RESEARCH TEAM
Mary F. Wheeler
Director, Center for Subsurface Modeling
Ernest and Virginia Cockrell Chair in Engineering
Professor, Aerospace Engineering & Engineering Mechanics, Petroleum & Geosystems Engineering
Todd Arbogast
Associate Director, Center for Subsurface Modeling
Professors, Mathematics
Mohdeh Delshad
Research Professor, Center for Subsurface Modeling and Geosystems Engineering
Sanjay Srinivasan
Professor, Petroleum and Geosystems Engineering
Ben Ganis
Associate Professor, Mathematics
Gergina Pencheva
Research Associate
Reza Tavakoli
Research Associate
Omair Al-Hinai
Postdoctoral Fellow
Changli Yuan
Postdoctoral Fellow
Xia Yang
Postdoctoral Fellow
Sanghyun Lee
Postdoctoral Fellow
Baehyun Min
Postdoctoral Fellow

STUDENTS
Gurpreet Singh
Jamie Pool
Mohammad Reza Beygi
Tameem Almani
Zhen Tao
Prashant Mital
Deandra White
Kwangjin Lee
Henry Li
Morteza Naraghi
Rencheng Dong

EXTERNAL COLLABORATORS
Ahmed ElSheikh
Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh, Scotland
Ivan Yotov
Department of Mathematics, University of Pittsburgh, Pittsburgh, Pennsylvania
Andro Mikelić
Département de Mathématiques, Université Lyon 1, Lyon, France
Vivette Girault
Université Pierre et Marie Curie – Paris 6, Paris, France
Thomas Wick
Johann Radon Institute for Computational and Applied Mathematics, Linz, Austria
Kundan Kumar
Department of Mathematics, University of Bergen, Bergen, Norway
Young Ju Lee
Department of Mathematics, Texas State University, San Marcos, Texas

STAFF
Connie Baxter  Sr. Administrative Associate
Dino Golgoon  Technology Strategist
Amy Manley  Administrative Associate

1 University Station
POB 5324, C0200
Austin, Texas 78712
http://csm.ices.utexas.edu

Center for Subsurface Modeling
Institute for Computational Engineering and Sciences

2014

The University of Texas at Austin
Professor Mary F. Wheeler, Director
mfw@ices.utexas.edu
Connie Baxter, Sr. Administrative Associate
connie@ices.utexas.edu
Tel 512.475.8625
Fax 512.232.2445
RESEARCH OBJECTIVES
The accurate and efficient simulation of subsurface phenomena requires a blend of physical and geometrical modeling of subsurface processes and careful numerical implementation. Compounding these issues is a general lack of high quality data for model calibration and verification. CSM researchers collaborate outside experts to find suitably accurate representations of physical systems, including such processes as fluid-phase behavior, particle transport and dispersion, capillary pressure effects, flow in highly heterogeneous media (possibly fractured and vuggy), geomechanical response and subsidence and well production. These and other processes must be simulated accurately so as to avoid nonphysical numerical artifacts that can cloud engineering judgment regarding risk assessment and the intervention and optimization of management objectives.

RESEARCH PROJECTS

- Eulerian-Lagrangian schemes for transport and fluid-structure interaction
- Discontinuous Galerkin method for two phase flow with capillary pressure
- Mimetic finite difference method on polyhedral elements
- Multipoint flux on distorted hexahedra, including full tensor permeability, iteratively coupled poroelasticity, and equation of state compositional flow
- Robust a posteriori error estimation with multiphase flow using temporal, nonlinear, linear, and spatial error indicators
- Representation of non-planar fractures and interfaces
- Enhanced velocity method with nonmatching hexahedral grids
- Convergence and stability analysis of iterative flow & geomechanics coupling algorithms

OPTIMIZATION, DATA ASSIMILATION, AND UNCERTAINTY QUANTIFICATION

- Multidimensional scaling, clustering, model selection, and parameterization
- Stochastic collocation and Monte Carlo methods
- Bayesian model comparison and model averaging
- Production optimization and control
- Reservoir history matching with parameter estimation using parallel ensemble-based workflow
- Integration of time-lapse (4D) seismic and geomechanical data into reservoir models

MODELING AND APPLICATIONS

- CO2 Sequestration Modeling
  - Long term storage evaluation in saline aquifers
  - Geochemical and physical (hysteresis, capillarity and relative permeability) trapping
  - Case studies: CO2 injection into Cranfield and Bravo Dome fields
  - Center for Frontiers of Subsurface Energy Security
- Enhanced Oil Recovery Modeling
  - Chemical enhanced oil recovery: alkaline, surfactant, polymer
  - Gas flooding: CO2, N2 + flue gases
  - Foam flooding
  - Phase behavior models: chemical and gas flooding
  - Indicators studies using parallel simulations
- Fractured Reservoir Modeling
  - Phase-field modeling for hydraulic fracture propagation
  - Coupled flow and geomechanics modeling for fractured reservoirs
  - Integrated toolset for fractured reservoir management
- Melt Migration
  - Multiphase Darcy-Stokes flow
  - Robust numerical algorithms

SOLVERS AND HIGH PERFORMANCE COMPUTING

- Domain decomposition and mortar method
- Multilevel, multigrd and other specialized preconditioners
- Multiscale, multisphysics, and multinumerics coupling (flow, mechanics, energy balance and chemistry)
- Unconstrained optimization algorithms for nonlinear flow solvers

Center for Subsurface Modeling
At the Center for Subsurface Modeling, we strive to meet today’s numerical modeling challenges by bringing together mathematicians, engineers, geoscientists, and computing experts in a cooperative environment. We believe that a multidisciplinary approach is the best way to obtain accurate, reliable, and efficient solutions to real-world problems. Our researchers work with visitors and industrial partners throughout the world to stay on the cutting edge of scientific advancement.

We continually seek to improve existing numerical models by using better physical interpretations, better numerical techniques, and high performance computing. Funds from our Industrial Affiliates program and federal agencies have helped us to develop our own parallel computing environment that enables us to test and prove new concepts in advanced modeling and simulation.

BENEFITS OF MEMBERSHIP
Corporate members have ready access to leading-edge research on a variety of issues in subsurface modeling, parallel processing, and high-performance computing, communicated by:

- Workshops
- Annual and scheduled meetings
- Campus visits by affiliates
- Corporate visits by faculty members
- CSM technical reports, publications and multimedia presentations of activities
- Funded short-term “residences” at CSM in which members of our Affiliates’ corporate staff work alongside CSM faculty, scientists, and students.

Software:
- Multipoint flux
- Geochemistry packages
- Parallel multiphase modules
- Integrated Parallel Accurate Reservoir Simulator (IPARS)
- Phase-field modeling

Access:
- To potential employees
- To early versions of technical reports
- To research results and to influence its future directions

CORPORATE MEMBERSHIP
Corporate sponsorship yields a highly leveraged return, thanks to the large and diverse portfolio of other funding within CSM. It also provides an effective means of conducting exploratory or fundamental research that would not be feasible to perform in-house.

PURPOSE
The Center for Subsurface Modeling established an Industrial Affiliates Program in order to foster frequent and open communication between participating researchers and the corporate community. Over the years, this Affiliates Program has proven itself an ideal gateway for launching and conducting collaborative research efforts.

MEMBERSHIP FEES
The annual fee for membership is $40,000. These funds primarily support basic research. A small portion defrays the costs of annual meetings, technical reports, computational facilities, travel, and other expenses for graduate students, post doctorates, visitors, and faculty.
The algorithm uses a fixed stress iterative coupling procedure to accurately compute the dynamic fluid flow, solid displacement, fluid leakage rate, and fracture width.

A rigorous theory has recently been developed demonstrating geometric convergence rates, and existence and uniqueness of the coupled system.

Parallel scalability has been demonstrated using a two-stage preconditioner on large-scale heterogeneous two-phase reservoir simulation problems with over 10 million elements and utilizing over 1000 processors.

The matrix and the fracture meshes are build separately and coupled via boundary conditions and well terms. We take advantage of the geometric flexibility of the Mimetic Finite Difference method in order to capture such a complex network. Fracture network geometry is courtesy of Prof. Sanjay Srinivasan.

Spatiotemporal scaling analysis can provide criteria for selection of time steps and spatial discretization optimal for model process (complements the CFL criterion).

The algorithm uses a fixed stress iterative coupling procedure to accurately compute the dynamic fluid flow, solid displacement, fluid leakage rate, and fracture width. A rigorous theory has recently been developed demonstrating geometric convergence rates, and existence and uniqueness of the coupled system.

Figure 1. Multiscale mortar simulation results on non-matching grids using a fully-implicit formulation for two-phase flow with capillarity, gravity, and compressibility in three dimensions

A global Jacobian algorithm forms a linear system in both subdomain (left) and interface (right) unknowns, giving an efficient solution procedure. Parallel scalability has been demonstrated using a two-stage preconditioner on large-scale heterogeneous two-phase reservoir simulation problems with over 10 million elements and utilizing over 1000 processors.

Figure 2. Water pressure for a two phase flow problem with a complex fracture network.

The matrix and the fracture meshes are build separately and coupled via boundary conditions and well terms. We take advantage of the geometric flexibility of the Mimetic Finite Difference method in order to capture such a complex network. Fracture network geometry is courtesy of Prof. Sanjay Srinivasan.

Figure 3. Effect of physical and chemical heterogeneities on process scale up

Spatiotemporal scaling analysis can provide criteria for selection of time steps and spatial discretization optimal for model process (complements the CFL criterion).

Figure 4. Simulation of fluid injection into a poroelastic reservoir with a non-planar fracture

The algorithm uses a fixed stress iterative coupling procedure to accurately compute the dynamic fluid flow, solid displacement, fluid leakage rate, and fracture width. A rigorous theory has recently been developed demonstrating geometric convergence rates, and existence and uniqueness of the coupled system.
A phase field fracture propagation model is used to simulate hydraulic fracture growth with fluid leak-off followed by coupling with a reservoir simulator (IPARS). This serves as an effective fractured reservoir management tool for evaluating production stimulation performance and its impact on long term recoveries.

The Mimetic Finite Difference method is used in discretizing the equations. For square cells, the method reduces to a classical two-point flux approximation.

The reservoir characterization has been performed by integration of field observation data which includes ground surface deformations (InSAR data) and injection rate and pressure data. The estimated rock mechanical material properties such as Young Modulus and Poisson Ratio are in the range of experimental values.

A phase field fracture propagation model is used to simulate hydraulic fracture growth with fluid leak-off followed by coupling with a reservoir simulator (IPARS). This serves as an effective fractured reservoir management tool for evaluating production stimulation performance and its impact on long term recoveries.