Agent-Based Computational Economics
Growing Economies from the Bottom Up

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Presentation Outline

◇ What is Agent-based Computational Economics (ACE) in a nutshell?

◇ Simple labor market illustration, implemented via the Trade Network Game (TNG) laboratory

◇ Four main strands of ACE research

◇ Potential advantages and disadvantages of ACE for economic modeling
What is ACE?

- *Computational modeling* of economic processes as open-ended dynamic systems of interacting agents

- A *culture-dish approach* to the conceptual and practical study of economic processes
ACE Culture-Dish Analogy

- Modeler constructs a virtual economic world populated by various agent types
- Modeler sets initial world conditions
- Modeler then steps back to observe how the world develops over time without intervention (no imposed equilibrium, rational expectations, etc.)
- World events are driven by agent interactions
ACE Agent Types

Agents = Encapsulated software programs representing individual, social, biological and/or physical entities

* Cognitive agents are capable (in various degrees) of
  - Behavioral adaptation
  - Social communication
  - Goal-directed learning
  - Endogenous evolution of interaction networks
  - “Autonomy” (self-activation and self-determinism based on private internal processes)
Initial World Conditions
(Experimental Treatment Factors)

* Structural conditions
* Institutional arrangements
* Behavioral dispositions of agents
ACE Culture Dish Analogy...

- **Initial World Conditions** (Experimental Treatment Factors)
- **World Develops Over Time** (Culture Dish of Agents)
- **Macro Regularities**
Illustrative ACE Application Area:
Labor Institutions and Market Performance

Some Key Issues:

◆ Labor contracts typically *incomplete*

◆ Supplemented by government programs with numerous eligibility restrictions

◆ **Difficult to test program effects** by means of conventional analytical and/or statistical tools
Example: U.S. State Programs Providing Unemployment Benefits (UB)

Typical Features of State Programs (e.g., Iowa):

- UB only paid to “no fault of their own” unemployed
- UB recipients must continue to seek employment
- UB levels based on past earnings
- UB of limited duration
- UB financed by employer contributions at rates determined in part by each employer’s “benefit ratio” = [UB paid out to former employees divided by the employer’s taxable payroll]
- Additional UB often granted when unemployment rate is abnormally high for prolonged periods

➔ Complicated Rules!!
ACE Labor Market UB Study: Pingle/Tesfatsion 2003
Experiments Implemented via the Trade Network Game (TNG) Lab

Preferential job search (workers $W \rightarrow$ employers $E$) with choice and refusal of partners:
Purple directed arrow $=$ Refused work offer.
12 workers with same observable structural attributes in initial period T=0

12 employers with same observable structural attributes in initial period T=0

Only observable source of heterogeneity among workers and among employers is their expressed behaviors on the work-site
ACE Labor Market ...

- Each worker can work for at most one employer in each period $T$

- Each employer can provide at most one job opening in each period $T$

- Work-site strategies in the initial period $T=0$ are randomly determined and private information
Each worker and employer has ...

- **Publicly available information** about various market/policy protocols (e.g., unemployment benefit eligibility rules)

- **Private behavioral methods** that can change over time

- **Privately stored data** that can change over time
A Computational Worker

Public Access:

// Public Methods
Protocols governing job search
Protocols governing negotiations with potential employers
Protocols governing unemployment benefits program
Methods for receiving data
Methods for retrieving Worker data

Private Access:

// Private Methods
Method for calculating my expected utility assessments
Method for calculating my actual utility outcomes
Method for updating my worksite strategy (learning)

// Private Data
Data about myself (my history, utility fct., current wealth...)
Data recorded about external world (employer behaviors,...)
Addresses for potential employers (permits communication)
A Computational Employer

**Public Access:**

// **Public Methods**
- Protocols governing search for workers
- Protocols governing negotiations with potential workers
- Protocols governing unemployment benefits program
- Methods for receiving data
- Methods for retrieving Employer data

**Private Access:**

// **Private Methods**
- Method for calculating my expected profit assessments
- Method for calculating my actual profit outcomes
- Method for updating my work-site strategy (*learning*)

// **Private Data**
- Data about myself (my history, profit fct., current wealth...)
- Data recorded about external world (worker behaviors,...)
- Addresses for potential workers (permits communication)
Flow of Activities in the ACE Labor Market

- Workers make offers to preferred employers at a small cost per offer (quits allowed)

- Employers accept or refuse received work offers (firings allowed)

- Each matched pair engages in one work-site interaction (PD game with 2 possible moves: cooperate or defect)

- Any unemployed (unmatched) worker or vacant (unmatched) employer receives a UB payment

- After 150 work periods, each worker and employer updates its work-site strategy
Flow of Activities in the ACE Labor Market

Initialization

Work Period:
- Search/Match
- Worksite Interactions
- Update Expectations

Evolution Step:
- Evolve Worksite Strategies

Do 150 Loops

Do 1000 Loops
Worksite Interactions as Prisoner’s Dilemma (PD) Games

D = Defect (Shirk);  C = Cooperate (Fulfill Obligations)
Key Issues Addressed

How do changes in the level of the unemployment benefits (UB) payment affect...

➢ Worker-Employer Interaction Networks

➢ Worksite Behaviors: Degree to which workers/employers shirk (defect) or fulfill obligations (cooperate) on the worksite

➢ Market Efficiency (total surplus net of UB program costs, unemployment/vacancy rates,...)

➢ Market Power (distribution of total net surplus)
Experimental Design

- **Treatment Factor:**
  Unemployment Benefits Payment (UB)

- **Three Tested Treatment Levels:**
  UB=0, UB=15, UB=30

- **Runs per Treatment:**
  20 (1 Run = 1000 Generations; 1 Gen.=150 Work Periods)

- **Data Collected Per Run:** Network patterns, behaviors, and market performance (reported in detail for generations 12, 50, 1000)
Three Unemployment Benefit (UB) Treatments in Relation to PD Payoffs

① UB=0 < L=10

② L=10 < UB=15 < D=20

③ D=20 < UB=30 < C=40

❖ NOTE: Work-site PD payoffs are given by:

L (Sucker) = 10 < D (Mutual-D) = 20
< C (Mutual-C) = 40
< H (Temptation) = 60
Market Efficiency Findings

As UB level **increases** from 0 to 30...

- **higher** average unemployment and vacancy rates are observed;  ⇦ **KNOWN EFFECT**

- **more** work-site cooperation observed on average among workers & employers who match.  ⇦ **NEW EX POST EFFECT**

**Note:** These two market efficiency effects have *potentially offsetting effects* on market efficiency.
Efficiency Findings ...

- Market Efficiency (Utility less UB Program Costs) Averaged Across Generations 12, 50, and 1000 for three different UB treatments
Efficiency Findings...

- UB=15 yields *highest* efficiency

- UB = 0 yields *lower* efficiency (too much shirking)

- UB=30 yields *lowest* efficiency (UB program too costly)
Multiple Attractors

Two “attractors” observed for each NEP treatment

- **UB=0 and UB=15:**
  - *First Attractor* = Latched network supporting *mutual cooperation*;
  - *Second Attractor* = Latched network supporting *intermittent defection*

- **UB=30:**
  - *First Attractor* = Latched network supporting *mutual cooperation*
  - *Second Attractor* = Completely disconnected network (*total coordination failure*)
Multiple Network Attractors ... Network Details

* Two “attractors” observed for each UB treatment

- **No UB (0) or Low UB (15):**
  - *First Attractor* = *Latched W-E network* supporting *mutual cooperation*;
  - *Second Attractor* = *Latched W-E network* supporting *intermittent defection*

- **High UB (30):**
  - *First Attractor* = *Latched W-E network* supporting *mutual cooperation*
  - *Second Attractor* = Completely disconnected network (*total coordination failure*)
The Following Diagrams Report ...

1. Two-sided (W-E) network distributions
   0 = Stochastic fully connected network
   12 = Latched in pairs
   24 = Completely disconnected

2. Worksite behaviors supported by these networks
Network Distribution for UB=0
(Sampled at End of Generation 12)
Network Distribution for UB=0
(Sampled at End of Generation 50)
Network Distribution for **UB=0**
(Sampled at End of Generation 1000)
Network Distribution for **UB=15**
(Sampled at End of Generation 12)
Network Distribution for **UB=15**
(Sampled at End of Generation 50)

Network Distribution for **LowT:50**

![Network Distribution Graph for LowT:50](image)
Network Distribution for UB=15
(Sampled at End of Generation 1000)
Network Distribution for UB=30
(Sampled at End of Generation 12)

Network Distribution for HighT:12

Network Distance
Number of Runs
Intermittent Defection Mutual Cooperation Coordination Failure

Network Distance
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Intermittent Defection Mutual Cooperation Coordination Failure
Network Distribution for **UB=30**
(Sampled at End of Generation 1000)

![Network Distribution for HighT:1000](image)

- **Network Distance**: x-axis
- **Number of Runs**: y-axis
- **Mutual Cooperation**: Green bars
- **Coordination Failure**: Black bars
Four Main Strands of ACE Research

- **Normative Understanding**
  (institutional design, policy selection, ...)

- **Empirical Understanding**
  (possible reasons for empirical regularities)

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

- **Methodological Advancement**
  (representation, visualization, empirical validation, ...)
ACE and Institutional Design

Key Issue: Does an institutional design ensure efficient, fair, and orderly social outcomes over time despite attempts by participants to “game” the design for their own personal advantage?

ACE Approach:

- **Construct an agent-based world** capturing salient aspects of the institutional design.

- **Introduce agents with behavioral dispositions, needs, goals, beliefs, etc.** Let the world evolve. Observe and evaluate resulting social outcomes.

*Examples:* Unemployment benefit programs, Internet auctions, stock markets, negotiation protocols, electricity markets...
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 the simultaneous explanation of financial market “stylized facts”

https://www2.econ.iastate.edu/tesfatsi/finance.htm
Illustrative Issue: What are the performance capabilities of decentralized markets? (Adam Smith, F. von Hayek, John Maynard Keynes, J. Schumpeter ...)

ACE Approach:

- **Construct an agent-based world** qualitatively capturing key aspects of decentralized market economies (firms, consumers, circular flow, limited information, ...)

- **Introduce traders with behavioral dispositions, needs, goals, beliefs, etc.** Let the world evolve. Observe the degree of coordination that results.

Examples: Decentralized exchange economies (no “Walrasian Auctioneer”), double-auction markets (learning traders vs. “zero intelligence” traders),...
Potential Disadvantages of ACE for Economic Modeling

- **Intensive experimentation is often needed** (fine sweeps of parameter ranges to attain robust findings)

- **Multi-peaked rather than central-tendency outcome distributions can arise** *(strong path dependence possible)*

- **Can be difficult to ensure platform robustness** *(i.e., results that are independent of the hardware and/or software implementation of a model)*

- **Effort required to gain computer modeling skills can be significant** *(creative computer modeling as opposed to use of existing comp labs requires good programming knowledge)*
Potential Advantages of ACE for Economic Modeling

- Permits systematic experimental study of empirical regularities, economic institutions, and dynamic behaviors of complex economic processes in general.

- Facilitates creative experimentation with realistically rendered economic processes:
  - Using ACE comp labs, researchers/students can evaluate interesting conjectures of their own devising, with immediate feedback and no original programming required.
  - Modular form of ACE software permits relatively easy modification/extension of features.
ACE Resources

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

  https://www2.econ.iastate.edu/tesfatsi/hbace.htm
Current ACE Research Areas

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

• Learning and embodied cognition
• Network formation
• Evolution of norms
• Specific market case studies (labor, electricity, finance...)
• Industrial organisation
• Technological change and growth
• Multiple-market economies
• Market design
• Automated markets and software agents
• Development of computational laboratories
• Parallel experiments (real and computational agents)
• Empirical validation.... and many more areas as well!