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 Computational Economics (ACE)?
- The places we could go: Challenging current issues and edgier explorations
  - Science-with-practice explorations of critical real-world systems
  - Comprehensive empirical validation
  - Standardized “Design Readiness Levels (DRLs)”
  - Spectrum of experimental approaches to the study of real-world economic systems, 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 Economic Systems are Locally-Constructive Sequential Games

1) Heterogeneous interacting participants

2) Open-ended dynamics

3) Human participants are strategic decision-makers.

4) All participants are locally constructive, i.e., their intended actions at any given instant are determined by their own states (data, attributes, and/or methods) at this instant.

5) Actions taken by participants at each given instant affect the states of participants at subsequent instances.
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](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.
ACE Modeling Principles
(MP1) – (MP7)

(MP1) Agent Definition: An agent is a software entity within a computationally constructed world that can affect world outcomes through expressed actions.

(MP2) Agent Scope: Agents can represent a broad range of entities, e.g., individual life-forms, social groupings, institutions, and/or physical phenomena.

(MP3) Agent Local Constructivity: An intended action of an agent at a given instant is determined by the agent’s state (data, attributes, and/or methods) at this instant.
(MP4) **Agent Autonomy:** All *agent interactions* (*expressed agent actions*) at a given instant are determined by the ensemble of agent states at this instant.

(MP5) **System Constructivity:** The *state of the world* at a given instant is determined by the ensemble of agent states at this instant.

(MP6) **System Historicity:** Given an initial ensemble of agent states, any subsequent *world event* (*change in agent states*) is induced by prior or concurrent agent interactions.

(MP7) **Modeler as Culture-Dish Experimenter:** Role of the modeler is limited to configuration and setting of initial agent states, & to non-perturbational observation, analysis, and reporting of world outcomes.
Together, principles (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 subsequent outcomes in modeled systems. This exploration process is *analogous to biological experimentation with cultures in Petri dishes*. 
Explorations of Real-World Economic 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**
   (empirical validation, representation, visualization, presentation protocols, ... )
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 coherent explanation of several “stylized facts” in combination.
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” the design for their own advantage?

ACE Approach:

- Construct an agent-based world capturing salient aspects of the proposed design.
- Introduce agents with initially configured states appropriate for the purpose at hand. Let the 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/aapplc.htm
3) ACE and Qualitative Analysis

Illustrative Issue: Performance capabilities of economies with decentralized markets?

(Adam Smith, L. von Mises, 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, ...)

- Configure decision-making agents 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
4) Method/Tool Advancement

*Example:* ACE Permits Comprehensive Empirical Validation

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

*Exogenous Inputs:* Initial state conditions, functional forms, shock realizations, data-based parameter estimates, 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?
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)
Illustrative ACE Applications

— Combined game & matching models
— Labor market modeling
— Macroeconomic modeling
— Critical infrastructure modeling
— Coupled natural and human system modeling
Decision-making agents in ACE models can …

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

Game Theory + 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
ACE Labor Market Study (Tesoatsion, *JEDC*, 2001)  
Worker-Employer Network Formation Game

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.

**Job search with preferential choice & refusal of worksite partners**

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

-紫色箭头=拒绝工作报价；
-黑色箭头=接受工作报价。

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ACE Macroeconomic Studies

\[ \text{DSGL} = \text{DSGE} + \text{Learning Agents} \]

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


https://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 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 all consumers and firms use rolling fixed-horizon (EO-FH) decision rules. This decision-rule configuration for firms and consumers is
  - *Pareto efficient*
  - *A Nash equilibrium*
ACE Electric Power Market Studies


ACE models can be used to represent real-world electric power markets

PLUS

ACE modeling principles can be used to design electric power markets for real-world implementation
North American Centrally-Managed Wholesale Electric Power Markets
Example: 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
ACE Studies of Coupled Natural and Human Systems

- ACE permits modeling of economic processes as critical components of Coupled Natural & Human (CNH) systems.
- CNH systems can be dynamic & spatial.

Broader ranges of possibly-correlated causal factors can be jointly considered.
Example: ACE Watershed Local Governance Study


https://www2.econ.iastate.edu/tesfatsi/WACCShedPlatform.RevisedWP15022.pdf
Decision-Making “Human” Agents

**Corn Farmers** (annual allocation of land, corn planting & harvesting, and consumption & savings);

**City Manager** (annual allocation of budget, Farmer subsidy payouts).

**Physical Agents (Data Driven)**

**Basin** (population, land attributes, ...)

**Climate** (20-year hourly rainfall pattern)

**Hydrology** (HEC-HMS, Feldman et al. 2000)

Maps farmer land allocations + land attributes (e.g., curve numbers) + rainfall (hourly depth in inches)

→ Water discharge rate into city (which affects extent of city flood damage)

**Institutional Agents (Data Driven)**

**Markets** (cost/price data)

→ Annual input planting cost ($/acre) and retail corn price ($/bushel).
Agent Taxonomy for the ACE Watershed World depicting “has a” (down-arrow) and “is a” (up-arrow) relations.
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
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:
  - 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
Conclusion

- **Agent-based Computational Economics (ACE)** is a useful addition to toolkits of economists studying real-world systems.

- ACE modeling principles have been designed to permit logical rigor, flexibility with regard to choice of model simplifications, and clarity of presentation.

- **But much remains to be done:**
  Empirical validation, Design Readiness Levels (DRLs), presentation protocols, edgier explorations demonstrating value-added for big-time applications, “valley of death” support for design development from concept to practice, ...
On-Line ACE Resource Sites

- **ACE Website: Homepage**
  
  https://www2.econ.iastate.edu/tesfatsi/ace.htm

- **Online Guide for Newcomers to Agent-Based Modeling**
  
  https://www2.econ.iastate.edu/tesfatsi/abmread.htm

  https://lib.dr.iastate.edu/econ_workingpapers/23