

Economic Systems as Locally-Constructive Sequential Games

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Outline

- ❑ What is a “locally constructive sequential game” ?
- ❑ What is **A**gent-based **C**omp **E**conomics (**ACE**)?
- ❑ Illustration: ACE macroeconomic modeling
- ❑ ***Challenging Issues and Edgier Explorations***
 - Comprehensive empirical validation
 - Standardized “policy readiness levels”
 - Standardized presentation protocols
 - Exploratory studies for 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?

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 local states (data, attributes, methods) at each given time
- 5) Actions taken by participants at any given time affect future local states

Locally-Constructive Sequential Games...

- **A**gent-based **C**omputational **E**conomics (**ACE**) permits the study of systems as locally-constructive sequential games

Agent-based Computational *Economics* (ACE)

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

- 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.

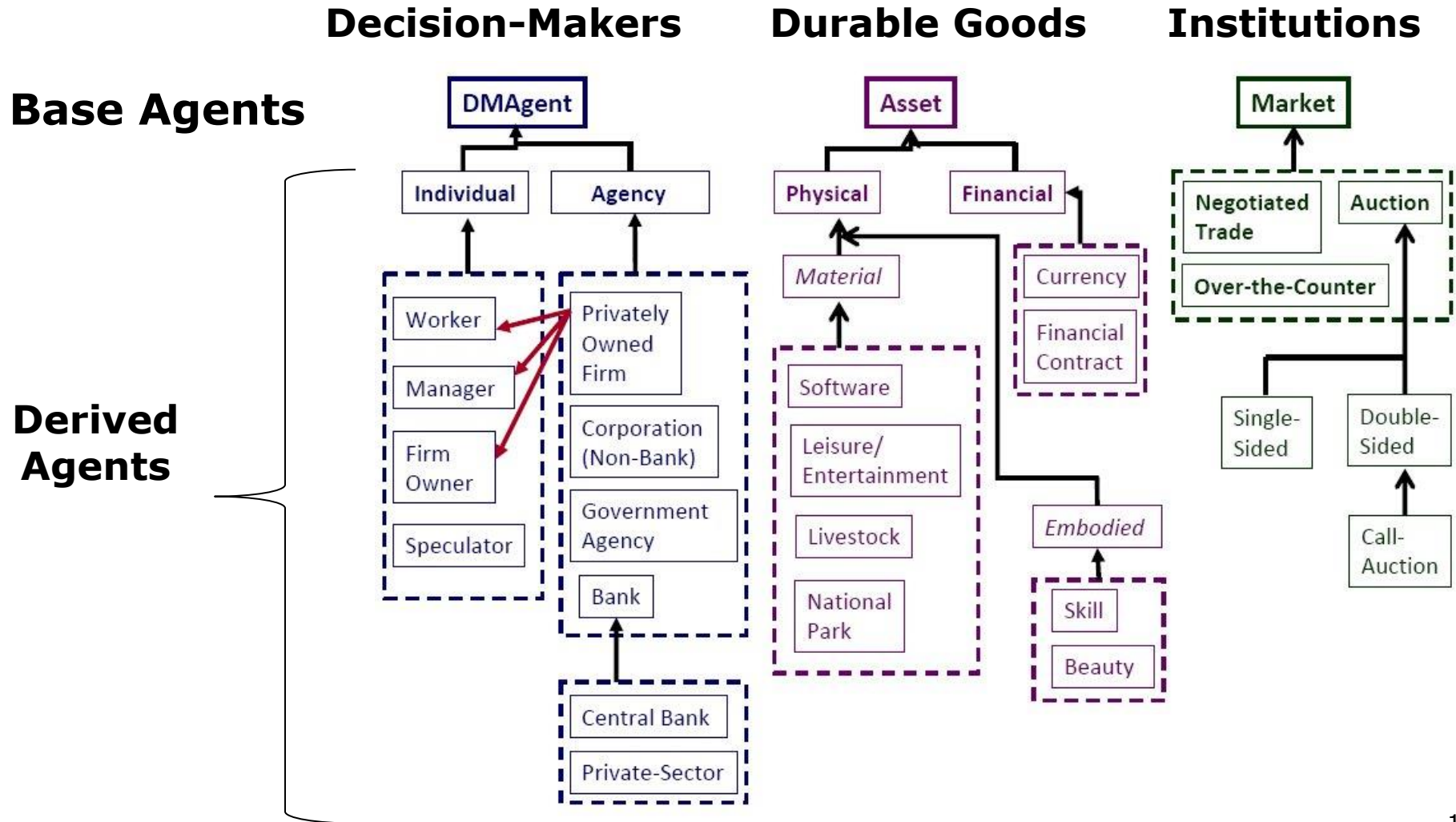
(MP7) Modeler as Culture-Dish Experimenter: The role of the modeler is limited to the setting of initial agent states and to the non-perturbational observation, analysis, and reporting of model outcomes.

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*.

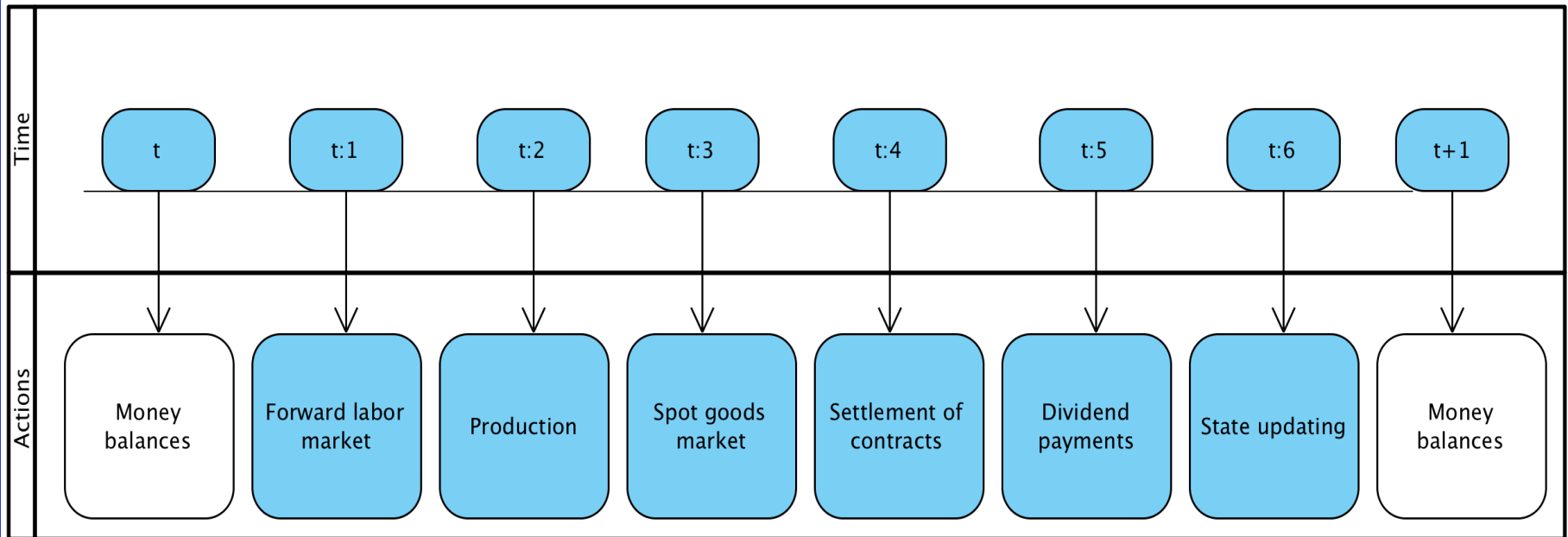
Illustration: ACE Macroeconomic Modeling

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 locally-constructive trading activities during a typical time period t

Four Tested Locally-Constructive 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:EO-FH, C:EO-FH) = Pareto-Optimal Nash Equilibrium
- **Consumer Payoff Matrix:** A darker color indicates a higher attained average utility for consumers

	C:RL	C:FL	C:EO-FH	C:EO-ADP
F:RL	N10	N21	N31	N39
F:FL	N22	N16	N32	N40
F:EO-FH	N33	N34	N26	N41
F:EO-ADP	N42	N43	N44	N36

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

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

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

	C:RL	C:FL	C:EO-FH	C:EO-ADP
F:RL	N10	N21	N31	N39
F:FL	N22	N16	N32	N40
F:EO-FH	N33	N34	N26	N41
F:EO-ADP	N42	N43	N44	N36

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, &/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 Policy Readiness Levels

PRL-1: Conceptual policy idea

PRL-2: Analytic formulation

PRL-3: Low-fidelity model

PRL-4: Moderate-fidelity small-scale model

PRL-5: High-fidelity small-scale model

PRL-6: Prototype small-scale model

PRL-7: Prototype large-scale model

PRL-8: Field study

PRL-9: Real-world implementation

Basic research
carried out at
universities...

**Infamous
“Valley of
Death”**

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

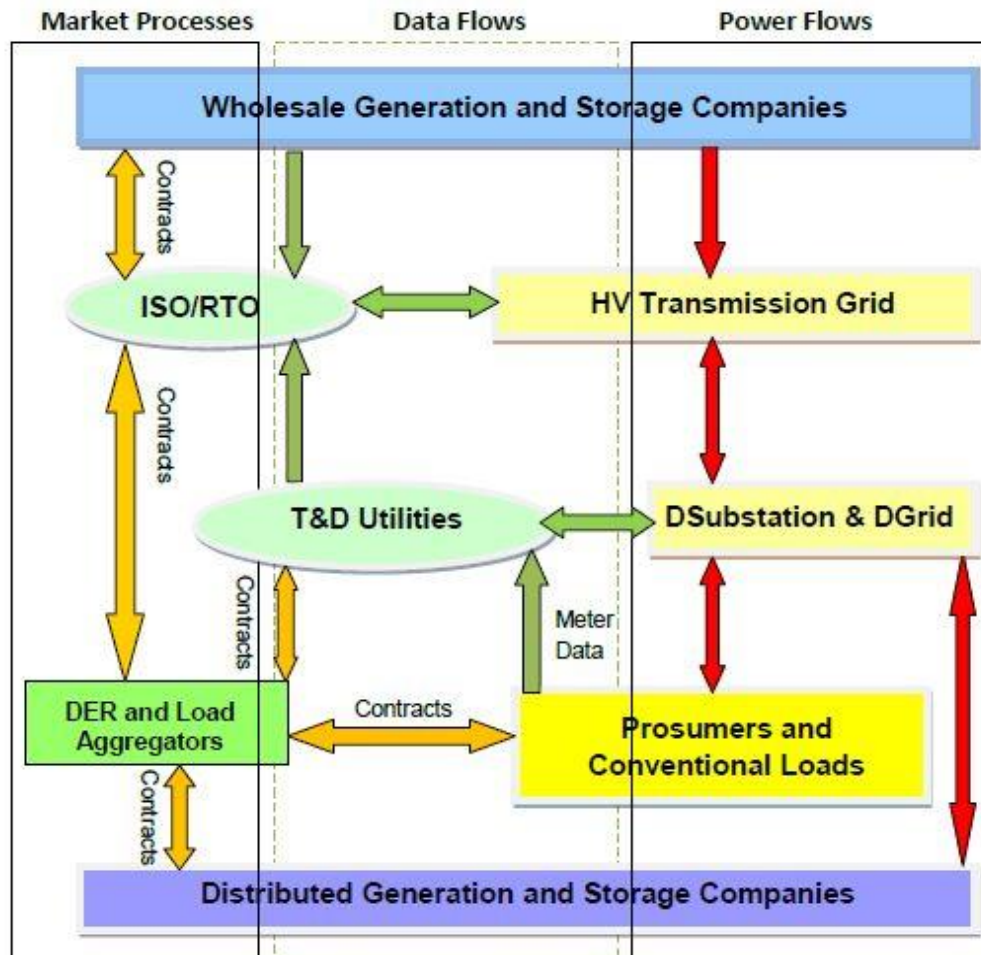
- How can ACE policy models & findings be clearly presented to stakeholders, regulators, and other interested parties?

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:

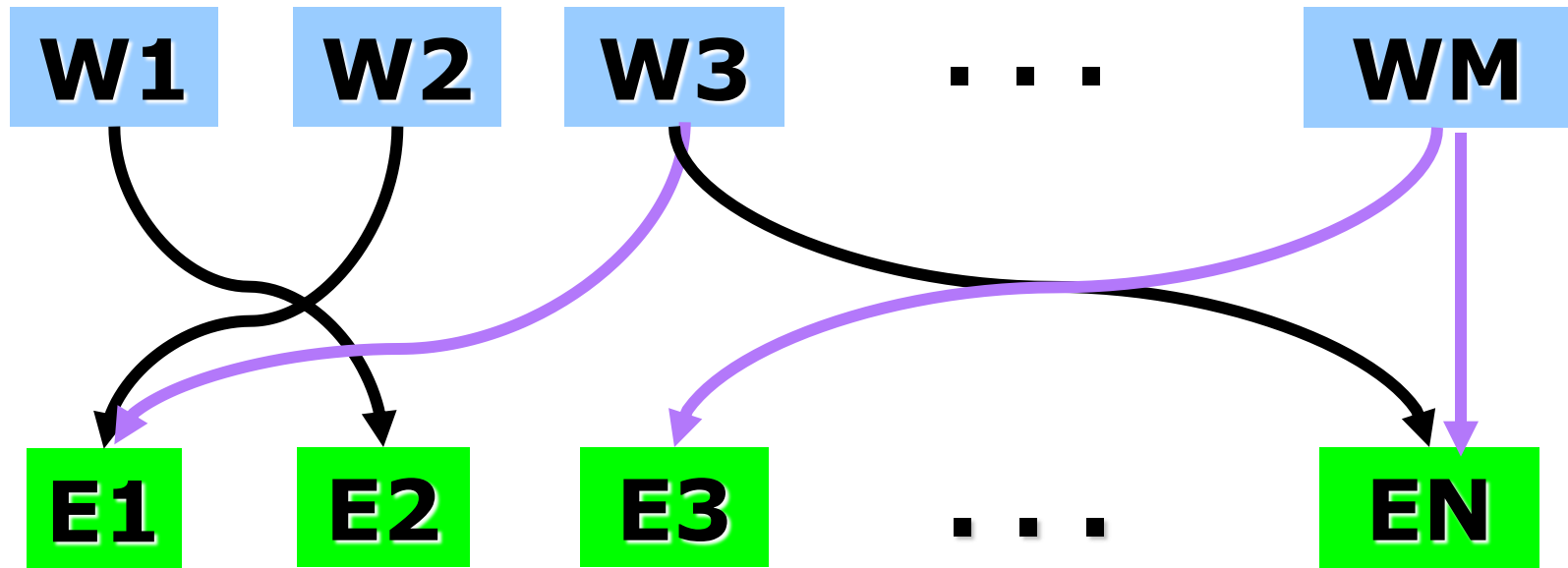
1) L. Tesfatsion, "Structure, Behavior, and Market Power in an Evolutionary Labor Market with Adaptive Search, *Journal of Economic Dynamics and Control*, 25(1), 2001, 419-457

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

2) **The Trade Network Game Laboratory: Homepage**

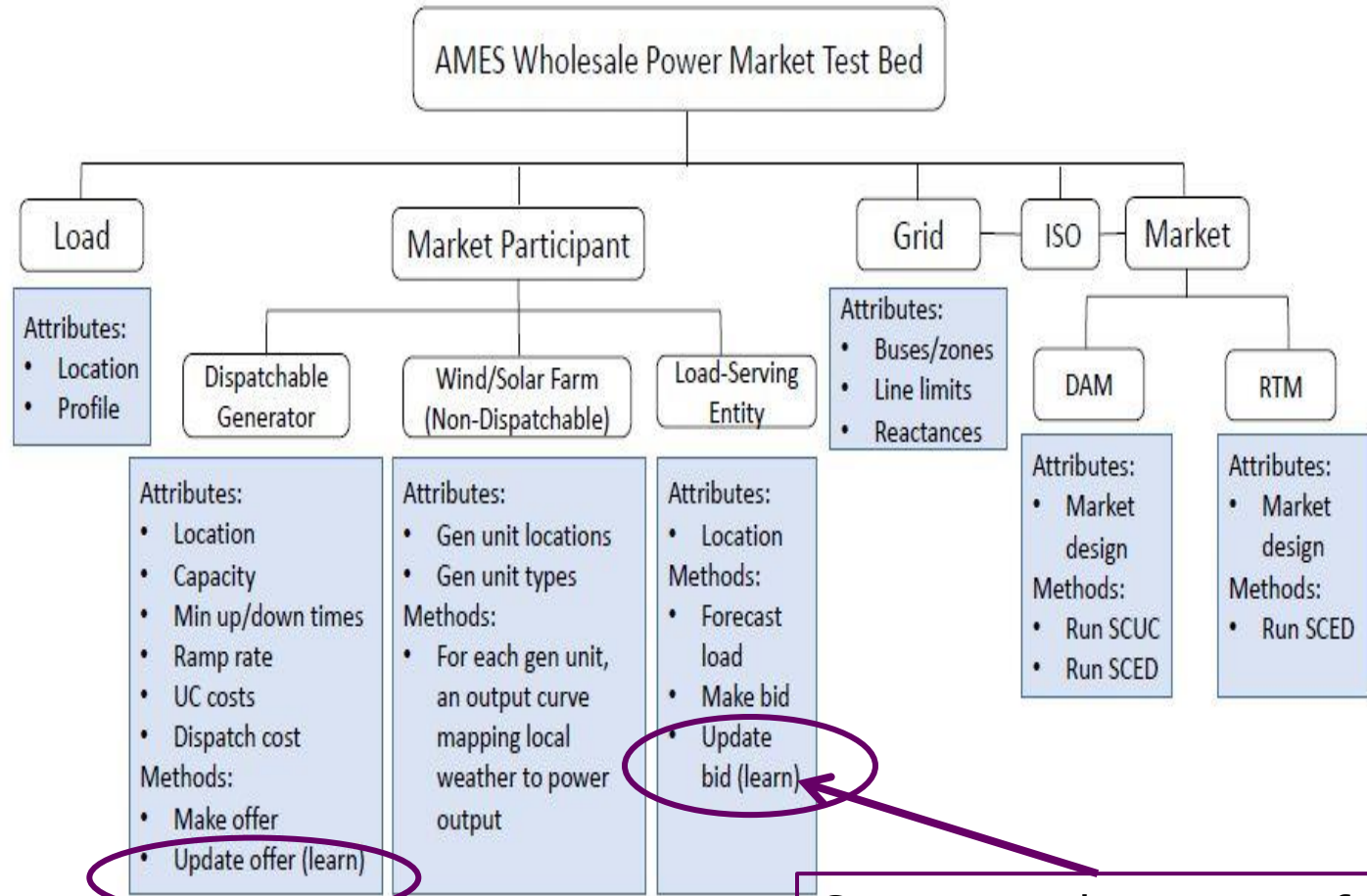
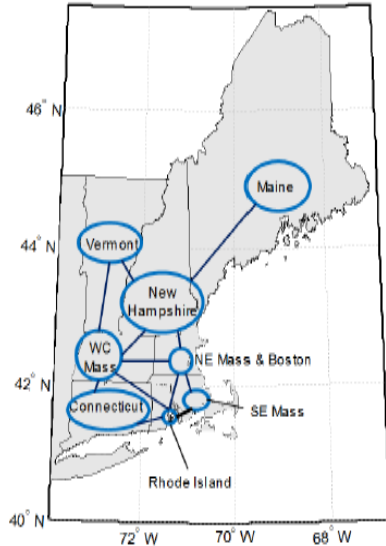
<http://www2.econ.iastate.edu/tesfatsi/tnghome.htm>

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 = Agent-based Modeling of Electricity Systems



AMES Wholesale Power Market Test Bed: Homepage

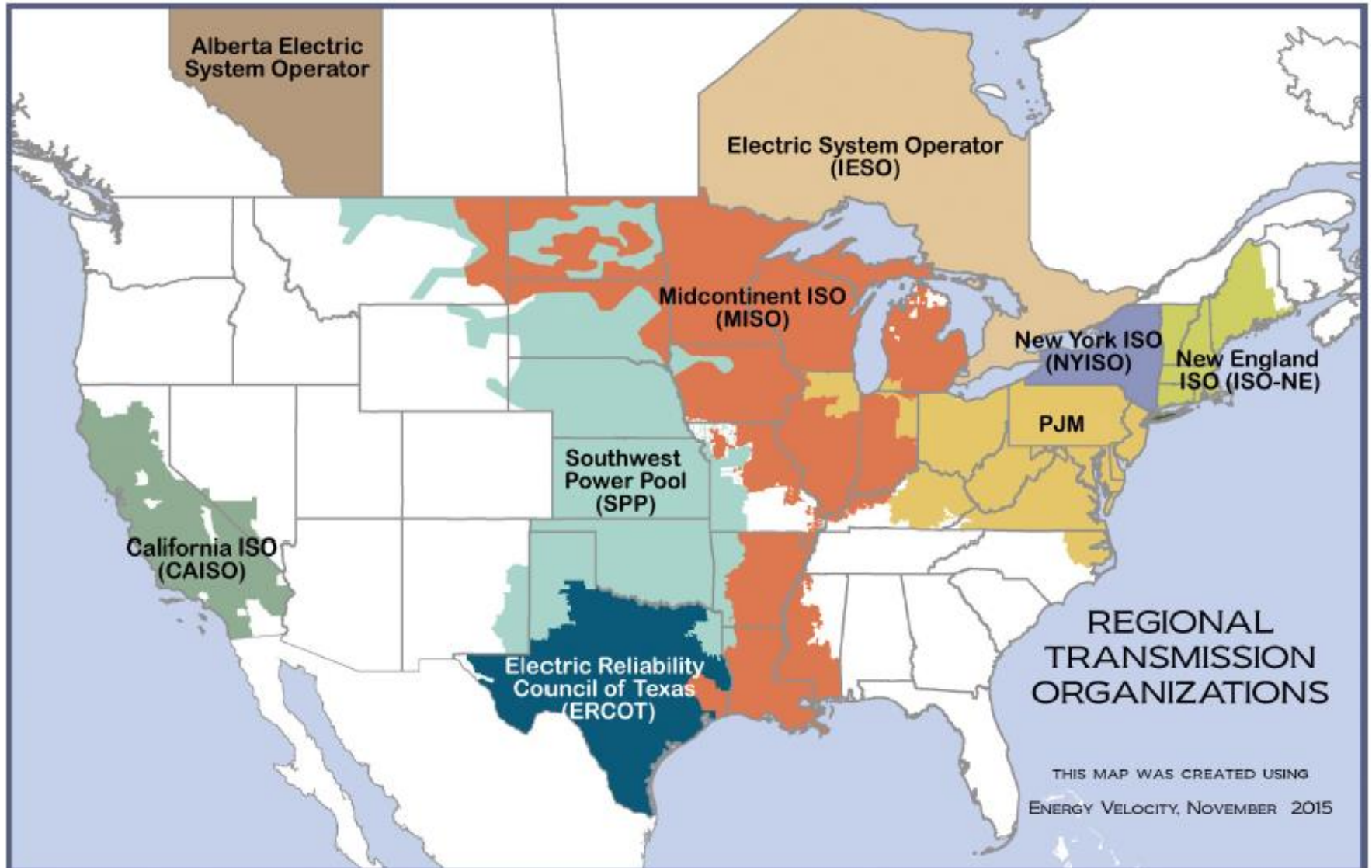
<http://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm>

Can test robustness of market rules to gaming


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>

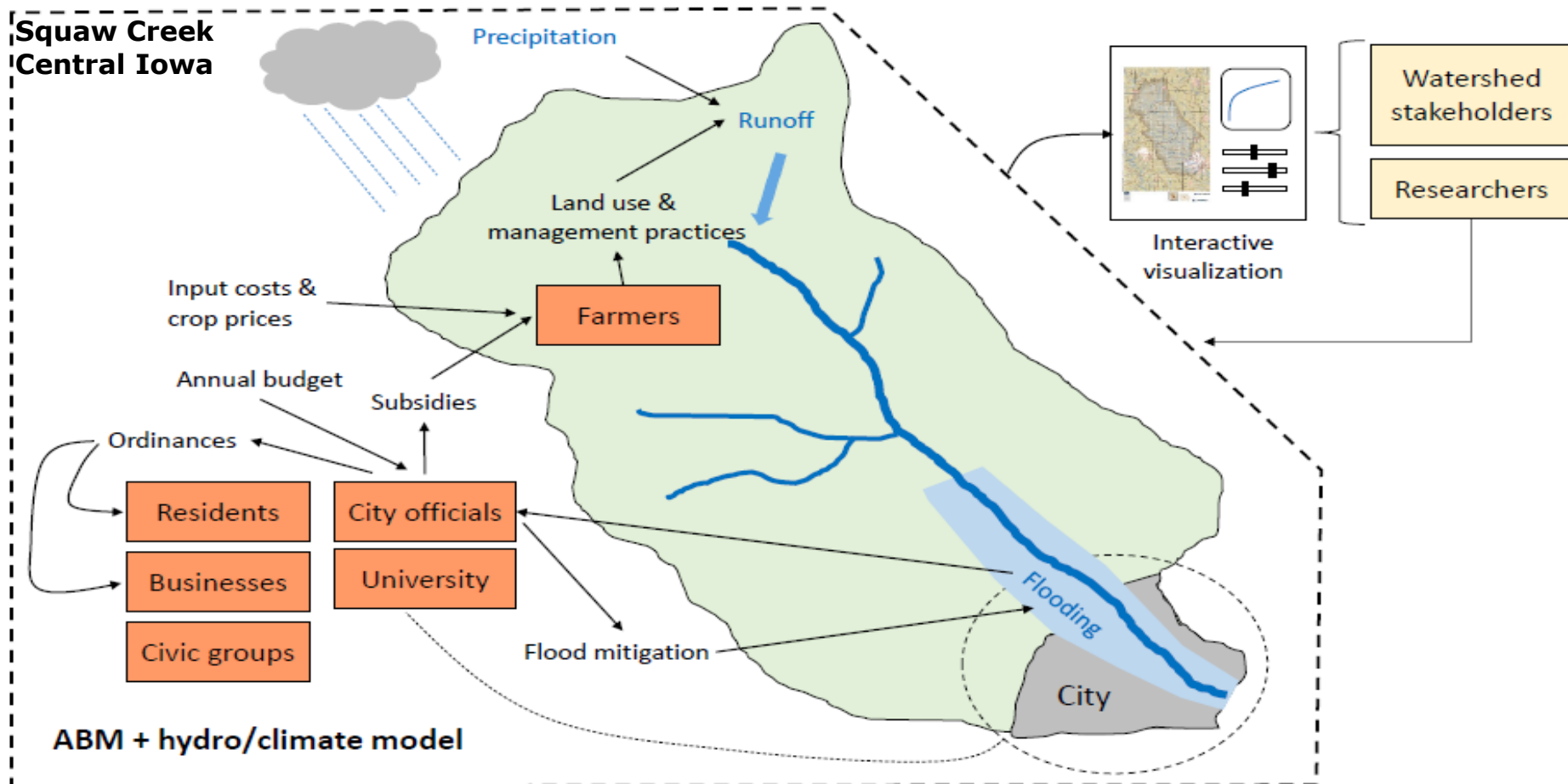
North American Centrally-Managed Wholesale Electric Power Markets



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)**

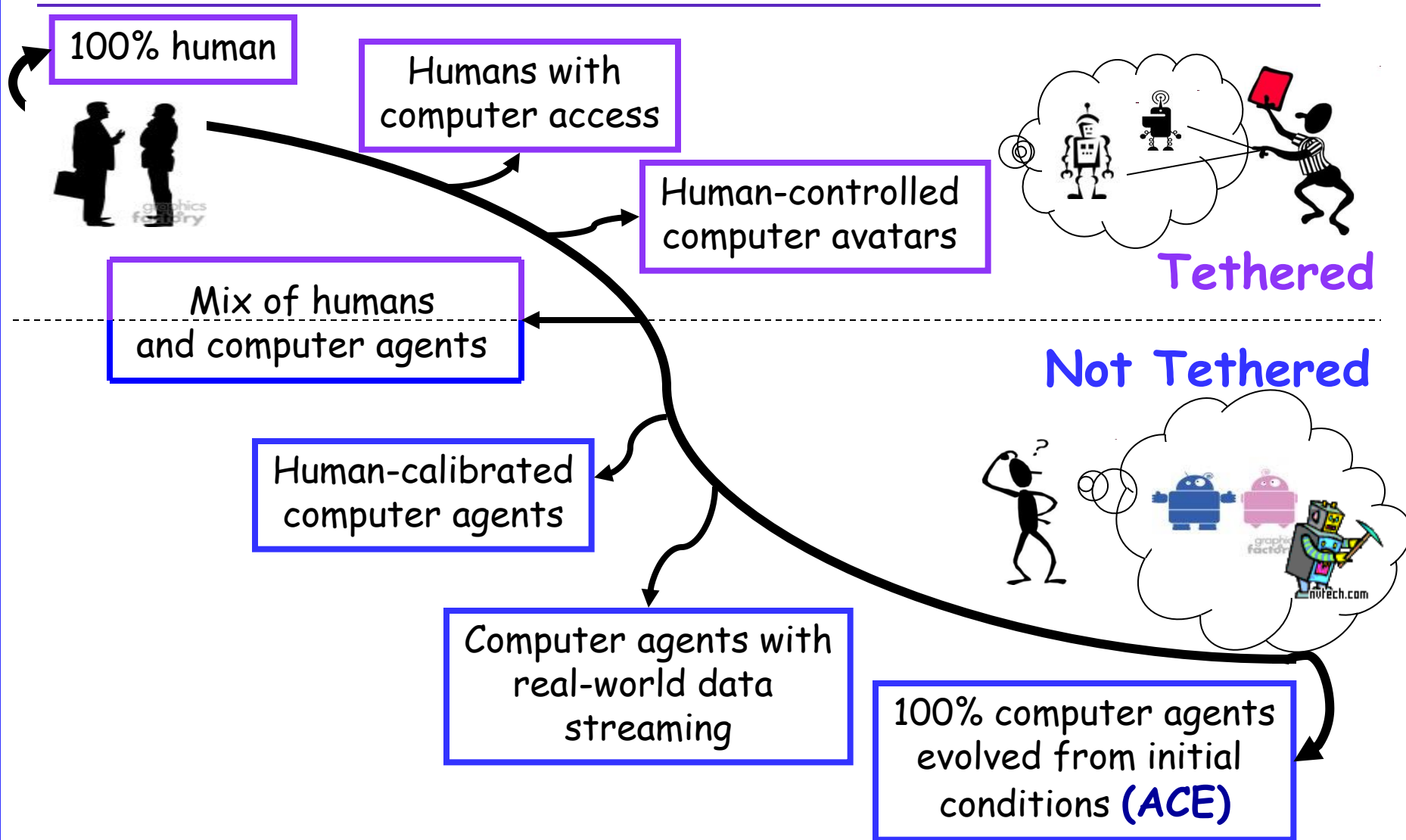
Example: ACE Watershed Local Governance Study



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



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, 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,” Economics Working Paper No. 17022, ISU, March 2017.
http://lib.dr.iastate.edu/econ_workingpapers/23