Situated Mathematics:
Agent-Based Test Beds for Mathematics in Practice

Mathematics for New Economic Thinking

Institute for New Economic Thinking (INET) Workshop

Fields Institute for Research in Mathematical Sciences

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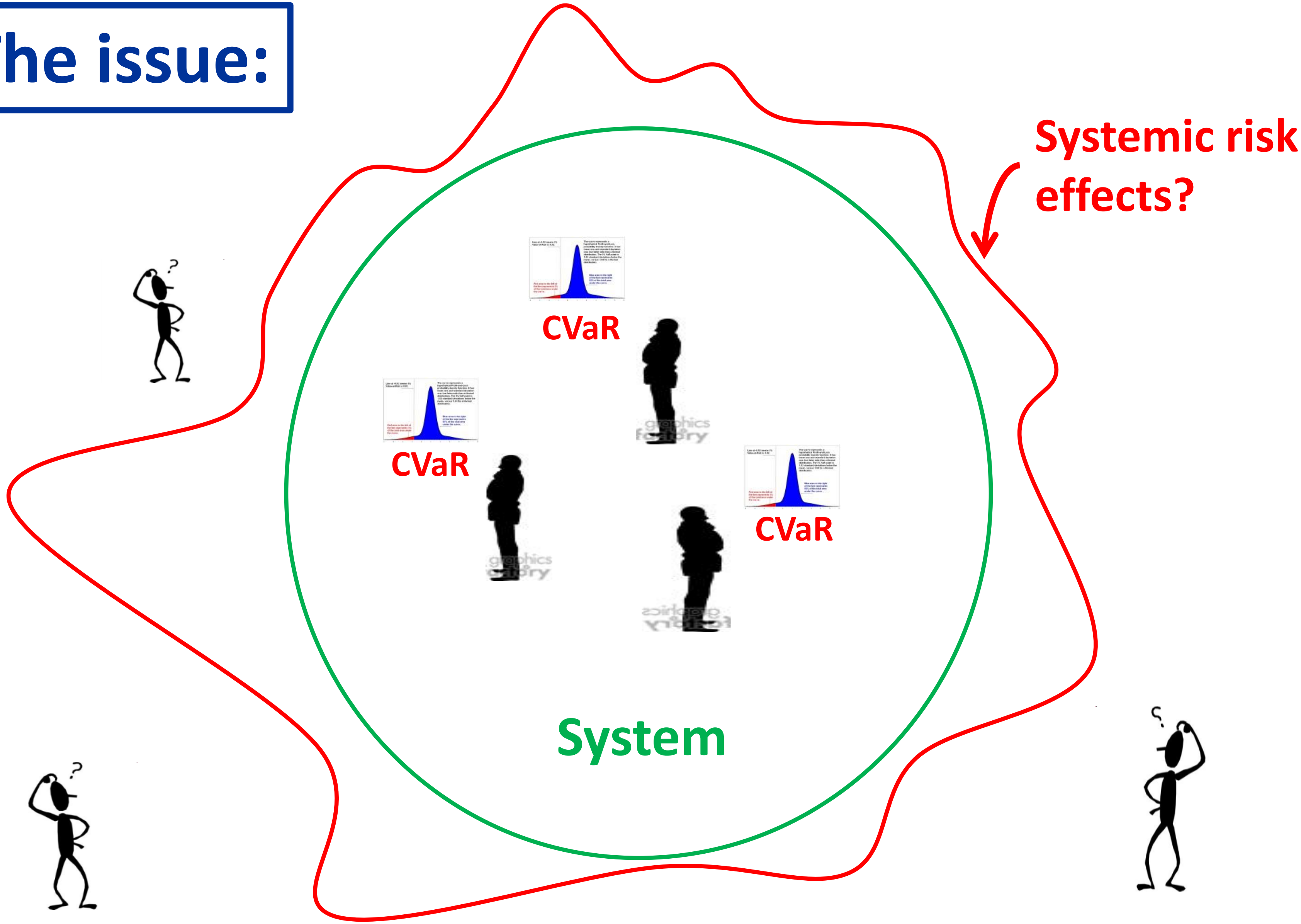
Leigh Tesfatsion

Professor of Economics, Mathematics, and Electrical & Computer Engineering

Iowa State University, Ames, Iowa

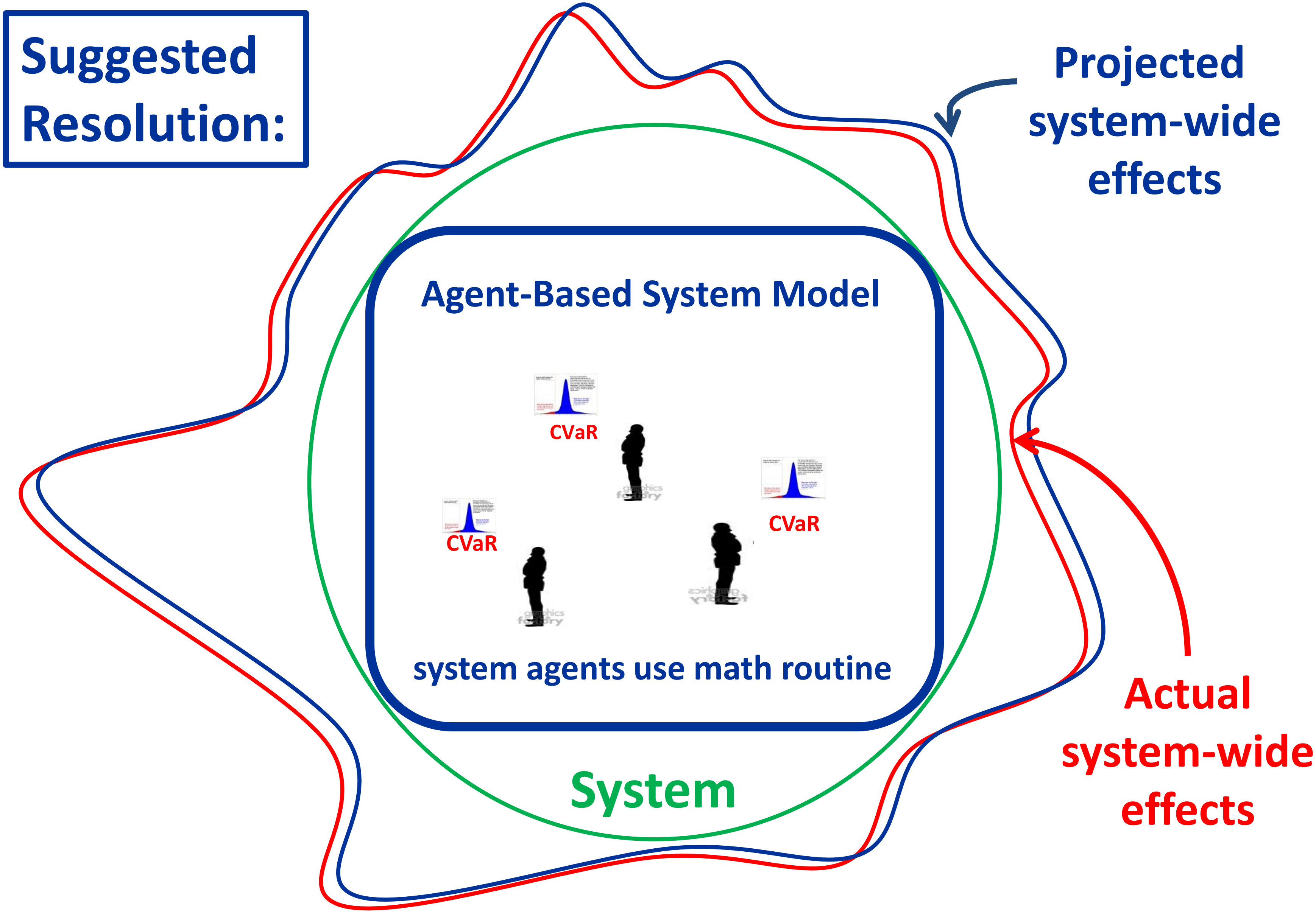
tesfatsi@iastate.edu

The issue:



Unknown system-wide effects of locally used mathematical routines

Suggested Resolution:



Explore system-wide effects via an agent-based test bed

Presentation Outline

- Complexity of Critical Infrastructure Systems (CIS)

- Agent-based test beds for exploring system-wide effects of locally used CIS decision support tools

- ***Illustration:*** System-wide effects from local use of DP and MIP optimization routines for electric power system operations are being tested via the

  Integrated ***R***etail & ***W***holesale (***IRW***) Power System Test Bed

  http://www.econ.iastate.edu/tesfatsi/irwprojecthome.htm

Complexity of Critical Infrastructure Systems (CIS)

- Modern societies depend on CIS for essential goods & services (electric power, credit, health services,…)

- CIS are large complex systems encompassing
  - Human decision-makers
  - Physical constraints
  - Institutional arrangements

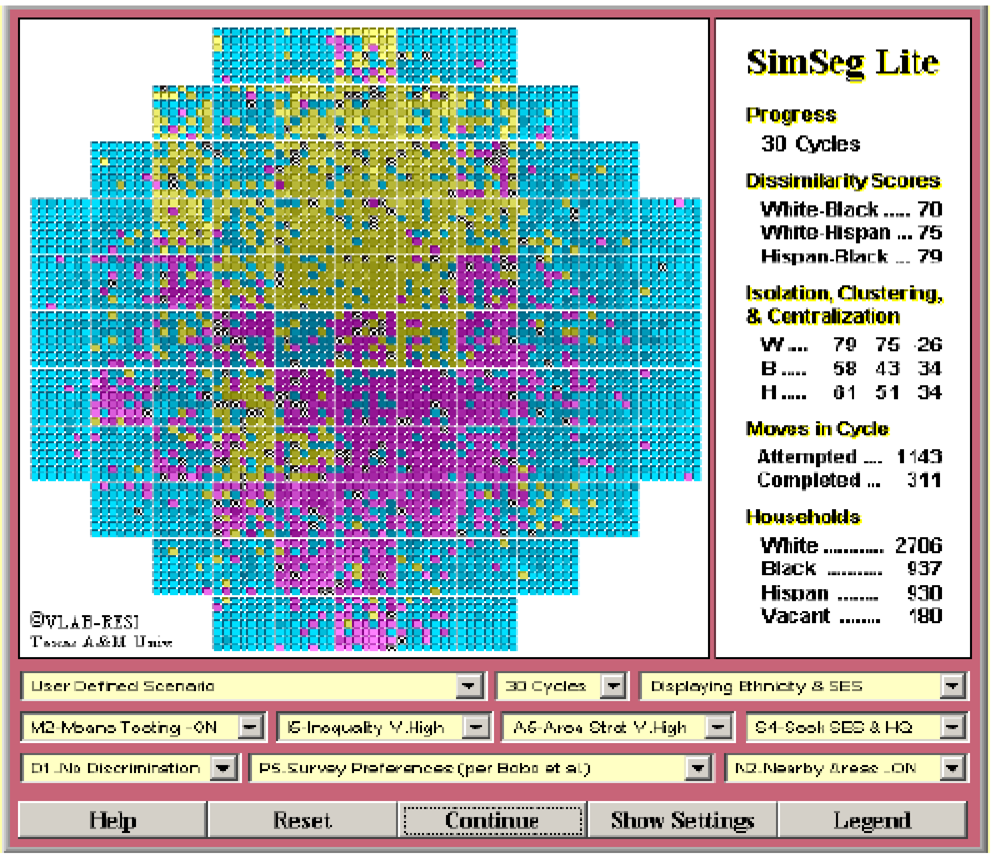
- Difficult to judge ex ante the system-wide effects of locally used CIS decision support tools

Can Agent-Based Modeling (ABM) help?

- **Classical Approach (Top Down):** Represent a system by means of parameterized differential equations
  - ***Example:*** *Archimedes*, a large-scale system of ODEs modeling pathways of disease spread under alternative possible health care response systems
- **ABM Approach (Bottom Up):** Represent a system as a virtual world of interacting agents
  - Each agent is an entity encapsulating data together with methods that act on this data.
  - Starting from user-specified initial conditions, world events are driven entirely by agent interactions.

Agent-Based Test Bed

ABM computational lab that permits controlled computational experiments and visualization of outcomes



Example:

An agent-based test bed implementing an extended Schelling model of urban segregation

Source: Mark Fossett, Texas A&M, http://vlab-resi.tamu.edu/vlab.htm

Meaning of “agent” in ABM

Agent = Encapsulated bundle of data and methods acting within a computationally constructed world

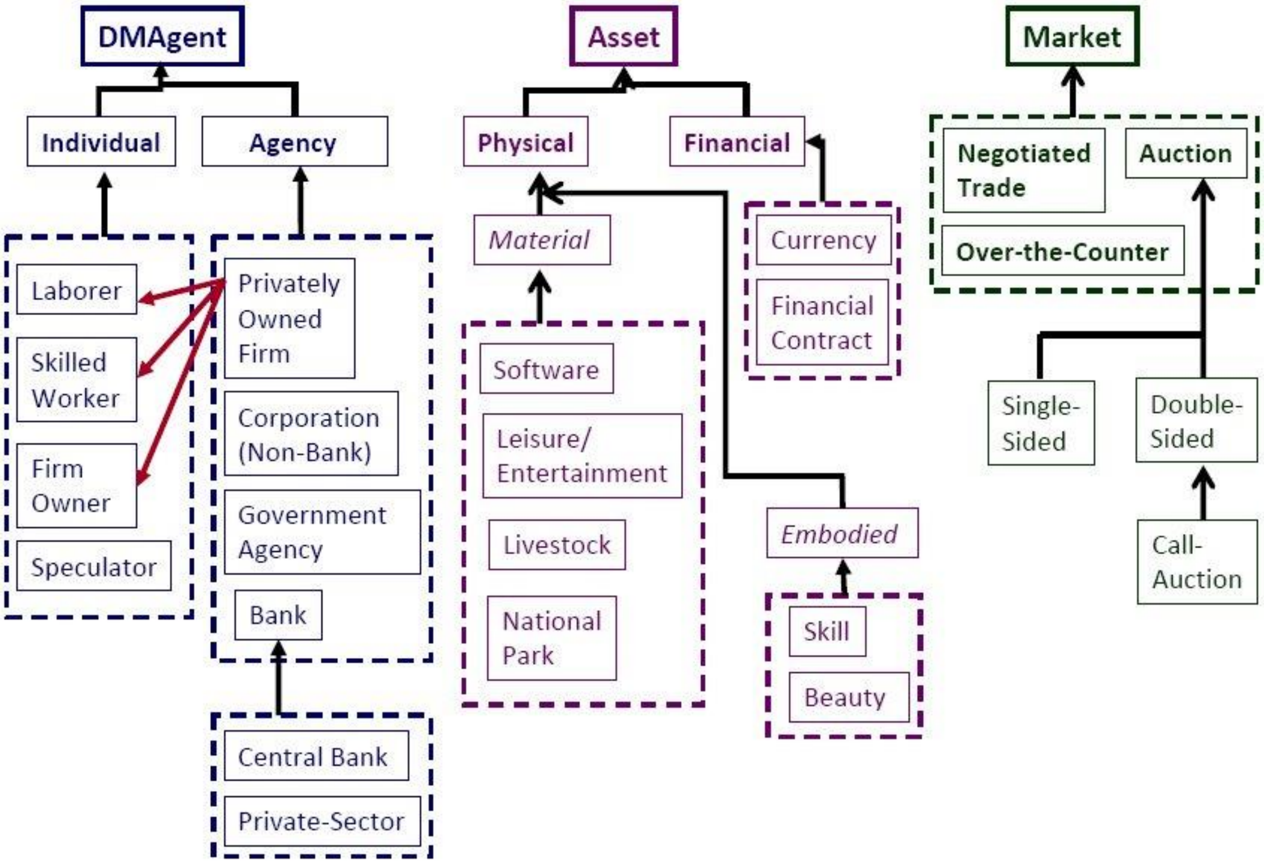
- Agents can represent:
  - Individuals (consumers, traders, entrepreneurs,…)
  - Social groupings (households, communities,…)
  - Institutions (markets, corporations, gov’t agencies,…)
  - Biological entities (crops, livestock, forests,…)
  - Physical entities (weather, landscape, electric grids,…)

Meaning of “agent” in ABM … Continued

Decision-making agents (DMAgents) are capable (in different degrees) of

- Behavioral adaptation
- Goal-directed learning
- Social communication (talking with each other!)
- Endogenous formation of interaction networks
- ***Autonomy***
  Self-activation and self-determination based on ***private internal*** data and methods as well as on external data streams (including from real world)

Partial depiction of agents for a macroeconomic ABM with "is a" ↑ and "has a" ↓ relations



Agent-based test bed development via Iterative Participatory Modeling (IPM)

- Stakeholders and researchers from multiple disciplines join together in a **repeated looping through four stages of analysis**:

1) Field work and data collection
2) Scenario discussion/role-playing games
3) Incorporate findings into agent-based test bed
4) Generate hypotheses through intensive computational experiments.

System-wide performance criteria for CIS decision support tools

- **For Users:**
  - Provides benefits that sustain voluntary use
- **For Regulators:**
  - Sustains/improves reliability of operations
  - Robust against gaming for unfair advantage
- **For Society as a Whole:**
  - Reduces inefficiency (wastage of resources)

Key Issue:

Does the ***local*** use of a CIS decision support tool enhance ***system-wide*** performance?

ABM Approach:

- Represent the CIS as an ABM “virtual world”.
- Let one or more virtual-world agents use the decision support tool in their decision-making.
- Let the virtual world evolve over time, starting from systematically varied initial conditions.
- Check resulting virtual-world outcomes to see if system-wide performance criteria are met.

Performance testing of CIS decision support tools for practical implementation

- Must cross "valley of death" between theory & practice
- **Valley of Death ⇨ Technology Readiness Levels 4–6**
  https://www.directives.doe.gov/directives/0413.3-EGuide-04a/view

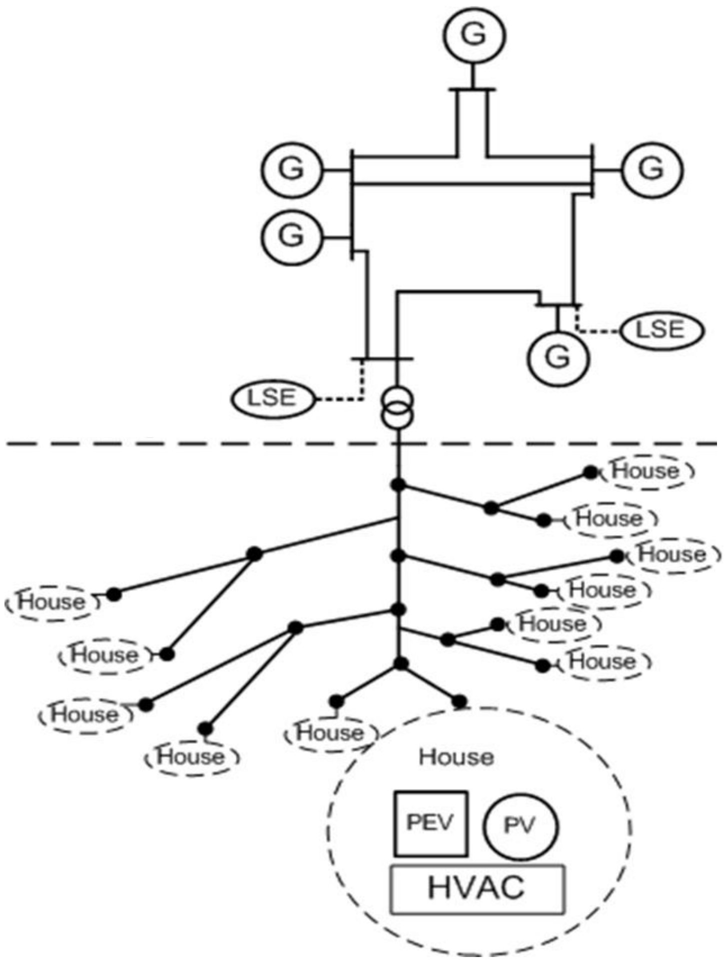
– **TRL 4:** Analytical/computational verification that the CIS decision support tool performs "locally" as expected

– **TRL 5:** Performance testing of the CIS decision support tool in a reasonably realistic CIS simulation

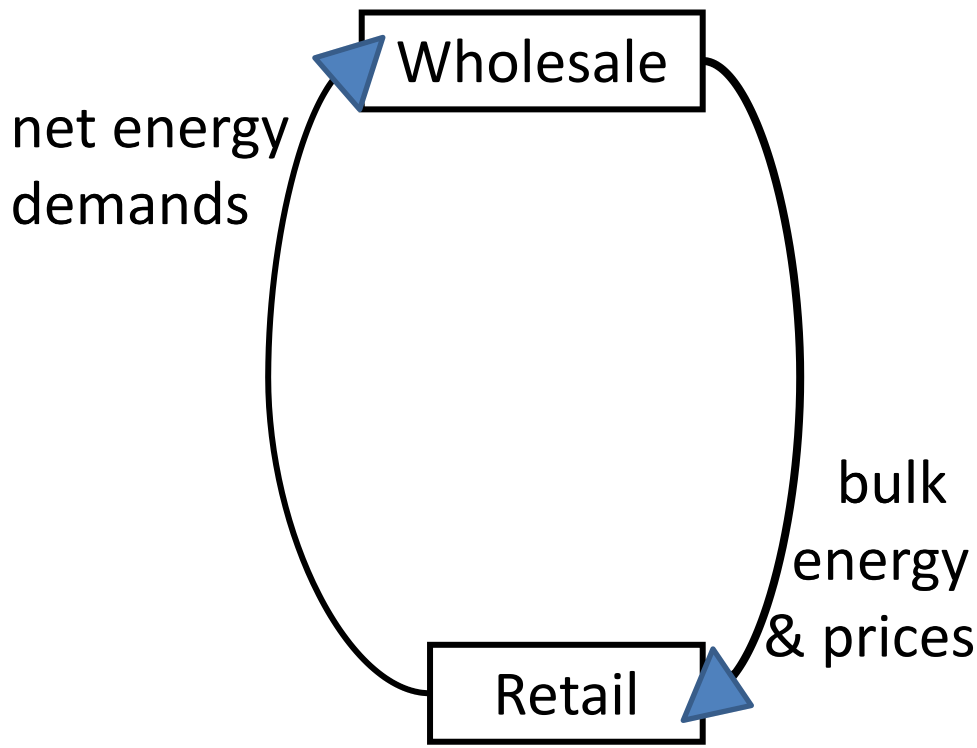
– **TRL 6:** Performance testing of the CIS decision support tool in a high-fidelity CIS simulation

TRL-5 Example: The Integrated Retail & Wholesale (IRW) Power System Test Bed

5-Bus 1-Feeder Example

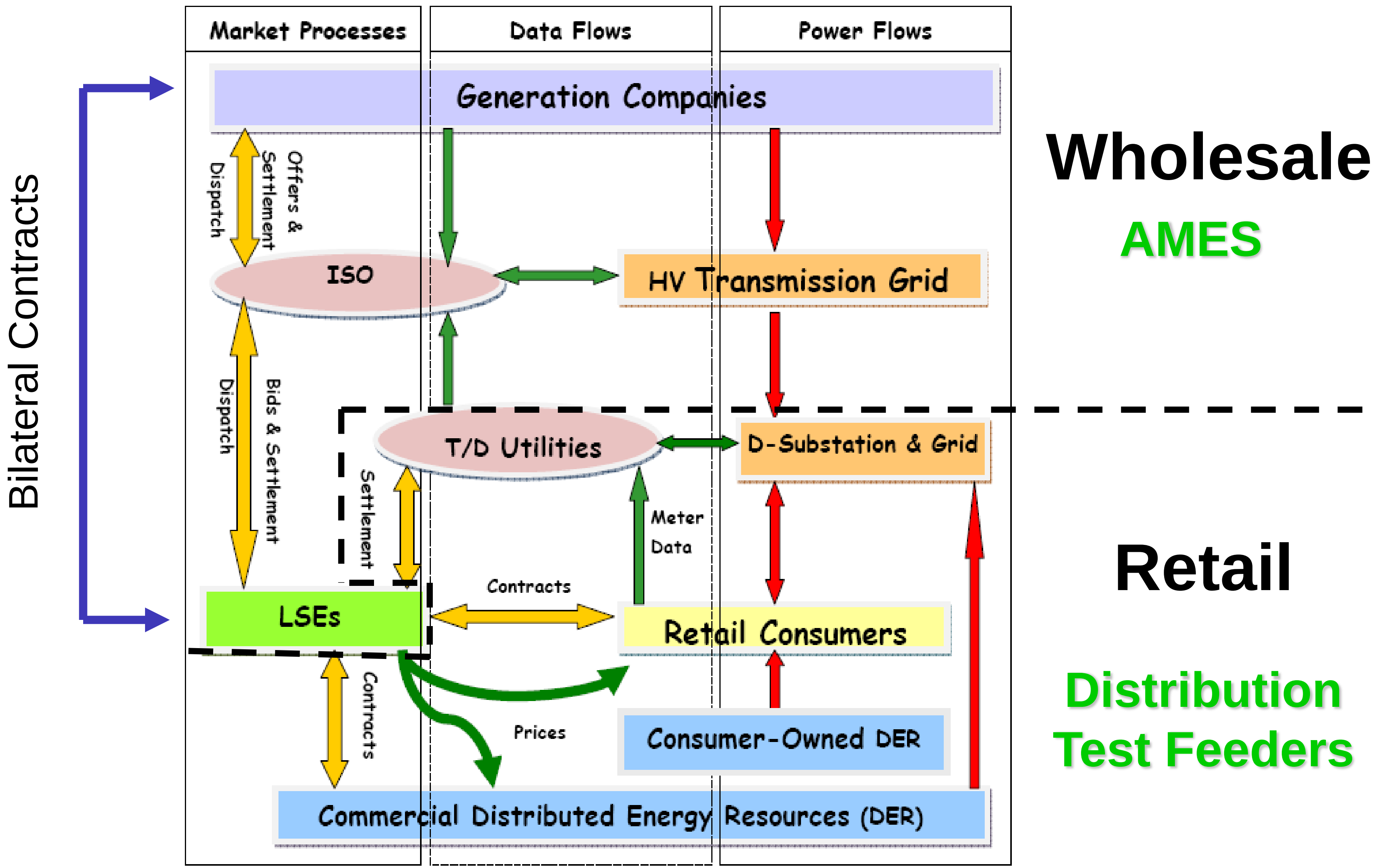


AMES Test Bed

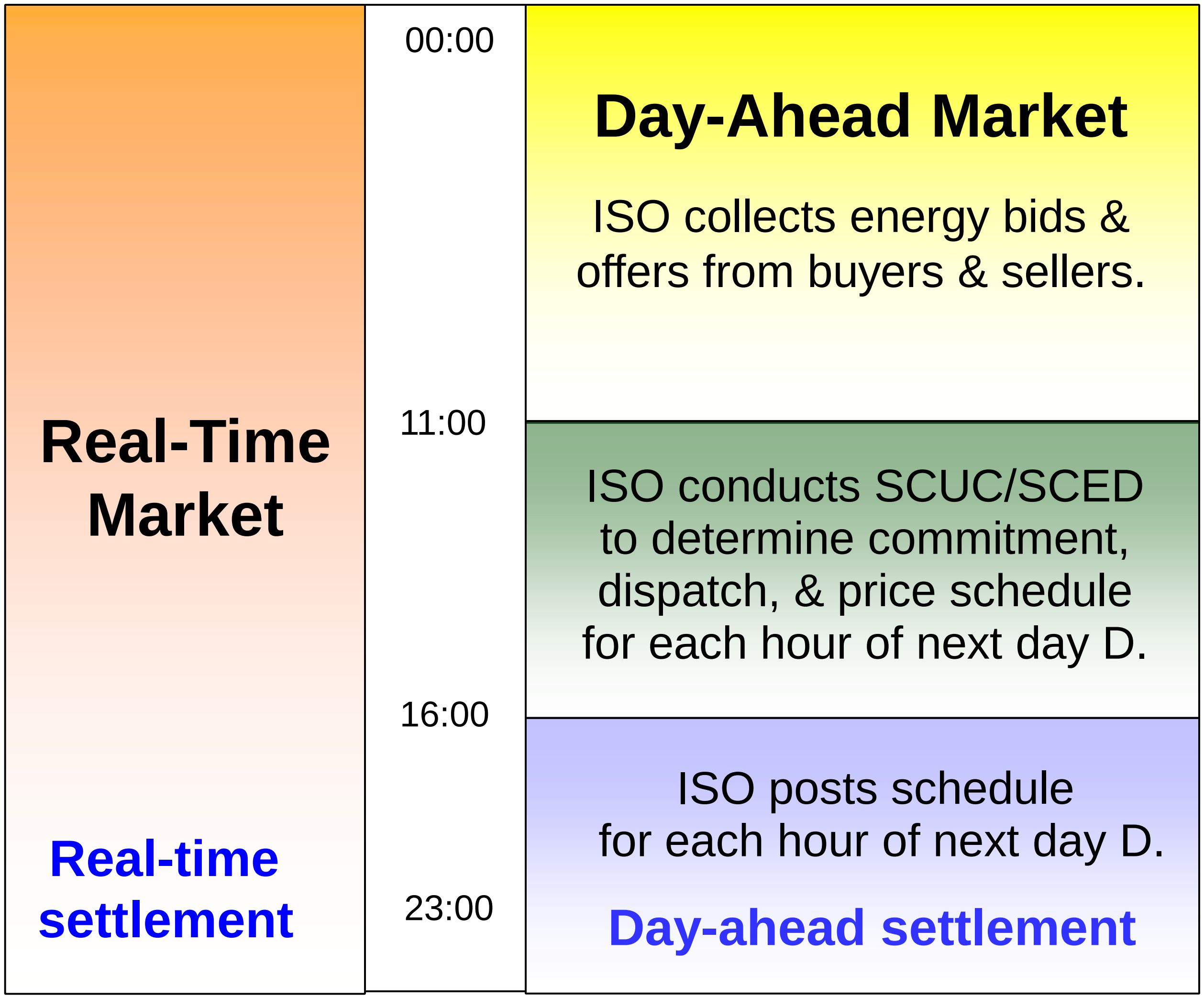


Distribution Test Feeders

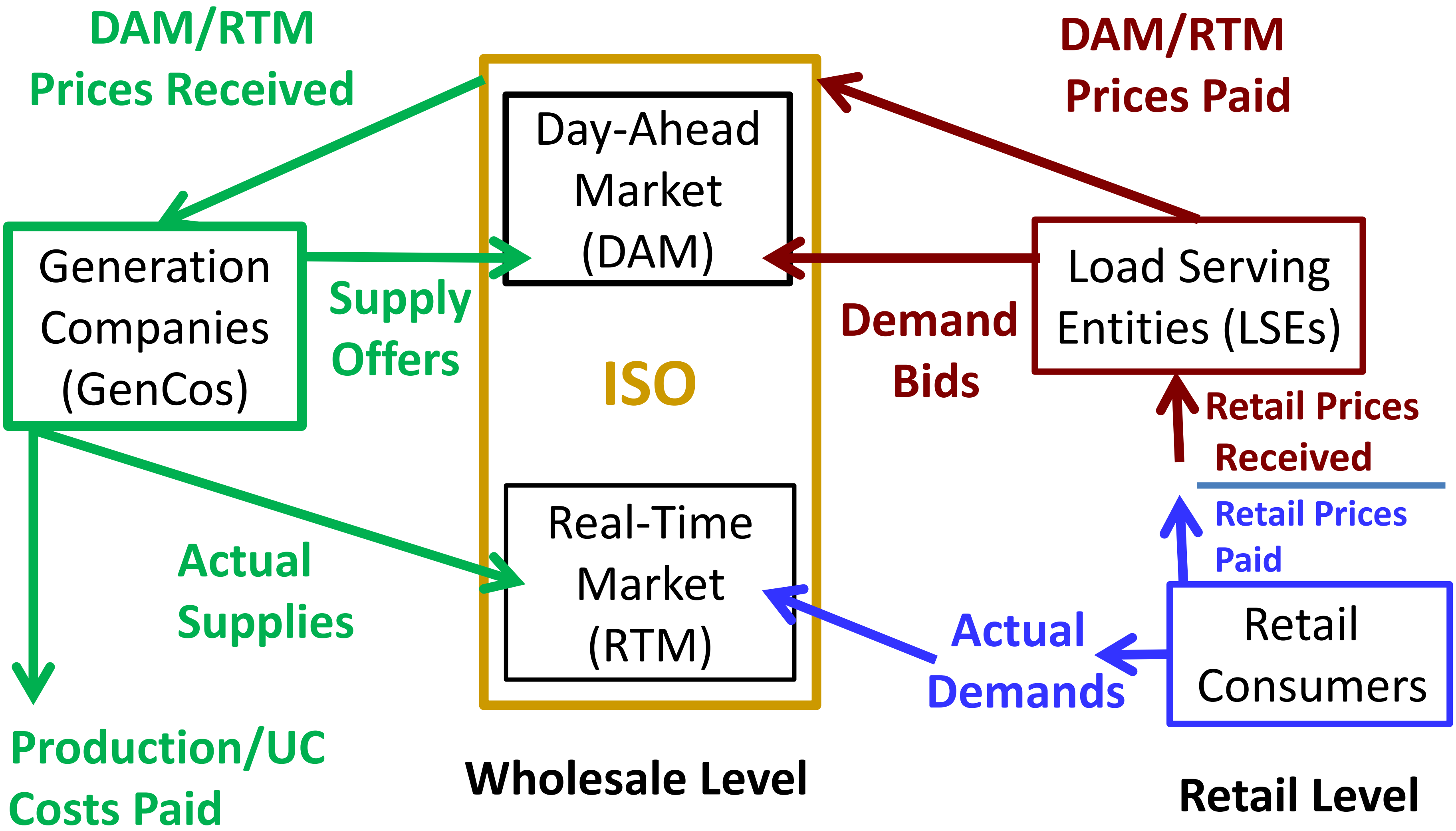
IRW Test Bed: An Agent-Based Test Bed for the TRL-5 Study of U.S. Electric Power Systems



Independent System Operator (ISO) activities during a typical day D-1



Economic Incentives for Retail & Wholesale Traders



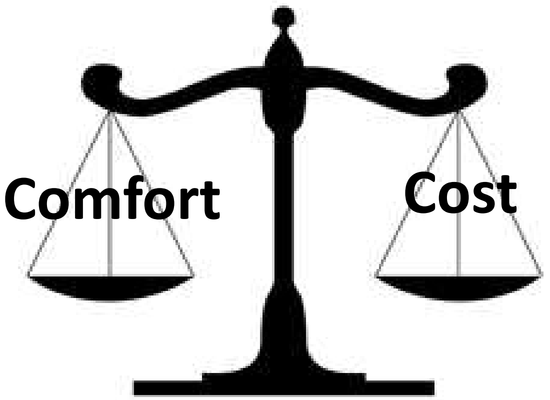
Application 1 (EPRC/PNNL Project):
System-wide performance when retail consumers use smart Air Conditioning (A/C) controllers

- A smart A/C controller for households has been developed by project members that implements a ***stochastic dynamic programming (DP) algorithm***

- On each day D-1, finds optimal 24-hour comfort/cost trade-offs (energy usages) for day D, given expected retail prices & environmental conditions for day D

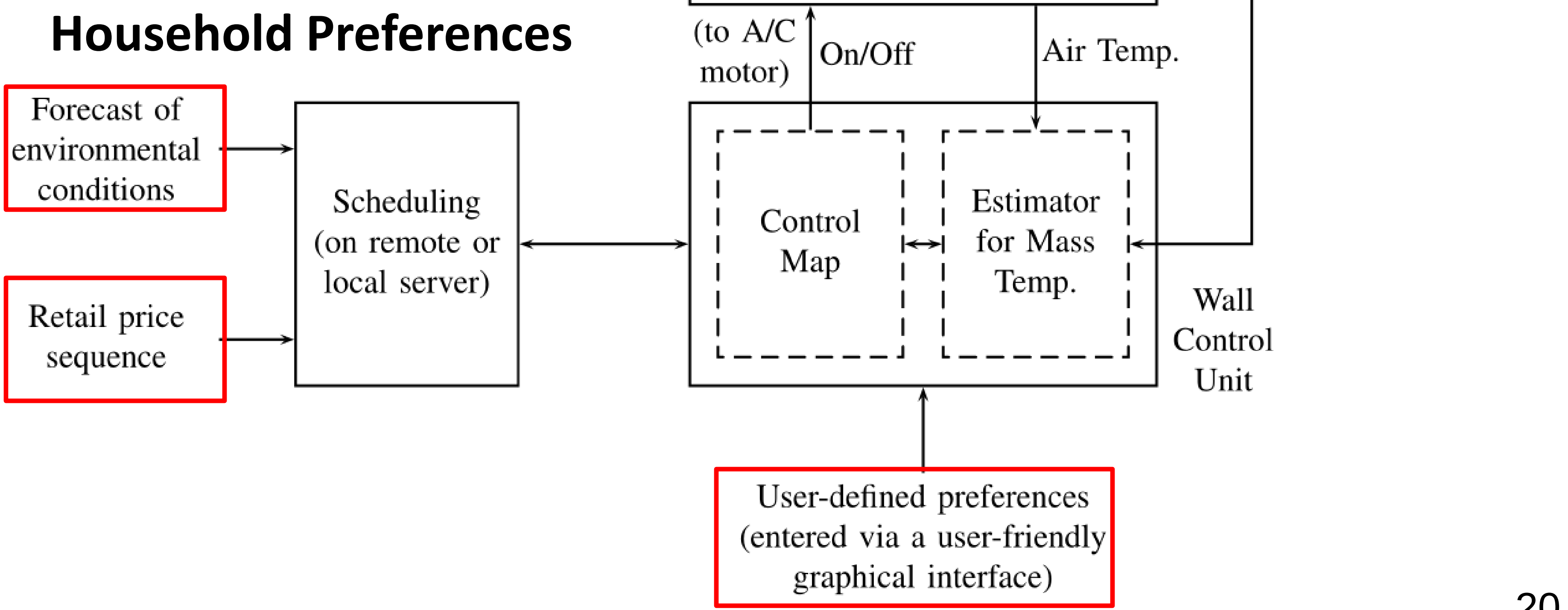
- IRW Test Bed is being used to study IRW effects when some households use this smart A/C controller

Application 1: Air-Conditioning (A/C) control via stochastic dynamic programming



Prices

Household Preferences



Application 2 (ARPAe/DOE project):

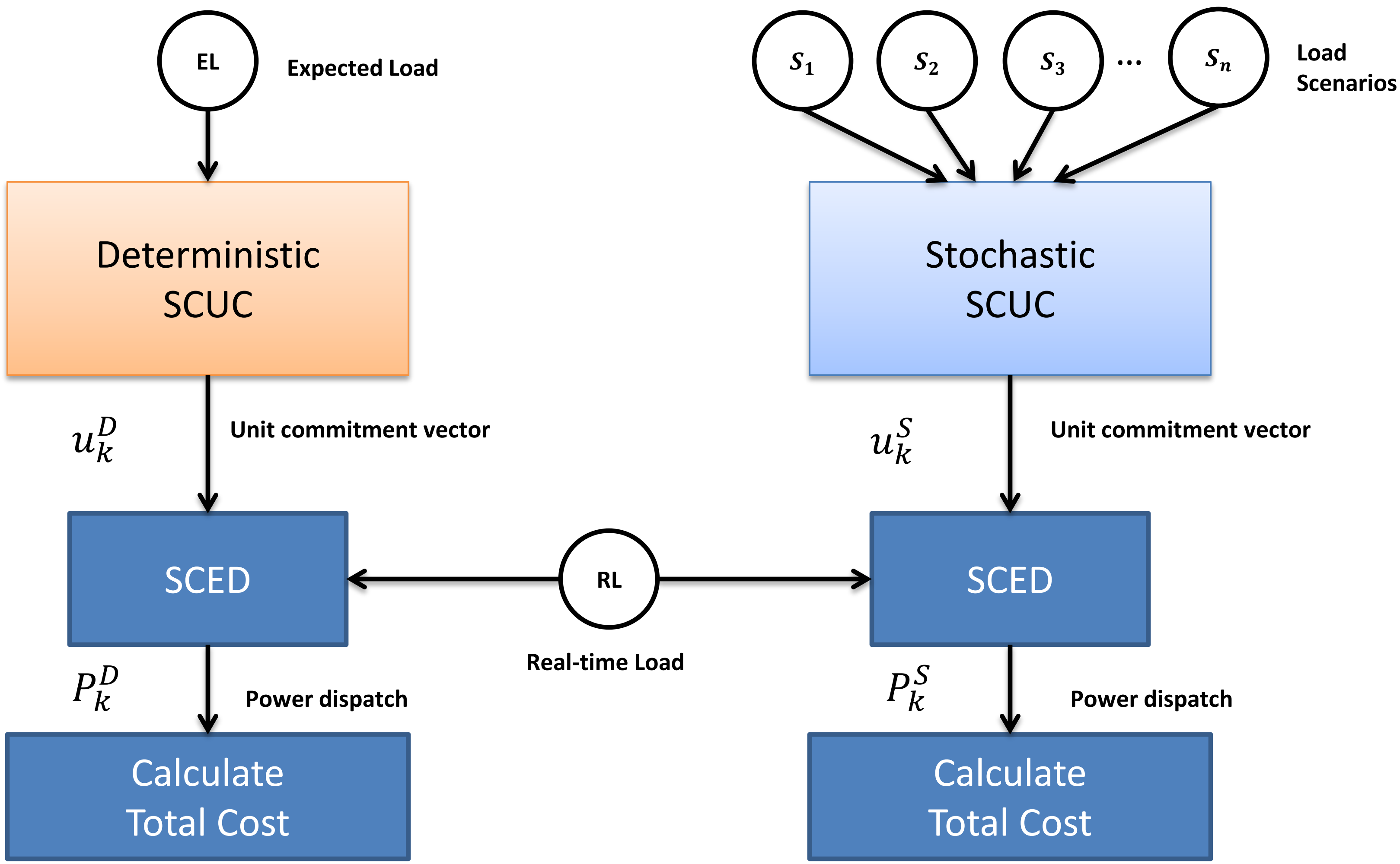
System-wide performance when ISO uses stochastic optimization for electric power generation scheduling

Project Goal:

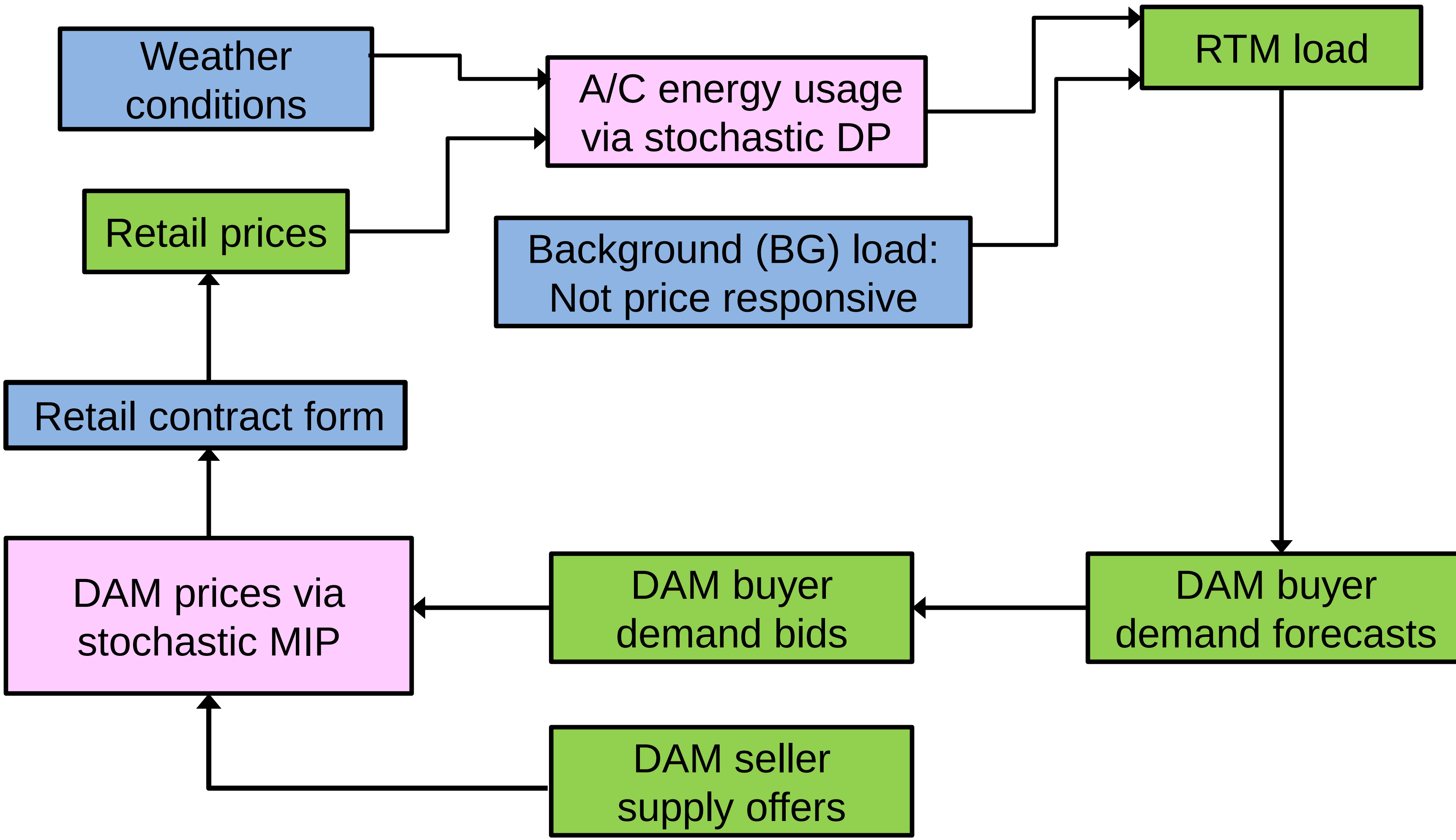
Develop/test a ***stochastic mixed-integer programming (MIP) algorithm*** for generation unit commitment under uncertainty

- ***Phase 1:*** Uncertainty arises from
  - variable conventional loads (washers, refrigerators,…)
  - wind generation
- ***Phase 2:*** Additional uncertainty arises from
  - price-sensitive retail demand (smart A/C, …)
  - strategic trading by learning traders

Application 2: Deterministic vs. stochastic MIP for Generation Security-Constrained Unit Commitment (SCUC)



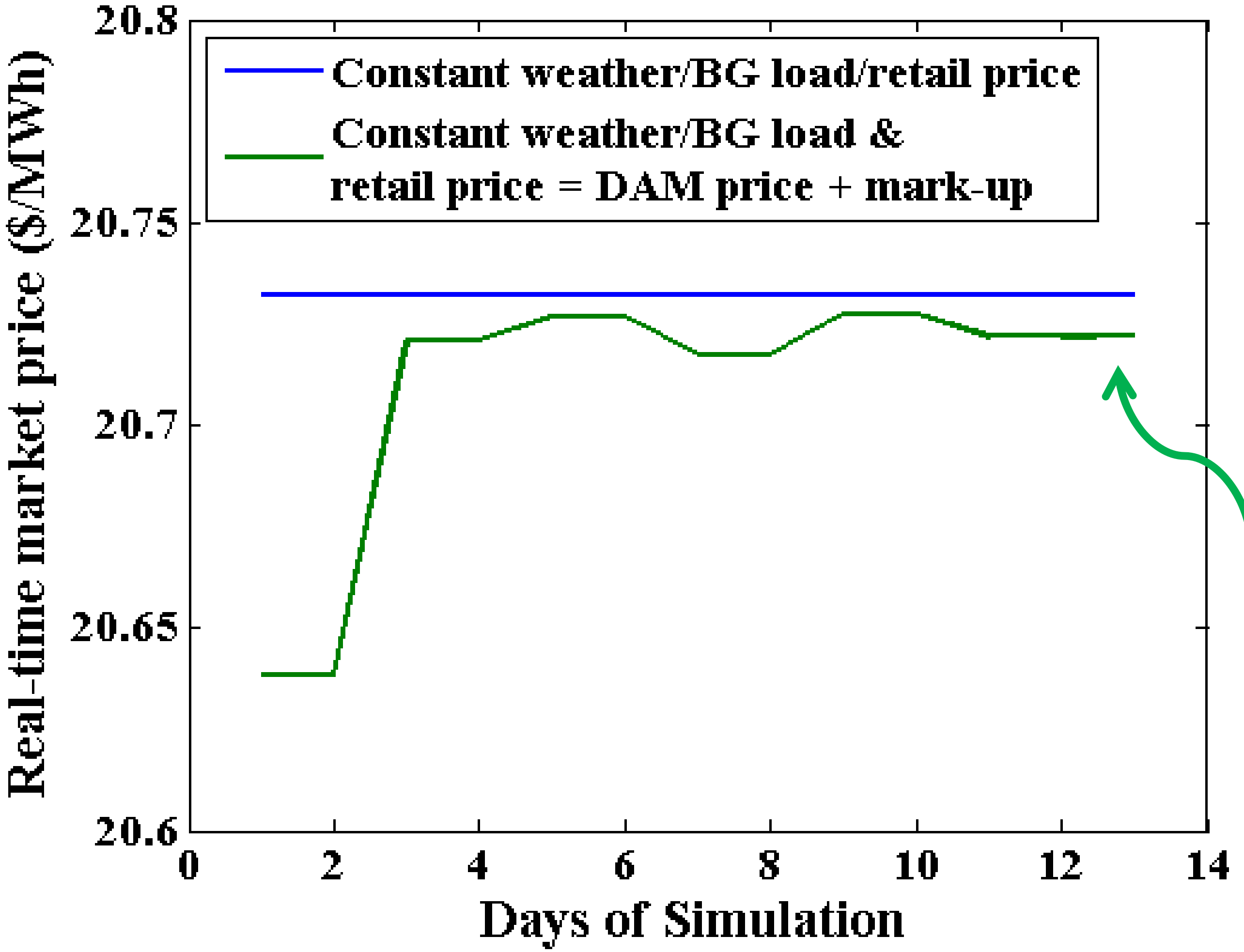
System-wide testing of stochastic DP & MIP optimization algorithms via IRW Test Bed



Illustrative System Outcomes for Application 1:

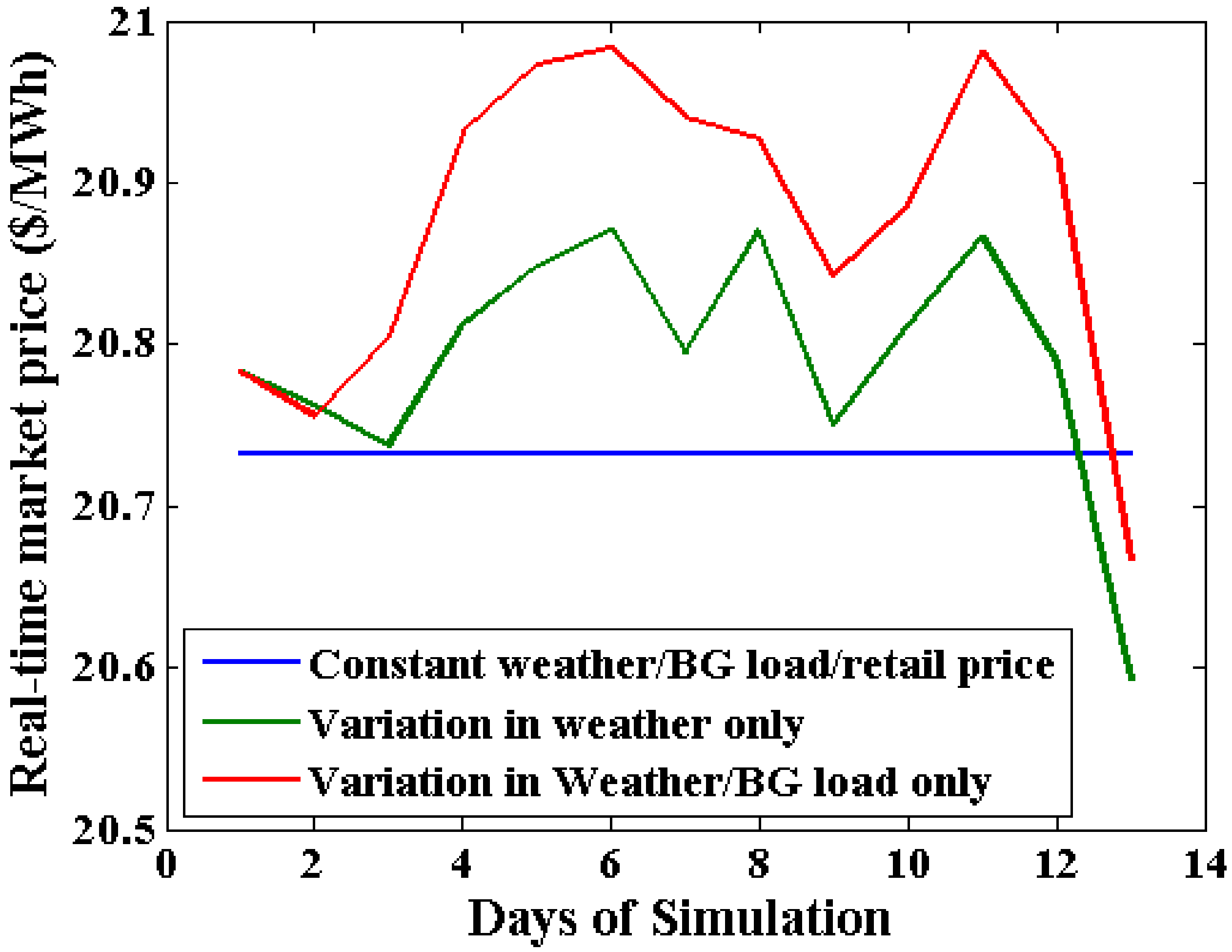
Retail A/C Energy Usage Determined via Stochastic DP

RTM price at feeder bus (peak hour 18) under different forcing-term & retail-price conditions

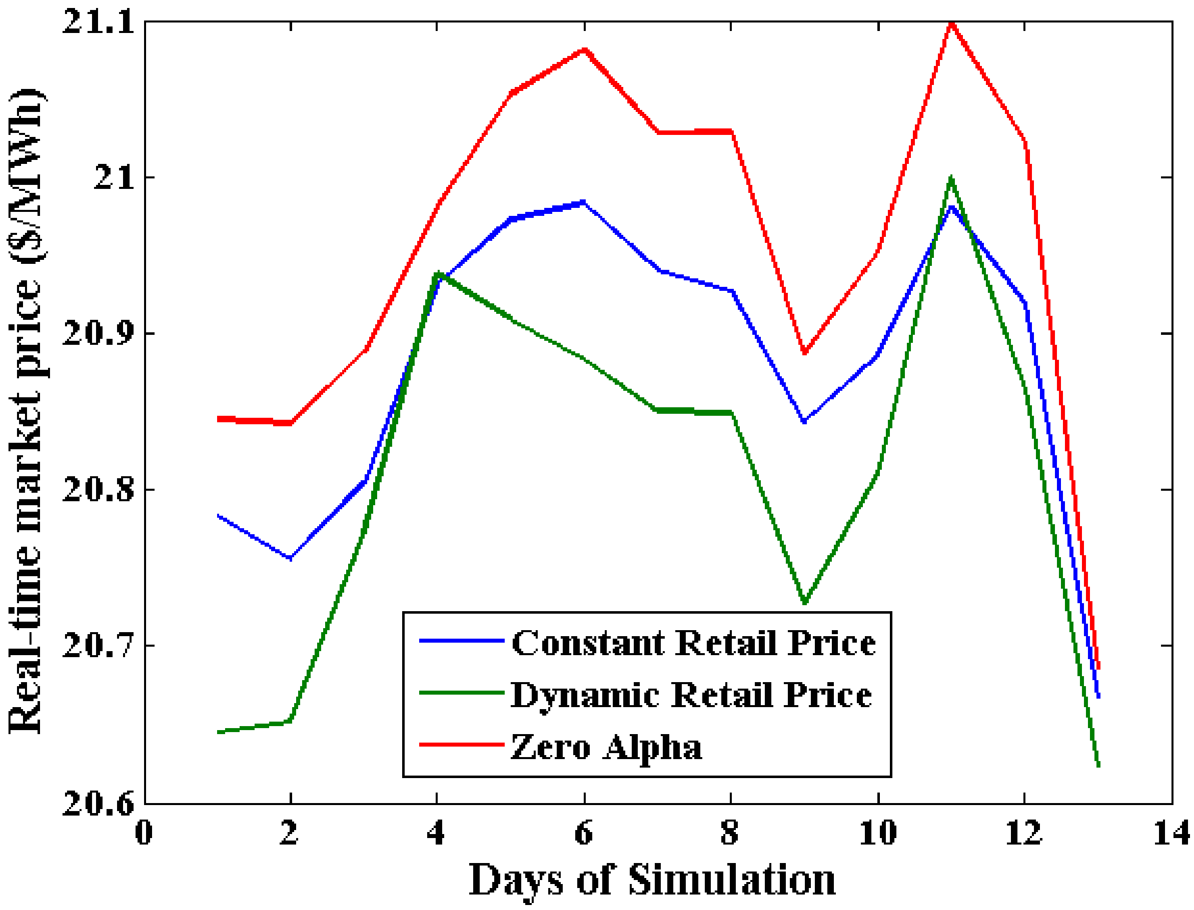


Wholesale price fluctuations arise due to price-responsive retail demand even ***without*** any variation in forcing terms

RTM price at feeder bus (peak hour 18)



RTM price at feeder bus (peak hour 18)



* Variation in weather and BG load

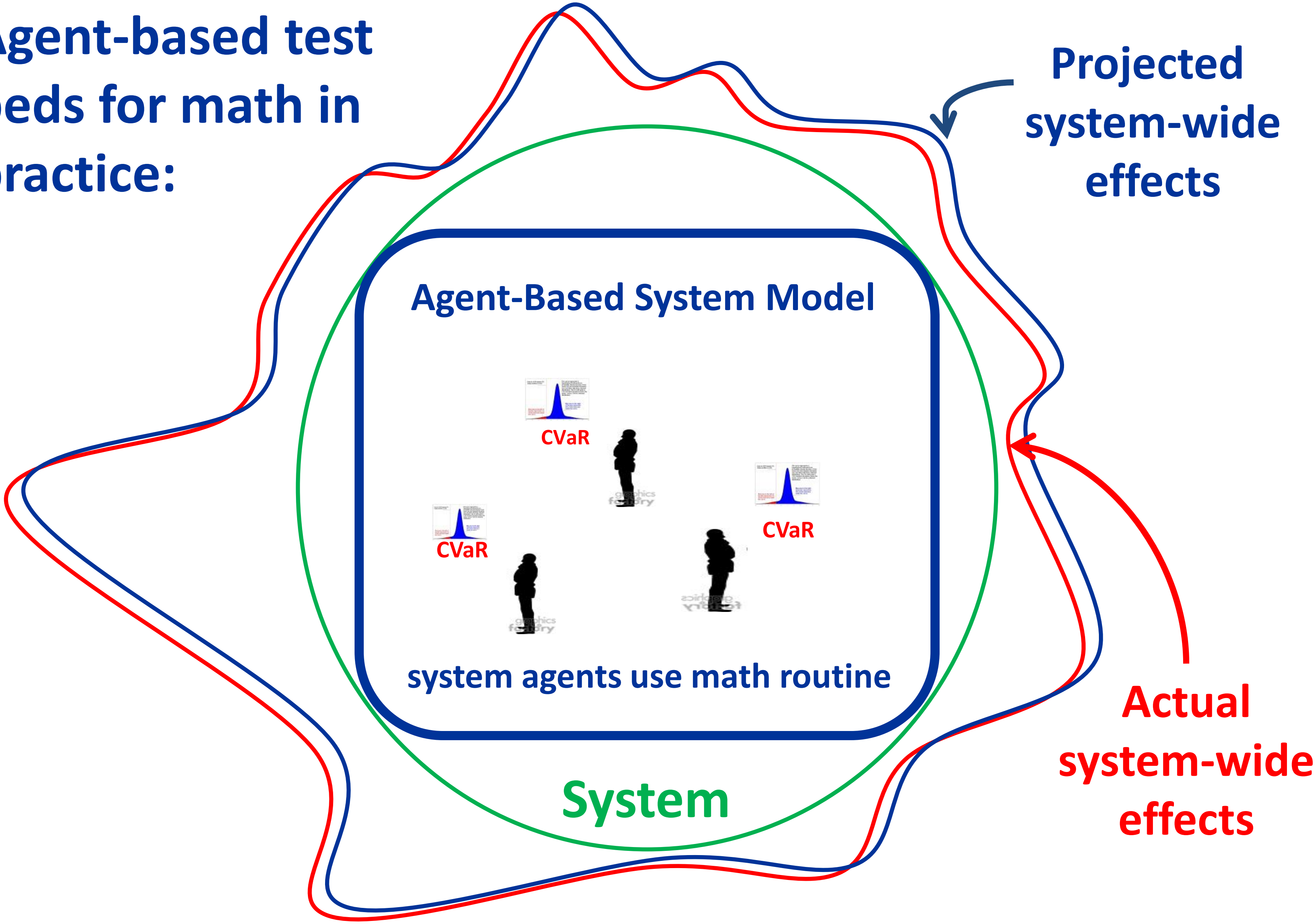
Illustrative System Outcomes for Application 2:

Deterministic vs. Stochastic MIP Optimization for Generation Unit Commitment

Start-Up & Shut-Down Cost Scaling Factor	No-Load Cost Scaling Factor	Deterministic Cost ($)	Stochastic Cost ($)	Total Cost Saving (%)
1	1	2231351	2188667	**1.912918**
	.5	2155709	2135438	**0.940348**
	.2	2115418	2107319	**0.382847**
.2	1	2224827	2195789	**1.305163**
	.5	2135083	2132208	**0.134664**
	.2	2116372	2102041	**0.677170**

* Outcomes for Base Test Case: Uncertainty arises from conventional load variation only, with 5% average load forecast error

Agent-based test beds for math in practice:



Explore system-wide effects via an agent-based test bed

On-Line Resources

- **IRW Project Homepage**

  www.econ.iastate.edu/tesfatsi/IRWProjectHome.htm

- **AMES Test Bed Homepage (Code/Manuals/Publications)**

  www.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

- **Agent-Based Electricity Market Research**

  www.econ.iastate.edu/tesfatsi/aelect.htm

- **Open Source Software for Electricity Market Research, Teaching, and Training**

  www.econ.iastate.edu/tesfatsi/electricoss.htm