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 Agent-based Comp Economics (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 (ACE) permits the study of real-world systems as locally-constructive sequential games.
Agent-based Computational Economics (ACE)
https://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 act within the real world.
(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/or 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.
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*.
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.

[https://www2.econ.iastate.edu/tesfatsi/afinance.htm](https://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

https://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

[https://www2.econ.iastate.edu/tesfatsi/amulmark.htm](https://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:

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

2) The Trade Network Game Laboratory: Homepage
   https://www2.econ.iastate.edu/tesfatsi/tnghome.htm
Job search with preferential choice & refusal of worksite partners

Purple arrow = Refused work offer; Black arrow = Accepted work offer.

Matched traders play worksite games. Workers use genetic algorithms (GAs) to evolve their game strategies. Hiring, quits, and firings are *endogenously* determined in each work period.
**Macroeconomic Application:**

**DSGL** = **DSGE** + Learning Agents

https://www2.econ.iastate.edu/tesfati/amulmark.htm

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https://www2.econ.iastate.edu/tesfati/MacroConstructiveRationalityWP.SinitskayaTesfatsion.pdf

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**Sequence of Activities During a Typical Period t**

- Money balances
- Forward labor market
- Production
- Spot goods market
- Settlement of contracts
- Dividend payments
- State updating
- Money balances
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**
  - **A Nash equilibrium**
AMES = Agent-based Modeling of Electricity Systems

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

https://www2.econ.iastate.edu/tesfatsi/8ZoneISONETestSystem.RevisedAppendix.pdf

Can test robustness of market rules to gaming
Electricity Market Design


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 economic processes as critical components **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


https://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 depicting “has a” (down-arrow) and “is a” (up-arrow) relations.
ACE Facilitates Comprehensive Empirical Validation

https://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 …

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 (DRLs)

DRL-1: Conceptual design idea
DRL-2: Analytic formulation
DRL-3: Low-fidelity model
DRL-4: Moderate-fidelity small-scale model
DRL-5: High-fidelity small-scale model
DRL-6: Prototype small-scale model
DRL-7: Prototype large-scale model
DRL-8: Field study
DRL-9: Real-world implementation

Basic research carried out at universities...
Infamous “Valley of Death”
Industry, government, regulatory agencies

Standardized Design Readiness Levels (DRLs)
ACE Can Help Bridge the “Valley of Death” (DRLs 4-6)

- Infrequency of studies within the “Valley of Death” (DRLs 4-6) 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

- 100% human
- Humans with computer access
- Mix of humans and computer agents
- Human-controlled computer avatars
- Human-calibrated computer agents
- Computer agents with real-world data streaming
- 100% computer agents evolved from initial conditions (ACE)

Tethered
Not Tethered
Agent-based **Computational Economics (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**
  
  [https://www2.econ.iastate.edu/tesfatsi/ace.htm](https://www2.econ.iastate.edu/tesfatsi/ace.htm)

- **Online Guide for Newcomers to ABM**
  
  [https://www2.econ.iastate.edu/tesfatsi/abmread.htm](https://www2.econ.iastate.edu/tesfatsi/abmread.htm)

  [https://lib.dr.iastate.edu/econ_workingpapers/23](https://lib.dr.iastate.edu/econ_workingpapers/23)