TEXAS A&M ENGINEERING

Systems Engineering Research at Texas A&M University

Abhijit Deshmukh
Lead SERC Researcher @ TAMU

Amarnath Banerjee, Yu Ding, Andrew Johnson, Sara McComb, Lewis Ntaimo, Brett Peters, Donald Phillips, James Wall, Martin Wortman, Justin Yates
Senior SERC Researchers @ TAMU

Texas A&M University

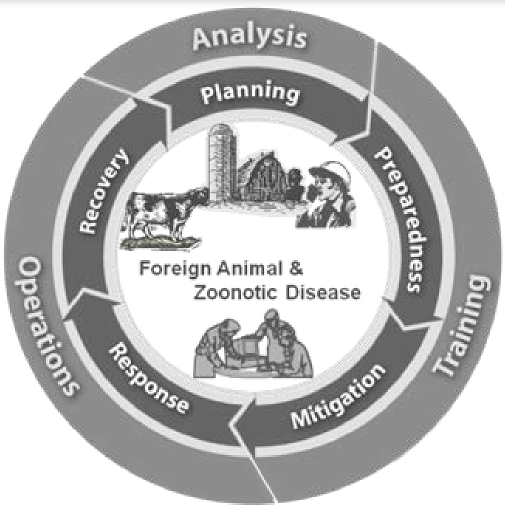
- **Texas' first public institution of higher learning** - founded in 1876
  - 48,000 student enrollment
  - $582 million annual research
  - Former home of Secretary Gates
- **Dwight Look College of Engineering**
  - One of the largest engineering colleges in the nation
  - 10,000 students, 400 tenured/tenure-track faculty
  - Systems engineering pervasive throughout the college
    - Industrial & Systems Engineering
    - Computer Science
    - Aerospace Engineering
    - Civil Engineering

Industrial & Systems Engineering

- **Ranked in Top-10 for over 25 years**
- **One of the Largest ISE Department**
  - 500+ undergraduates, 275+ graduate students and 28+ faculty
- **Systems Engineering Education**
  - Master of Science in Engineering Systems Management
  - Master of Engineering specializing in Systems Engineering
  - PhD with focus on Systems Engineering
- **Systems Engineering Research**
  - Visual analytics, simulation
  - Distributed decision-making, cognitive science
  - Complex adaptive systems
  - Optimization, stochastic models
  - Enterprise systems, supply chain management
  - Technology assessment

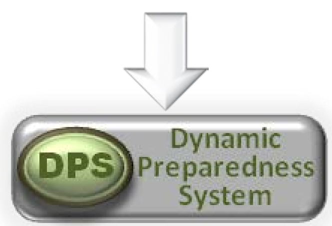
Visual Analytics and Simulation

Defining the Need



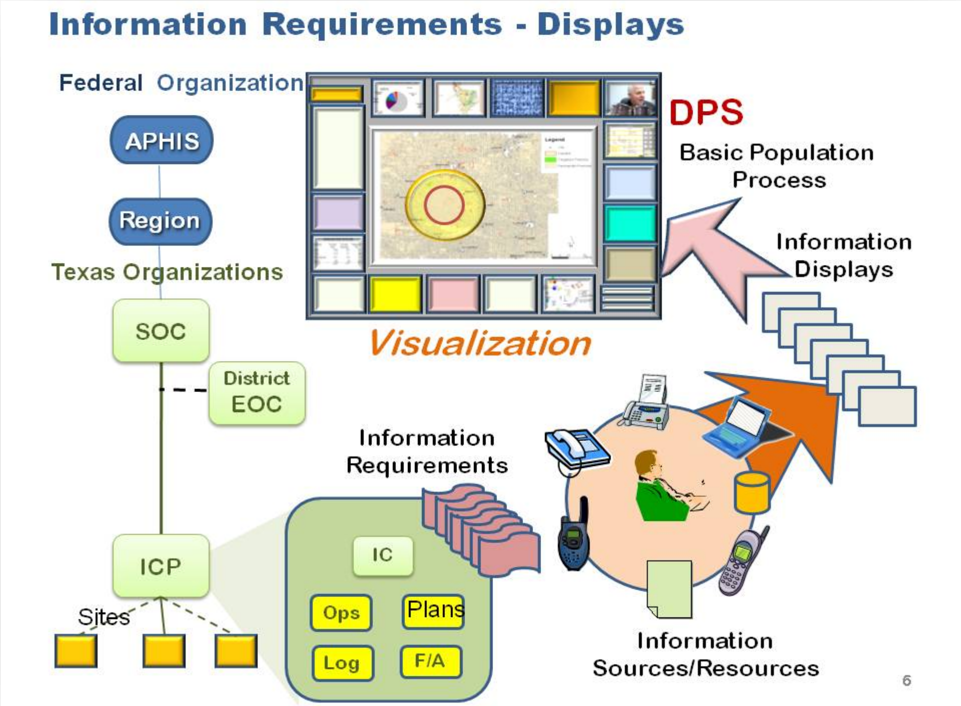
The Emergency Response Lifecycle

- An animal disease outbreak, whether naturally occurring or human-induced, presents a complex response challenge and very quickly involves several levels of decision makers (local, state, and federal).
- A need exists for a consolidated view of the incident being presented to the full array of decision makers with synchronized data being represented from multiple distributed sources.
- Such an integrated view with these diverse data representations provides a useful tool for both training, operational (incident management), and analytical applications.



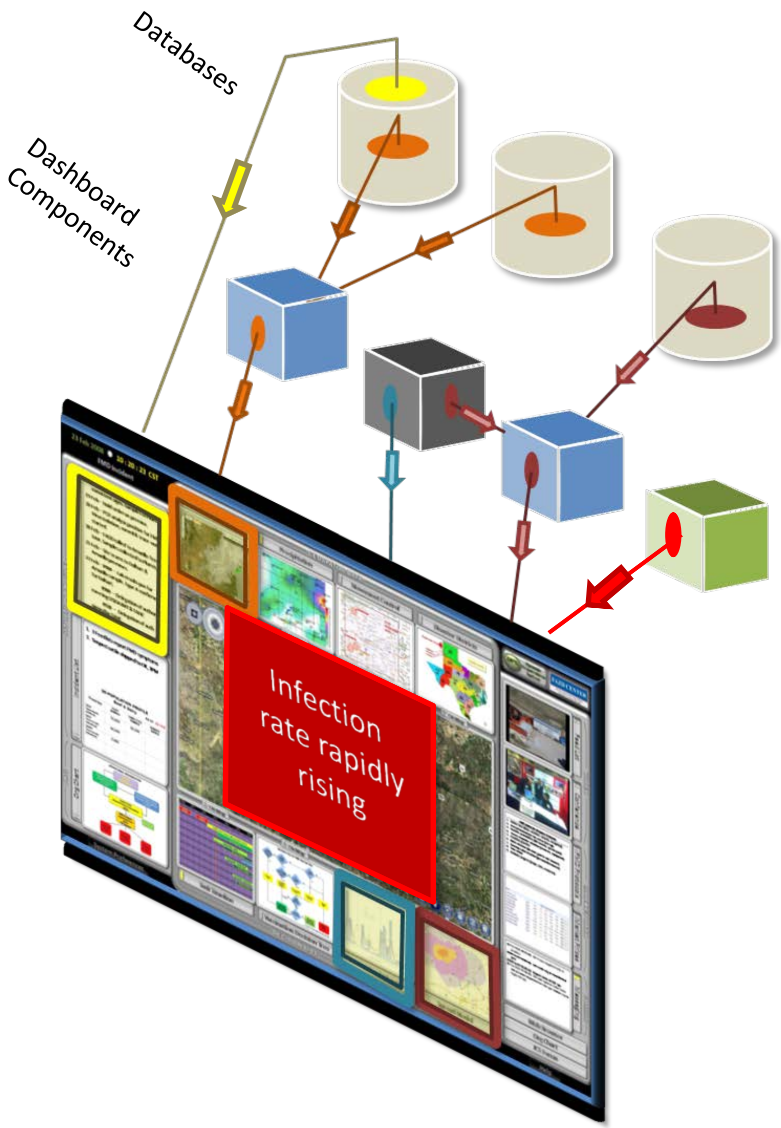
Scalable … Multi-level Perspective … Multiple Incidents

Dynamic Information Dashboard



Mapping	Resource Mgmt	Planning	Admin	Sim Engine	Checklists and Forms	Exercise Mgmt
Logs	Reporting	Comms	External Links	Models and Data	After Action Review	O/C Forms

Dashboard Components



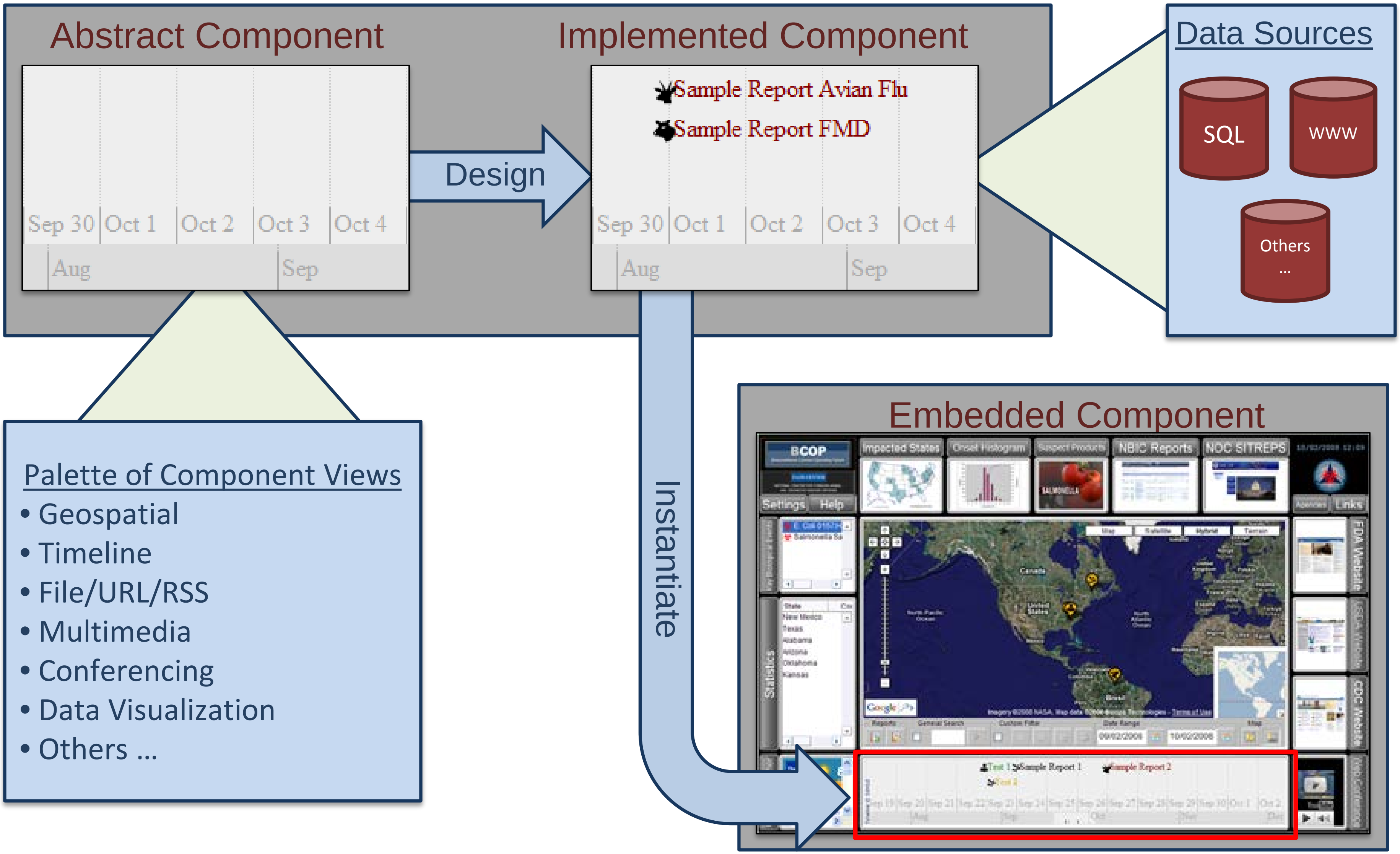
Levels of Integration

- Visual
- Middleware (converging data streams)
- Application to Application Data Sharing
- Hybrid (any combination of the above)

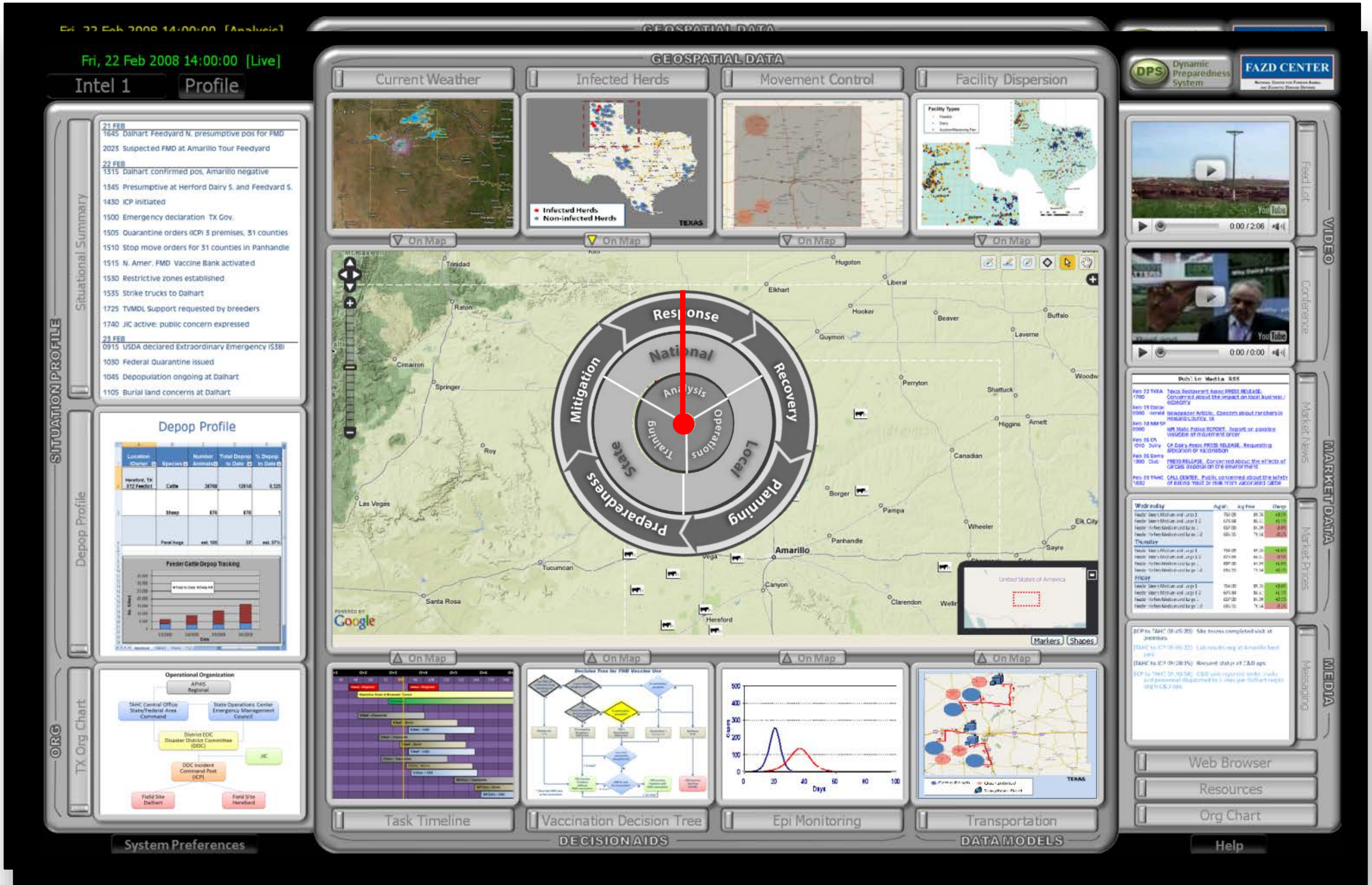
Decision Support Tools

- Manual – visual integration of data
- Assisted – visualization development using visual programming
- Automated – monitoring agents

Dashboard Framework



Dynamic Preparedness System (DPS)

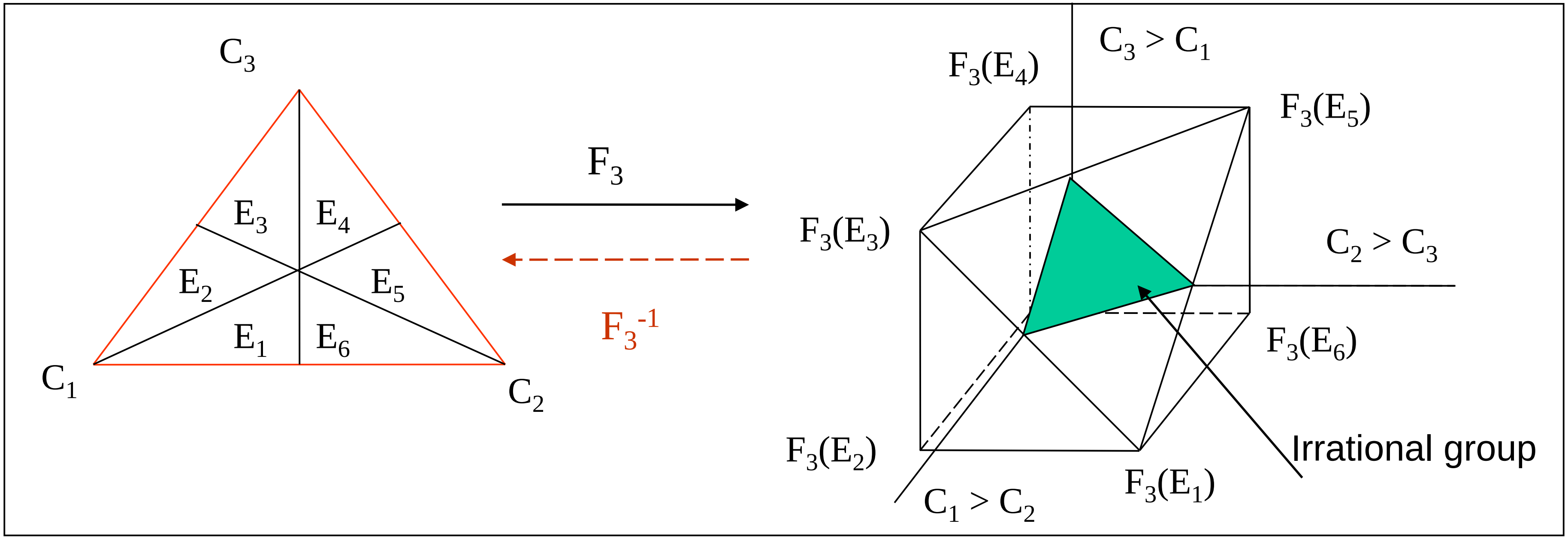


- Common integrated display driven by data from authoritative data sources.
- Customization achieved by selecting a tailored set of components.
- Plug-in architecture (documented) allows 3rd party developers to contribute components.

Distributed Decision-Making

Preference Aggregation

Goal: To identify the agent profiles leading to irrational group outcomes



6 (US > EU > PR) **5 (PR > EU > US)** **4 (EU > PR > US)**

Plurality Vote (one person, one vote)

US > EU > PR

Pair-wise Comparison (Condorcet)

EU > US & **EU** > PR & PR > US

EU > PR > US

Runoff Elections (two rounds of plurality)

First Round : US > EU > PR

Second Round: **EU** > US

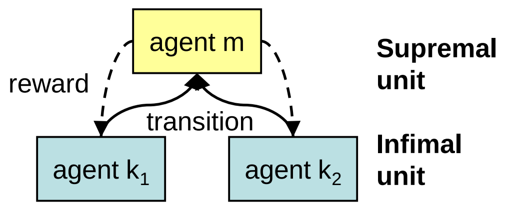
Positional Voting (Borda)

2-1-0 scale : **EU** > PR > US

100-10-1 scale : **US** > PR > EU

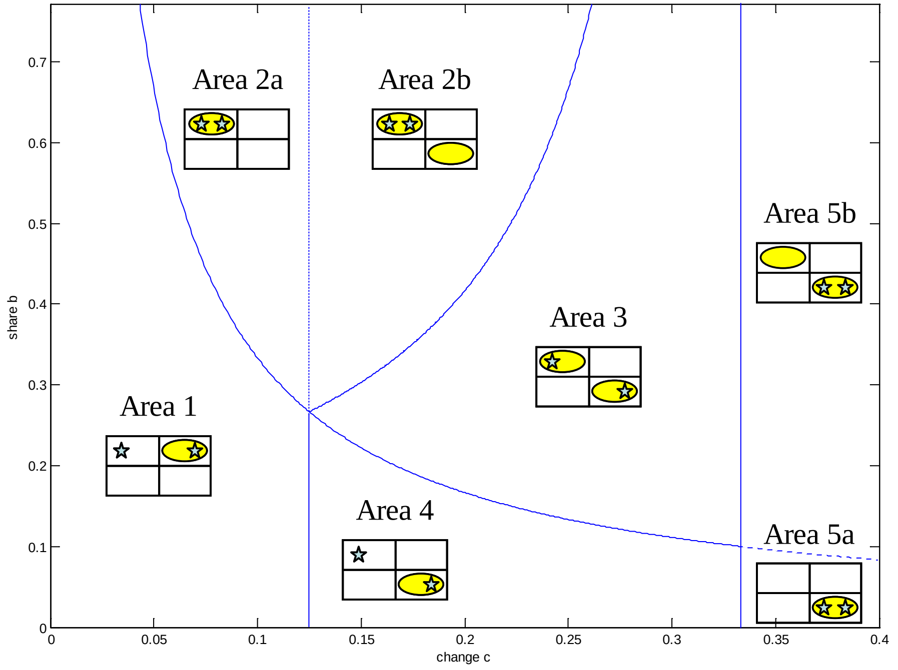
Multi-Scale Decision-Making

Organization



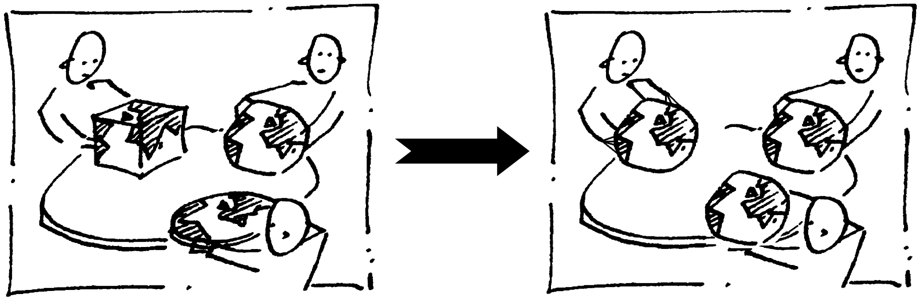
In a hierarchical organization, decision makers on different levels *influence* each other with their decisions. To determine the *optimal decision* each agent has to engage in *game theoretic* reasoning under *uncertainty* in a multi-period decision process.

Depending on how strongly agents affect each others' rewards and transition probabilities - different equilibrium scenarios can emerge.



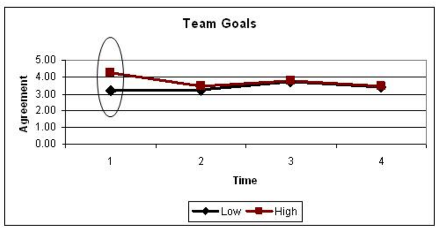
Result: Optimal decision strategy and information / communication needs for each agent in organization.

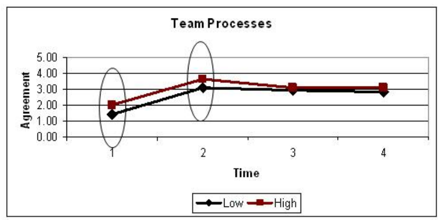
Mental Model Convergence

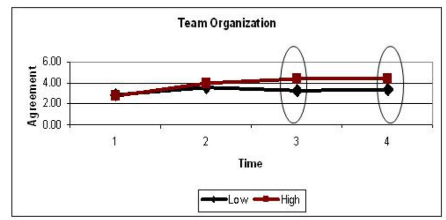


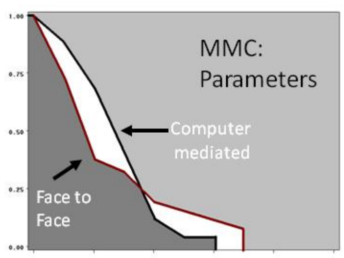
Research Focus:
- Multiple Teamwork Mental Models
- Temporal Patterns among Mental Models

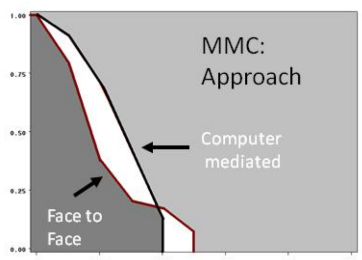
Findings:

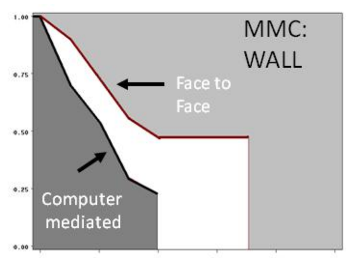


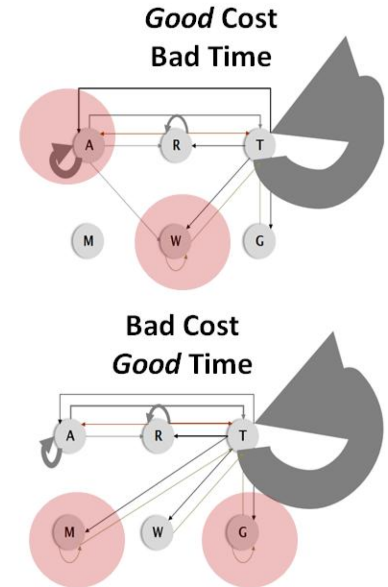












Parameters Approach Work Allocation

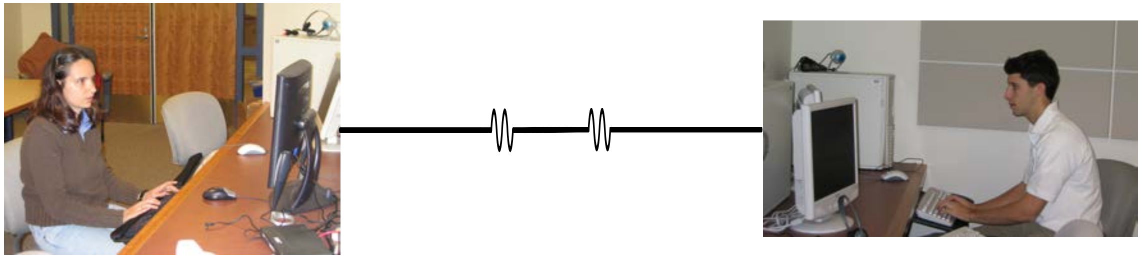
Agent-Mediated Shared Mental Models

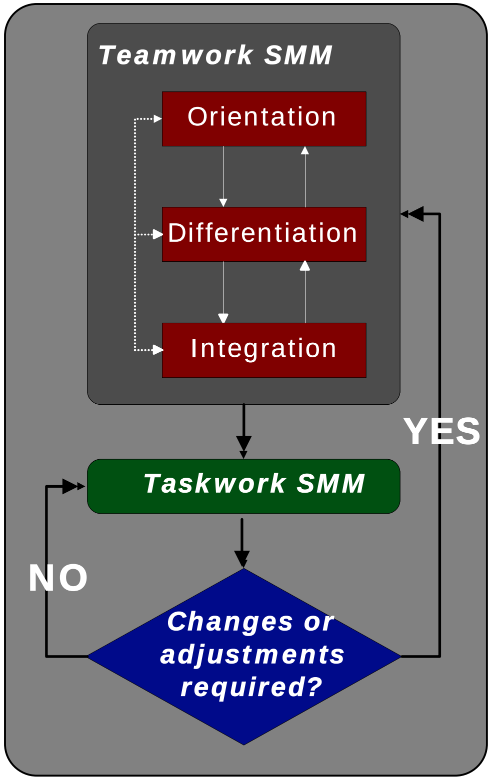
Goal:

Determine what and how team members share information, and develop autonomous agents to enhance team collaboration

Results:

- Individual's mental models converge over time
- Communication and coordination methods affect mental model convergence rates
- Focused mediation improves mental model convergence
- Agent augmentation can help at individual and team level
- Optimal levels, in terms of frequency and content, of augmentation exist at both levels

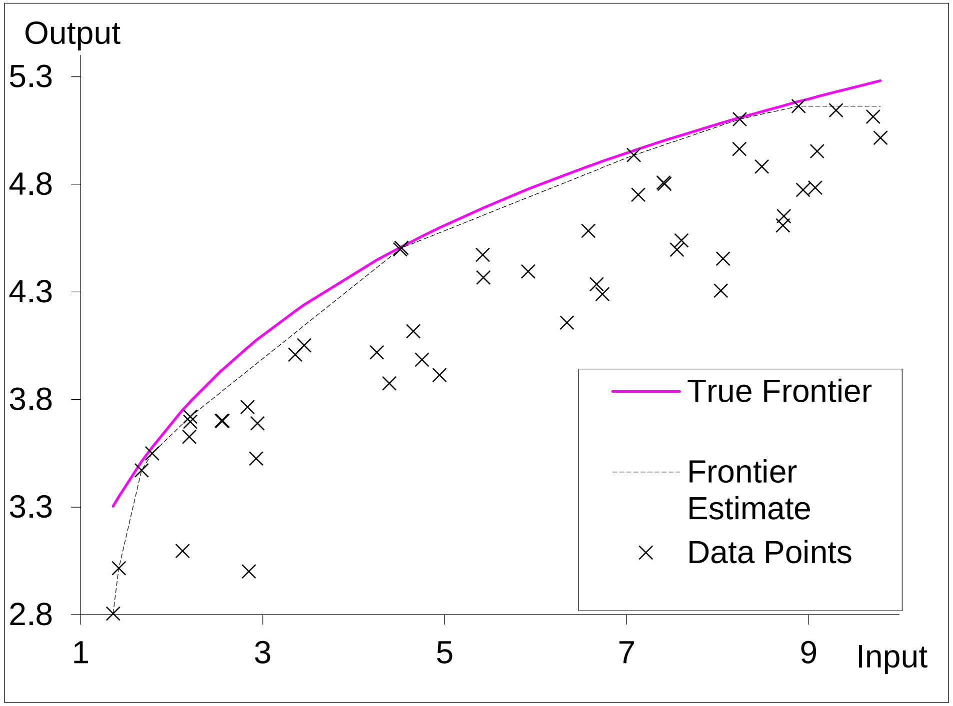




Benchmarking and Strategic Improvement

How do we estimate best performance given a set of data?

As a first approximation we can use Pareto dominance, but we also need to account for uncertainty in our measurements. To move to a multiple input / multiple output production process linear or non-linear programming approaches are used



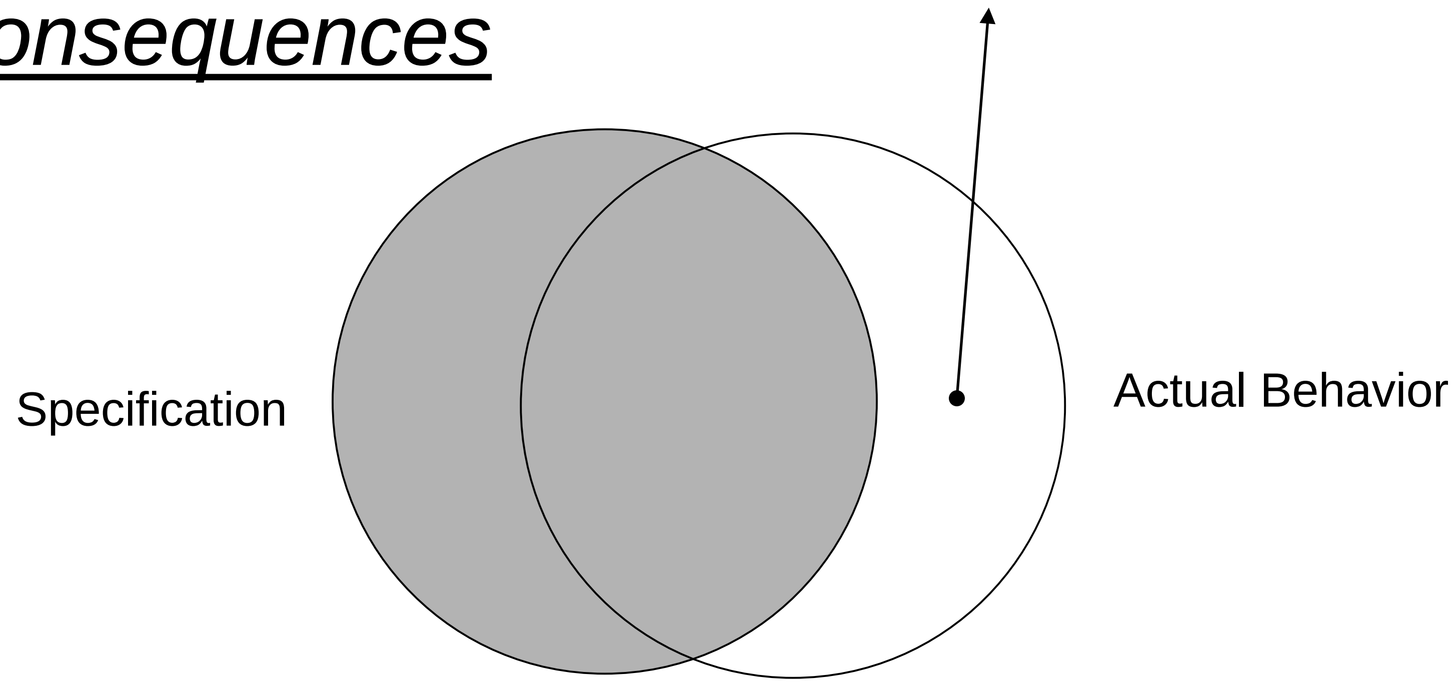
How do we model noise in the measurements or account for potentially omitted variables?

We can use tools from econometrics, namely a Gauss-Markov error model to capture some of the factors that are not modeled explicitly.

Complex Adaptive Systems

Characteristics of Complex Systems

- Emergent Behaviors and ***Unintended Consequences***



- What are the limits on predictability of performance and robustness of complex systems?

Is Systems Engineering Process a Complex Adaptive System ?

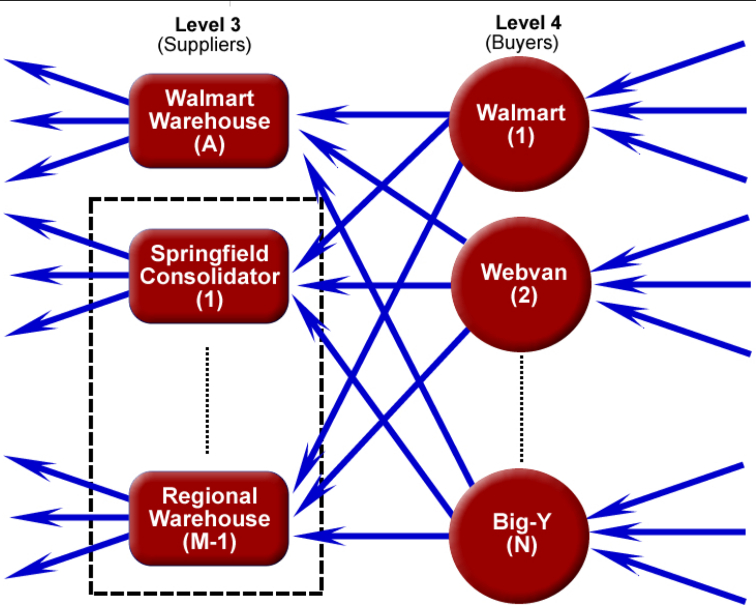
Interacting Particle Models

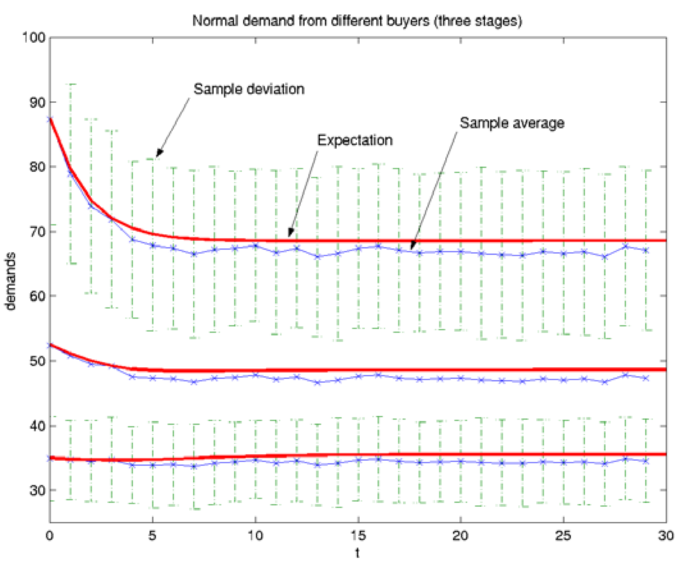
Particle Systems

- Particles interact with each other by exerting force fields
- Particles coalesce into groups to form molecules
- Mass properties of the ensemble of particles depend on interactions between particles and external conditions

Multi-Agent Supply Chains

- Agents coordinate by transferring materials or information
- Companies jointly form supply networks
- Performance of agent systems depends on the interactions between agents and the operating environment





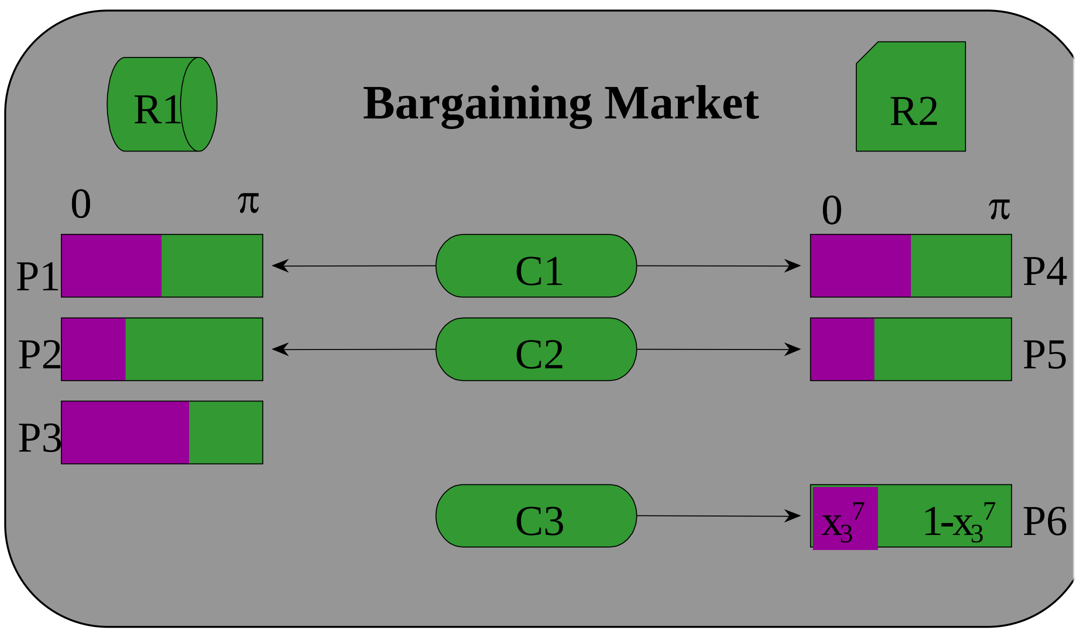
Coordination via Bargaining

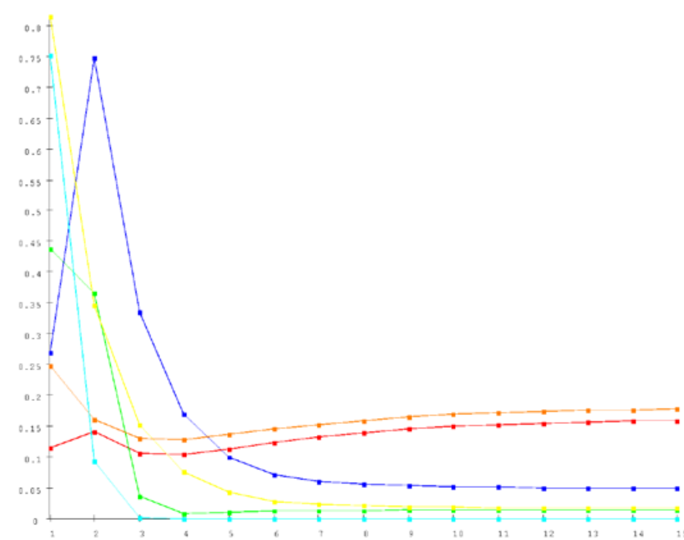
Goals:

- Precise model of bargaining in networks
- Develop explicit models of strategic interactions
- Characterize the equilibrium and its values

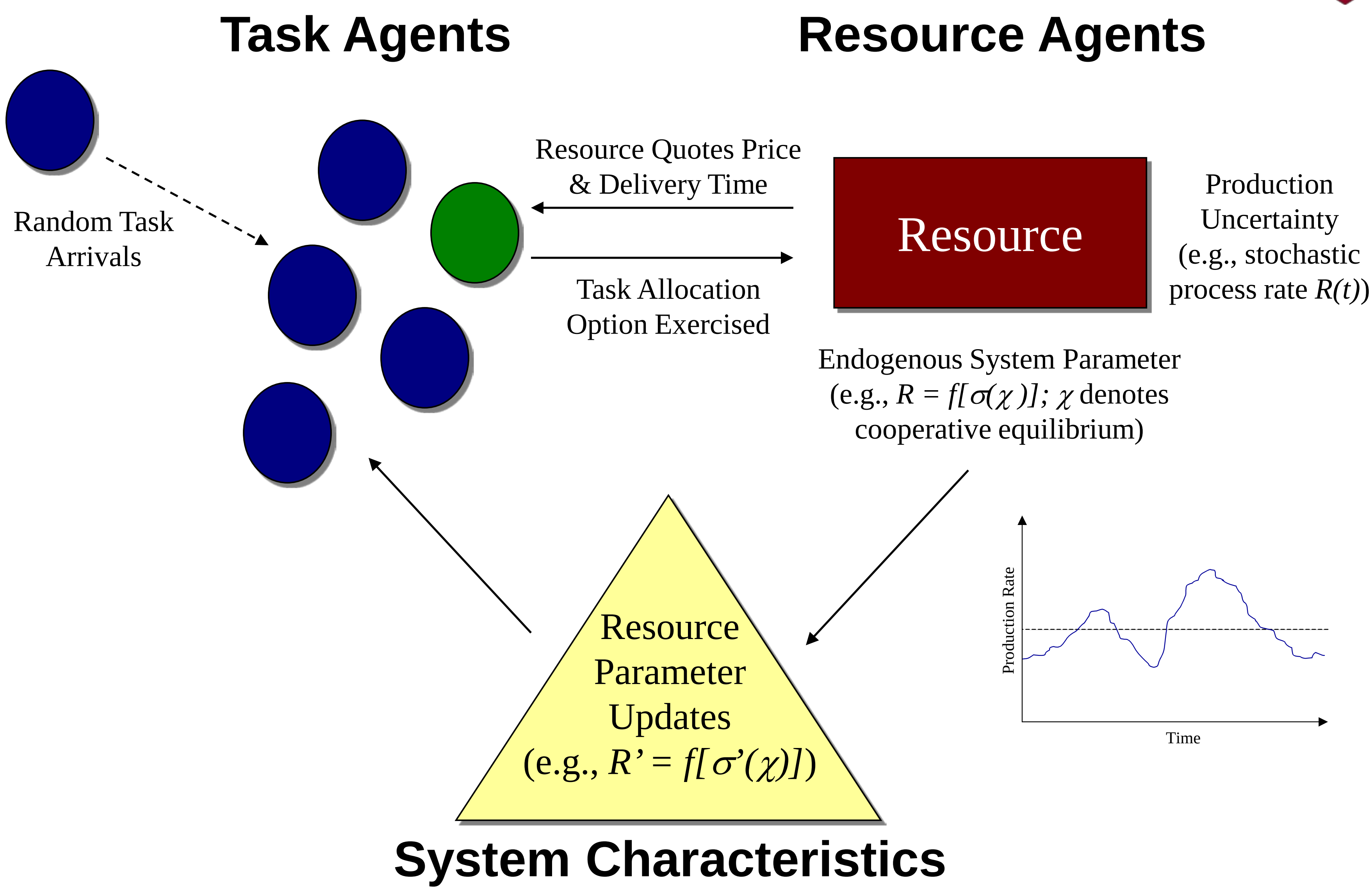
Results:

- Shared surplus model of resources
- Decentralized resource allocation policy
- Directly computable equilibrium values





System Flexibility with Real Options



Manage systemic performance risk by incorporating options-based flexibility with the relationship between agent decisions and underlying system parameters

Open Research Questions

- **What <u>architectures</u> underlie (physical, behavioral & social) phenomena of interest?**
  - Conceptual frameworks, representations, structures, models, etc.
- **How are <u>architectures</u> a means to desired system characteristics?**
  - Modeling vs. sensing; harmonization; economics of architectures
- **How can <u>architectures</u> enable resilient, adaptive, agile, evolvable systems?**
  - What is fixed and what changes?
- **What are the <u>fundamental limits</u> of information, knowledge, model formulation, observability, controllability, scalability, etc.?**
  - Goal is to understand limits to prediction, control, operation and to know what new mechanisms are needed to enable systems performance