An Integrated Portal for Managing Energy Resources

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http://www.ucoms.org

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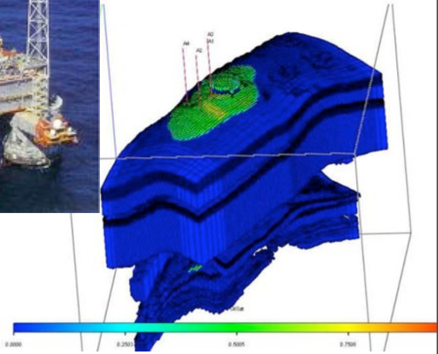
UCoMS “Ubiquitous Computing & Monitoring System for Discovery & Management of Energy Resources”

- DOE/BOR EPSCOR Research Infrastructure Project
  - University of Louisiana at Lafayette (ULL), Louisiana State University (LSU), Southern University (SUBR)
- Research areas:
  - Petroleum engineering application scenarios (reservoir simulations, seismic analysis, well/pipeline surveillance, drilling performance, production recovery)
  - Wireless sensor networks, mesh networks
  - Grid computing, high performance computing



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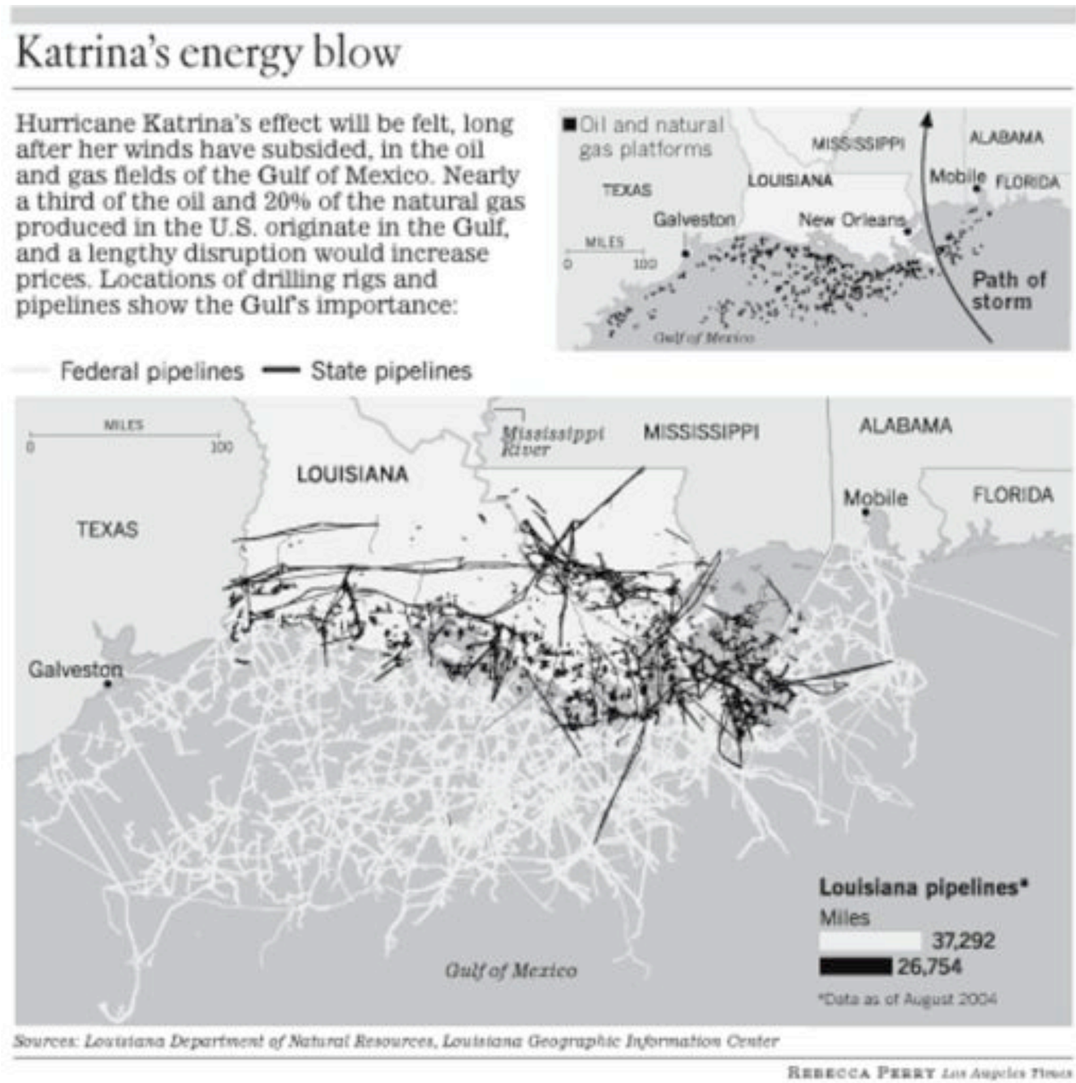
Oil Industry in Louisiana

- Major oil producing state in US:
  - Production/reserves
  - Home to 2 of 4 strategic petroleum reserves
  - 17 petroleum refineries (capacity 2.8M barrels/ day)
  - Ports receive ultra large oil tankers
  - 20,000 oil producing wells, around 4K offshore
- New deep sea well in Gulf ~ $100M, field projects ~$B: risky because of uncertainty in size/properties



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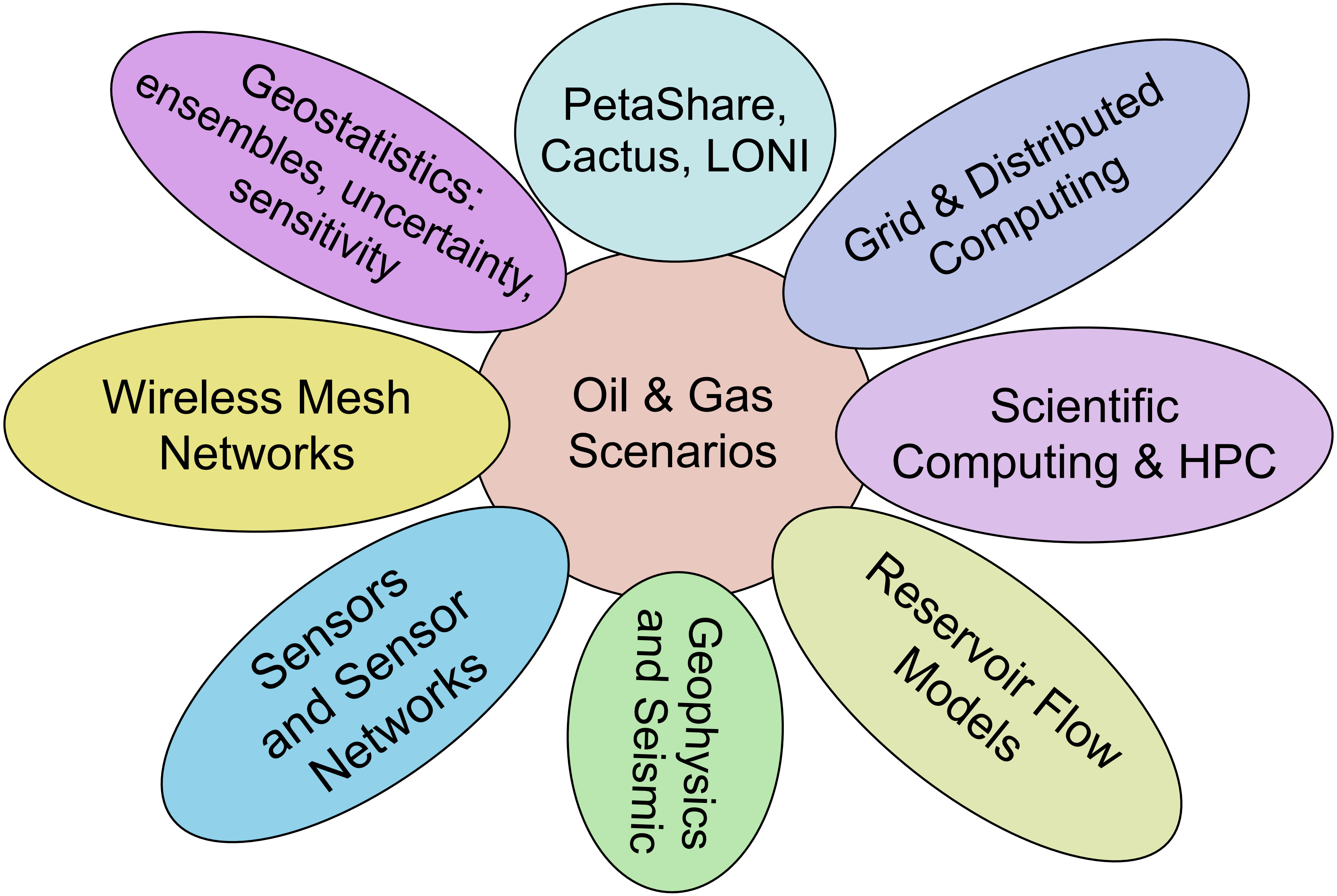
UCOMS Components



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Overall UCoMS IT Goals

- Sensor-to-simulation-to-control system
- Improved sensor technologies
  - Localization, power consumption, capability
  - Image acquisition & processing for security
- Sensor-to-grid connectivity
  - Data compression, formats, and interfaces
- Modular, grid-based access
  - Portals for sensor monitoring, model construction and execution, inversion, and visualization
- Improved work and data flow
  - Transparent, high-bandwidth, re-usable
- Efficient scientific computing

Reservoir Studies

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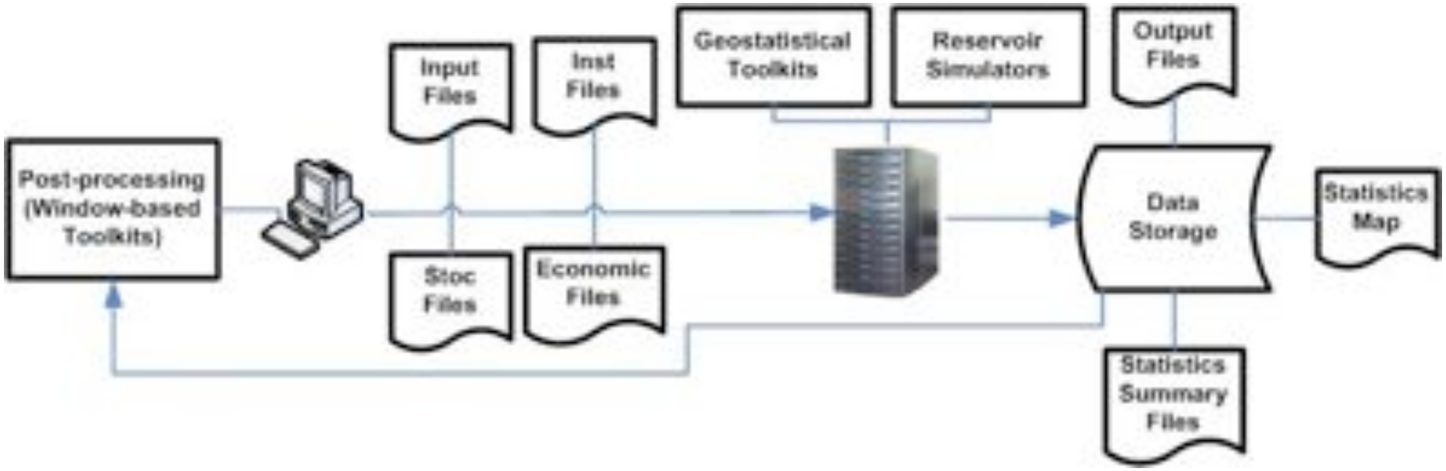
- Assessments and predictions of oil/gas reservoir performance, depending on
  - Geological heterogeneity
  - Engineering choices
- Used for development and operational decisions … models assess different production scenarios.
- Applications:
  - Sensitivity analysis & uncertai… …al & experimental design for paramete…
  - History matching (model verificatio… (inversion, ensembles)
  - Well placement & performance prediction

Integration of real time sensor data

Usual Workflow for Uncertainty



- Example case: Eleven geological factors (e.g. pressure, reservoir size, porosity) + three engineering factors (tube diameter, head pressure) with either 3 or 4 levels.
- Factorial design:
  - 4^6 x 3^8 = 26,873,856 reservoir simulations
  - 100 days on 1024 proc cluster (at 6 mins per run)
- Even with experimental design many runs needed

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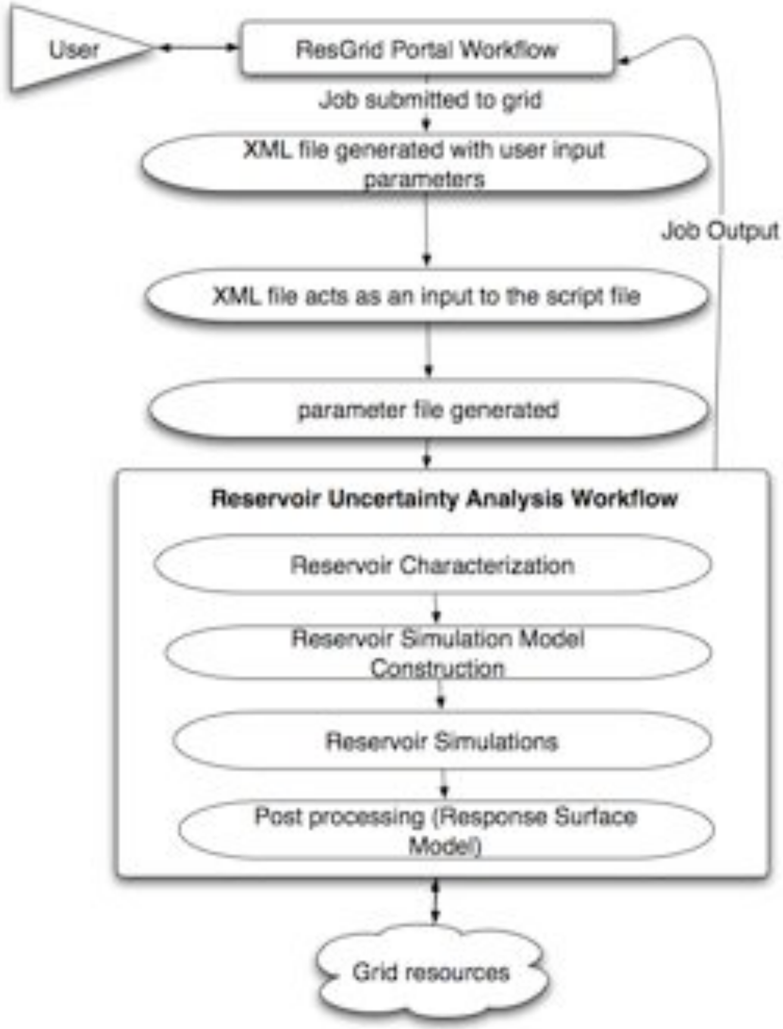
ResGrid Toolkit

- UCoMS Grid enabled toolkit originally for Experimental Design Framework:
  - Select relevant models, records factor settings, controls execution, creates response models.
  - Post processing, analysis and visualization Including RSMCB (Response surface models, Monte Carlo Simulation, and Bayesian techniques)
- Interface to general flow models (initially UTChem, more added)
- Extend to more complex, dynamic workflow

Implementing ResGrid

- 4 major steps:
  - Characterization: feeding data into geological models
  - Model Construction
  - Simulation
  - Post processing & archiving



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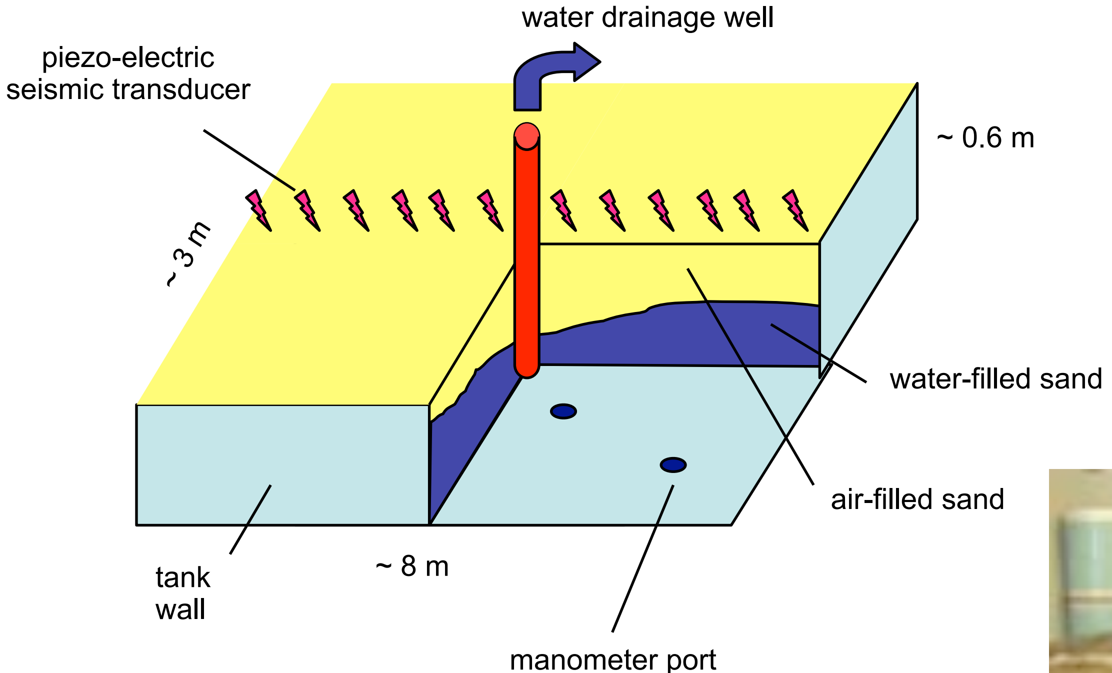
Recovery "Closed Loop" Scenario

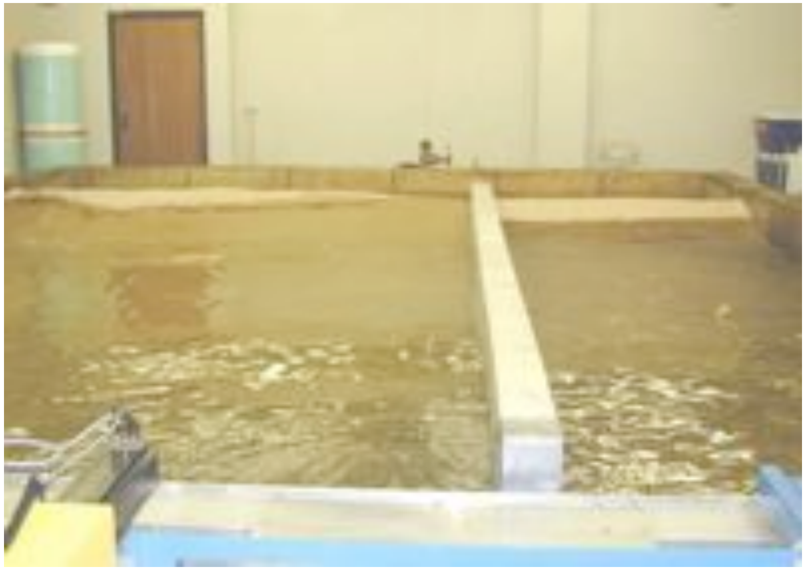
- Compelling oil & gas exploration and production case
  - Leads to ensemble of complex *a priori* geomodel, multiphase flow, and diverse measurements (seismic, production, pressure data).
- Real-time flow of data from sensors to grid resources
  - Automated allocation, location, transfer, and archiving
- Transparent scientist-oriented interfaces
  - Portals for job submission, monitoring
- Use emerging inversion & uncertainty methods
  - Sampling and experimental design, statistics, and Ensemble Kalman Filter (EnKF)

Experiment Design for Recovery



Scaled version of real field scenario with velocimeter sensors and explosion sources.

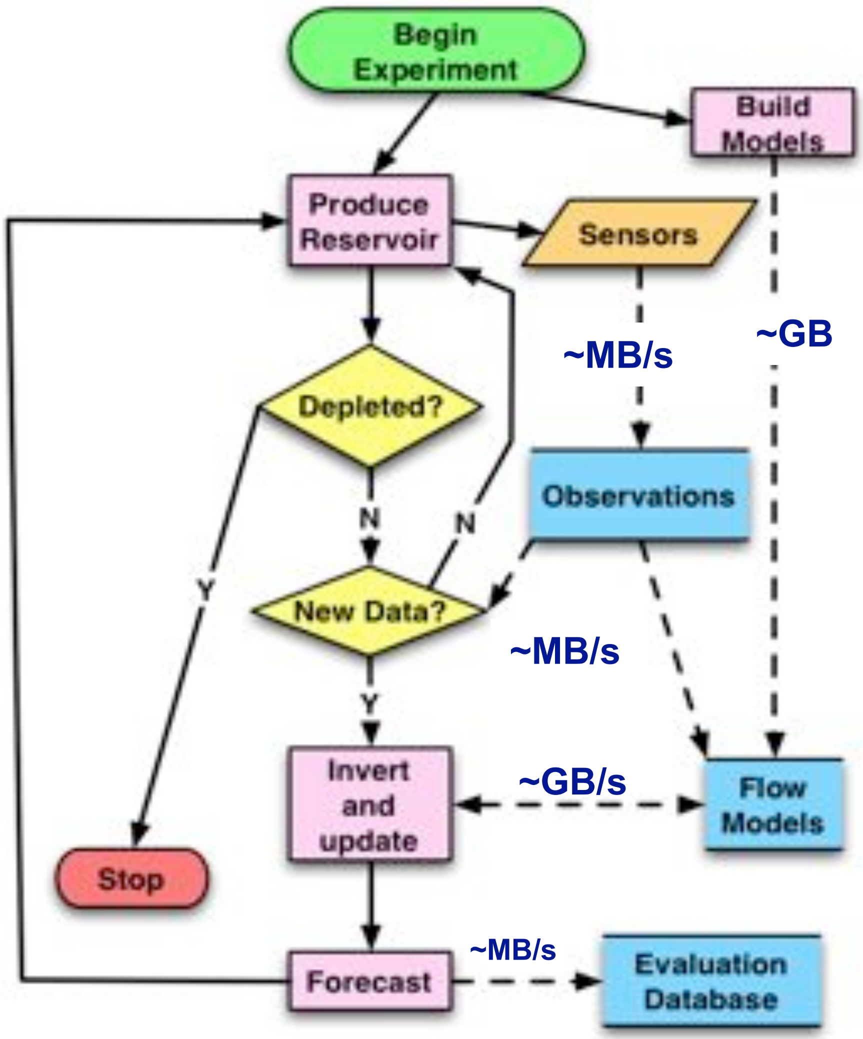
Piezoelectric transducers
40-600 kHz
for source AND receiver



http://wavcis.csi.lsu.edu/wavetank/wavetank.asp

Closed Loop Components

- Physical experiment
- Sensors
  - With signal processing and local storage
- Transmission to HPC
- Data store
- Flow model
- Inversion method
  - Complex Workflow
- Integration



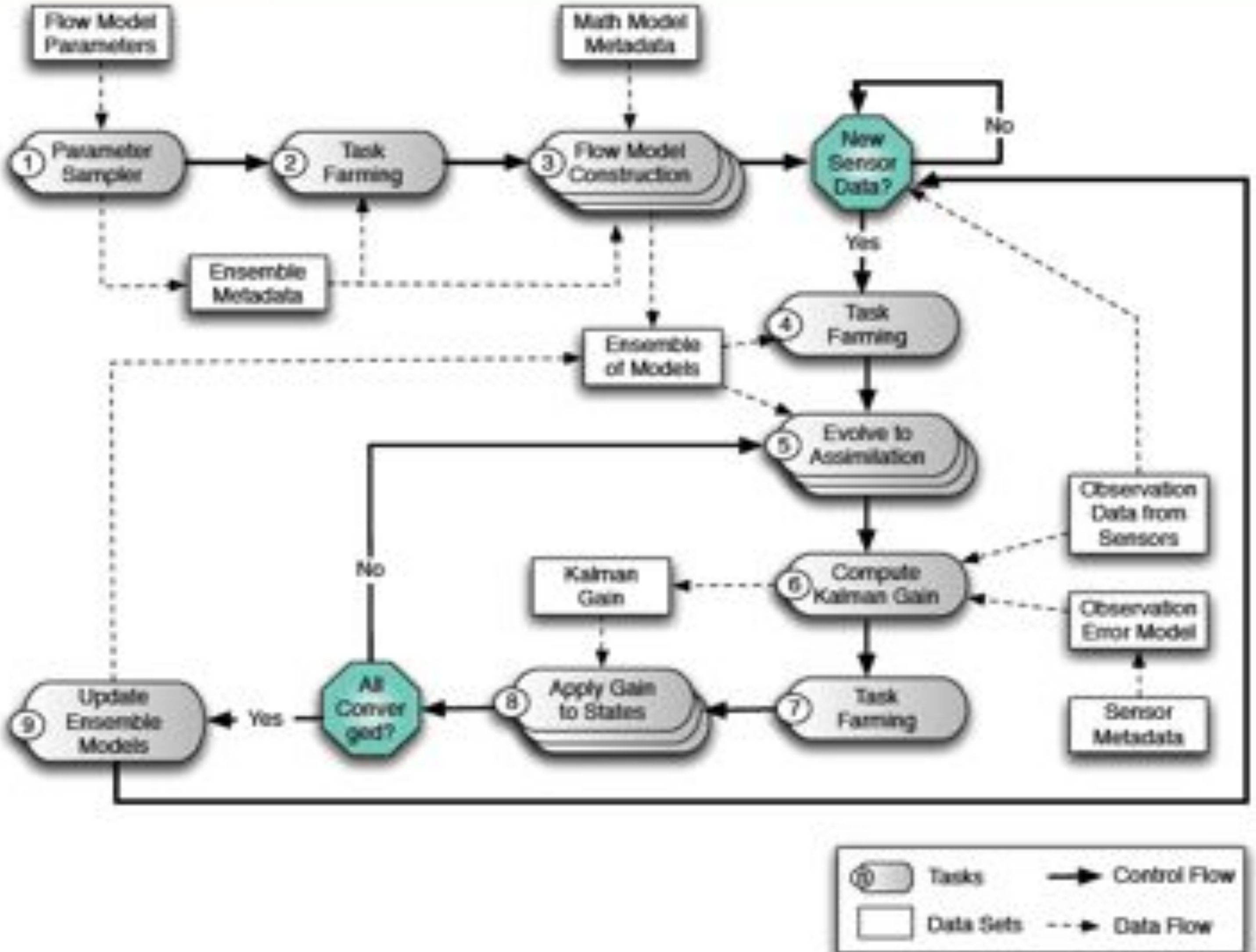
Closed Loop Components

1. Model inversion, forecasting:
    - *EnKF*
2. Workflow:
    - *DAGMAN, Condor-G, Stork*
3. Reservoir simulator:
    - *Cactus BlackOil*
4. Sensor networks:
    - *Mesh networks, wireless sensor networks*
5. Portal:
    - *GridSphere*

1. Model Inversion using Ensemble Kalman Filters

- *Ensemble Kalman Filters (EnKF):* Recursive filter suitable for problems with large numbers of variables. Used for data assimilation for ensemble forecasting
- *Objective*: Use dynamic production data and the prior geologic models provides the posterior geomodel parameters and forecast uncertainties.
- *Motivation*: Grid computing is attractive because of parallelism between ensemble

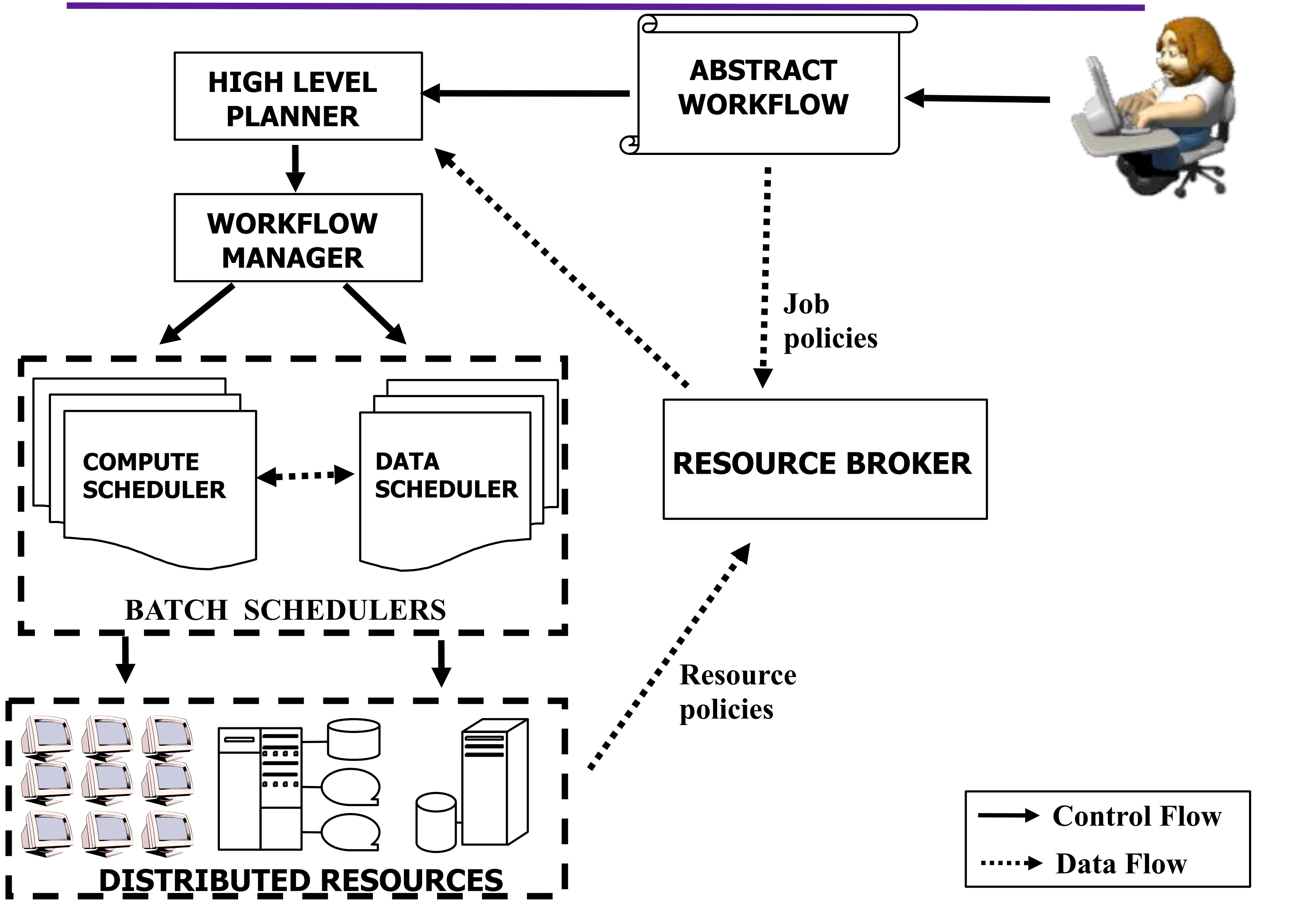
EnKF Workflow in ResGrid



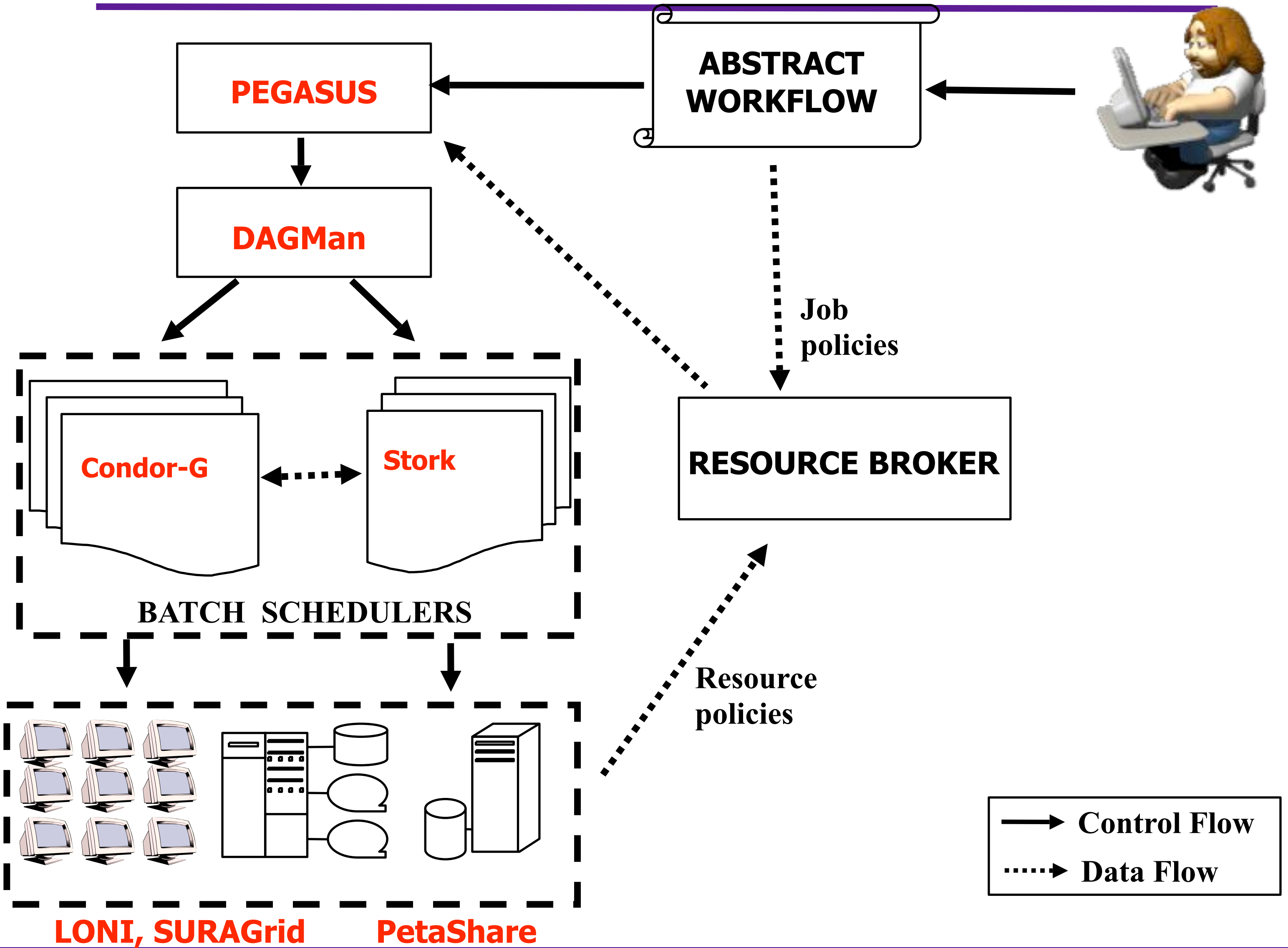
Computational Challenges

- EnKF is expensive; many simulations
- Kalman gain calculation is global; synchronize all members at each assimilation step.
  - Members have different run times -> load balancing challenge
  - Large data from members must be transferred to the Kalman gain processor and back to the member processors at each assimilation.
- Ensembles have ~100 members; each state vector has ~100 reals; ~100 assimilation steps

2. Workflow Execution (conceptual)



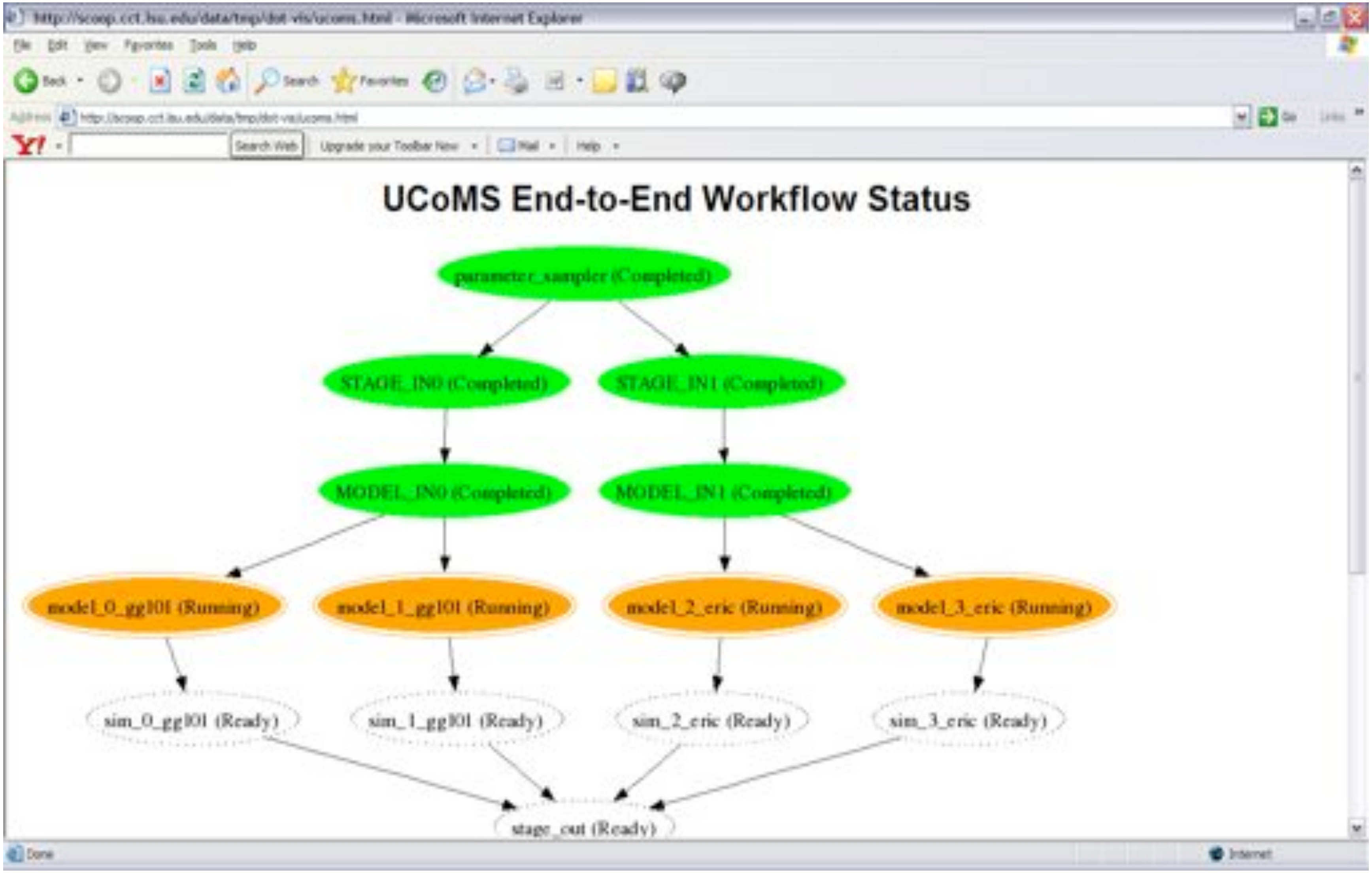
Workflow Execution (components)



Workflow Middleware Components

- **[PEGASUS**: takes the abstract workflow and maps it to the available grid resources (creates concrete workflow)]
- **DAGMan**: executes the concrete workflow
- **Condor-G**: schedules tasks to multiple Grid resources via Globus
- **Stork**: specialized batch scheduler for data movement and I/O; can optimize data movement between tasks
- **PetaShare**: multi-institutional data archival system; enables transparent data handling

Example Workflow



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3. Reservoir Flow Simulation

- Black Oil Equations
  - Mathematical model for multiphase (gas, oil, water) fluid flow in a reservoir
  - Basic equation to solve is:

$$\Sigma_i \frac{\partial}{\partial x_i}\left[\lambda_l\left(\frac{\partial p_l}{\partial x_i} - \gamma_l \frac{\partial z}{\partial x_i}\right)\right] = \frac{\partial}{\partial t}\left(\phi \frac{S_l}{B_l}\right) + q_l, l = gas, oil, water$$

  - Where p , S are the pressure and saturation of a particular phase.
- Resulting system of equations is non-linear and requires an iterative algorithm at each timestep

UCoMS "BlackOil" Parallel Reservoir Simulator

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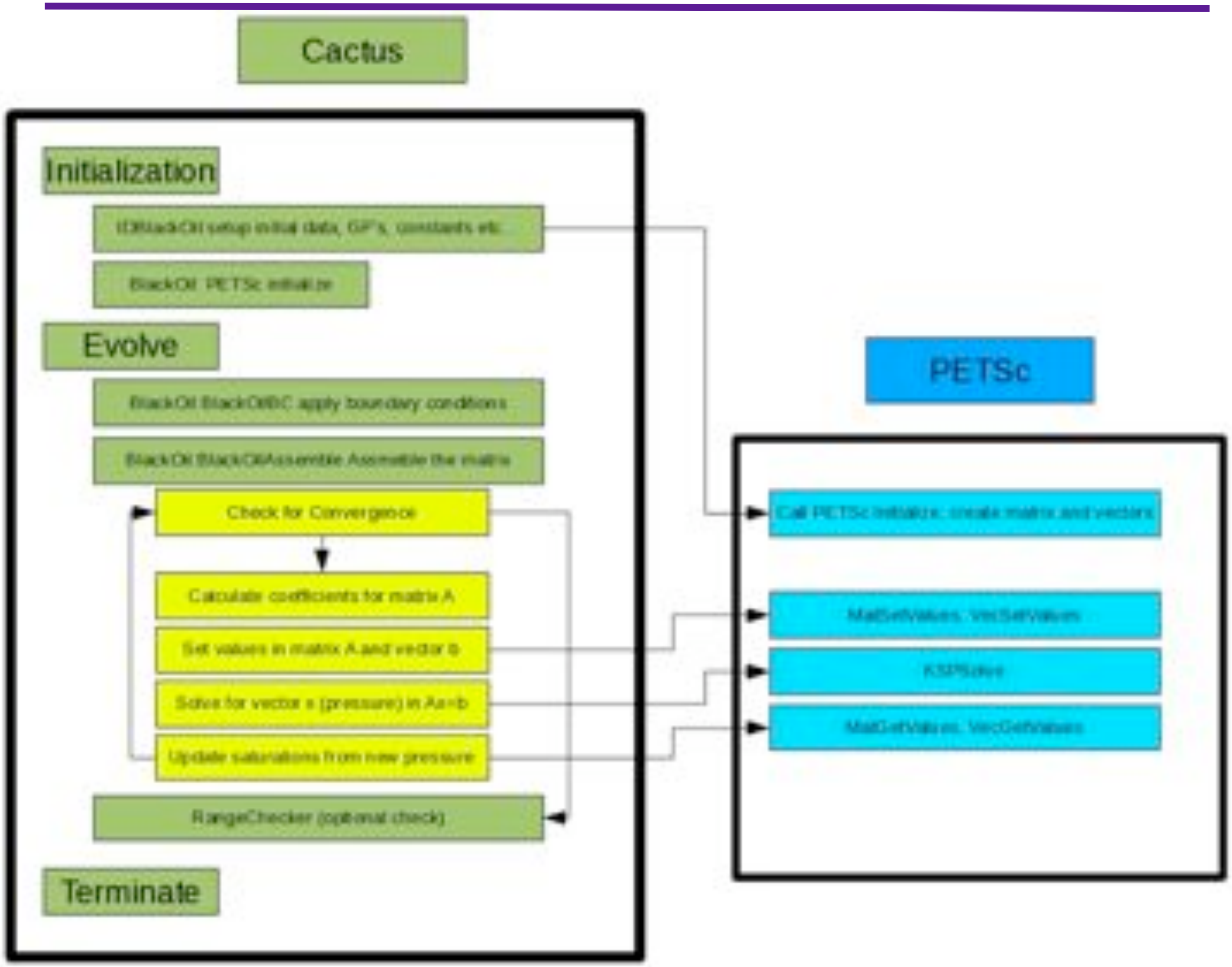
Parallel, modular framework designed for high throughput, large scale simulations:

- uses the Cactus Code parallel framework (http://www.cactuscode.org)
- implements the implicit pressure-explicit saturation (IMPES) scheme
- uses Portable Extensible Toolkit for Scientific computation (PETSc) solver
- designed to scale to thousands of processors, integrate with Grid technologies, extend solvers & physics

www.CactusCode.org

Cactus BlackOil Flowchart



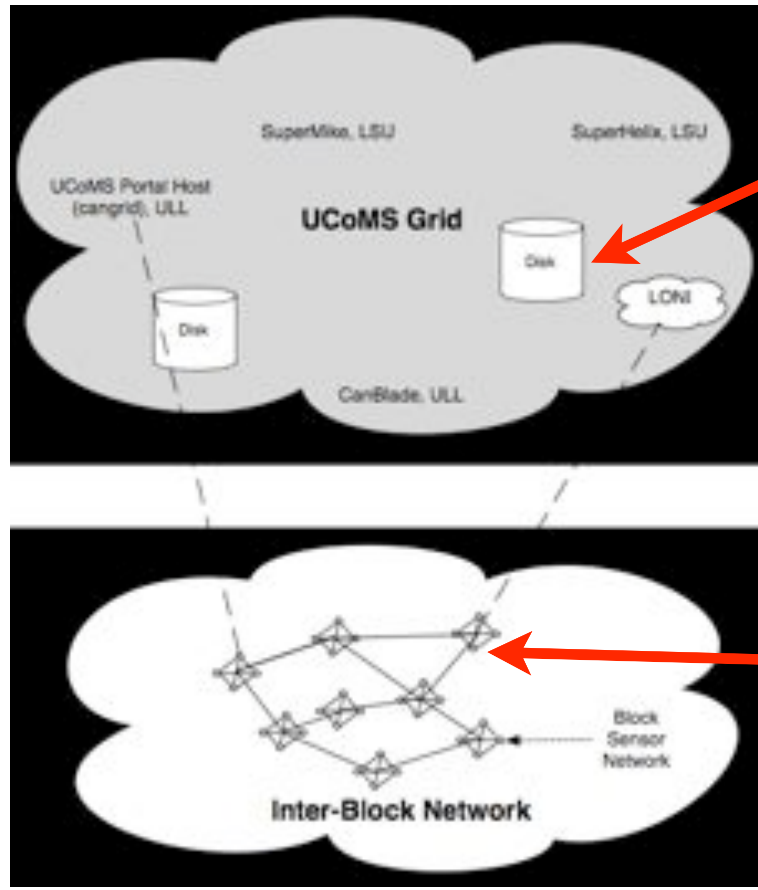
Cactus BlackOil

- Implementing the BlackOil reservoir simulator as a set of Cactus thorns provides:
  - Fast parallel IO and check-pointing
  - Remote simulation control and visualization
  - Inherent parallelism via the PUGH Cactus driver
  - High-end visualization: Amira, OpenDX, vtk
  - Also adaptive mesh refinement, task farming…
  - Interacts well with Grid technologies
    - E.g. Cactus-SAGA interface (Jha)

4. Sensor Network Infrastructure

Wireless Sensor Network

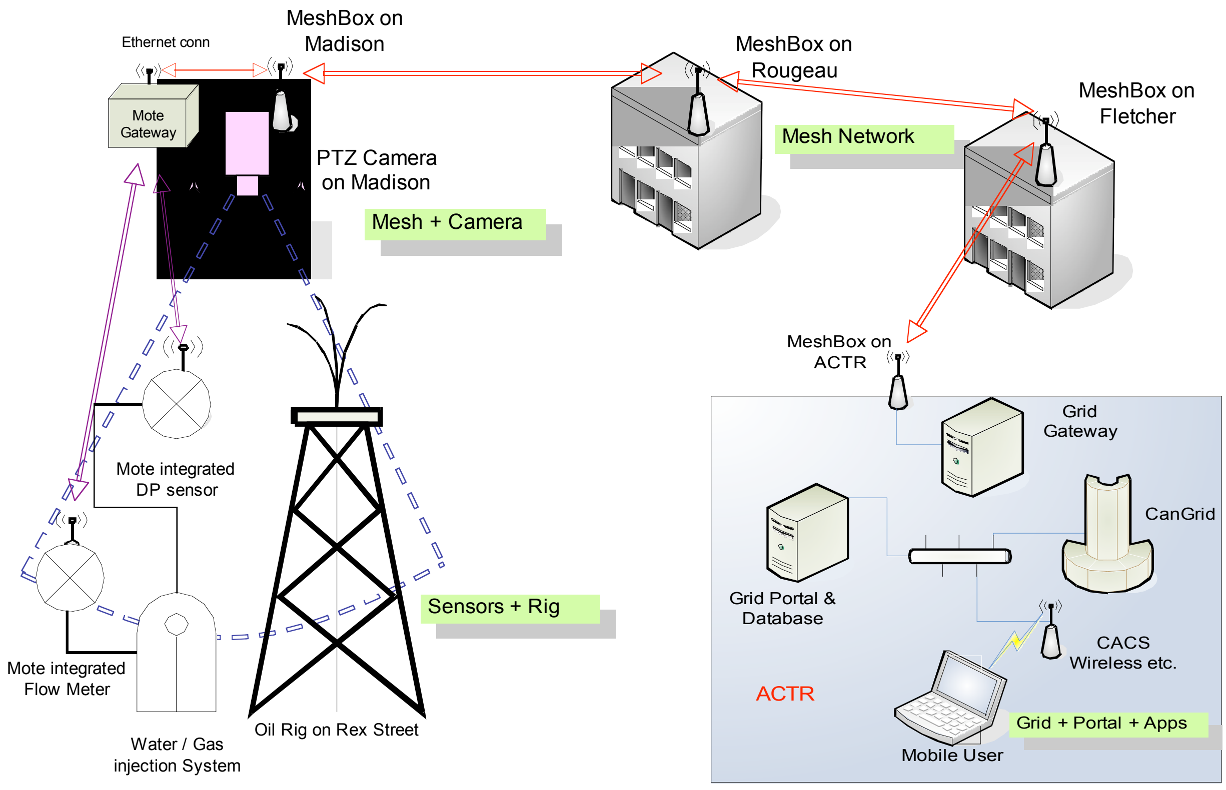
- Block Sensor Network (BSN): cluster of sensors
- Block Gateway (BGW): each cluster has a BGW to communicate
- Inter-block Wireless (IBW) wireless mesh network: connects BSNs in adhoc manner
- Internet Access Point (IAP): connects IBW to the Internet

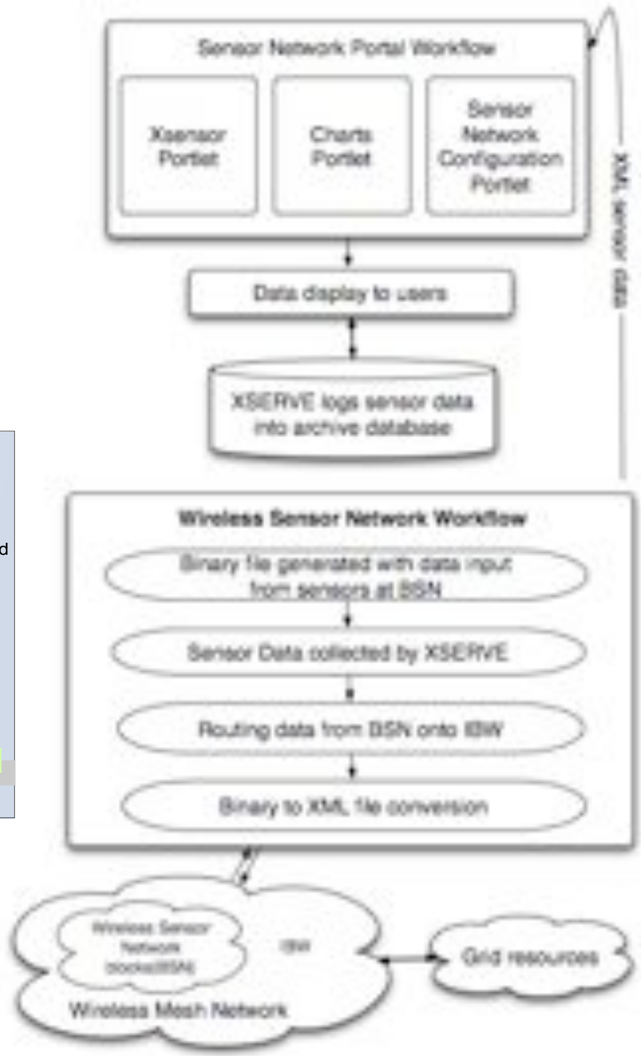


Data: archiving, processing, live to sims

Sensors: low power, low computational capability

Collection of Data

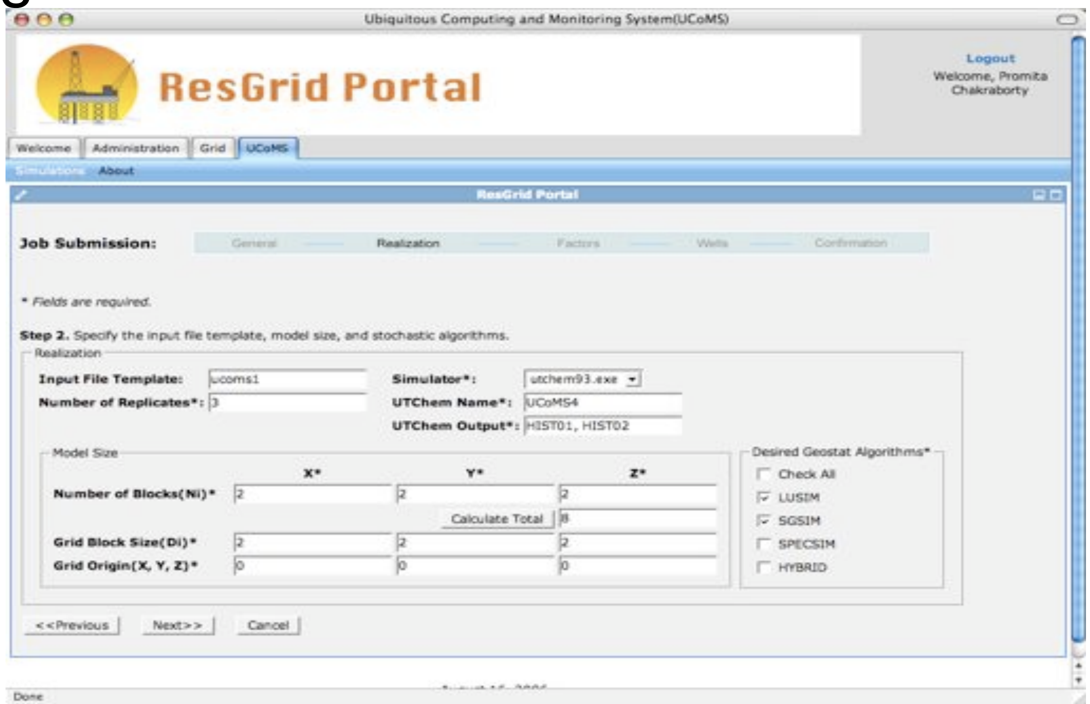




5. Integrating User Portal

Configuration of flow models

Workflow for compute-intensive simulations



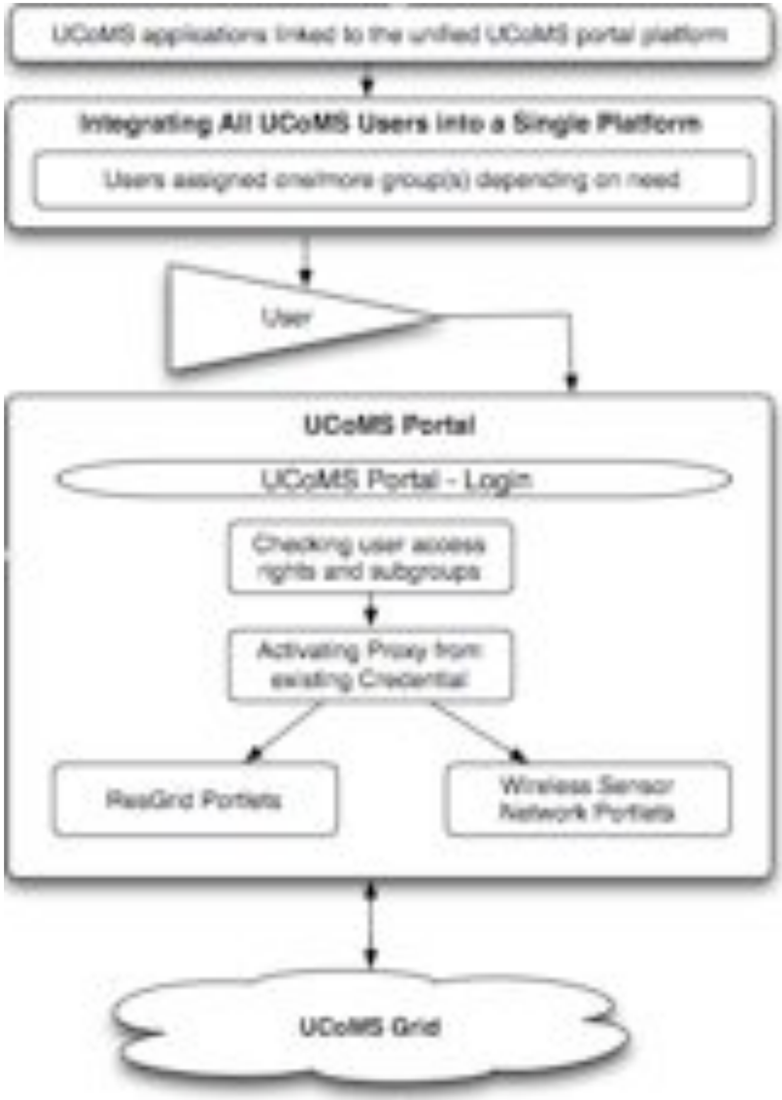
Notification of events

Data collection from wireless sensor network

Interface to data archive

Portal Design

- GridSphere: Java based open-source web portal framework
- JSR-168 compliant API
- GridPortlets provide underlying core grid tools which are used in UCOMS portlets
- Different user groups implemented: super, sensor-admins, resgrid-admins, sensor-users, resgrid-users



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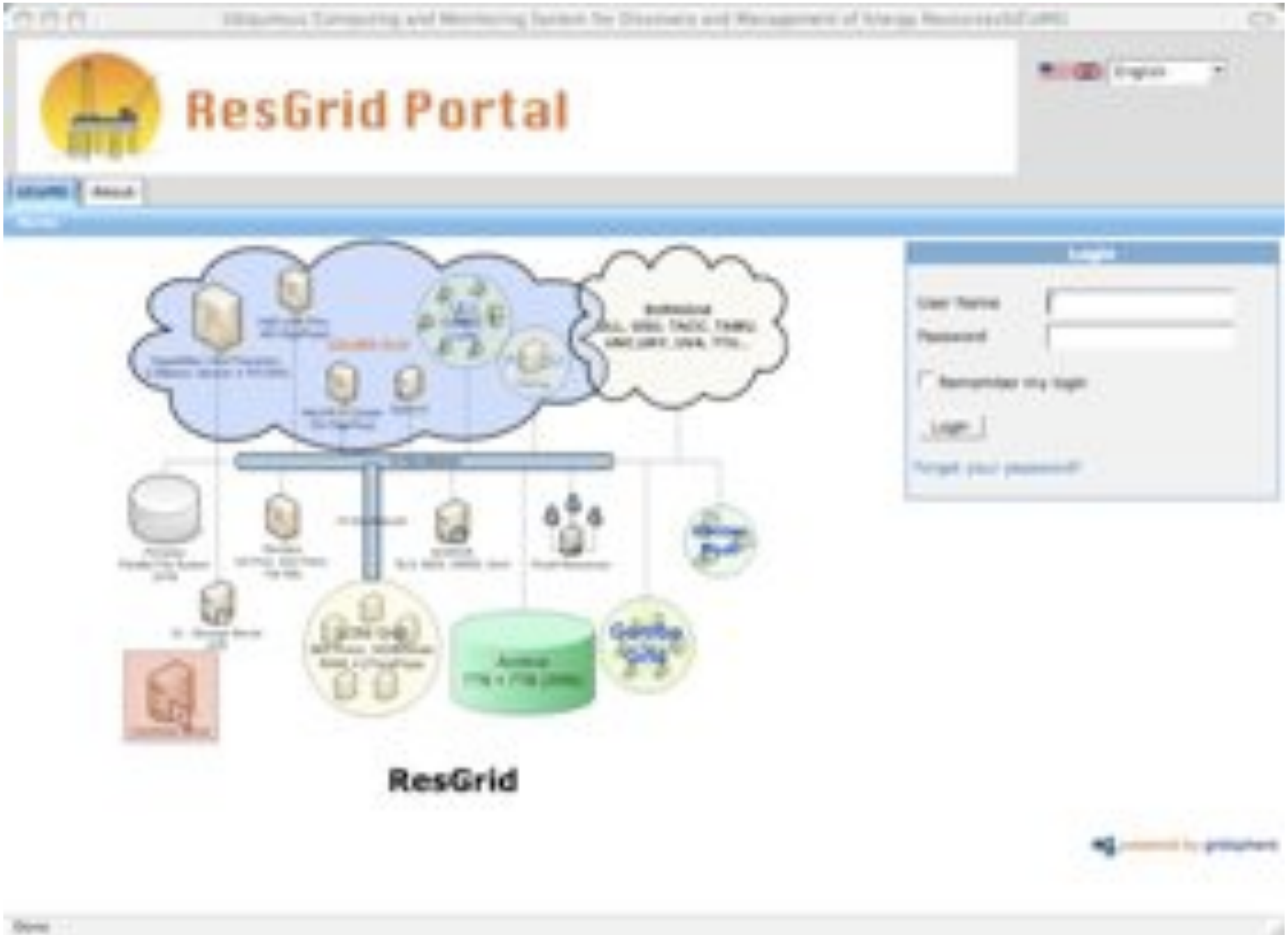
UCoMS Portal



1.Login page
2.Flow model geometry, geostatistic methods and simulators
3. Check parameters
4. Job monitoring
5. Raw sensor output
6. Sensor data
7. Sensor topology

Credits

- The work presented here is a collaborative effort from the UCoMS project
  - http://www.ucoms.org
- **LSU**: Chris White, Tevfik Kosar, Juan Lorenzo, Gabrielle Allen, Mayank Tyagi, Zhou Lei, Xin Li, Emrah Ceyhan, Promita Chakraborty, John Lewis
- **ULL**: Nian Tzeng, Magdy Bayoumi, Hongwi Wu, Dimitri Perkins, Buyon Guo, Adam Lewis, I. Chang-Yen, I. Jangjaimon
- **Southern**: Doug Moreman