Economic Systems as Constructively Rational Games

Oh, the Places We Could Go!

Presenter:

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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…"

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

Presentation Outline

- What is ***constructive rationality*** ?
- What is ***A***gent-based ***C***omp ***E***conomics (***ACE***)?
- Illustration: ACE macroeconomic modeling
- ***The places we could go!***
  - Comprehensive empirical validation
  - Standardized “policy readiness levels”
  - Standardized presentation protocols
  - Edgier explorations for critical real-world systems
  - 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?

Constructively Rational Systems

A system is ***constructively rational (CR)*** if:

1) Every decision maker (DM) is locally constructive
   - A DM's current decision process must be entirely expressible as a function of the DM's current ***state:***
     - **data** (observations, statistical summaries,…)
     - **attributes** (physical, financial, beliefs, preferences…)
     - **methods** (information collection, math routines…)
2) The system constitutes an historical process
   - Events proceed through time from cause to effect

Examples of CR Systems

- All real-world systems
- Any modeling of a real-world system via Agent-based Computational Economics!

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

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

- Constructively rational modeling tool
- 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.

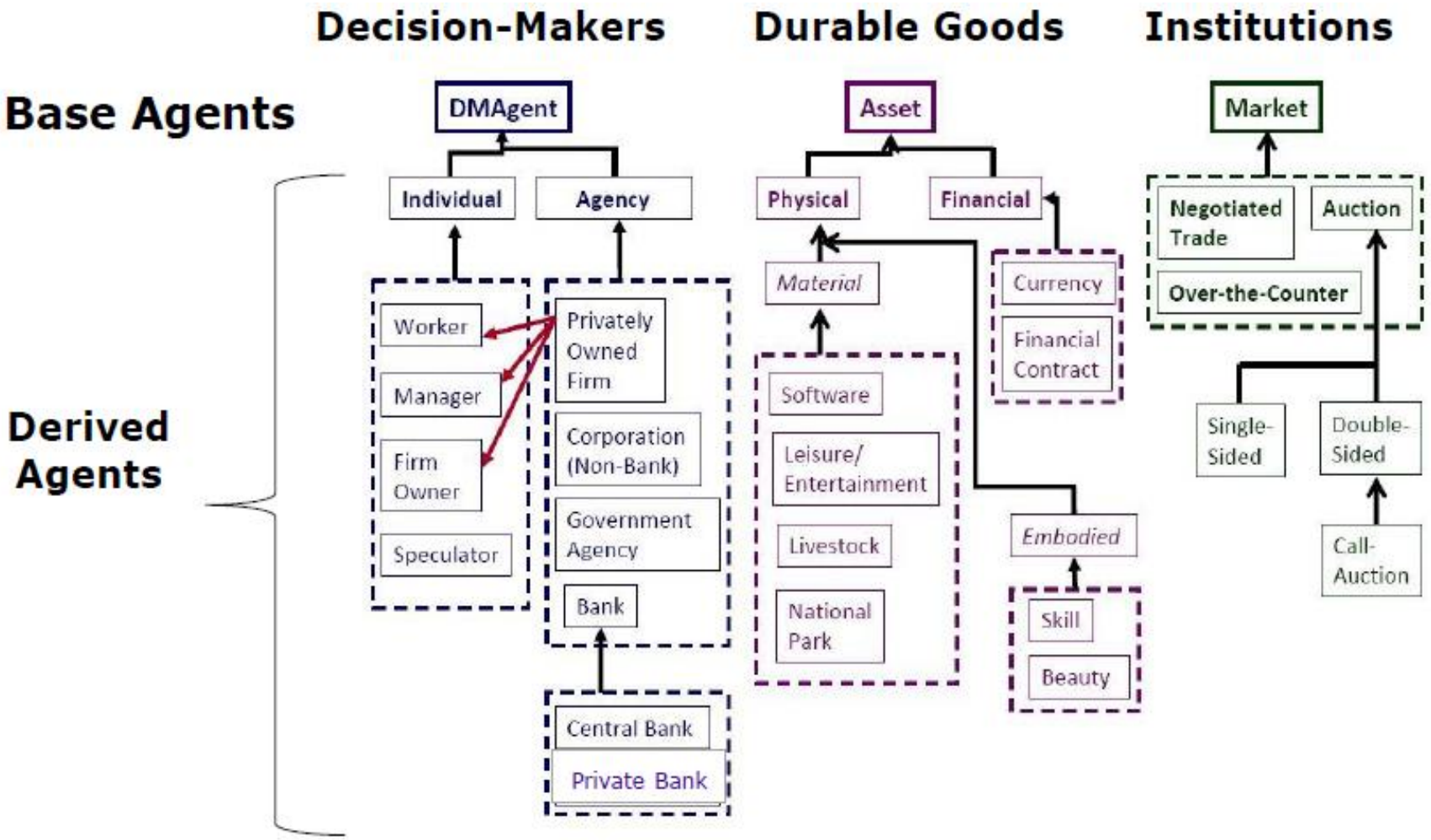
(MP7) Modeler as Culture-Dish Experimenter: The role of the modeler is limited to the setting of initial agent states and to the non-perturbational observation, analysis, and reporting of model outcomes.

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*.

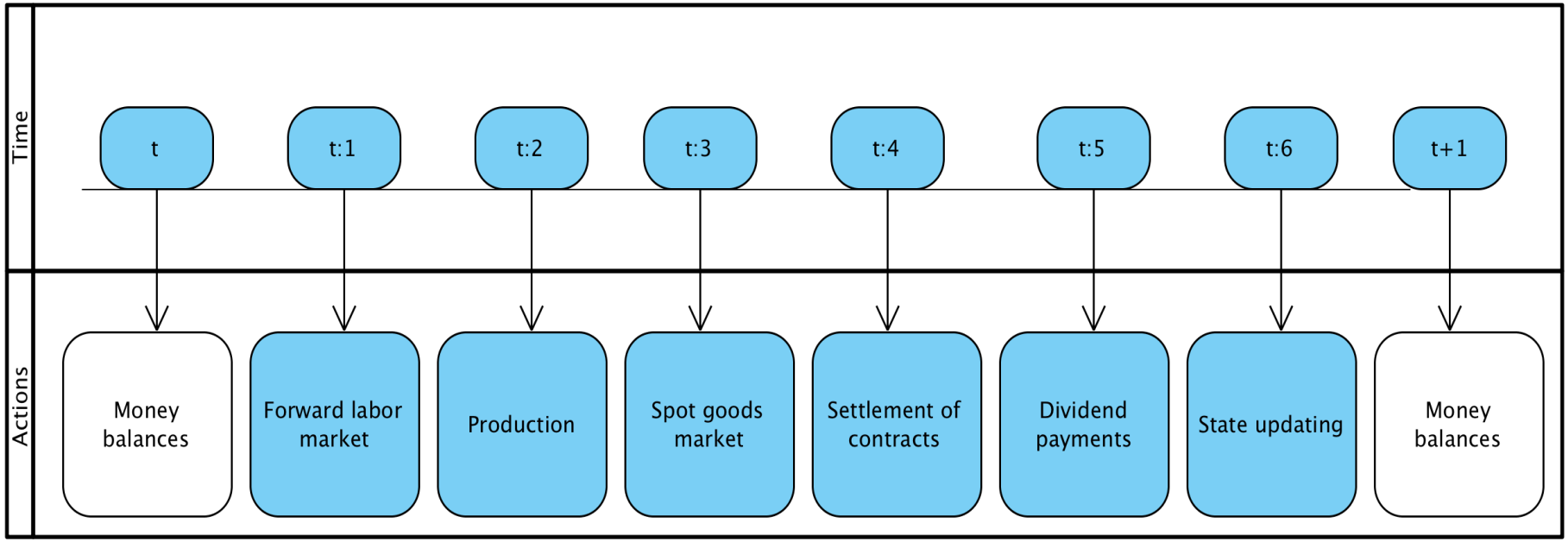
Illustration: ACE Macroeconomic Modeling

Partial agent hierarchy for a macroeconomy illustrating "is a" (↑) and "has a" (↓) agent relations



Illustrative Application:
DSG-LA = ~~DSGE~~ + Learning Agents

E. Sinitskaya & L. Tesfatsion, Macroeconomies as Constructively Rational Games, *Journal of Economic Dynamics and Control,* 61, 2015, 152-182.



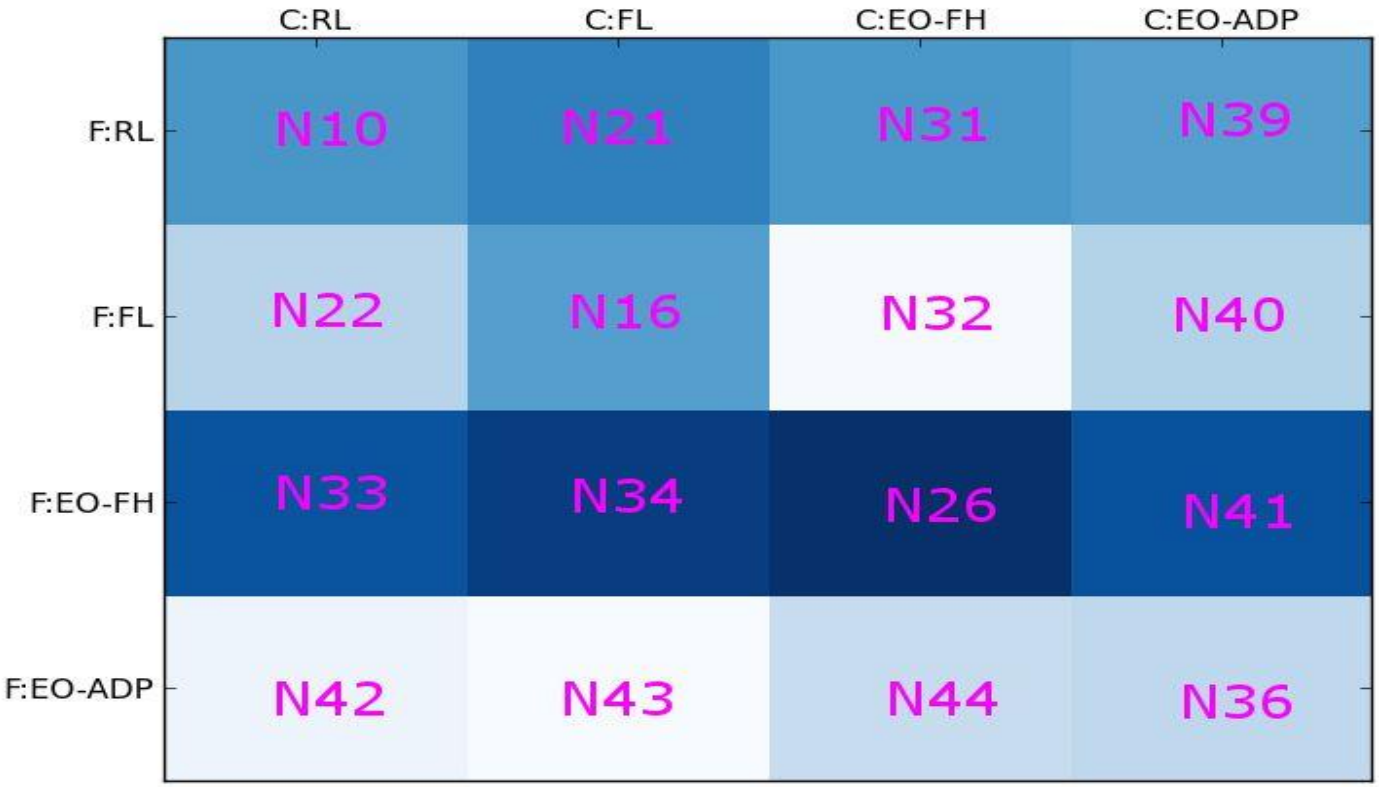
Sequence of constructively-rational trading activities during a typical time period t

Four Tested Constructively-Rational Decision Methods 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)

Rolling-Horizon Decision Rule EO-FH Does Best

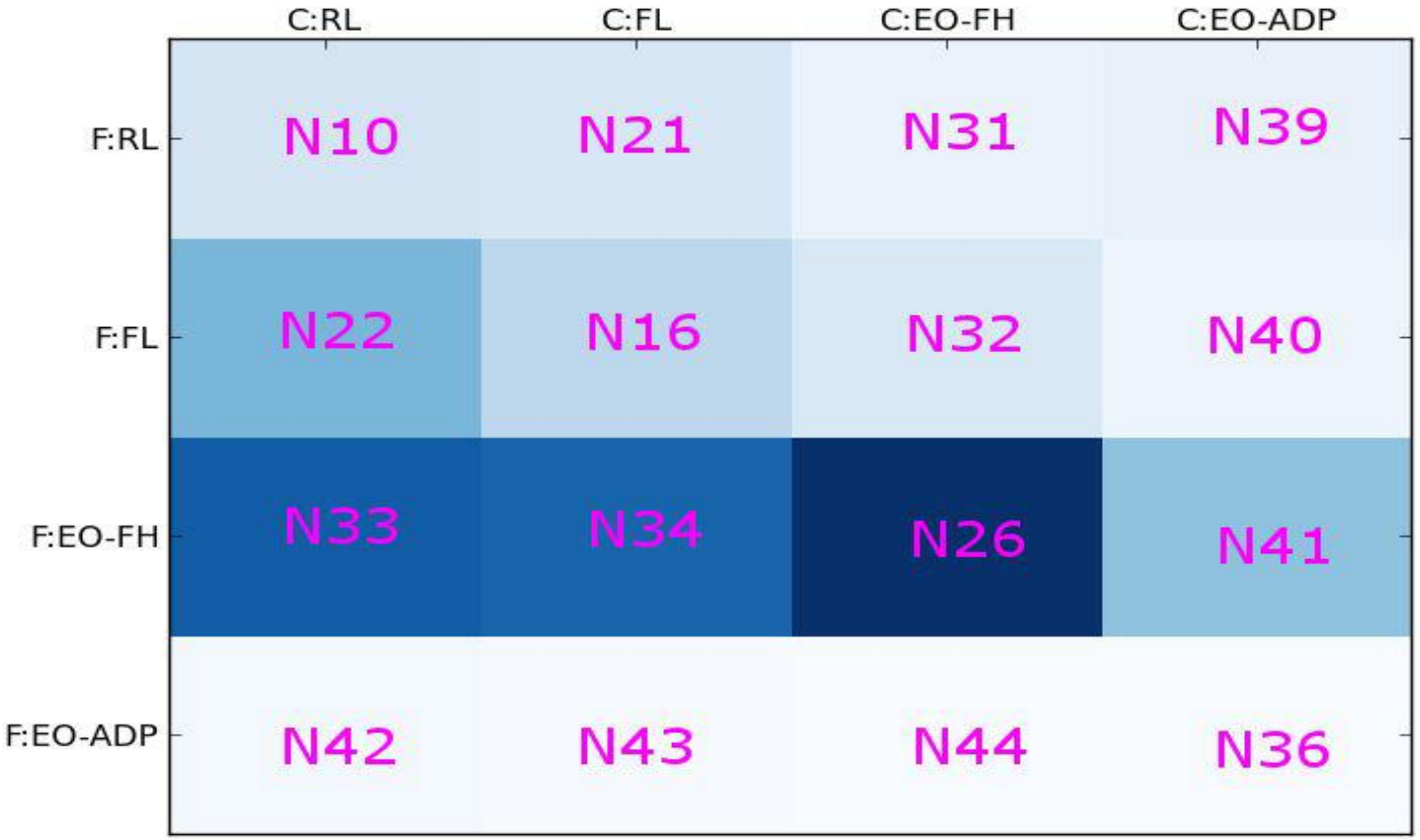
- (F:E0-FH, C:E0-FH) = Pareto-Optimal Nash Equilibrium
- **Consumer Payoff Matrix**: A **darker color** indicates a **higher attained average utility for consumers**



Note: The "Nxy" terms, above, are test case designations, not payoffs.

Rolling-Horizon Decision Rule EO-FH Does Best…Cont'd

- (F:E0-FH, C:E0-FH) = Pareto-Optimal Nash Equilibrium
- **Firm Payoff Matrix:** A **darker color** indicates **higher attained average profit for firms**



Note: The "Nxy" terms, above, are test case designations, not payoffs.

The Places We Could Go!

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

- Comprehensive empirical validation
- Standardized “policy readiness levels”
- Standardized presentation protocols
- Edgier explorations of critical real-world systems
- Spectrum of models: 100% human➡100% agents

Comprehensive Empirical Validation:
Four Different Aspects (EV1-EV4)
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:*** Functional forms, shock realizations, data-based parameter estimates, and/or parameter values imported from other studies

EV2. Process Validation: How well do modeled physical, biological, institutional, & 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, & 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 Policy Readiness Levels

PRL-1: Conceptual policy idea

PRL-2: Analytic formulation

PRL-3: Low-fidelity model

Basic research carried out at universities...

PRL-4: Moderate-fidelity small-scale model

PRL-5: High-fidelity small-scale model

PRL-6: Prototype small-scale model

Infamous "Valley of Death"

PRL-7: Prototype large-scale model

PRL-8: Field study

PRL-9: Real-world implementation

Industry, government, regulatory agencies

PRLs 4-6: Valley of Death

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

Standardized Presentation Protocols

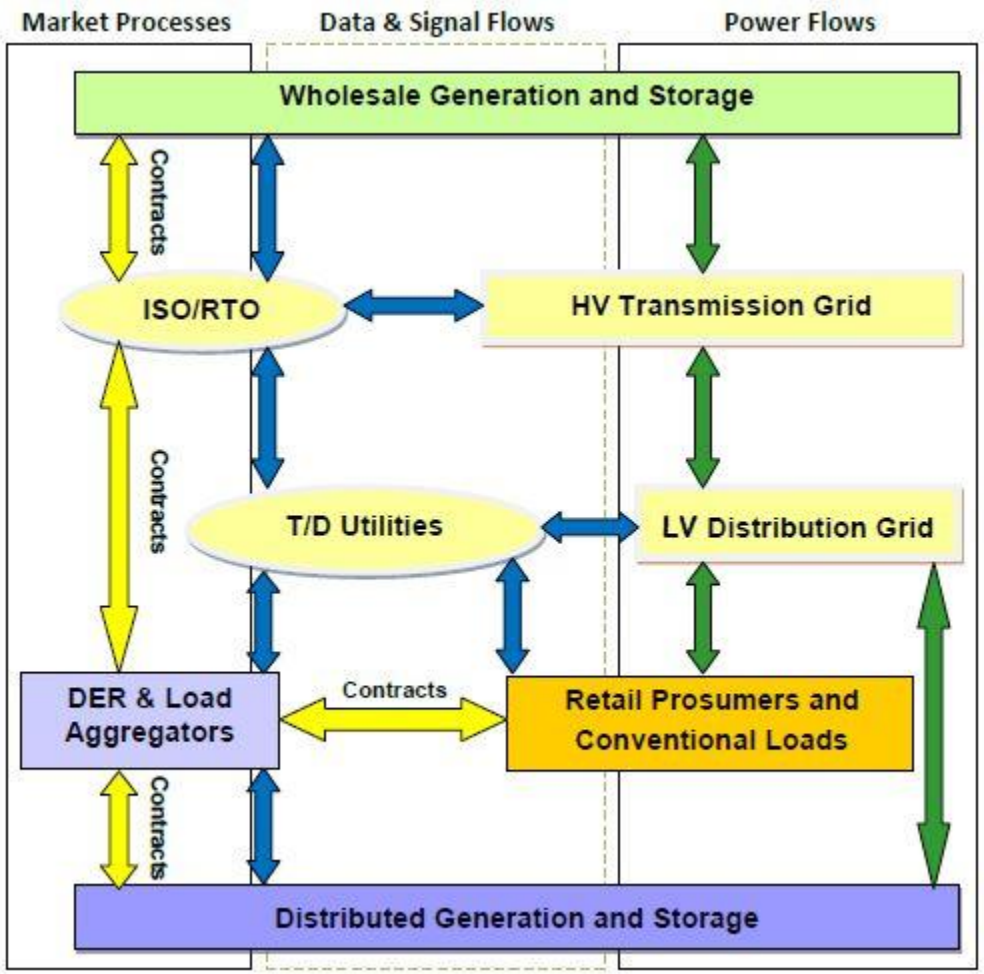
- How can ACE policy models & findings be clearly presented to stakeholders, regulators, and other interested parties?

Proposal: Develop a nested sequence of standardized presentation protocols tailored to the PRL of a modeling effort.

  - **Example:** Extend the current "one size fits all" ODD protocol (Grimm et al.) to a sequence ODD-1, ODD-2,… in parallel with PRL-1, PRL-2,…

Edgier Explorations

L. Tesfatsion, "Electric Power Markets in Transition: Agent-Based Modeling Tools for Transactive Energy Support," to appear in Hommes/LeBaron (Eds.), Handbook of Computational Economics IV, Elsevier, 2017.



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

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

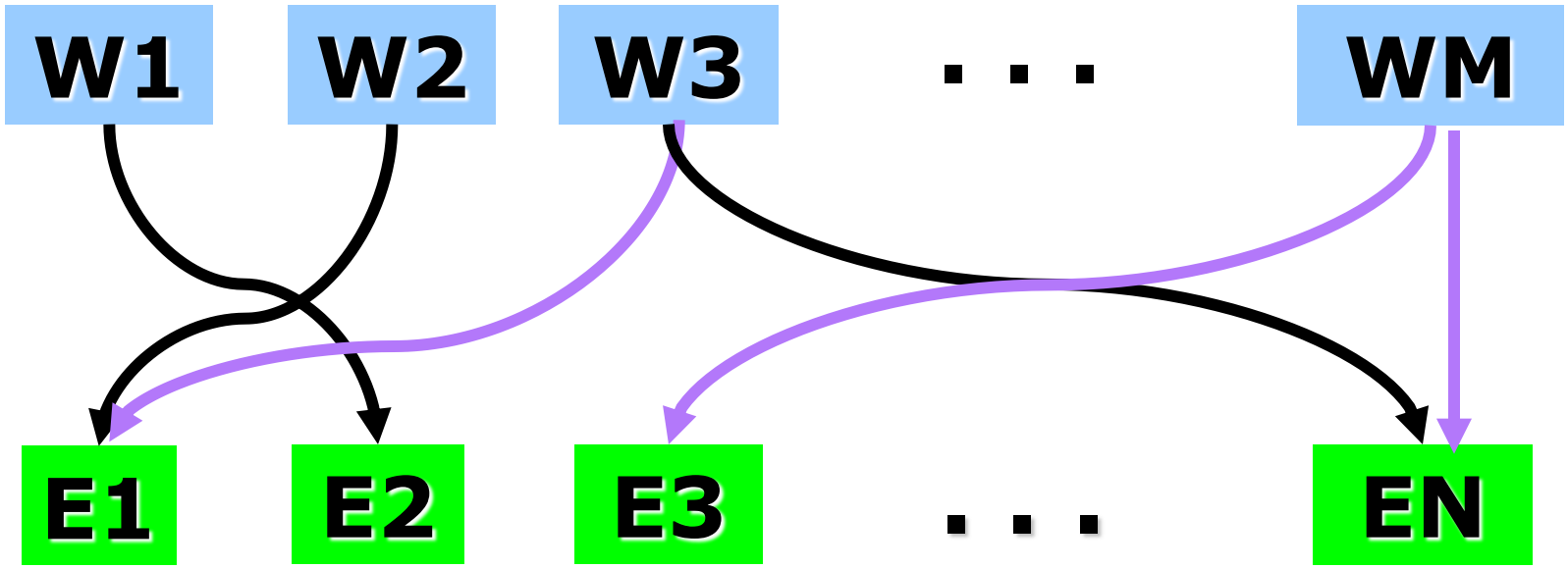
Examples:

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

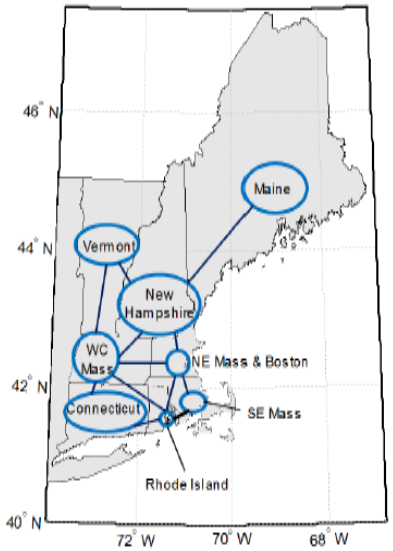
2) **The Trade Network Game Laboratory: Homepage**
http://www2.econ.iastate.edu/tesfatsi/tnghome.htm

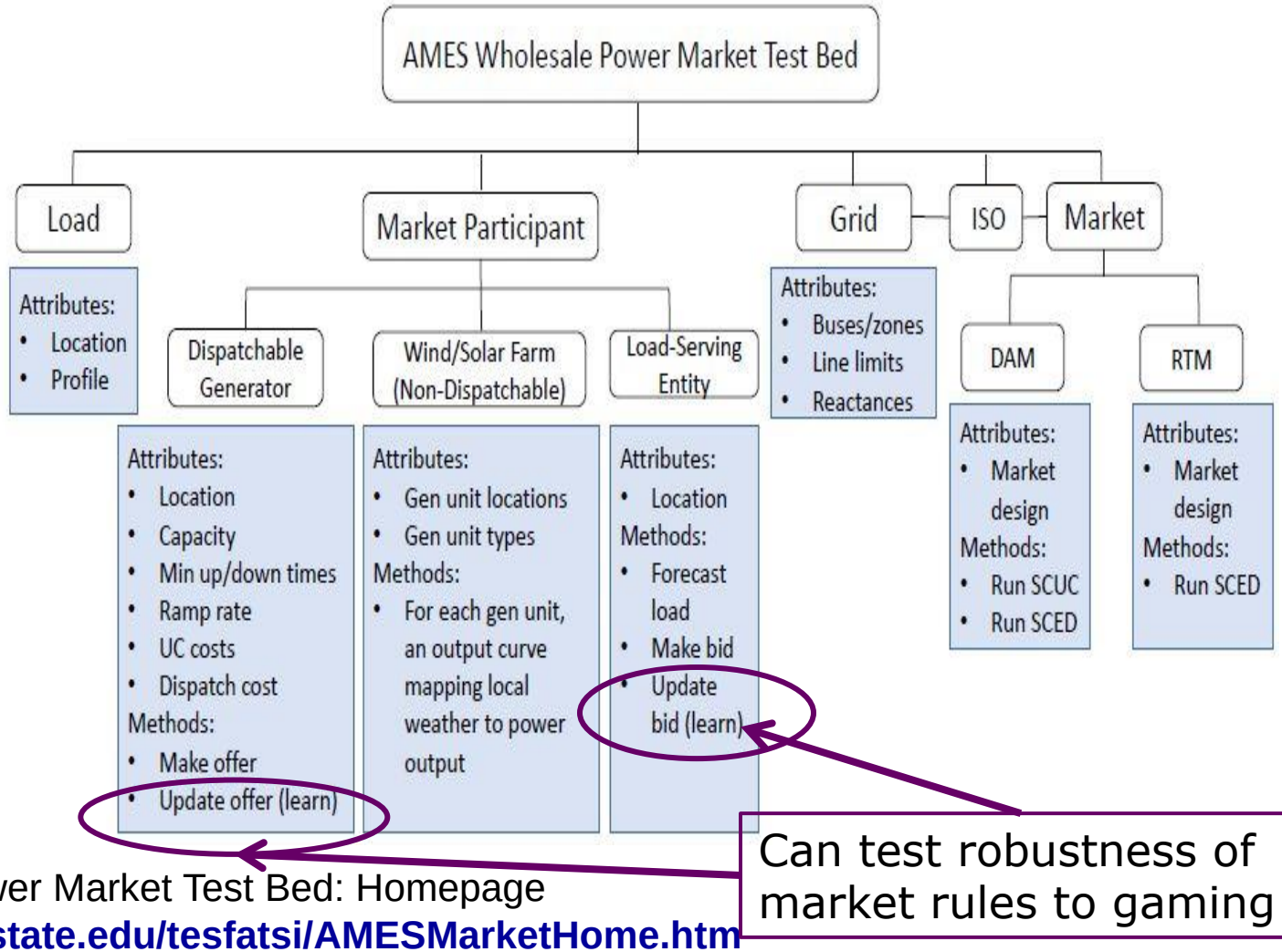
ACE Labor Market in JEDC (2001): Worker-Employer Network Formation Game



Job search with choice & refusal of worksite partners. **Purple = refused work offers; Black = accepted work offers.** Matched traders play worksite PD games. Workers use GA to evolve "personalities". *Endogenous* hiring, quits, and firings …

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

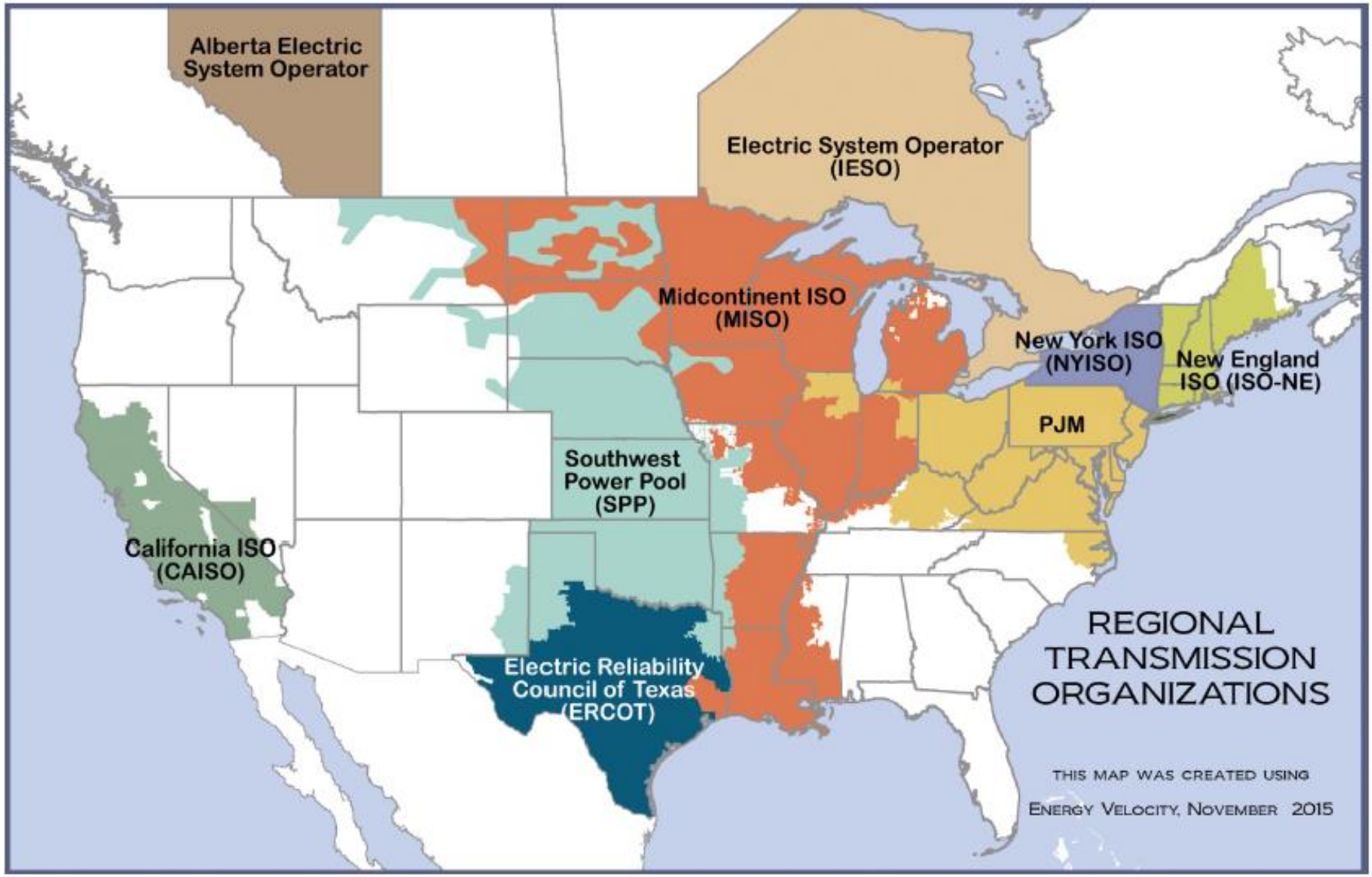




AMES Wholesale Power Market Test Bed: Homepage
http://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

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



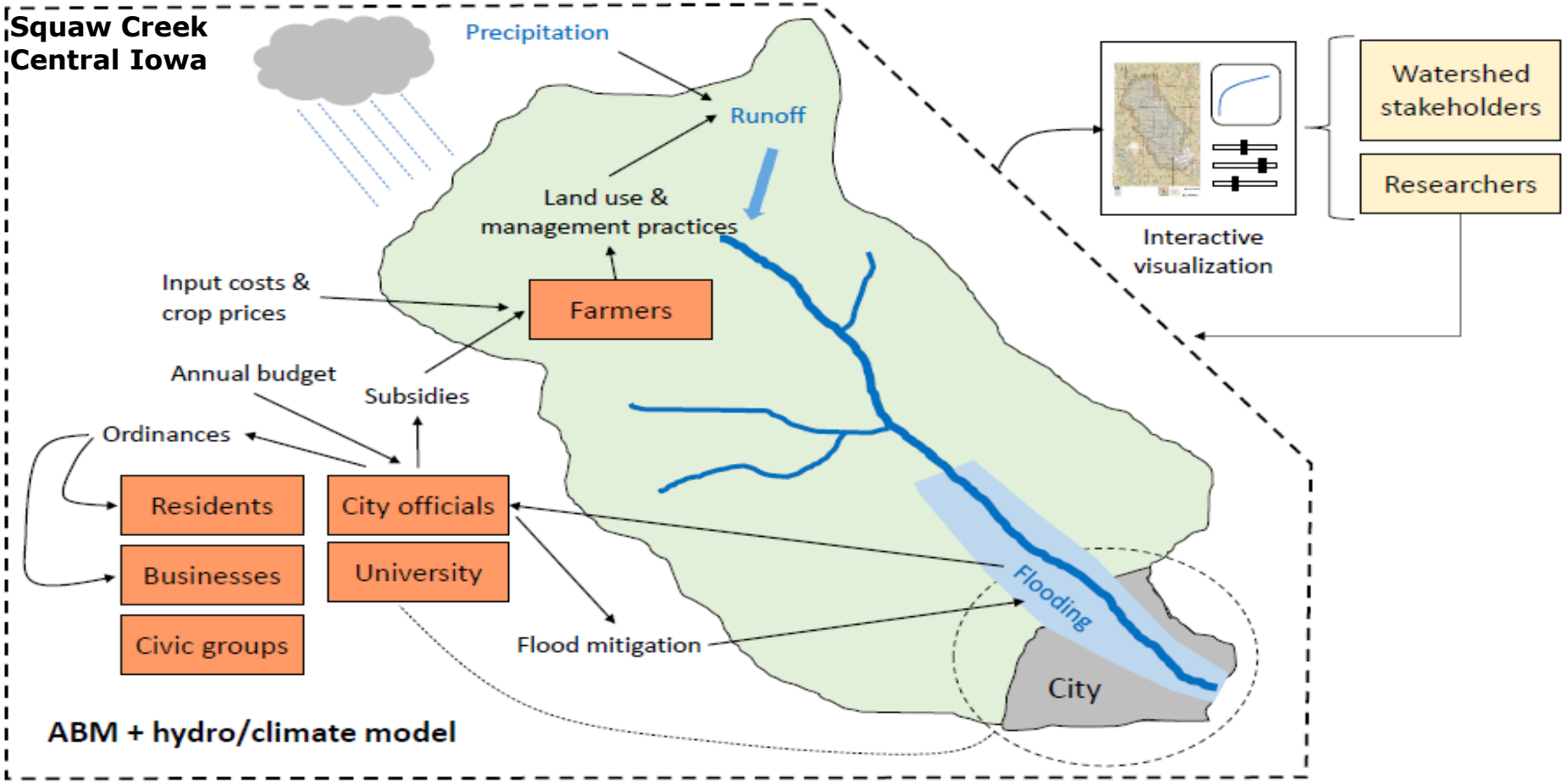
Economic Processes as Key Components of Larger Systems

- 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

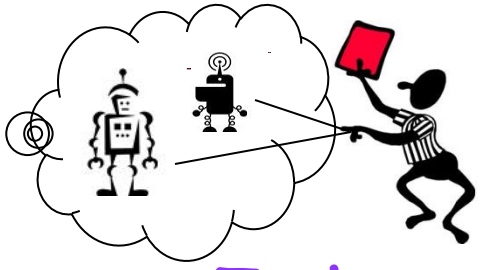
http://www2.econ.iastate.edu/tesfatsi/WACCShedPlatform.RevisedWP15022.pdf

A Spectrum of Experimental Approaches

100% human

Humans with computer access

Human-controlled computer avatars

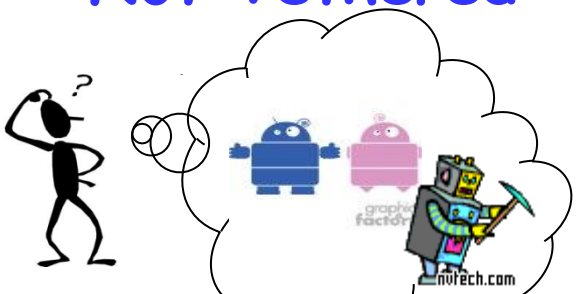


Tethered

Mix of humans and computer agents

Not Tethered

Human-calibrated computer agents



Computer agents with real-world data streaming

100% computer agents evolved from initial conditions **(ACE)**

Conclusion

- ACE/ABM 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, PRLs, 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
- **ACE Research Areas: Linked Listing**
  http://www2.econ.iastate.edu/tesfatsi/aapplic.htm
- **Empirical Validation of Agent-Based Models**
  http://www2.econ.iastate.edu/tesfatsi/EmpValid.htm
- **Presentation Protocols for Agent-Based Models**
  http://www2.econ.iastate.edu/tesfatsi/amodguide.htm
- **Background Paper:** L. Tesfatsion, "Modeling Economic Systems as Locally-Constructive Sequential Games," *Journal of Economic Methodology*, 2017, to appear.
  http://lib.dr.iastate.edu/econ_workingpapers/23