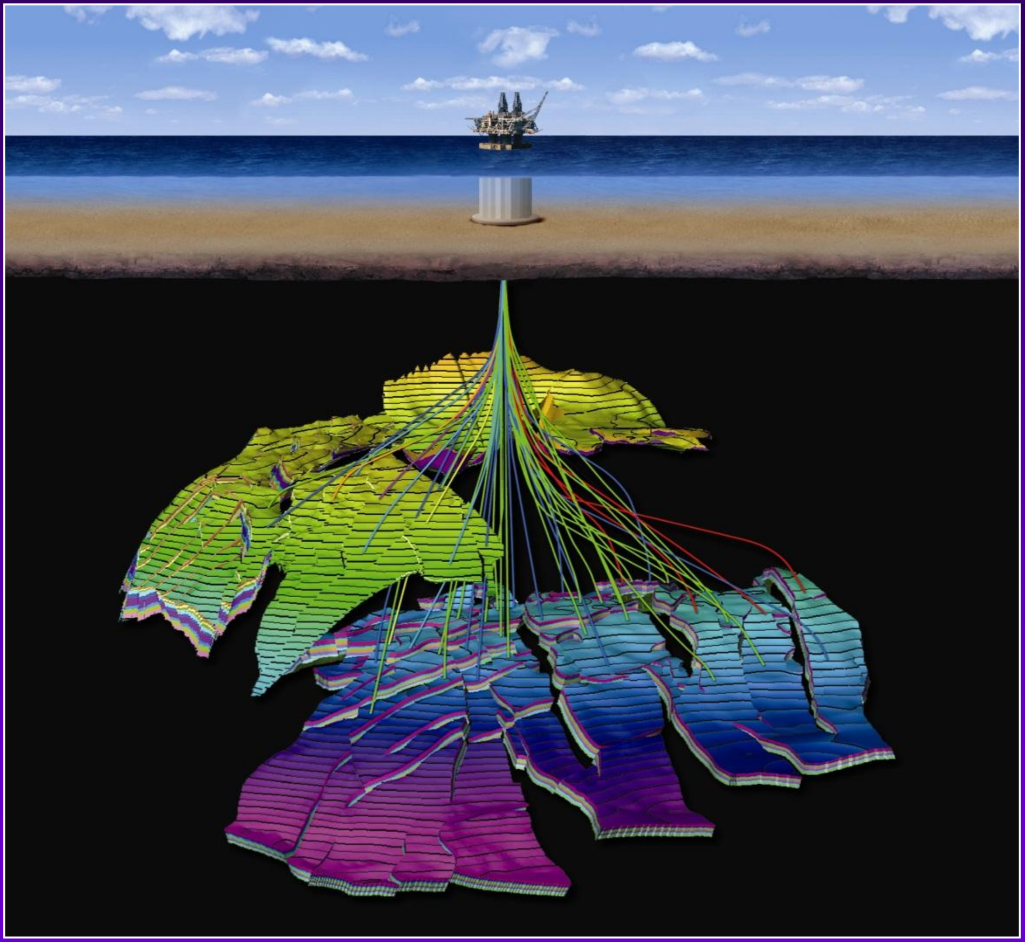
Simultaneous Solution of

- Multiple Reservoir Models
- Surface Facilities Nodes and Reservoir Nodes

Controlled By

- User Programmable Logic
- Pre-packaged Libraries

Multi-Field Simulations

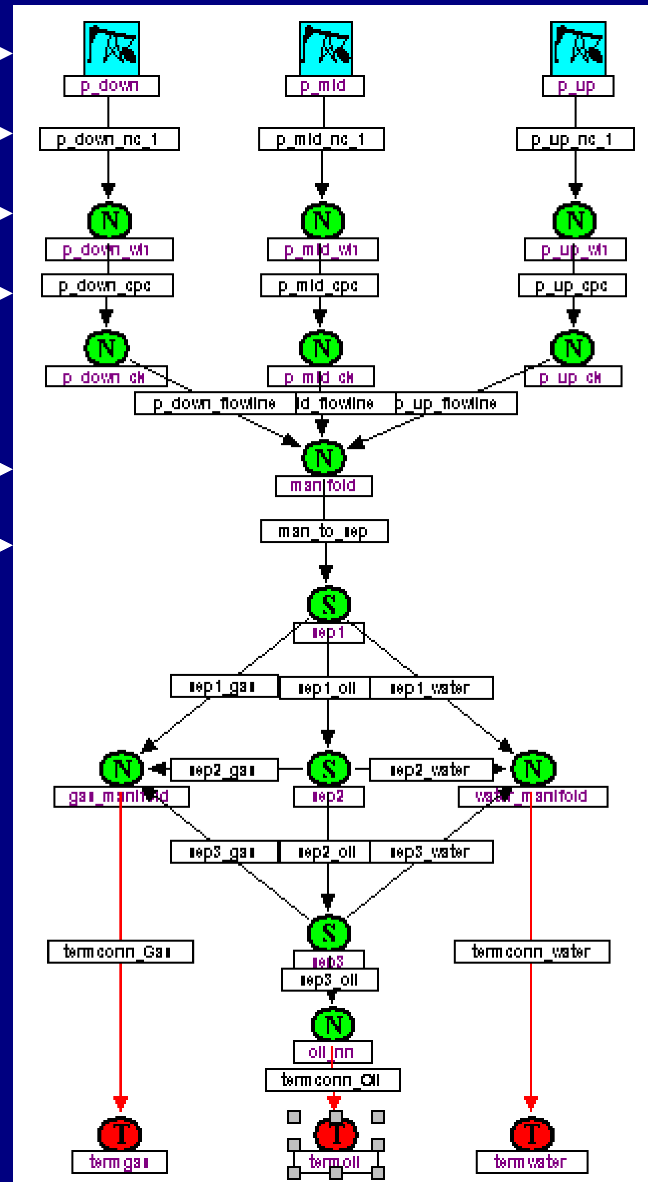


Integrated Facilities – Simple Example

Bottomhole Producer
Hydraulic Flowline
Wellhead Node
Variable Choke
Hydraulic Flowline
Manifold
Fixed Pressure Drop

Fixed Pressure
and Temperature
Separators

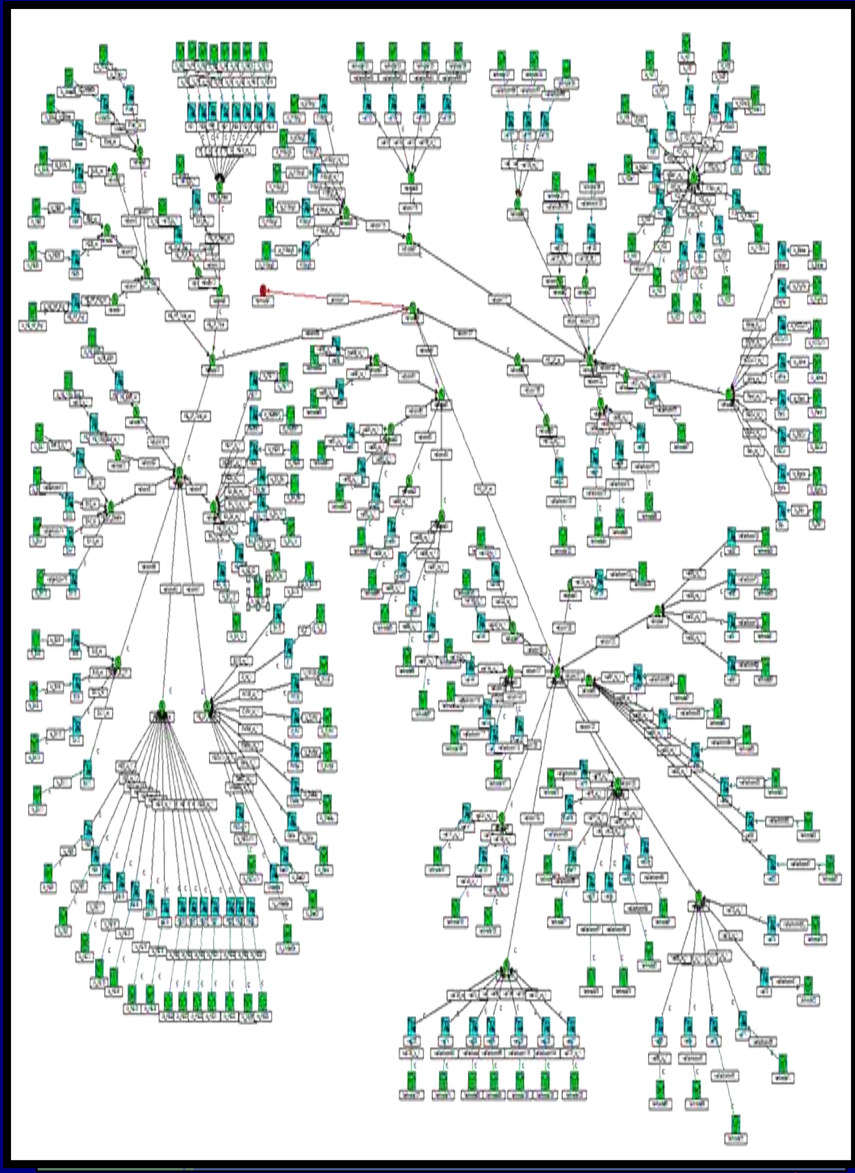
Terminal Nodes



Multi Reservoir Models

Multi-Field Capabilities to Optimize Production Through Shared Infrastructure

- Integrated Assessment of Alternative Development Concepts
- Include/Exclude Different Reservoir Units As Needed
- Accurately Account For Interaction Through Facilities
- Model Flow Behavior Within Production Network As Well As Reservoir



Sakhalin Facility Model

Next Generation Reservoir Simulation

Parallel Reservoir Simulation

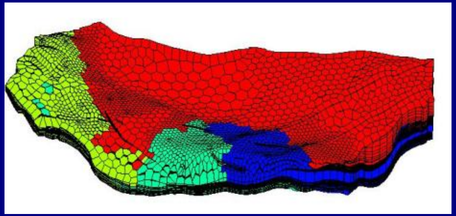
Reservoir Simulation Implementation Challenges

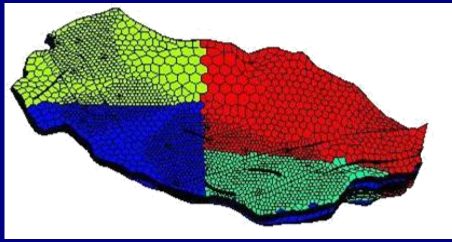
Difficult To Do
- Major Portions Of Simulation Have Serial Nature
- Existing Codes Expensive To Modify For Parallelization
- Conflict Between Parallel Systems
  - HPC Linear Solver Libraries – MPI Based
  - Users Have SMP Machines (Desktops)

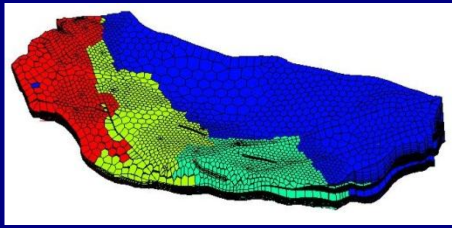
Difficult To Use
- Parallel Algorithms May Not Be Robust
- Wide Range of Problem Types and Sizes
- Little User Experience

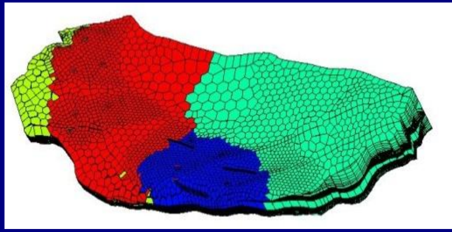
But Need For Significantly Larger, Faster Models Exists
- Ultra Large Reservoirs
- Thermal Recovery
- Tight Gas
- Multi-Field

Four Partitions Of A Reservoir Model to Four CPUs Which is Best?



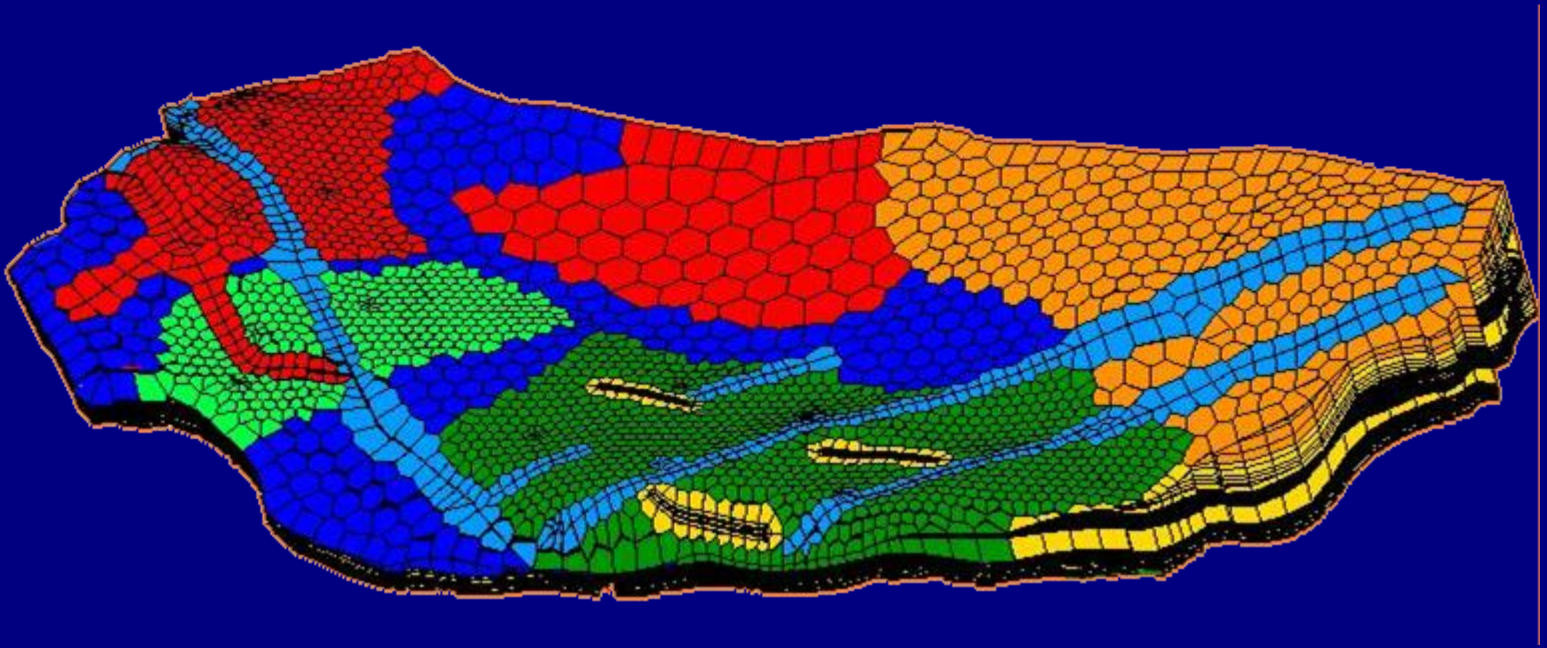






Unfortunately, No Clear Answer

Parallel Reservoir Simulation

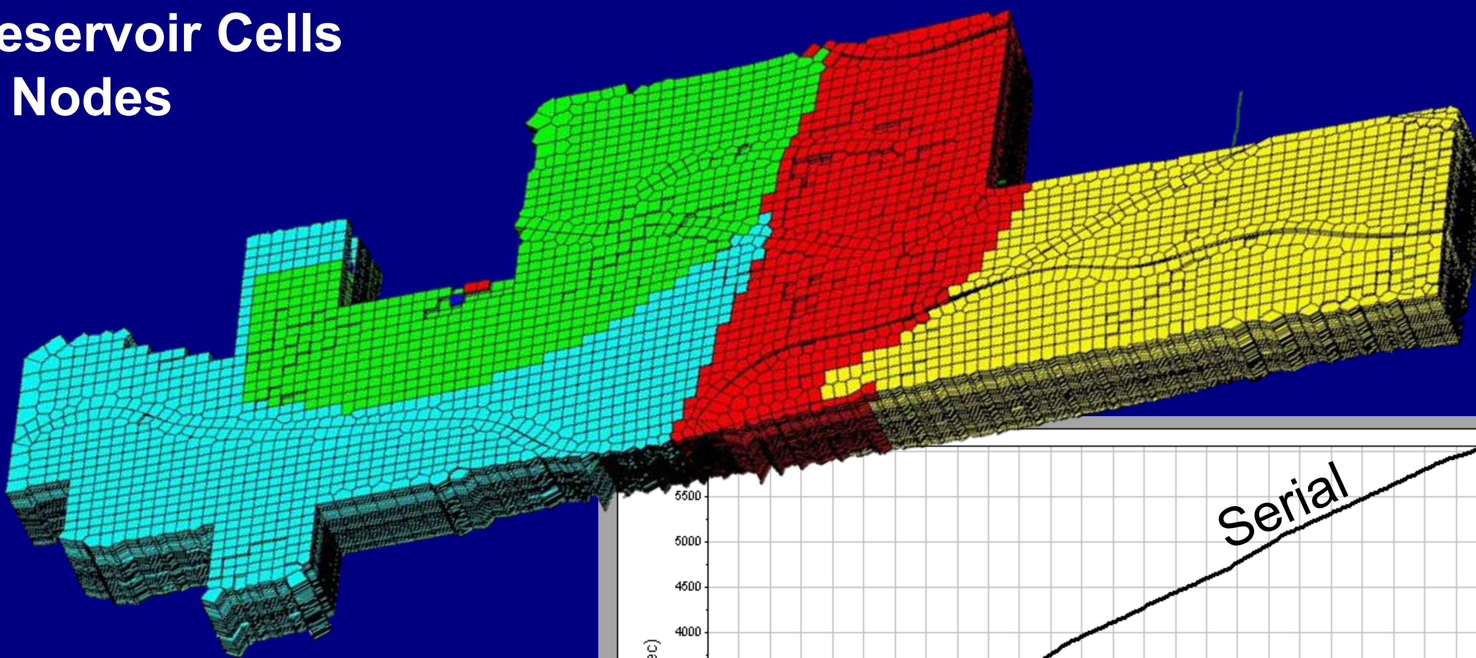


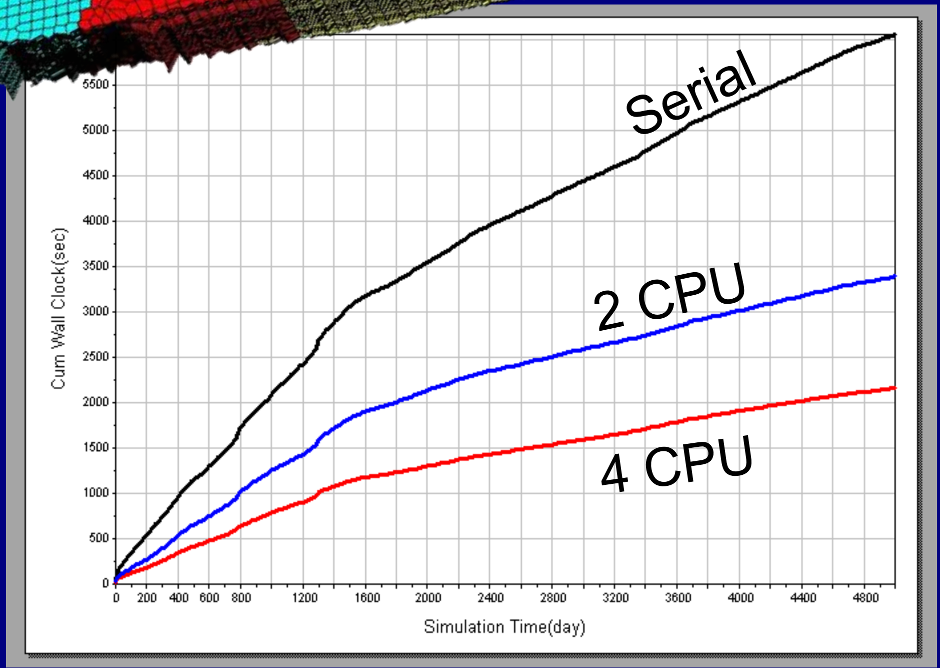
Partition of 16 CPU Nigerian Field

Complex Interplay Between Gridding and Partitioning

Parallel Reservoir Simulation – Field Application

- **Black-Oil Case**
- **103K Reservoir Cells**
- **79 Well Nodes**



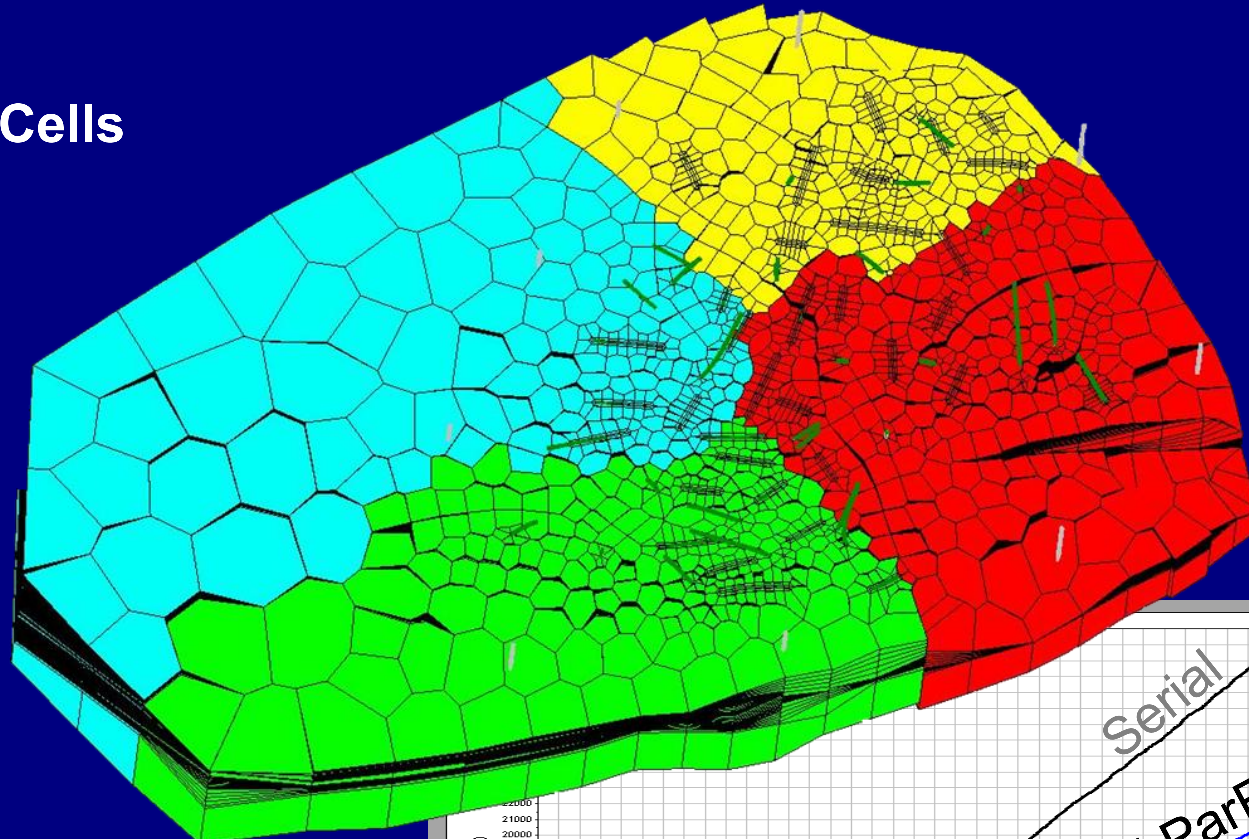


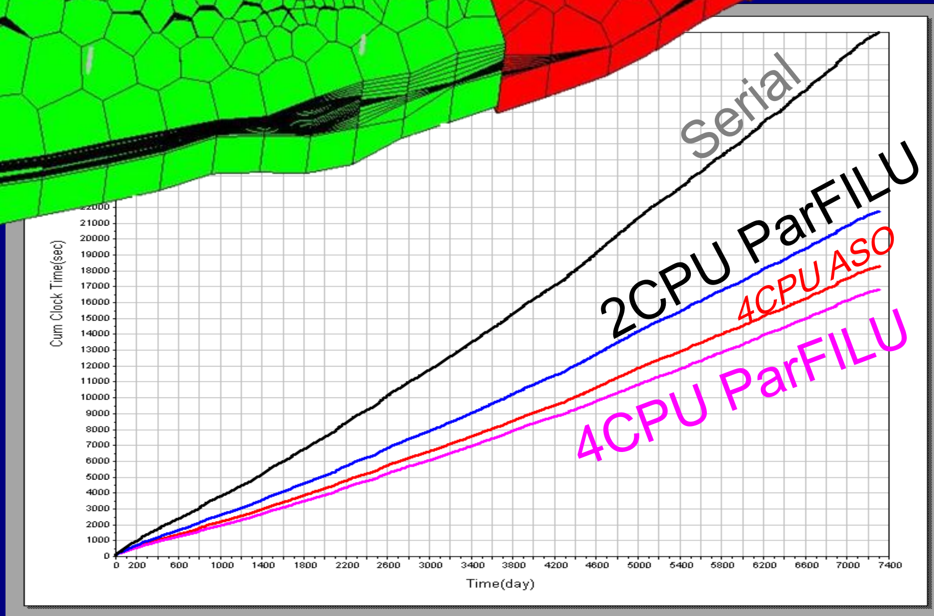
Speedup vs. Serial

	2CPU	***4CPU***
Solver	1.9	3.4
Total	1.8	2.8

Parallel Reservoir Simulation – Field Application

- Black-Oil Case
- 241K Reservoir Cells
- 258 Well Nodes



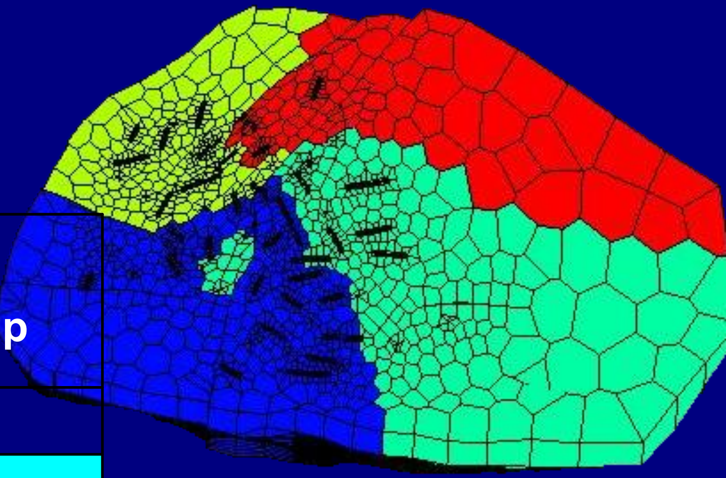


Speedup vs. Best Serial

	2CPU	4CPU
Solver	1.6	2.2
Total	1.5	2.0

Parallel Reservoir Simulation

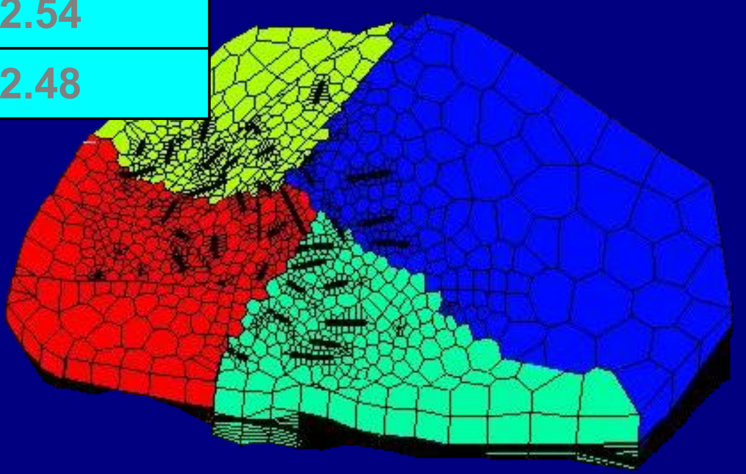
Chaco Partition



Partitioning Effects on Parallel Performance

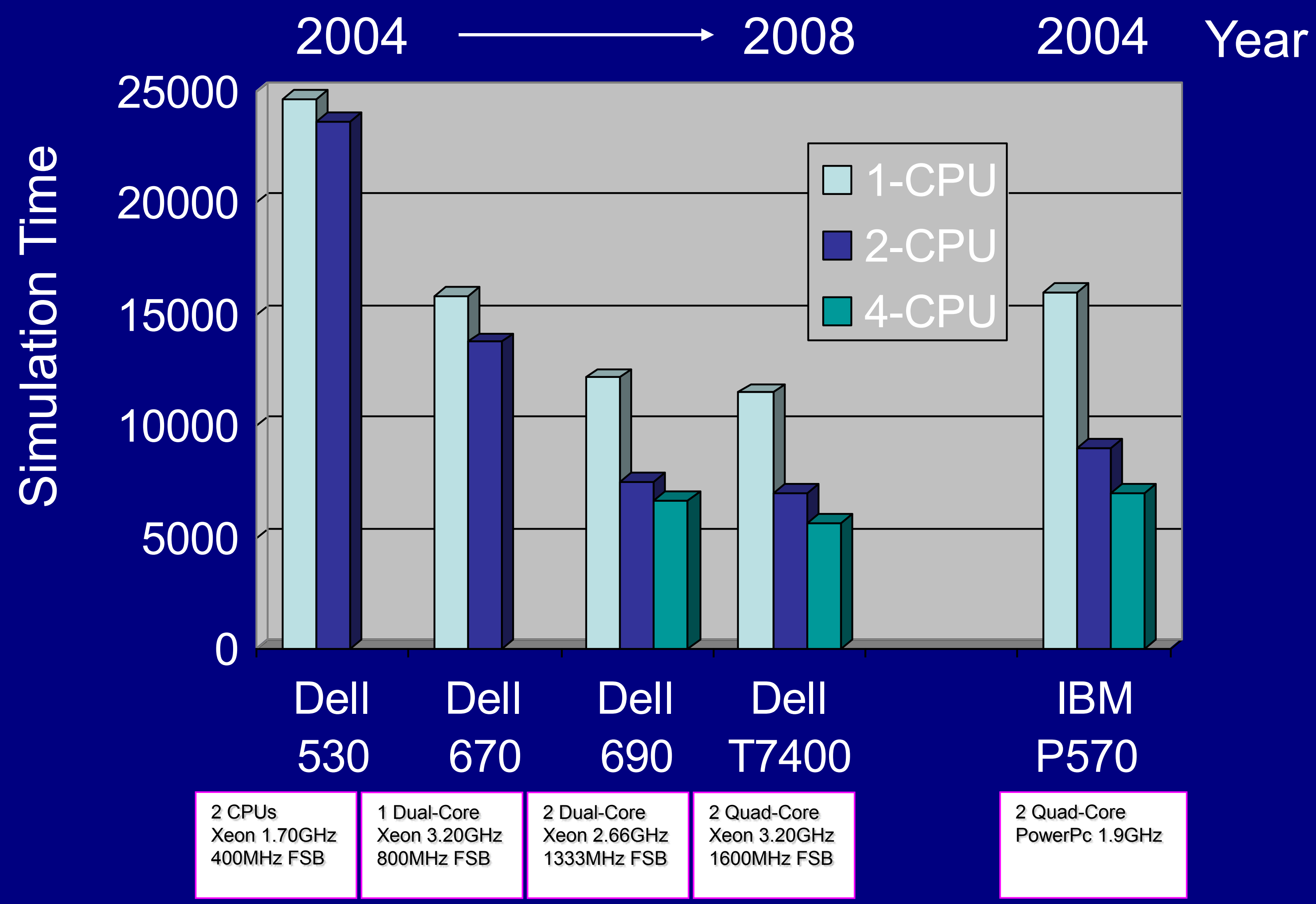
	Domains	Number of Iterations	Solver speed-up
Geometric	2	2335	1.72
Metis	2	1995	1.91
Chaco	2	2185	1.75
Geometric	4	2958	1.98
Metis	4	2638	2.54
Chaco	4	2625	2.48

Geometric Partition



Parallel Performance Of Different Desktops

800k cell, 500+ Well Nodes
6 Component Compositional



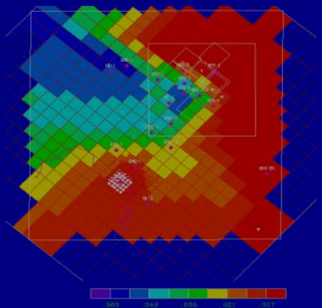
Concluding Remarks

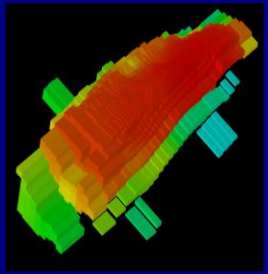
- Next Generation Reservoir Simulation is Mature Enough for Wide Application for Reservoir Management by Reservoir Engineers

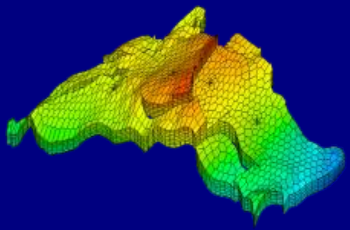
- Next Generation Reservoir Simulation Has Several “New” Technologies
  - Unstructured Grids
  - Integration of Facilities and Reservoir for Multiple Fields
  - Robust Parallel Execution

- These Technologies Are Robust Enough For Mainstream Use In Reservoir Simulation Applications That Will Enable Better Integrated Solutions Over Larger Models With Greater Precision

Reservoir Simulation Timeline







Formative R&D	Full Field Simulators	Complex Physics Simulators	Flexible Gridding

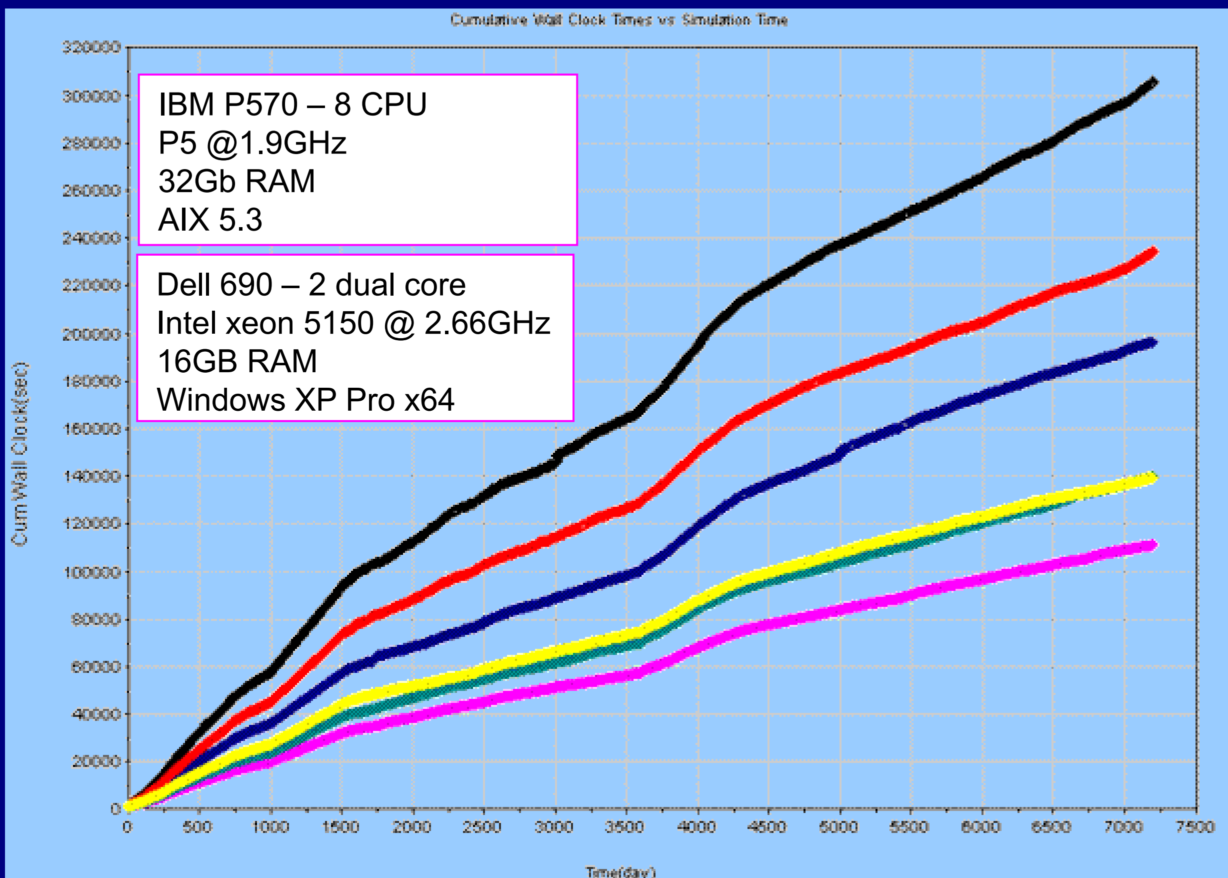
1950 1960 1970 1980 1990 2000 2010

Experimental Codes	2D And 3D Codes	Compositional	Unstructured Grids
Single Well Models	Fully Implicit Methods	Thermal	Surface Facilities
			Parallel Computing

Parallel Reservoir Simulation

Parallel Performance of Different Hardware

800k cell, 500+ Well Nodes
6 Component Compositional
Sequential Formulation



IBM P570 – 1 CPU

Dell 690 – 1 CPU

IBM P570 – 2 CPU

Dell 690 2D – 2 CPU

IBM P570 4D – 4CPU

Dell 690 4D - 2CPU x 2Core

Next Generation Reservoir Simulation

What about new challenges?

Explosive growth of Geological Modeling

- **Near doubling of application Usage from 2006 to 2009**
- **New demands on simulation accuracy and speed**

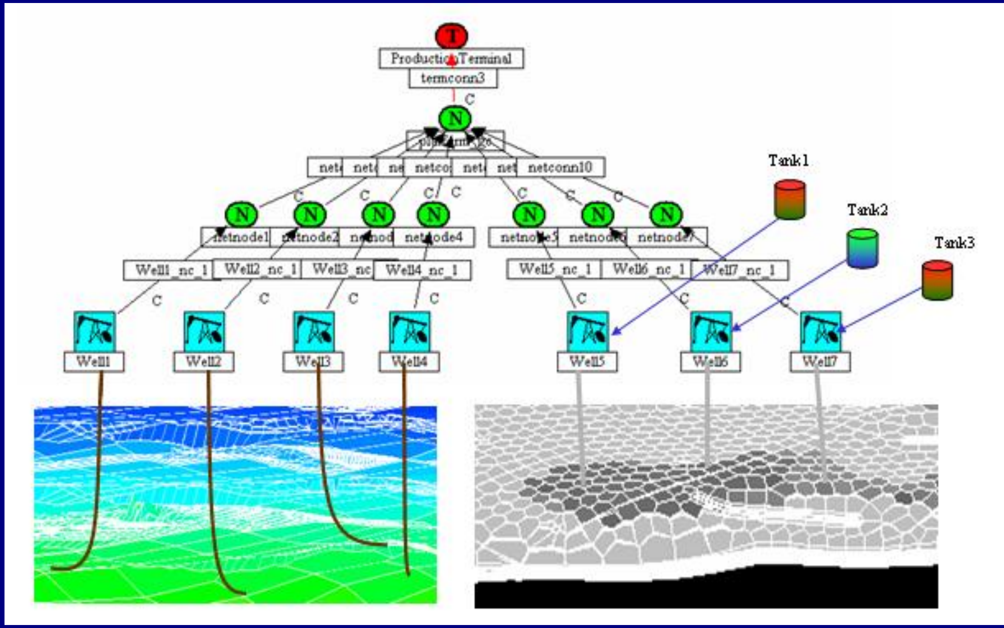
Oil Price growth puts complex assets “in play”

- **Thermal, IOR**
- **Tight Gas, Shale Gas, CBM**

Are You Using All Reservoir Simulation Technologies You Can?

Next Generation Reservoir Simulation

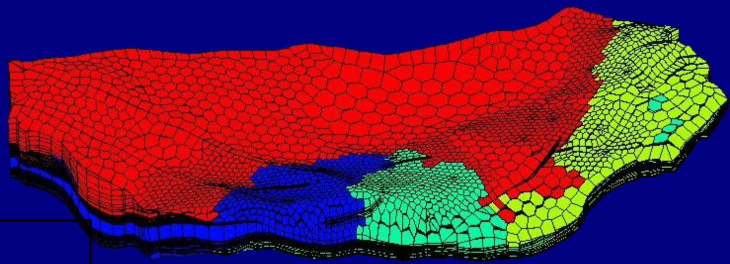
Unstructured Gridding - Summary



Parallel Reservoir Simulation

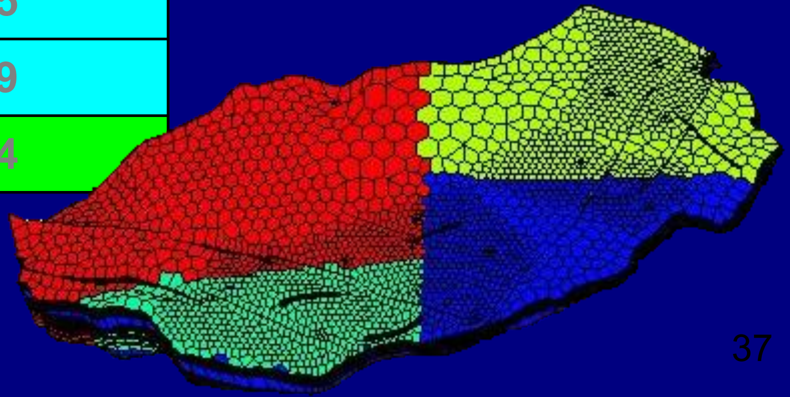
Partitioning Effects on Parallel Performance

Chaco Partition



	Domains	Solver speed-up	Overall speed-up
Geometric	2	1.41	1.28
Metis	2	1.58	1.32
Chaco	2	1.66	1.27
Geometric	4	2.06	1.15
Metis	4	2.35	1.29
Chaco	4	2.50	1.44

Geometric Partition



Next Generation Reservoir Simulation

Summary Unstructured Grids

Arbitrarily Shaped Grids

Accurate Representation of Geologic Features

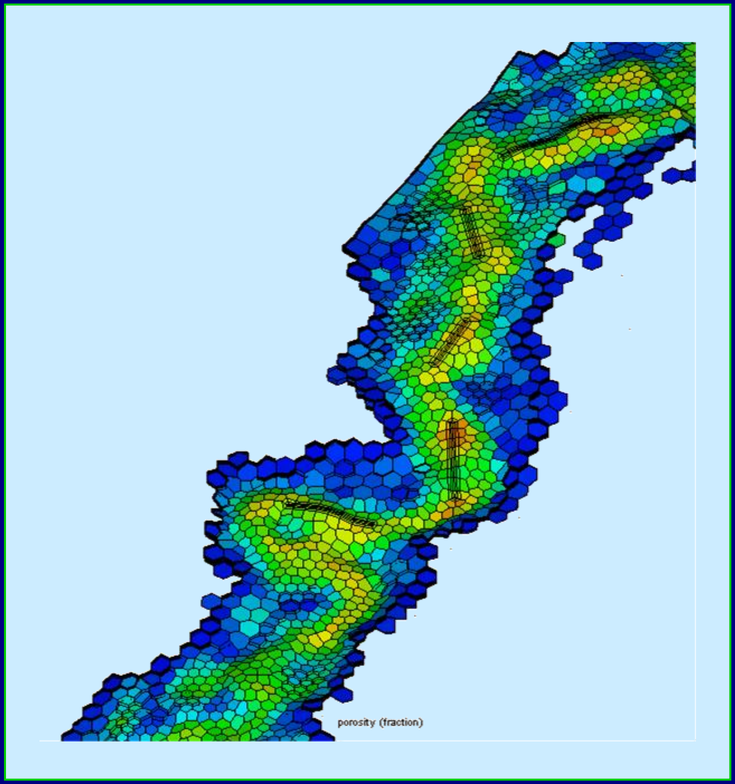
Irregular Shapes (i.e. Channels)

Fault Planes

Pinchouts and Internal Stratigraphy

More Efficient

Natural Fit to Arbitrary Boundaries

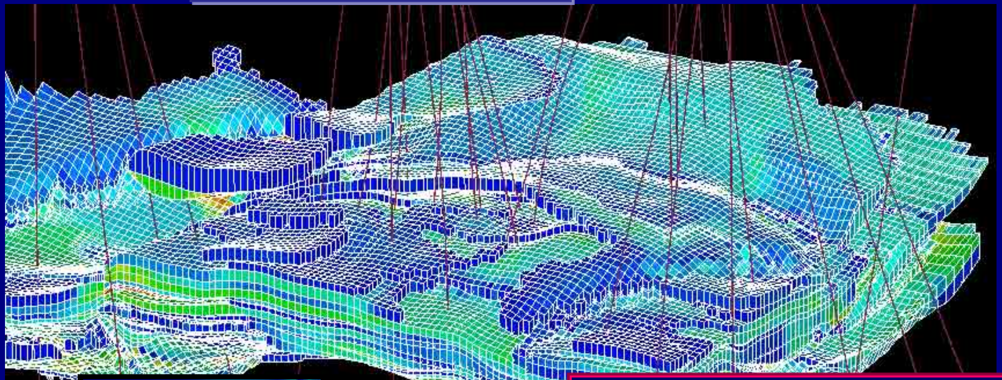


Benefits of Unstructured Grids

- Greatly Improves Ability to Honor:
  - Geologic Features (Complex Faults, Channels, Pinchouts, Fluid Contacts)
  - Engineering Detail (Wells, “Sweet-spot” Development)

- Eliminates “non-essential” grids, putting detail where needed

Gridding to Faults

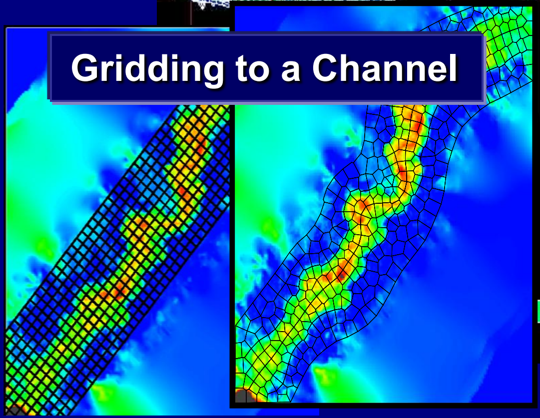


Example

With structured grid: 1,600,000 gridblocks

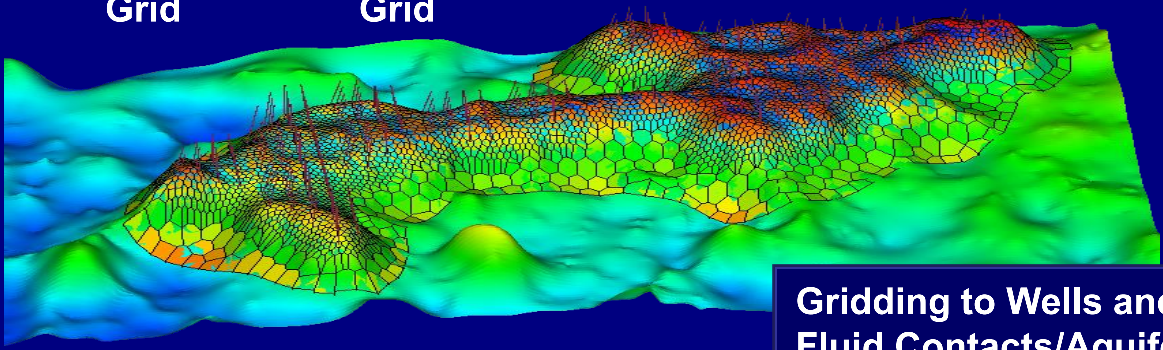
With flexible grid: 119,000 cells

Gridding to a Channel



Structured Grid   Unstructured Grid

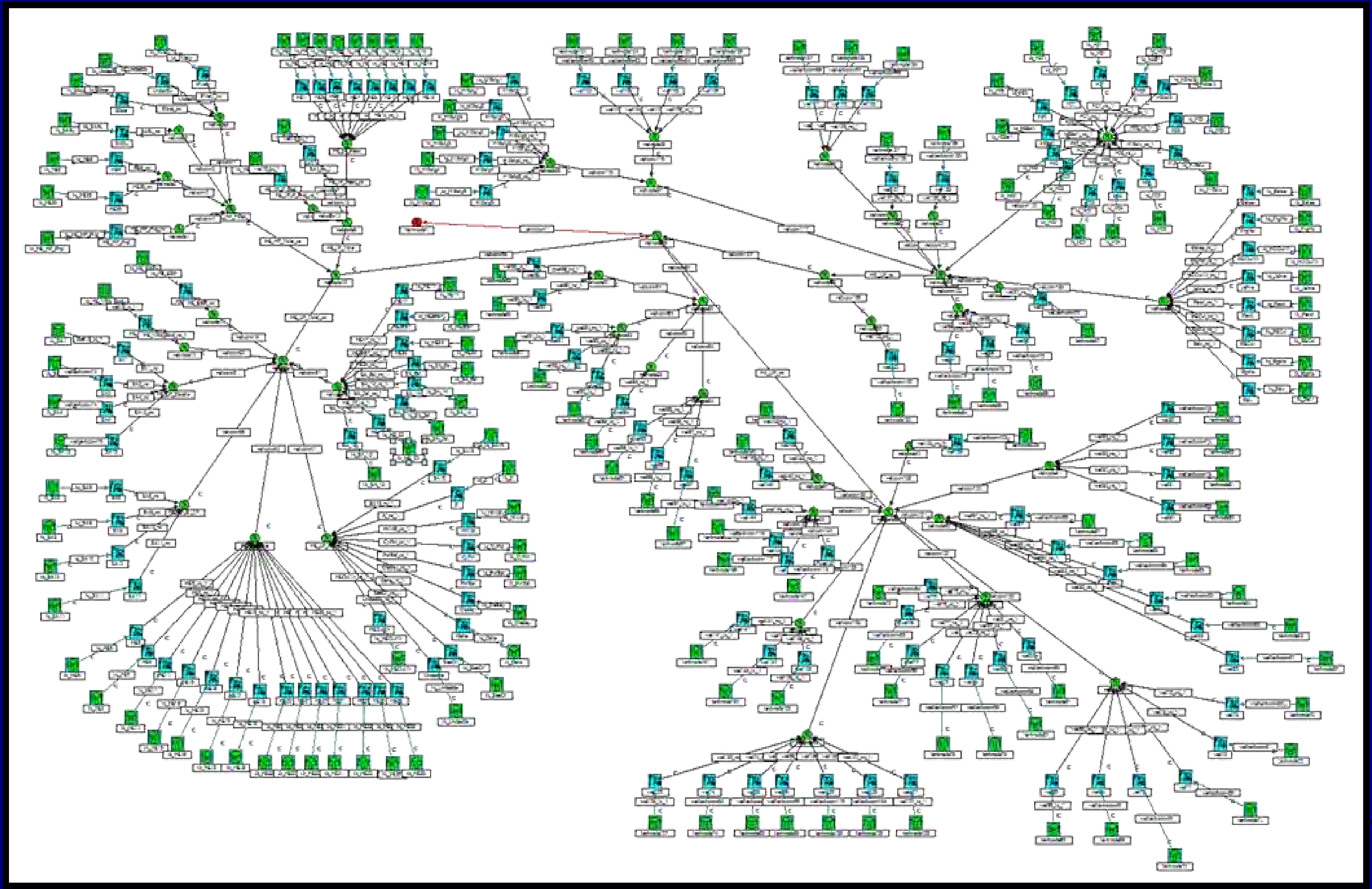
Gridding to development area / sweet spots



Gridding to Wells and Fluid Contacts/Aquifer

Integrated Facilities – Field Application Example

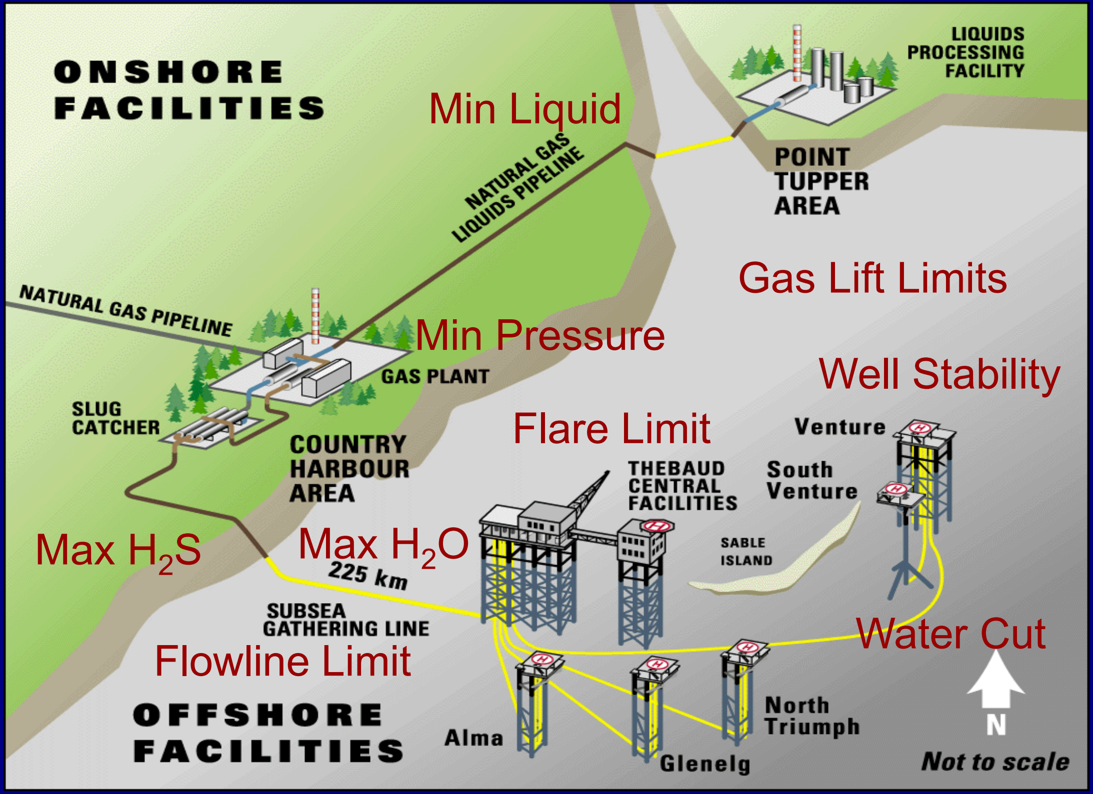
Integrated Surface Facility Model



Integrated Facilities – Control

Well Management in Reservoir Simulation

- Well Scheduling
- Production Allocation
- Injection Allocation
- Remedial Actions



Need For Integrated Solution

Next Generation Reservoir Simulation

Unstructured Grids

Accurate Representation of Engineering Features

Natural grid refinement

Wells