Economic Systems as Locally-Constructive Sequential Games

The Places We Could Go!

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"You have brains in your head. You have feet in your shoes. You can steer yourself any direction you choose. You're on your own. And you know what you know. And YOU are the (one) who'll decide where to go…"

From: Dr. Seuss, 1990, *"Oh, the Places You'll Go!"*

Outline

- What is a “locally constructive sequential game” ?
- What is ***A***gent-based ***C***omp ***E***conomics (***ACE***)?
- ***The places we could go: Challenging issues and edgier explorations***
  - Explorations of critical real-world systems
  - Comprehensive empirical validation
  - Standardized “design readiness levels”
  - Spectrum of models from 100% human to 100% agents

Concerns All Economists Share

Real-world economic systems …

- How do they work?
- How could they work better?

Real-World Systems are Locally-Constructive Sequential Games

1) Heterogeneous interacting participants
2) Open-ended dynamic systems
3) Human participants are strategic decision-makers
4) All participants are locally constructive, i.e., constrained to act on the basis of their own states (data, attributes, methods) at each given time
5) Actions taken by participants at each given time affect states at subsequent times

Real-World Systems …

"Agent-based computational economics" permits the study of real-world systems as locally-constructive sequential games.

*A*gent-based *C*omputational *E*conomics (*ACE*)

http://www2.econ.iastate.edu/tesfatsi/ace.htm

- ***ACE*** is the computational modeling of economic processes (including whole economies) as open-ended dynamic systems of interacting agents

Goals:

- Enable modeling of systems for which coordination is a possibility, not a modeler-imposed restriction
- Let agents be as free to act within their virtual worlds as their empirical counterparts within the real world

ACE Modeling Principles (MP1) – (MP7)

(MP1) Agent Definition: An ***agent*** is a software entity within a computationally constructed world capable of acting over time on the basis of its own state, i.e., its own internal data, attributes, and methods

(MP2) Agent Scope: Agents can represent individuals, social groupings, institutions, biological entities, &/or physical entities

(MP3) Agent Local Constructivity: The action of an agent at any given time is determined as a function of the agent's own state at that time.

ACE Modeling Principles…

(MP4) Agent Autonomy: Coordination of agent interactions cannot be externally imposed by means of free-floating restrictions, i.e., restrictions not embodied within agent states.

(MP5) System Constructivity: The state of the modeled system at any given time is determined by the ensemble of agent states at that time

(MP6) System Historicity: Given initial agent states, all subsequent events are determined solely by agent interactions.

(MP7) Modeler as Culture-Dish Experimenter: The role of the modeler is limited to the setting of initial agent states and to the non-perturbational observation, analysis, and reporting of model outcomes.

ACE Modeling Principles …

- Together, (MP1) through (MP7) embody the idea that an ACE model is a *computational laboratory.*
- An ACE model *permits a user to explore* how changes in initial conditions affect outcomes in modeled systems over time.
- This exploration process is *analogous to biological experimentation with cultures in petri dishes*.

Explorations of Critical Real-World Systems

ACE modeling tools can be used to

- Advance traditional economic goals
- Conduct edgier explorations

Four Main Strands of ACE Research

1) **Empirical Understanding**
   (possible explanations for empirical regularities)

2) **Normative Design**
   (institutions, policies, regulations …)

3) **Qualitative Insight/Theory Generation**
   (e.g., self-organization of decentralized markets, …)

4) **Method/Tool Advancement** (representation, visualization, empirical validation, …)

1) ACE and Empirical Regularities

Key Issue: Is there a causal explanation for persistently observed empirical regularities?

ACE Approach:

- Construct an agent-based world capturing salient aspects of the empirical situation.
- Investigate whether the empirical regularities can be reliably generated as outcomes in this world.

Example: ACE financial market research seeking explanation of several "stylized facts" in combination.
http://www2.econ.iastate.edu/tesfatsi/afinance.htm

2) ACE and Normative Design

Key Issue: Will a proposed design ensure efficient, fair, and orderly outcomes over time, even if participants attempt to "game" it for own advantage?

ACE Approach:

- Construct an agent-based world capturing salient aspects of the design.
- Introduce decision-making agents with behavioral dispositions, needs, goals, beliefs, and feasible action domains appropriate for purpose at hand. Let world evolve. Observe and evaluate resulting outcomes.

EXAMPLES: Design of auctions, stock exchanges, electricity markets, automated Internet markets (B2B, job markets, eBay,…), policy rules

http://www2.econ.iastate.edu/tesfatsi/aapplic.htm

3) ACE and Qualitative Analysis

Illustrative Issue: Performance capabilities of macroeconomies based on decentralized markets? *(Adam Smith, F. von Hayek, J.M. Keynes, J. Schumpeter, ...)*

ACE Approach:

- Construct an agent-based world qualitatively capturing key aspects of the economy (firms, consumers, banks, government, circular flow, limited information, …)
- Introduce traders with behavioral dispositions, needs, goals, beliefs, … . Let the world evolve & observe results.

ACE Macro Resource Site: (Annotated pointers to research papers, software, and research groups)

http://www2.econ.iastate.edu/tesfatsi/amulmark.htm

Illustrative ACE Applications

- Combined game & matching models
- Labor markets
- Macroeconomics
- Critical infrastructure systems
- Coupled natural and human systems

Decision-making agents in ACE models can …

- Talk back & forth with each other
- Choose/refuse whom they interact with
- Behave strategically with selected partners
- Evolve their behavioral strategies over time

Evolutionary game theory + Search/matching theory

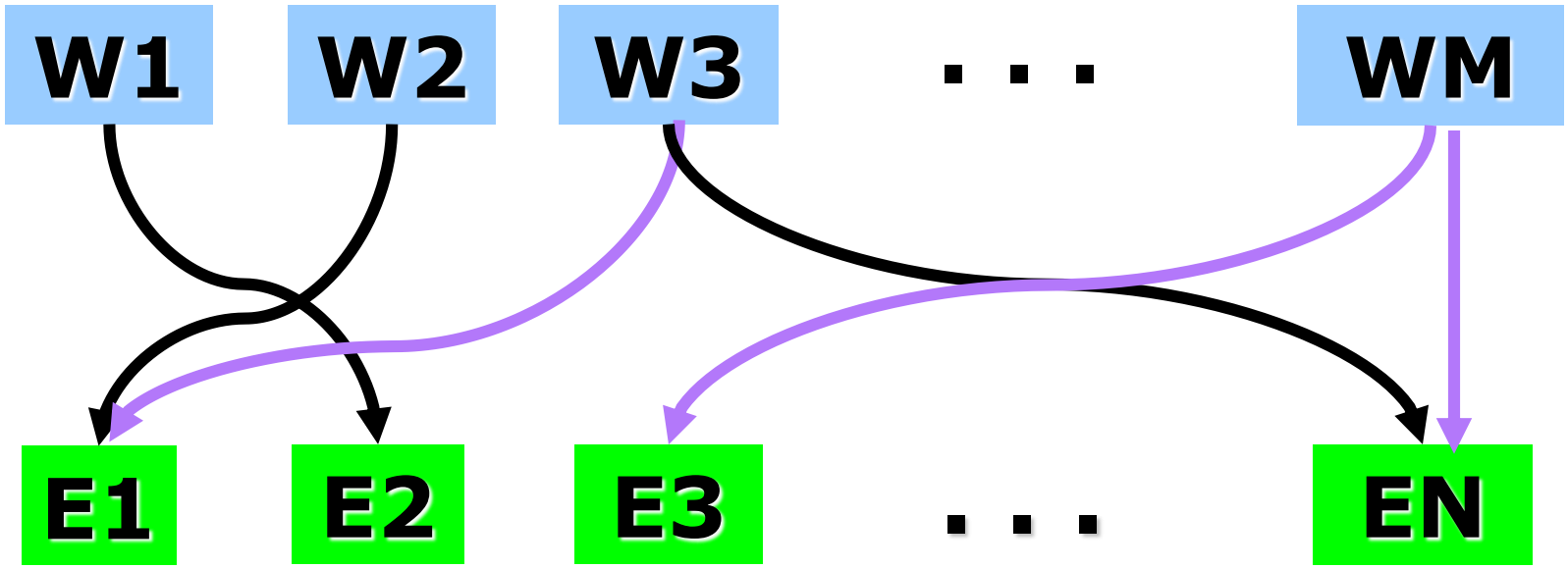
Examples:

1) L. Tesfatsion, "Structure, Behavior, and Market Power in an Evolutionary Labor Market with Adaptive Search, *Journal of Economic Dynamics and Control,* 25(1), 2001, 419-457

http://www2.econ.iastate.edu/tesfatsi/StructBehMPLabor.JEDC01.LT.pdf

2) **The Trade Network Game Laboratory: Homepage**
http://www2.econ.iastate.edu/tesfatsi/tnghome.htm

ACE Labor Market in JEDC (2001): Worker-Employer Network Formation Game



Job search with preferential choice/refusal of worksite partners. **Purple = refused work offers; Black = accepted work offers.** Matched traders play worksite games. Workers use genetic algorithms to evolve game strategies. Hiring, quits, and firings are *endogenously* determined in each work period.

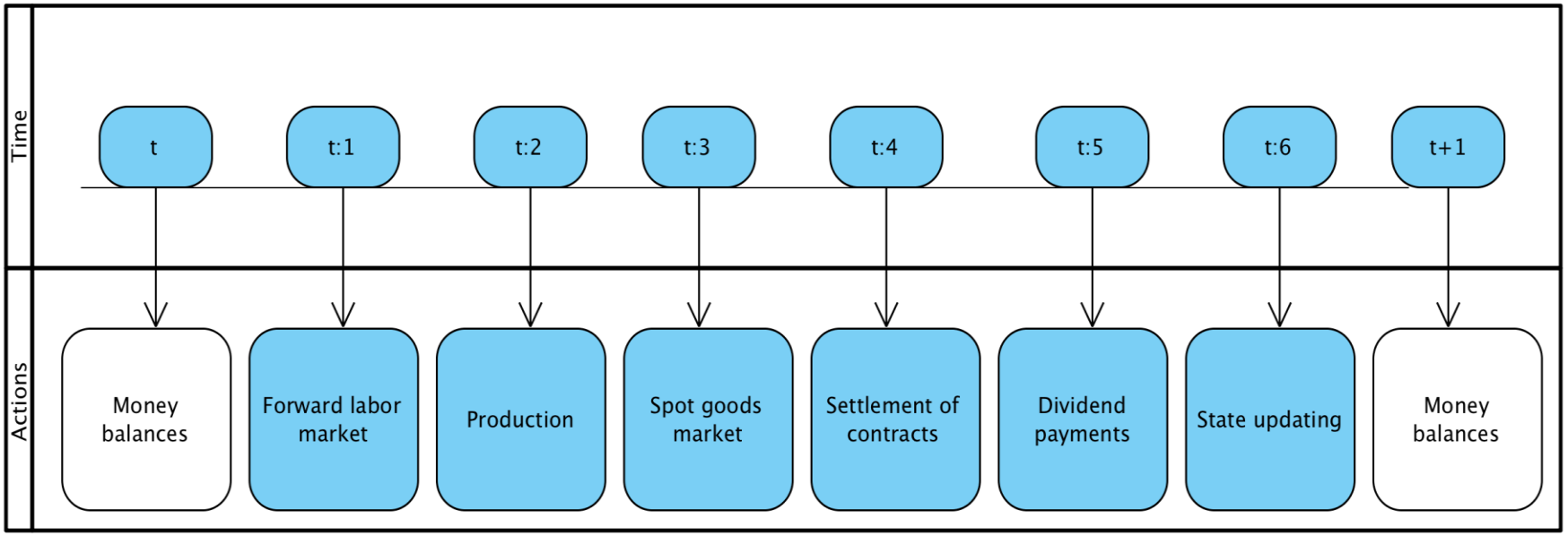
Macroeconomic Application:

DSGL = DSGE + Learning Agents

http://www2.econ.iastate.edu/tesfatsi/amulmark.htm

Example: E. Sinitskaya & L. Tesfatsion, "Macroeconomies as Constructively Rational Games," *Journal of Economic Dynamics and Control*, Vol. 61, 2015, 152-182. Working Paper version online at:

http://www2.econ.iastate.edu/tesfatsi/MacroConstructiveRationalityWP.SinitskayaTesfatsion.pdf



Sequence of Activities During a Typical Period t

- **Consumers and firms have intertemporal utility/profit maximization goals**
- **Four types of locally-constructive decision methods are tested for consumers and firms**

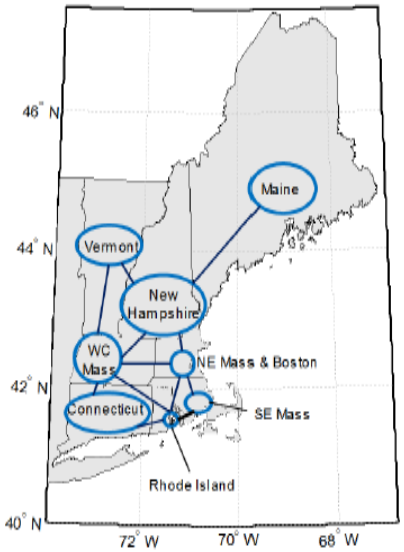
- ***Reactive Learner:*** If this has happened, what should I do?
  - **RL**: Reactive learner that uses a modified version of a Roth-Erev reinforcement learning algorithm (Roth/Erev GEB 1995, AER 1998)

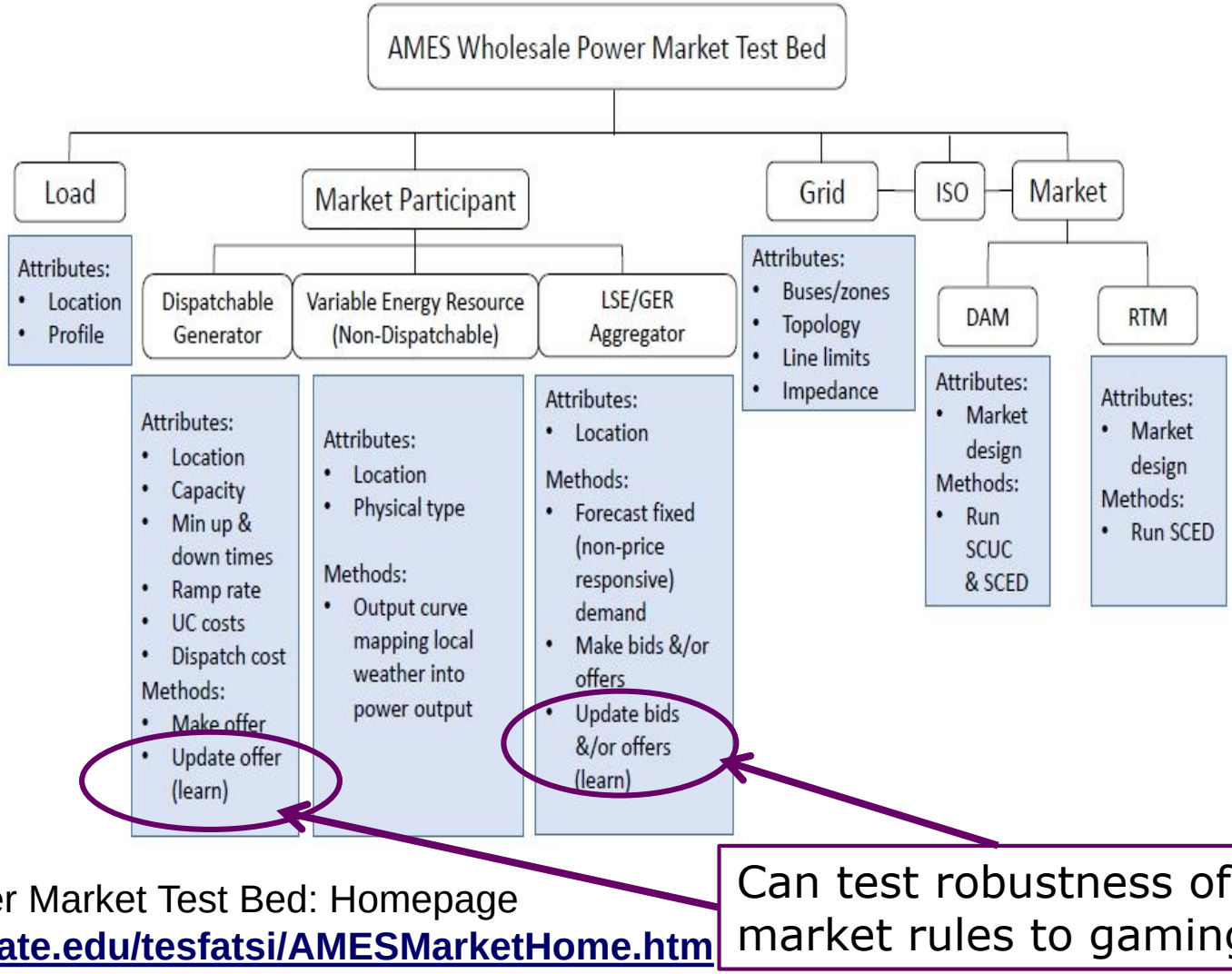
- ***Anticipatory Learner:*** If I do this, what will happen?
  - **FL**: Forward-learner that uses Q-learning (Watkins, 1989)
  - **EO-FH**: Explicit optimizer that uses a rolling-horizon learning method
  - **EO-ADP**: Explicit optimizer that uses an adaptive dynamic programming learning method (value function approximation)

Key Findings: E. Sinitskaya & L. Tesfatsion, JEDC, 2015

- Good performance requires decision-makers to engage both in the exploitation of their current information and in searches for new information.
- Simpler decision rules with some degree of anticipatory learning can outperform more sophisticated decision rules.
- **Best performance is attained when consumers and firms *all* use rolling fixed-horizon (EO-FH) decision rules.** This decision-rule configuration for firms and consumers is
  - ***Pareto efficient***
  - ***Nash equilibrium***

AMES = *A*gent-based *M*odeling of *E*lectricity *S*ystems



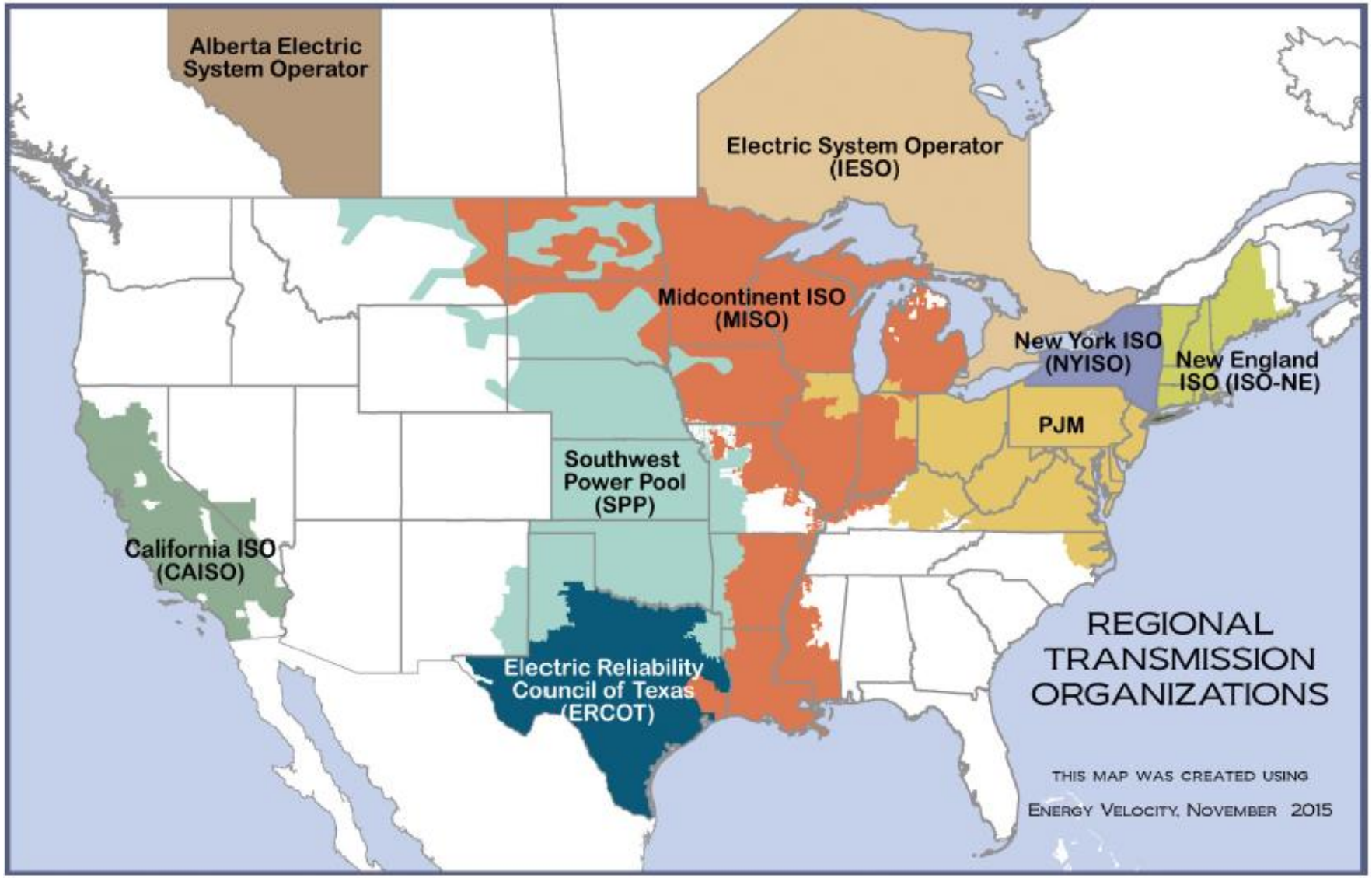


Can test robustness of market rules to gaming

AMES Wholesale Power Market Test Bed: Homepage
http://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

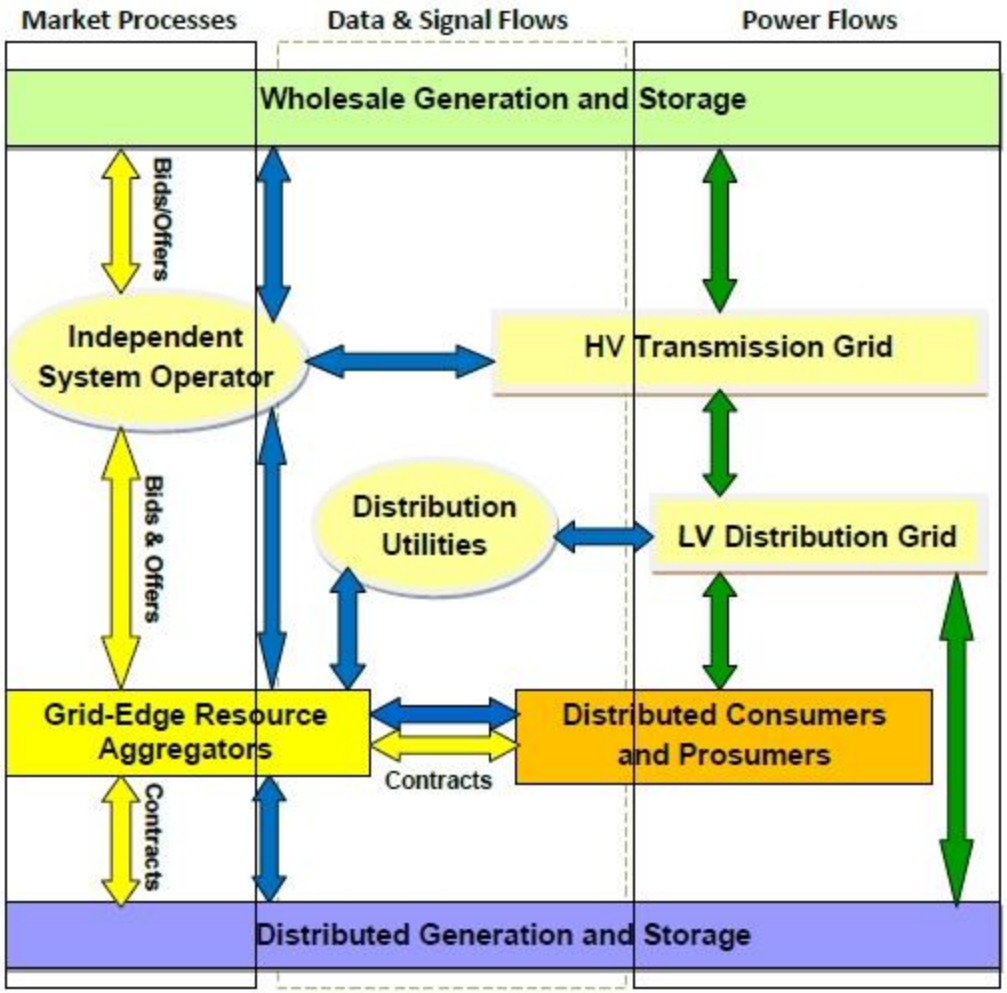
D. Krishnamurthy, W. Li, L. Tesfatsion, An 8-Zone Test System based on ISO New England Data: Dev. and Application, *IEEE Transactions on Power Systems* 31(1), 2016, 234-246.
http://www2.econ.iastate.edu/tesfatsi/8ZoneISONETestSystem.RevisedAppendix.pdf

North American Centrally-Managed Wholesale Electric Power Markets (2015)



Electricity Market Design

L. Tesfatsion, "Electric Power Markets in Transition: Agent-Based Modeling Tools for Transactive Energy Support," Chapter 13 (pp. 715-766) in Hommes & LeBaron (Eds.), Handbook of Computational Economics IV, Elsevier, 2018.
http://www2.econ.iastate.edu/tesfatsi/ElectricPowerMarketDesign.TESHandbookChapter.LTesfatsion.pdf



ACE models can be used to ***represent*** real-world market processes

PLUS

ACE modeling principles can be used to ***design*** markets for real-world implementation

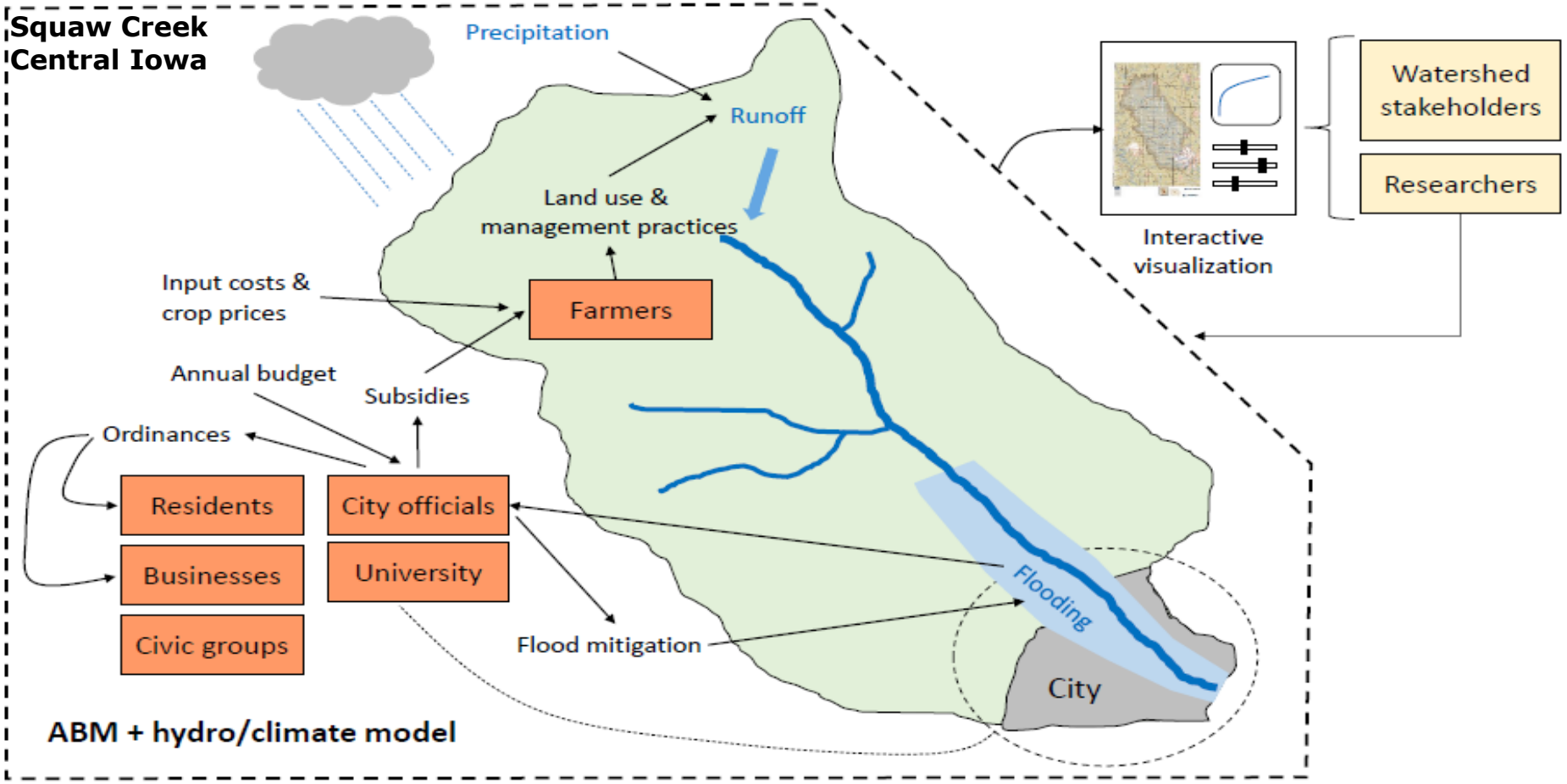
Economic Processes as Key Components of Larger Systems

- ACE permits modeling of econ processes as critical components of ***Coupled Natural & Human (CNH) systems***

- CNH systems can be dynamic & spatial

→ **Broader ranges of causal factors can be considered (not just economic)**

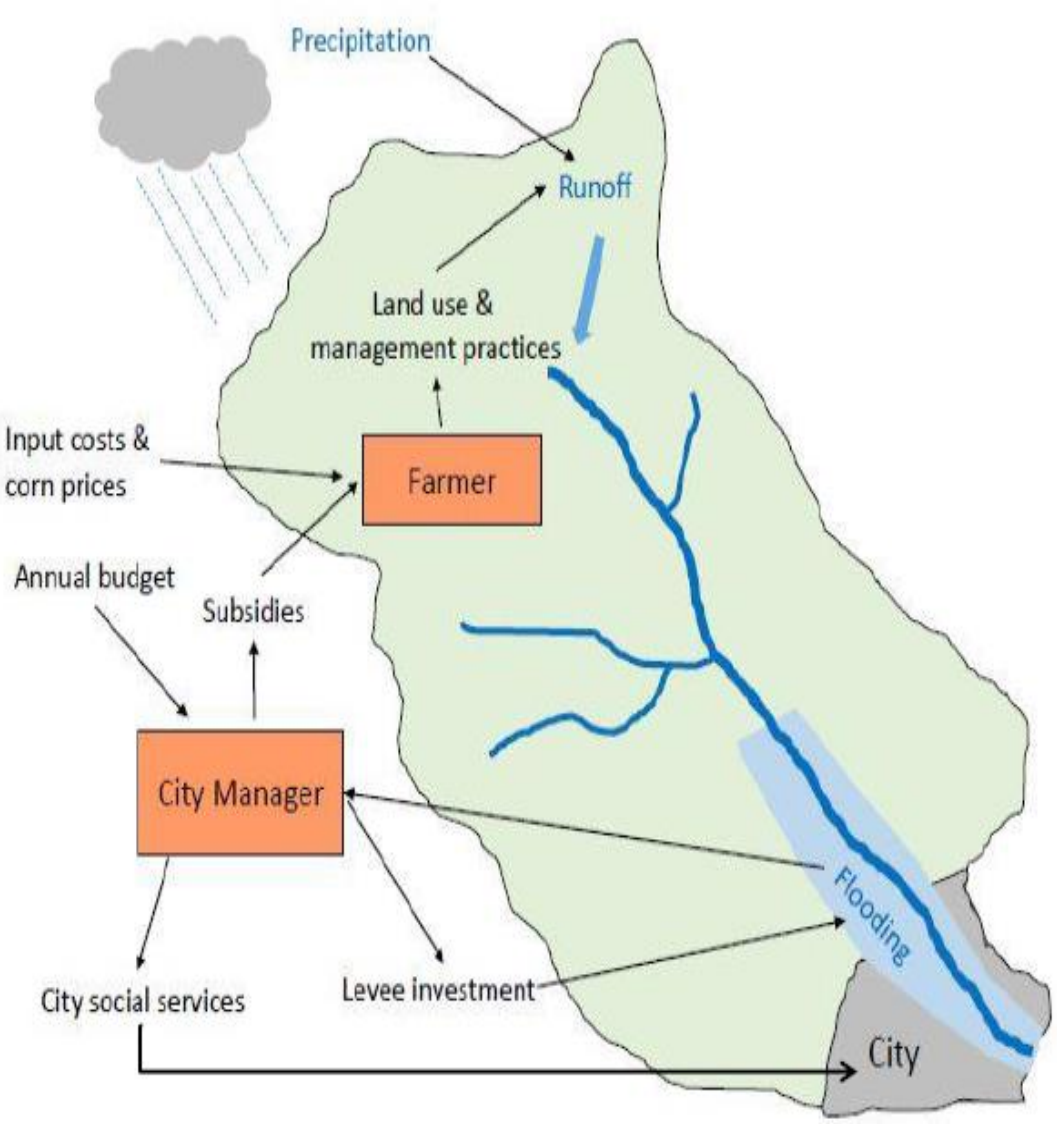
Example: ACE Watershed Local Governance Study



L. Tesfatsion, C.R. Rehmann, D.S. Garcia, Y. Jie, W.J. Gutowski, An Agent-Based Platform for the Study of Watersheds as Coupled Natural and Human Systems, *Environmental Modelling & Software,* Vol. 89 (March), 2017, 40-60

http://www2.econ.iastate.edu/tesfatsi/WACCShedPlatform.RevisedWP15022.pdf

Basic ACE Watershed Model:



Decision-Making Agents:

Corn Farmers (land allocation, planting)

City Manager (budget allocation, subsidies)

Physical Environment:

Weather (precipitation)

Watershed hydrology

- water inflow → discharge rate

Land attributes

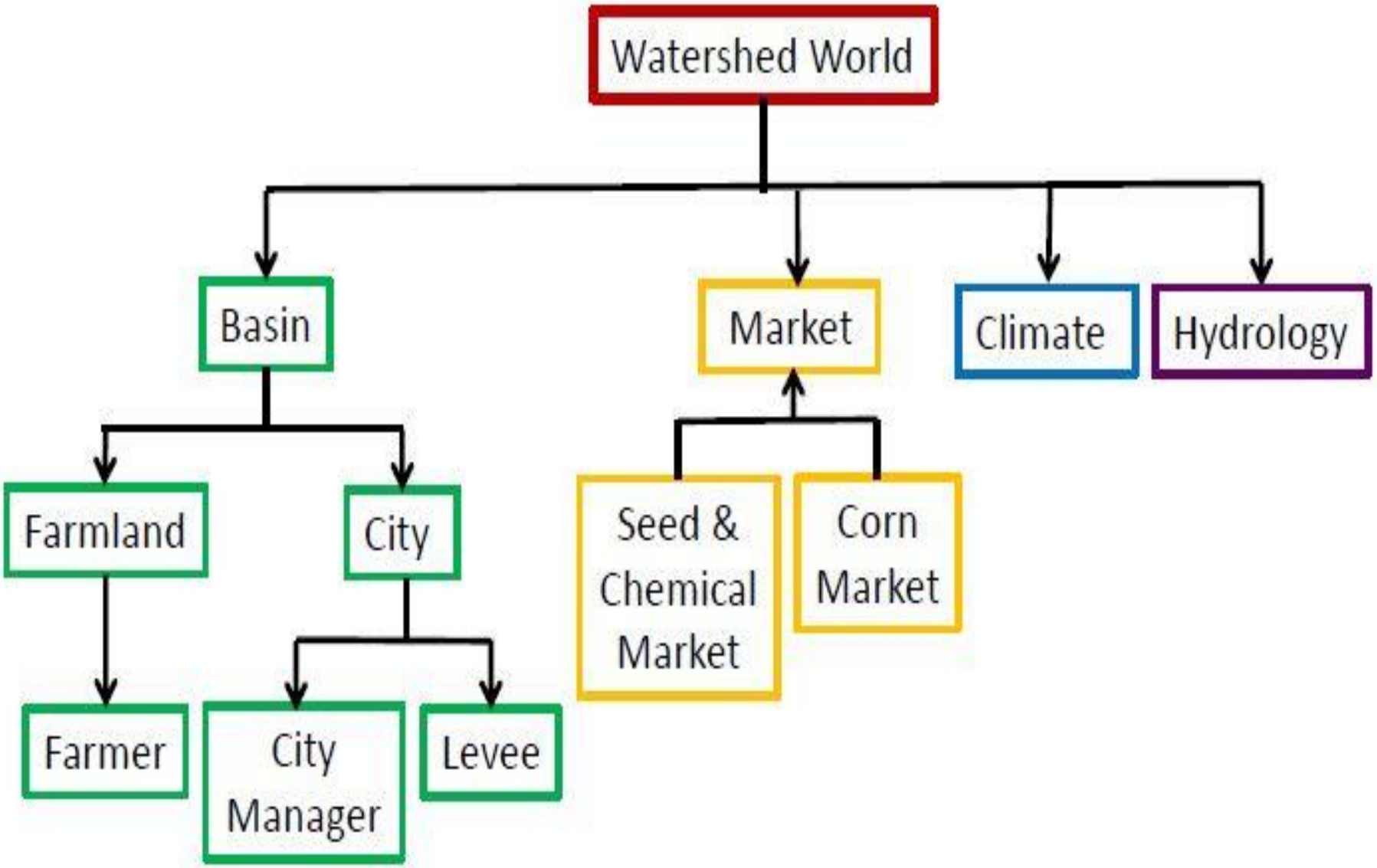
- run-off, harvest productivity

Market Environment:

Input costs ($/acre) for planting

Market price of corn ($/bushel)

Agent Taxonomy for the Basic ACE Watershed Model



ACE Facilitates Comprehensive Empirical Validation

http://www2.econ.iastate.edu/tesfatsi/EmpValid.htm

EV1. Input Validation: Are the exogenous inputs for the model empirically meaningful and appropriate for the purpose at hand?

> ***Examples:*** Initial state conditions, functional forms, shock realizations, data-based parameter estimates, &/or parameter values imported from other studies

EV2. Process Validation: How well do modeled physical, biological, institutional, and social processes reflect real-world aspects important for the purpose at hand? Are all process specifications consistent with essential scaffolding constraints, such as physical laws, stock-flow relationships, and accounting identities?

Comprehensive Empirical Validation…Cont'd

EV3. Descriptive Output Validation:
How well are model-generated outputs able to capture the salient features of the sample data used for model identification? (**in-sample fitting**)

EV4. Predictive Output Validation:
How well are model-generated outputs able to forecast distributions, or distribution moments, for sample data withheld from model identification or for data acquired at a later time? (**out-of-sample forecasting**)

Standardized Design Readiness Levels

DRL-1: Conceptual design idea

DRL-2: Analytic formulation

DRL-3: Low-fidelity model

Basic research carried out at universities...

DRL-4: Moderate-fidelity small-scale model

DRL-5: High-fidelity small-scale model

DRL-6: Prototype small-scale model

Infamous "Valley of Death"

DRL-7: Prototype large-scale model

DRL-8: Field study

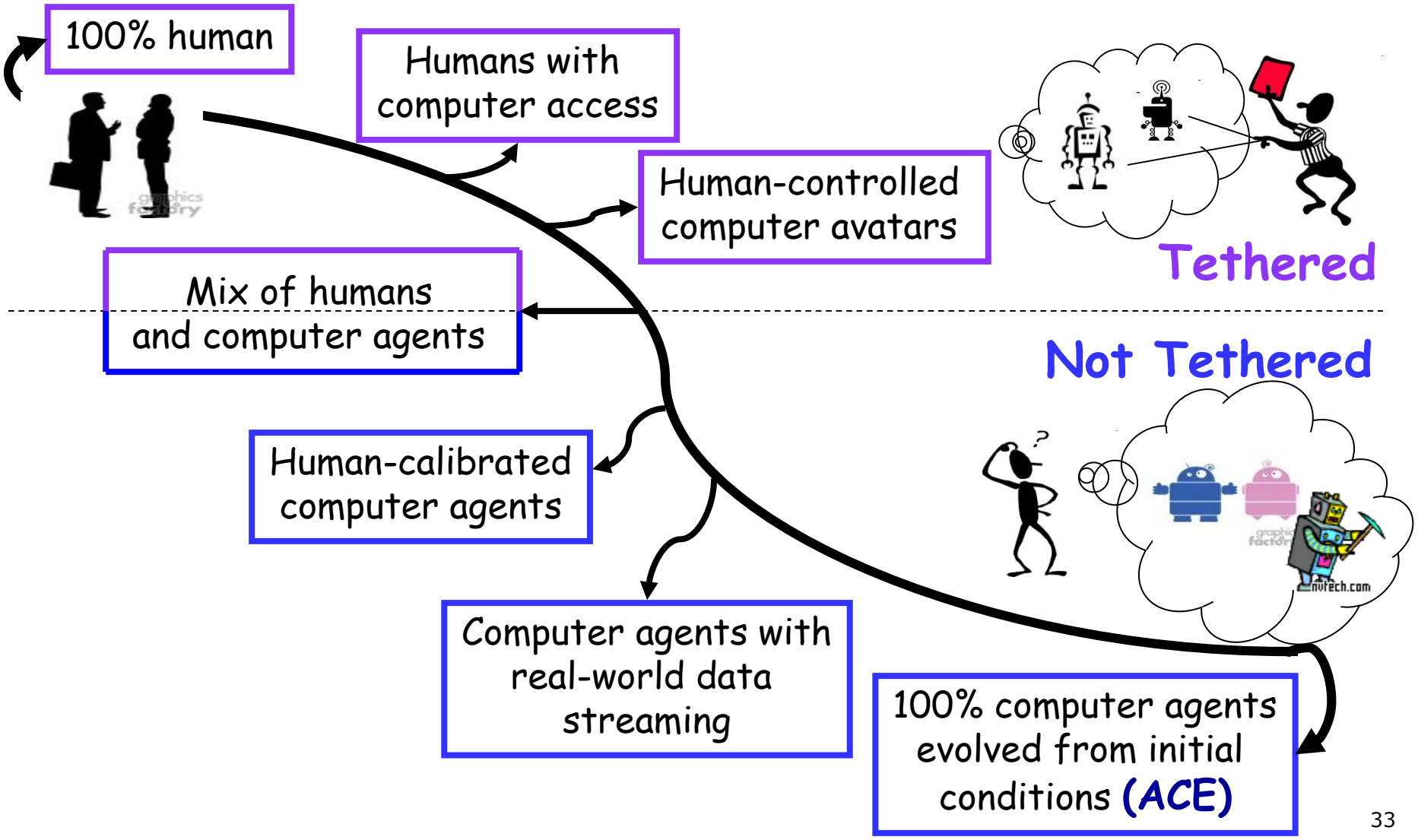
DRL-9: Real-world implementation

Industry, government, regulatory agencies

ACE Can Help Bridge the Valley of Death (DRLs 4-6)

- Infrequency of studies within DRLs 4-6 ("Valley of Death") hinders development of designs from *Concept* ➡ *Implementation*
- ACE is well suited for bridging this valley
- ACE computational platforms permit design performance testing at DRLs 4-6
- Proof-of-Concept: Electricity market research

ACE is a Limit Point for a Spectrum of Possible Experiment-Based Modeling Methods



Conclusion

- ACE is a useful addition to the toolkits of researchers studying real-world systems
- ACE modeling principles have been designed to promote clarity and practical applicability
- **But much remains to be done**

  Empirical validity, DRLs, presentation protocols, edgier explorations, demonstrate value-added for big-time applications, explore spectrum of models…

On-Line ACE Resource Sites

- **ACE Website: Homepage**

  http://www2.econ.iastate.edu/tesfatsi/ace.htm

- **Online Guide for Newcomers to ABM**

  http://www2.econ.iastate.edu/tesfatsi/abmread.htm

- **Background Paper:** L. Tesfatsion (2017), "Modeling Economic Systems as Locally-Constructive Sequential Games," *Journal of Economic Methodology*, Volume 24, Issue 4, 384-409.
  http://lib.dr.iastate.edu/econ_workingpapers/23