# Agent-Based Computational Economics

## Growing Economies from the Bottom Up


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**Lecture Notes**

# Presentation Outline

- What is **A**gent-based **C**omputational **E**conomics **(ACE)** in a nutshell?
- Simple labor market illustration, implemented via the **T**rade **N**etwork **G**ame (**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**

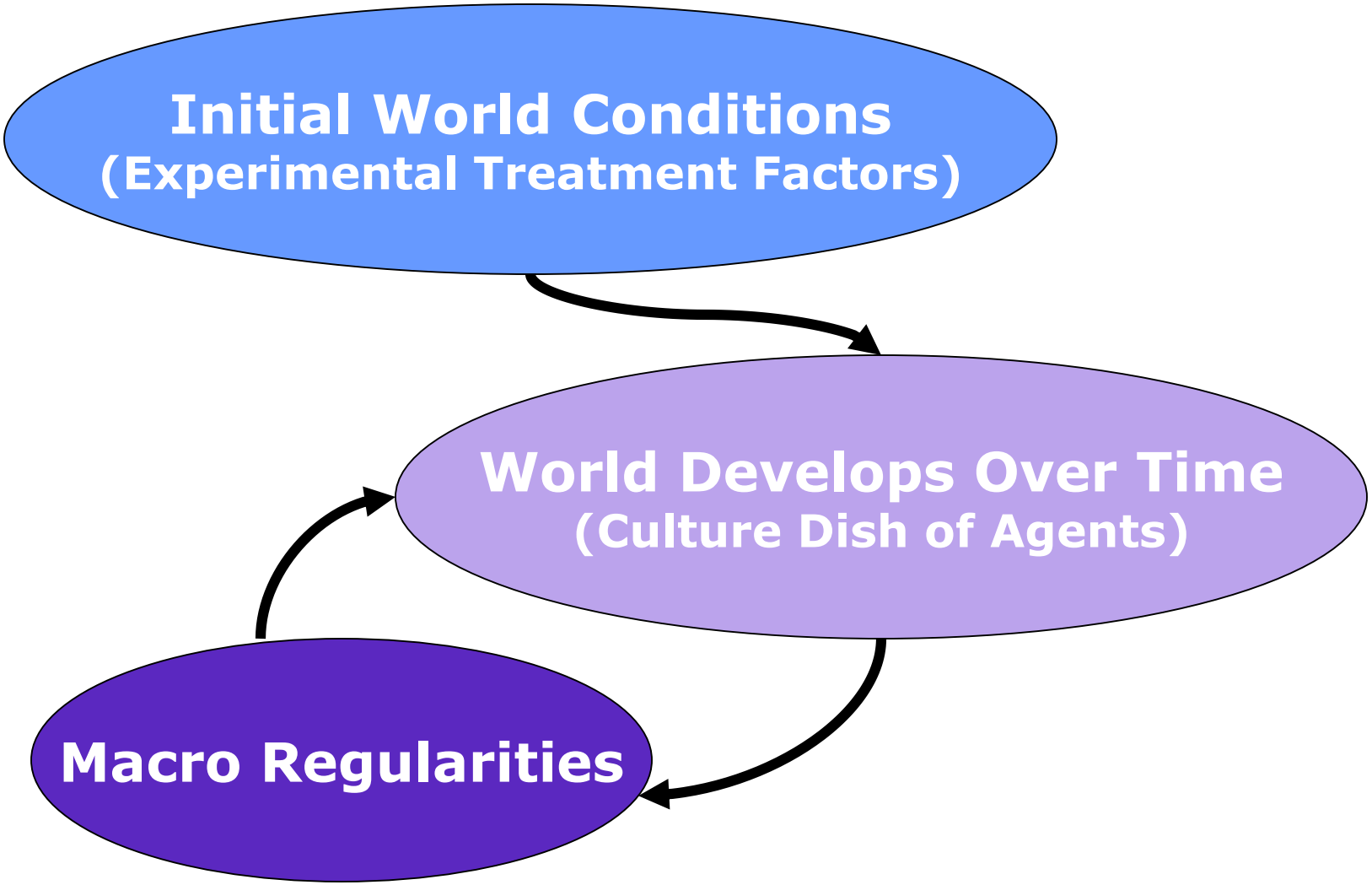
✱ **Cognitive agents** are capable (in various degrees) of

- **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



# 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)

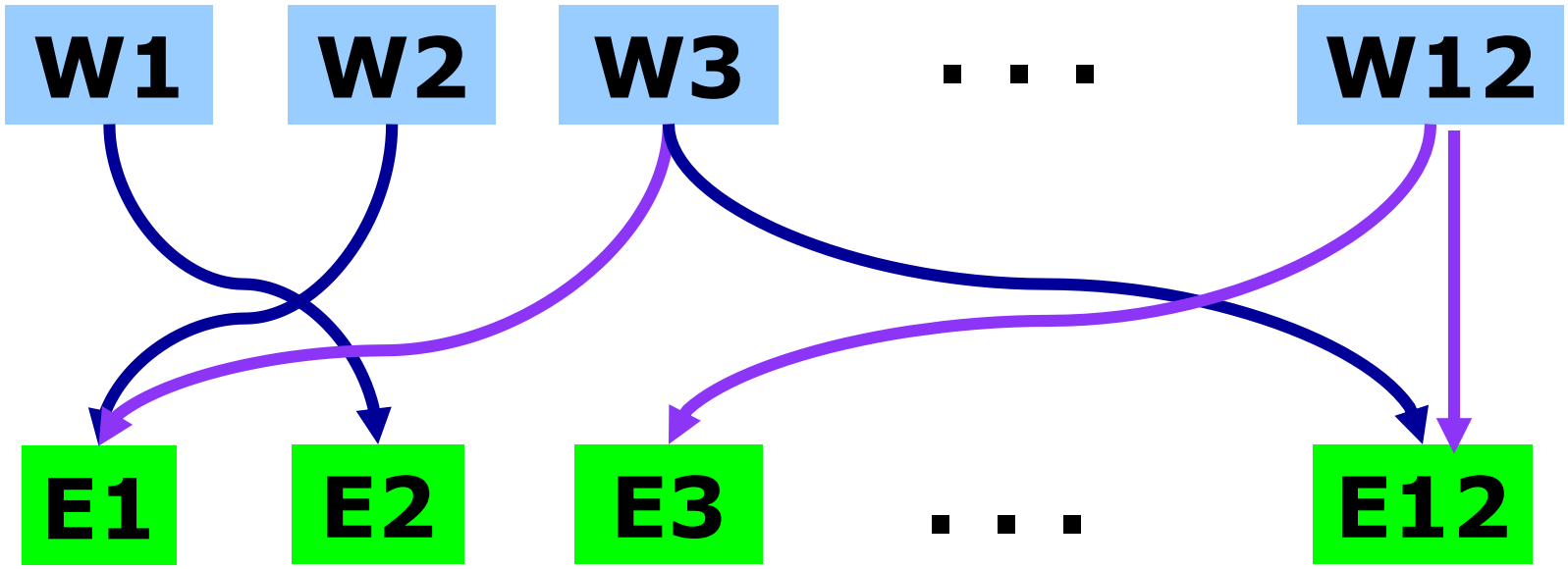
**Typical Features of State Programs (e.g., Iowa)**:

- 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 Implemented Via TNG Lab

Mark Pingle and Leigh Tesfatsion, **"Evolution of Worker-Employer Networks and Behaviors Under Alternative Non-Employment Benefits: An Agent-Based Computational Study"** [**(pdf,269KB)**, **(SlideSet,pdf,88KB)**], pp. 256-285 in Anna Nagurney (ed.), *Innovations in Financial and Economic Networks*, New Dimensions in Networks Book Series, Edward Elgar Publishers, 2003.




Preferential job search (workers W ➔ employers E)
with choice and refusal of partners

**Purple directed arrow =: Refused work offer**

**Blue directed arrow = : Accepted work offer**

# ACE Labor Market

- 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

# Worker Agent

**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)

# Employer Agent

**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**)

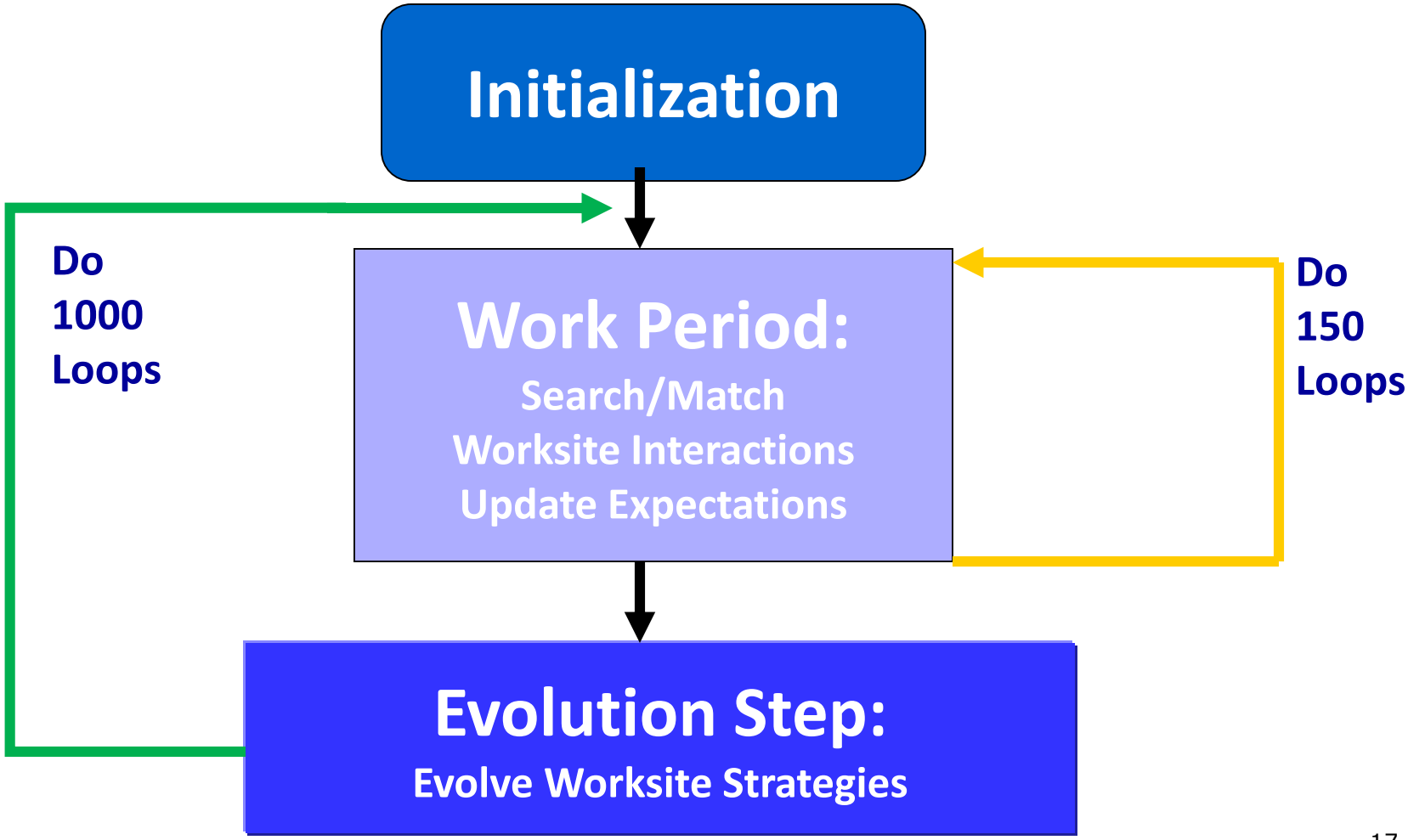
// **Private Data**

Data about myself (my history, profit fct., current wealth…)
Data recorded about external world (worker behaviors,…)
Addresses for potential workers (permits communication)

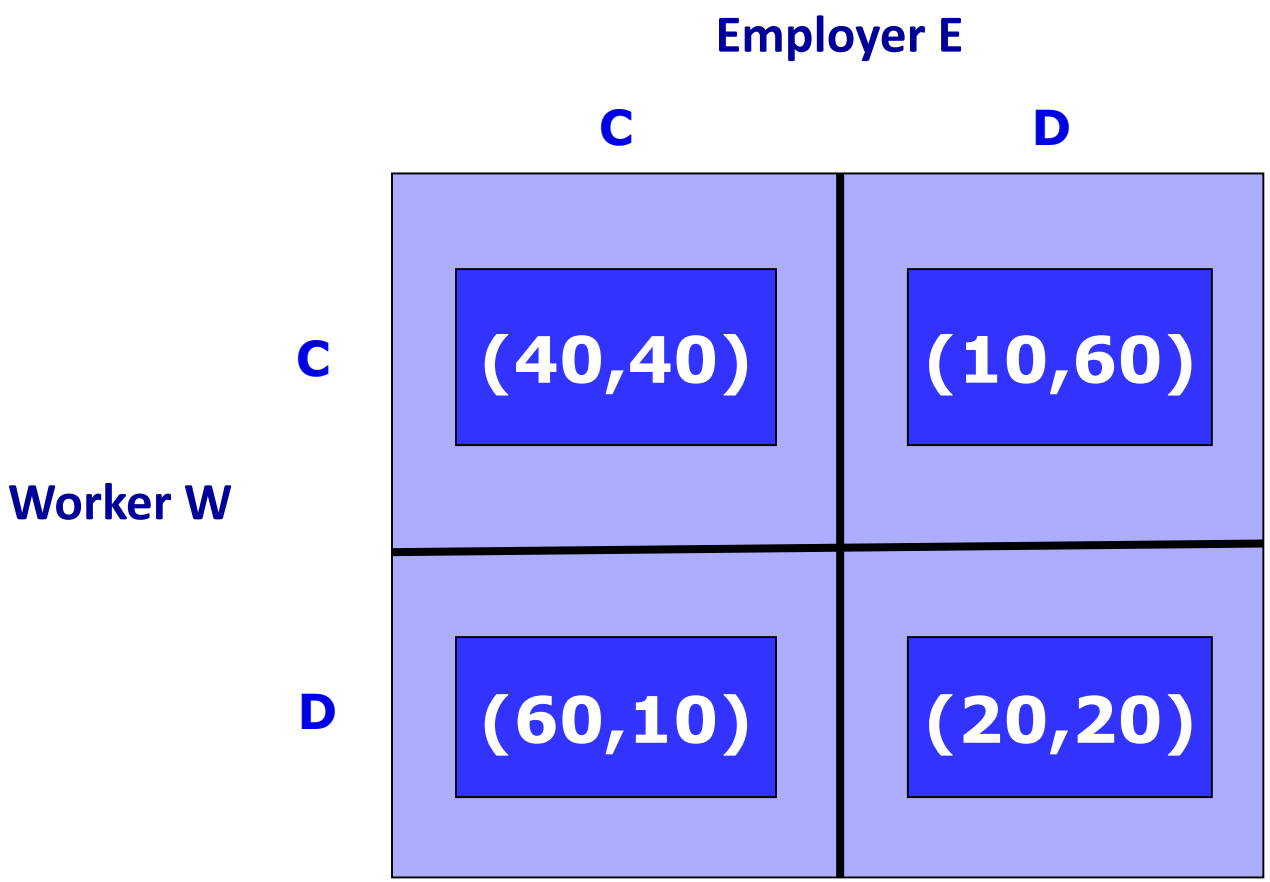
# Flow of Activities in the ACE Labor Market

- 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



# Worksite Interactions as Prisoner's Dilemma (PD) Games




**Sucker Payoff L=10:**
I choose **C**; the other player chooses **D**

**Temptation Payoff H=60:**
I choose **D**; the other player chooses **C**.

**Mutual Cooperation Payoff CC=40:** Both players choose **C**.

**Mutual Defection Payoff DD =20:** Both players choose **D**.

**Possible W and E Player Moves:** **D = Defect (Shirk); C = Cooperate (Fulfill Obligations)**
**Resulting W and E Player Payoffs: (WPayoff, EPayoff)**

# Key Issues Addressed

How do **changes** in the unemployment benefit UB 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 Generation = 150 Work Periods)

- **Data Collected Per Run:** Network patterns, behaviors, & market performance (reported in detail for generations 12, 50, 1000)

# Three Unemployment Benefit (UB) Treatments in Relation to Possible PD Game Payoffs

**First UB Treatment:** **UB=0** < **L** = 10

**Second UB Treatment:** **L** = 10 < **UB=15** < **DD** = 20

**Third UB Treatment:** **D** = 20 < **UB=30** < **CC** = 40

- **NOTE:** Possible work-site PD game payoffs for each player are:

**L** (Sucker) = 10 < **DD** (Mutual-D) = 20
< **CC** (Mutual-C) = 40
< **H** (Temptation) = 60

# Market Efficiency Findings

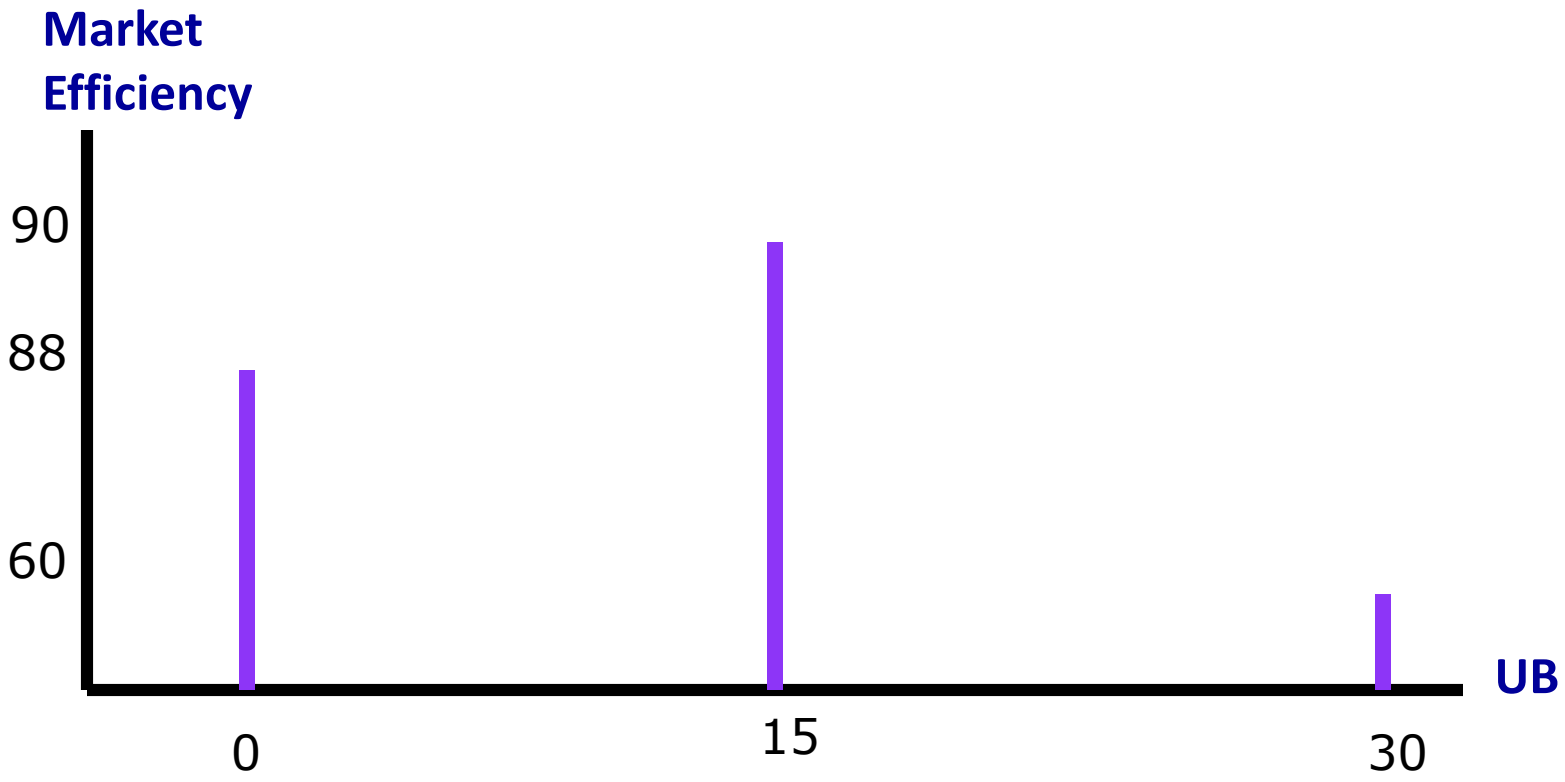
As UB level increases from 0 to 30…

- ***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 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 Network Attractors

- **Two "attractors" observed for each UB treatment**

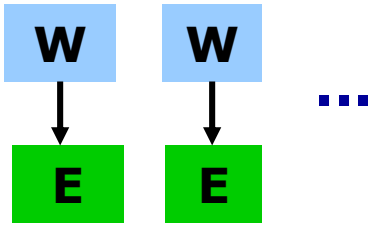
- **No UB (0) or Low UB (15) :**
  - ***First Attractor*** = *Latched W-E network* supporting *mutual cooperation*;
  - ***Second Attractor*** = *Latched W-E network* supporting *intermittent defection*

- **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, classified by distance (0 to 24) from a "stochastic fully connected" network:**

**0** =: Stochastic fully connected network (random recurrence)

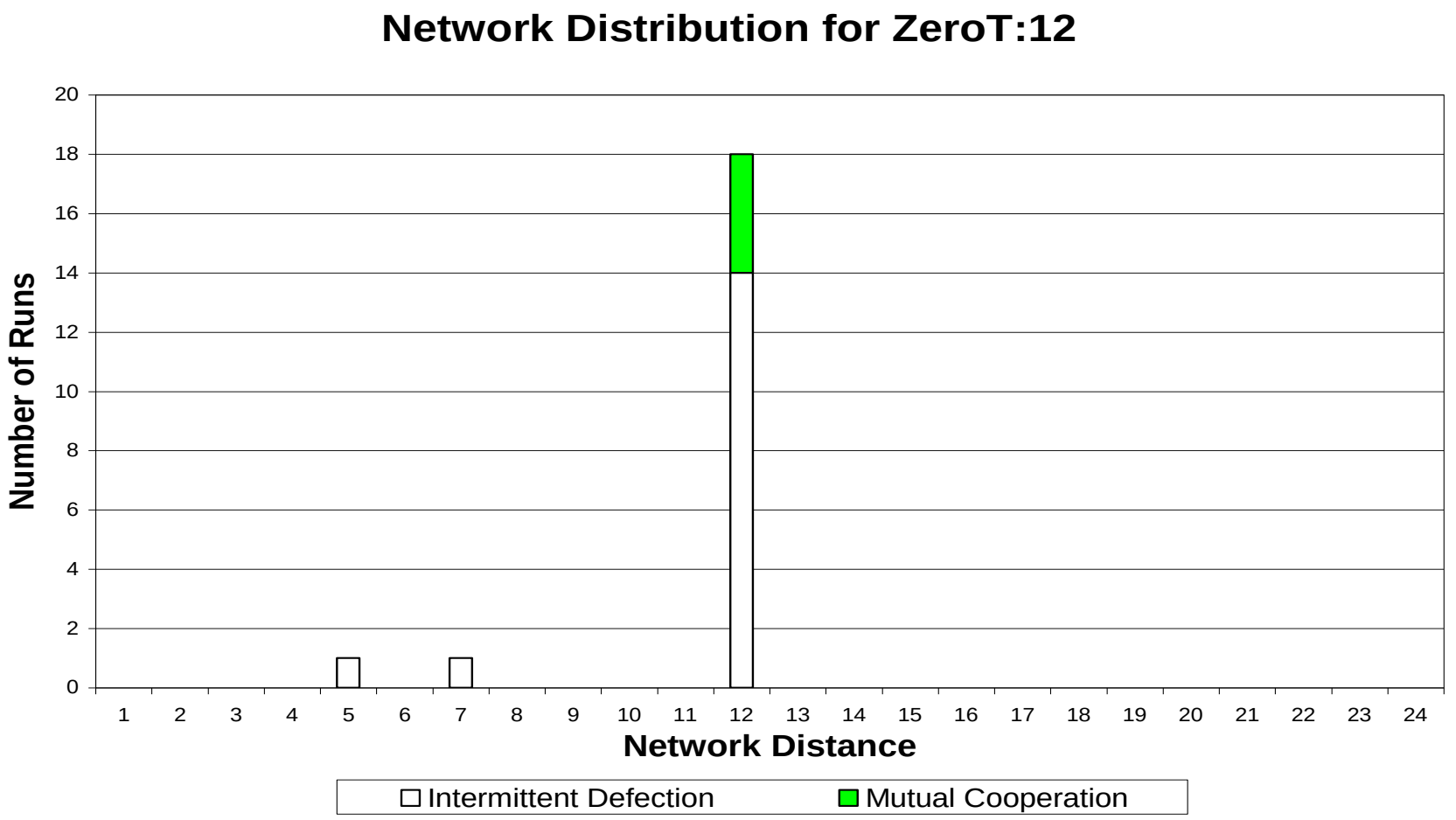
**12** =: Latched in pairs 


**24** =: Completely disconnected (no W-E matches)

② **Worksite behaviors supported by these networks**

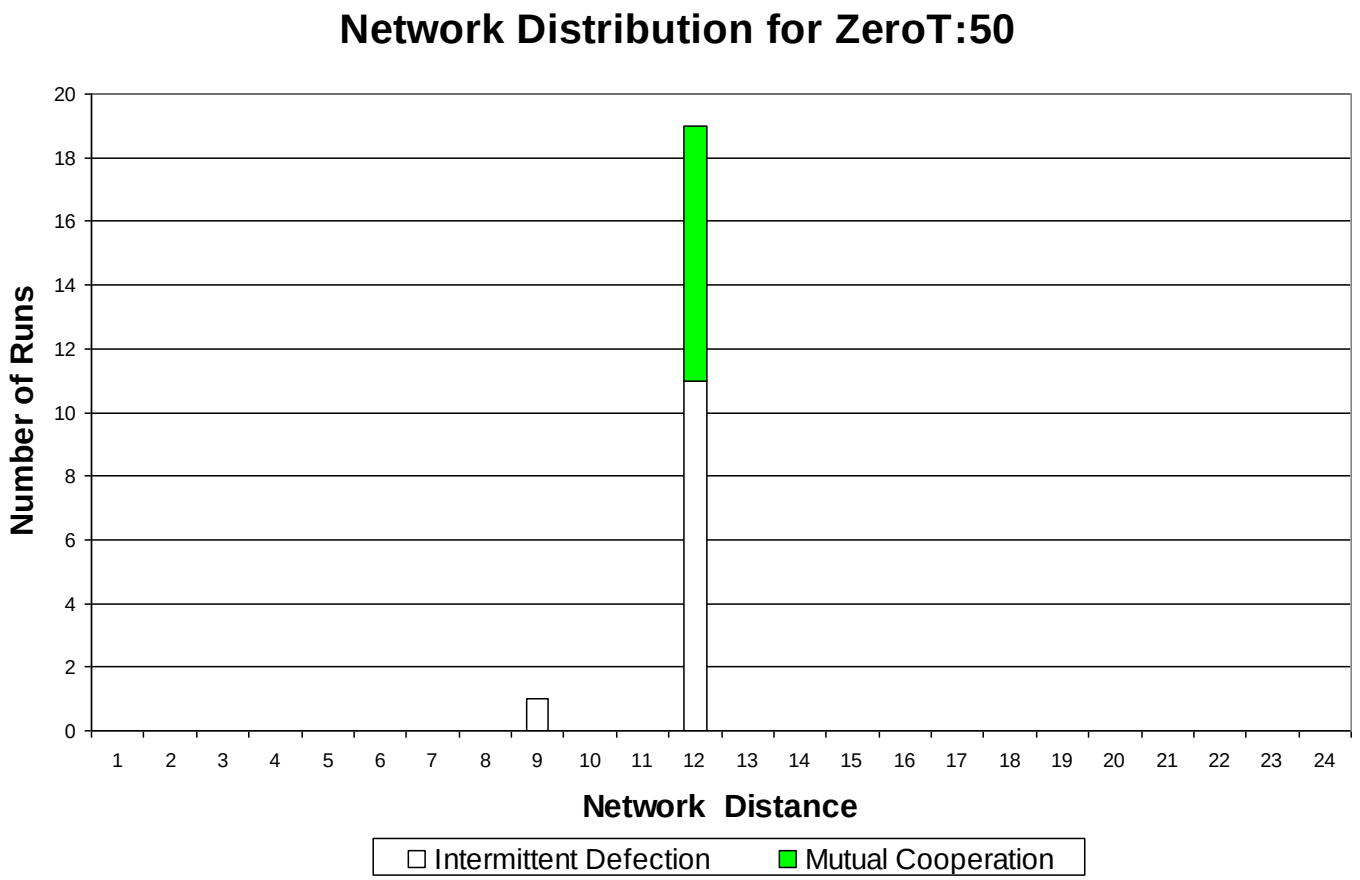
# Network Distribution for UB=0

## (Sampled at End of Generation 12)



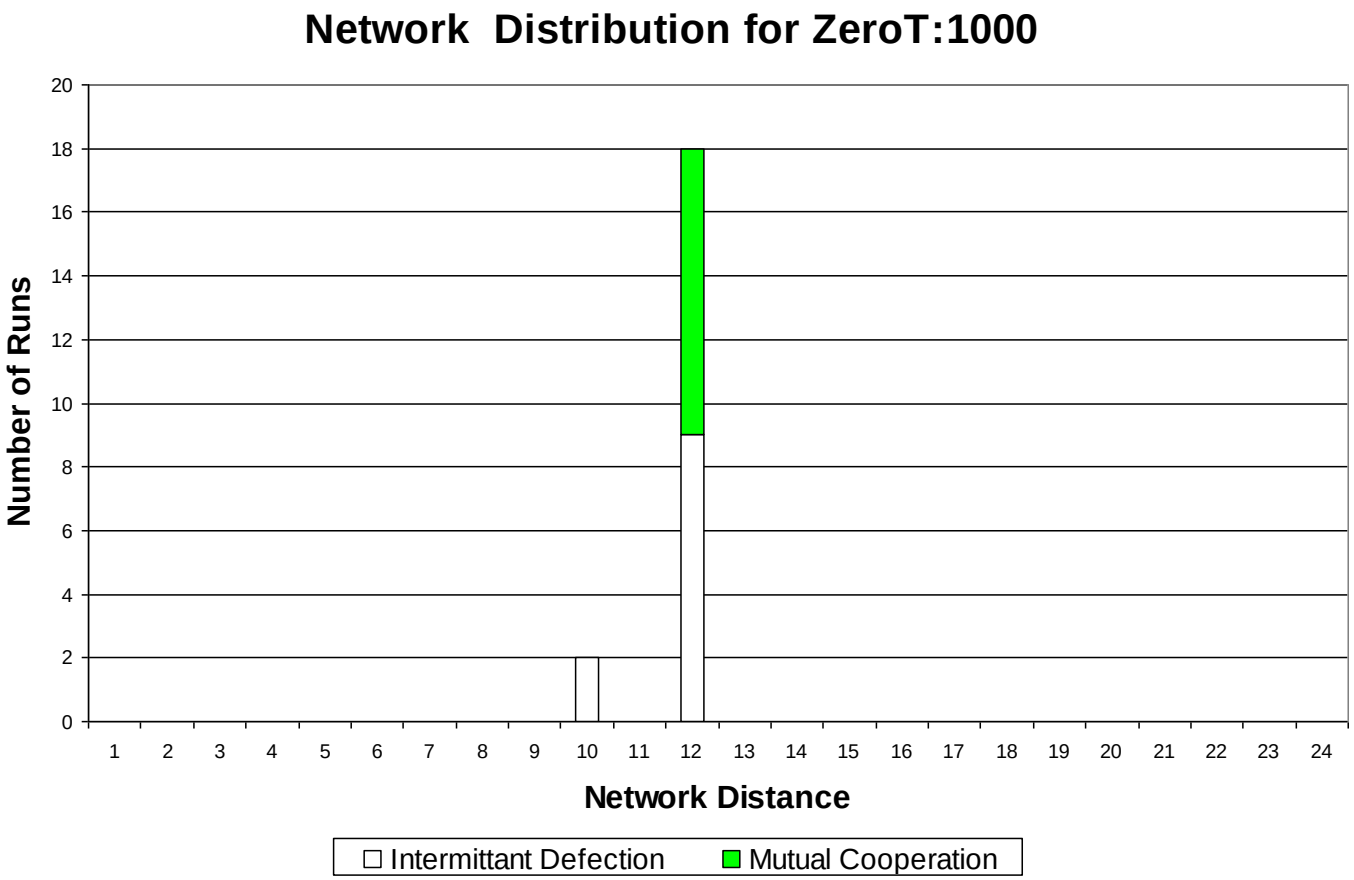
# Network Distribution for UB=0

## (Sampled at End of Generation 50)



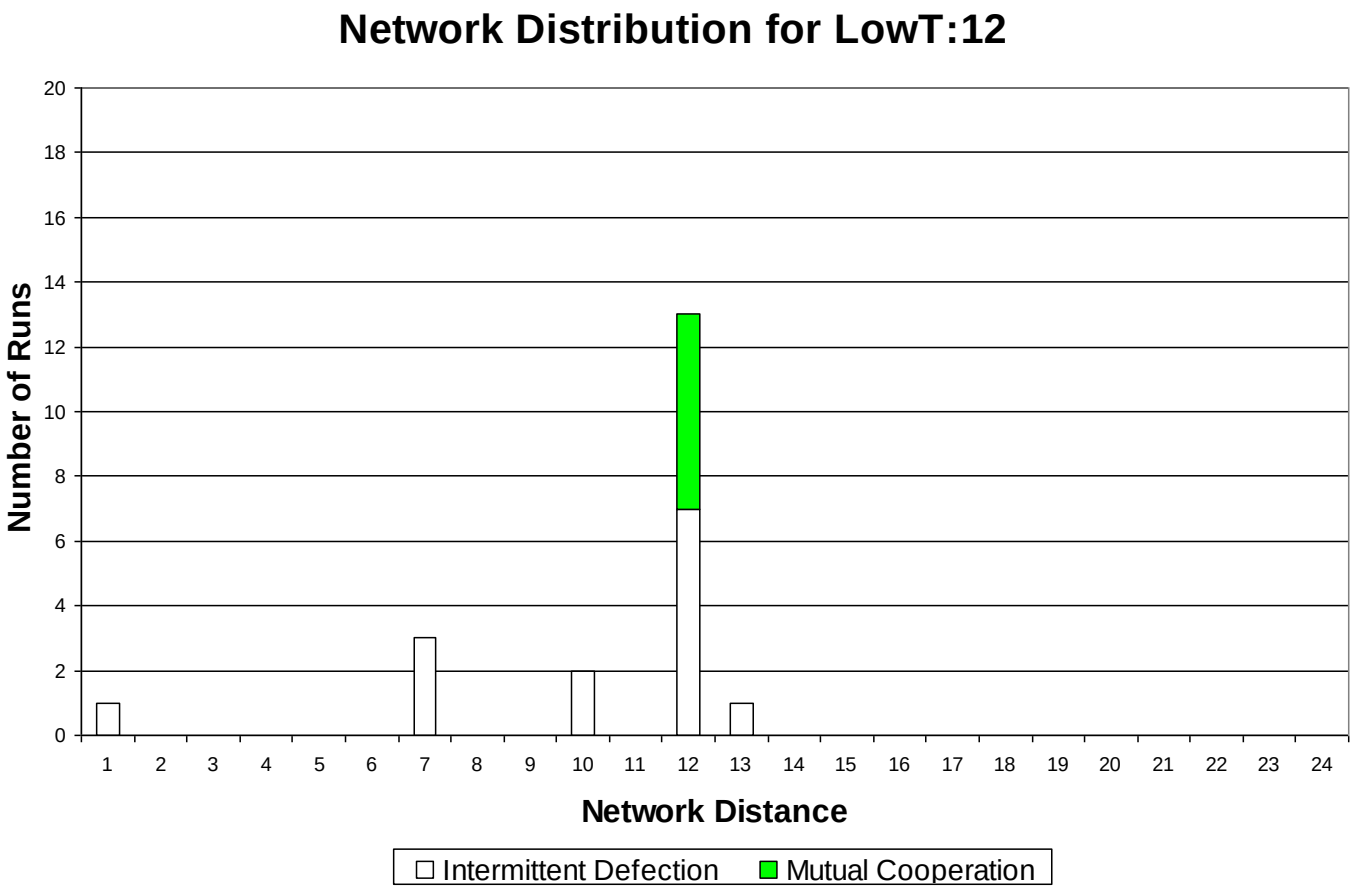
# Network Distribution for UB=0

## (Sampled at End of Generation 1000)



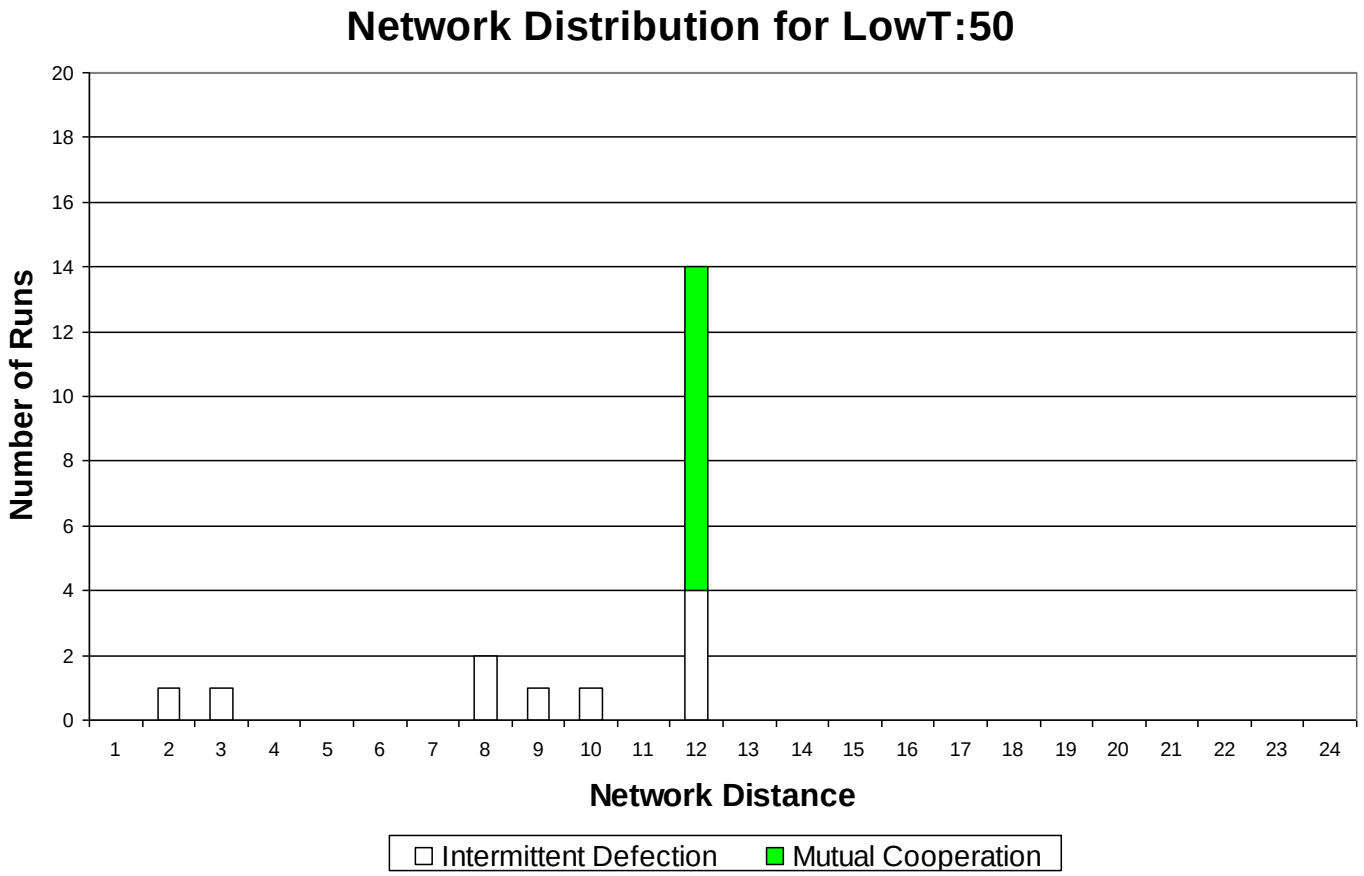
# Network Distribution for UB=15

## (Sampled at End of Generation 12)



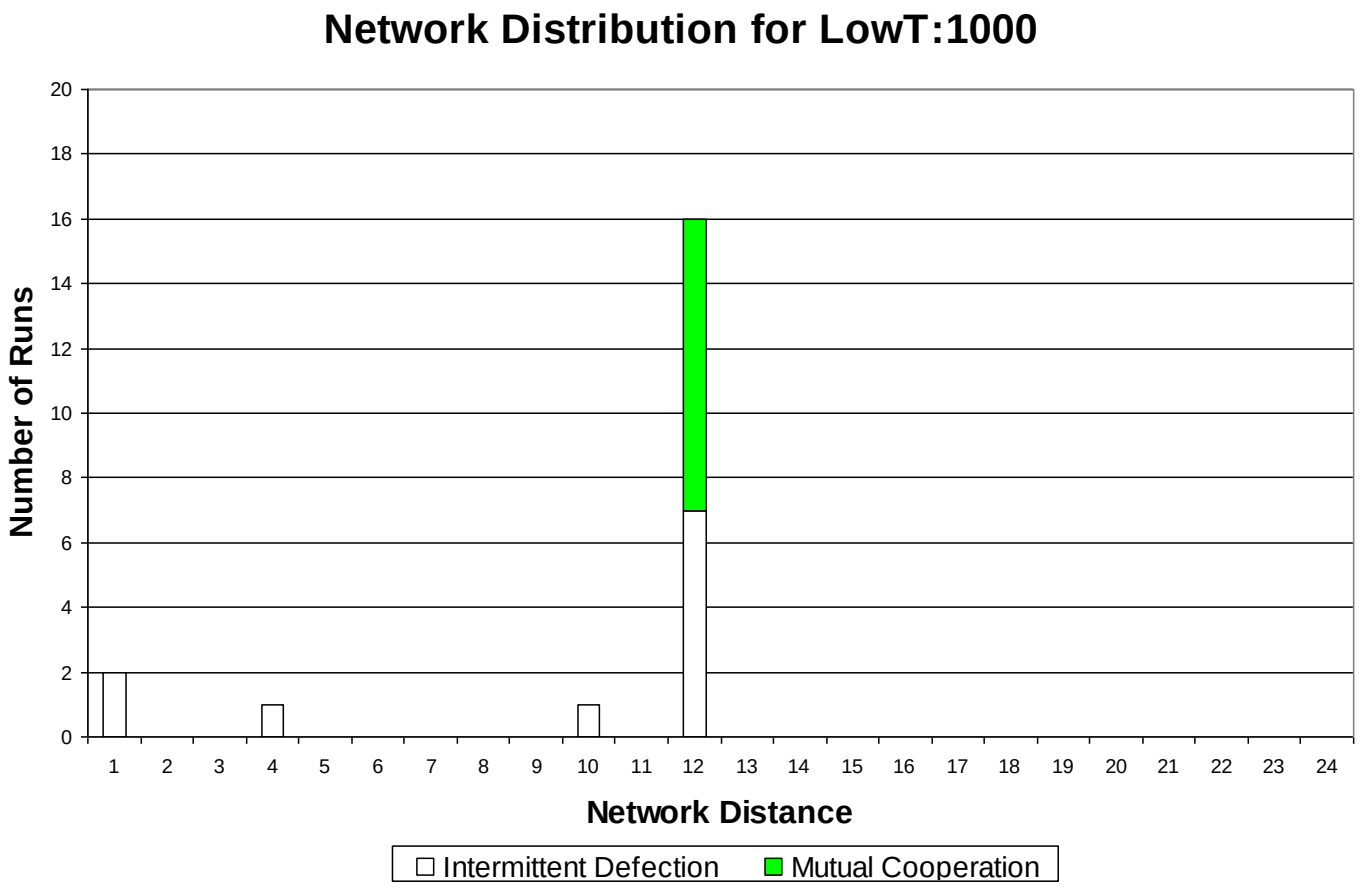
# Network Distribution for UB=15

## (Sampled at End of Generation 50)



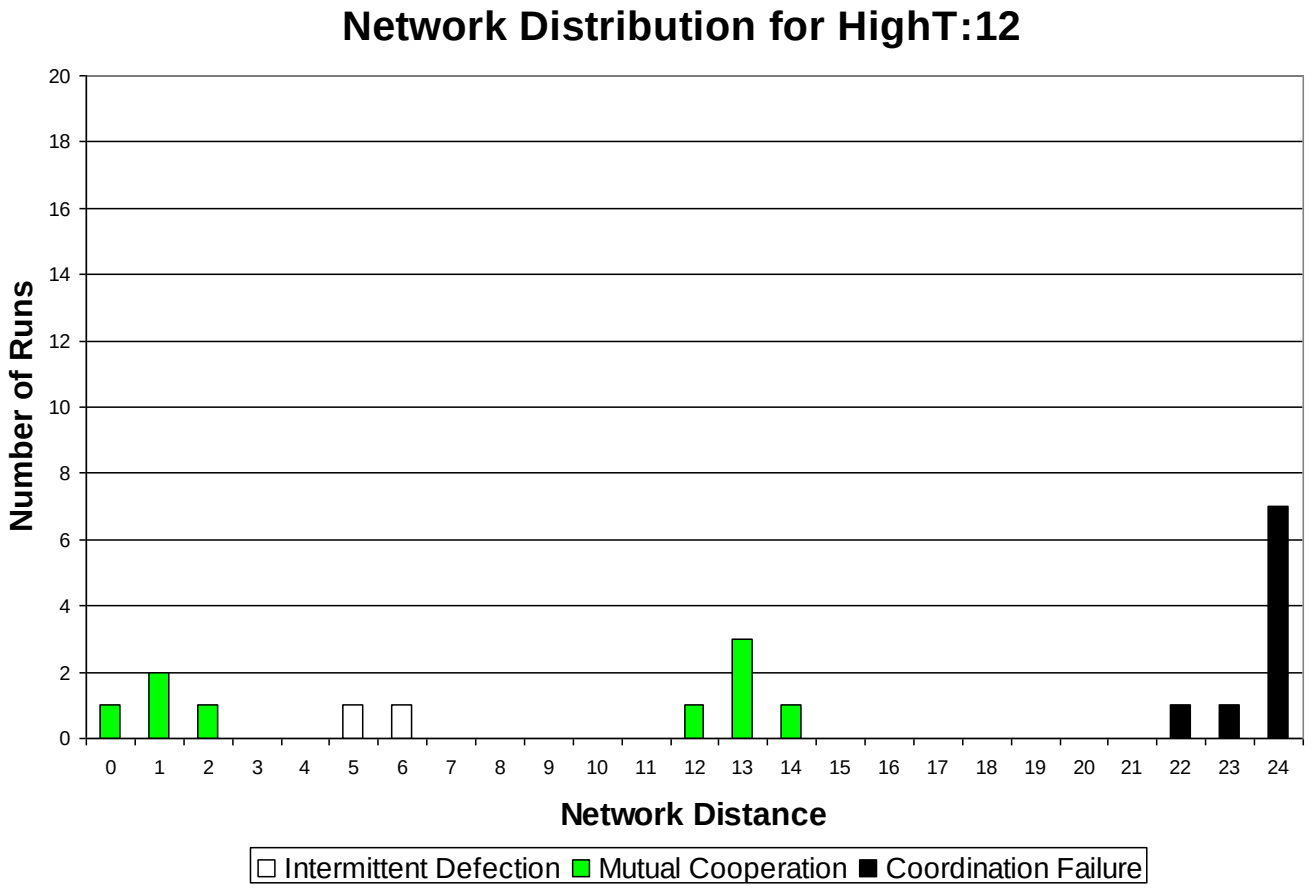
# Network Distribution for UB=15

## (Sampled at End of Generation 1000)



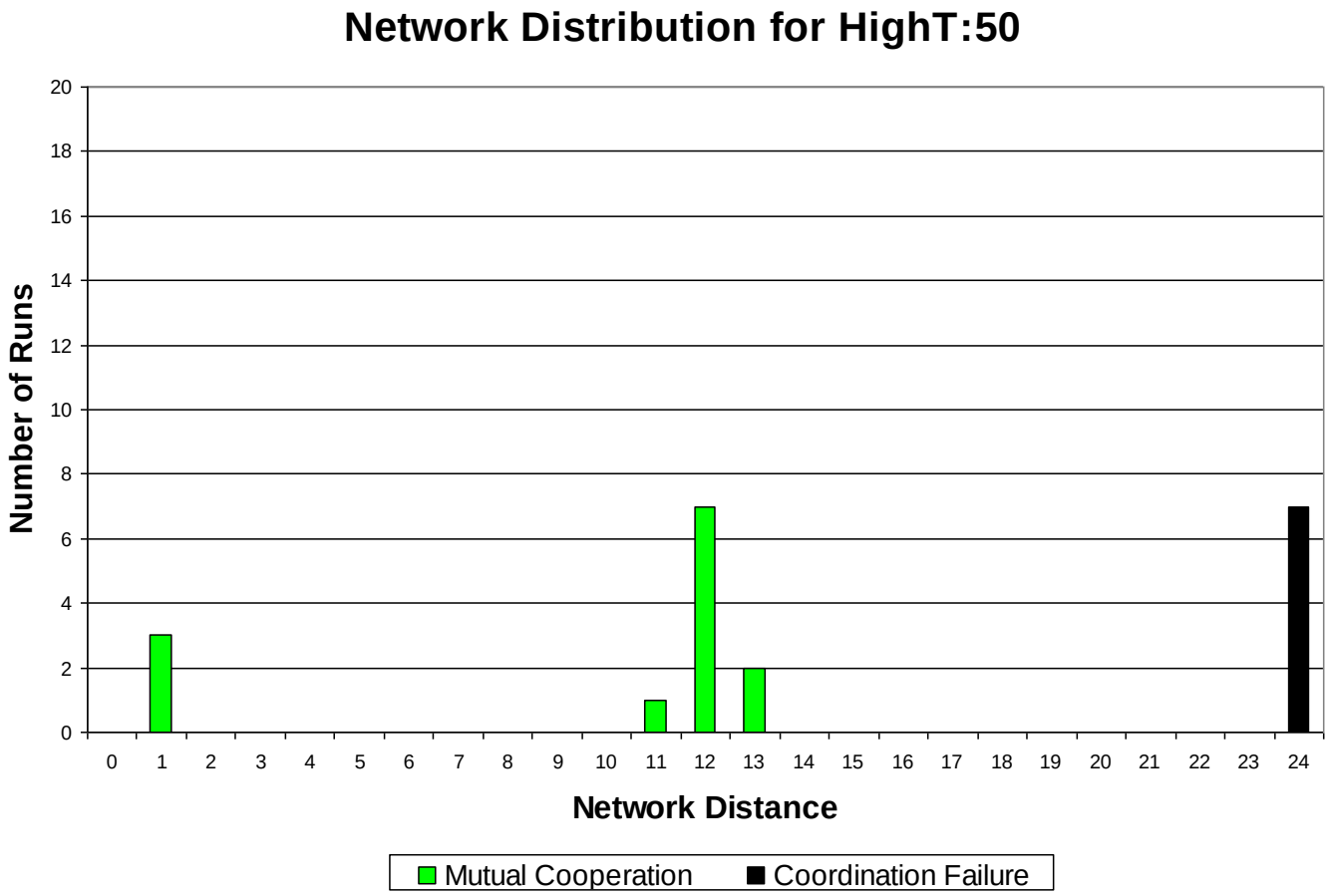
# Network Distribution for UB=30

## (Sampled at End of Generation 12)



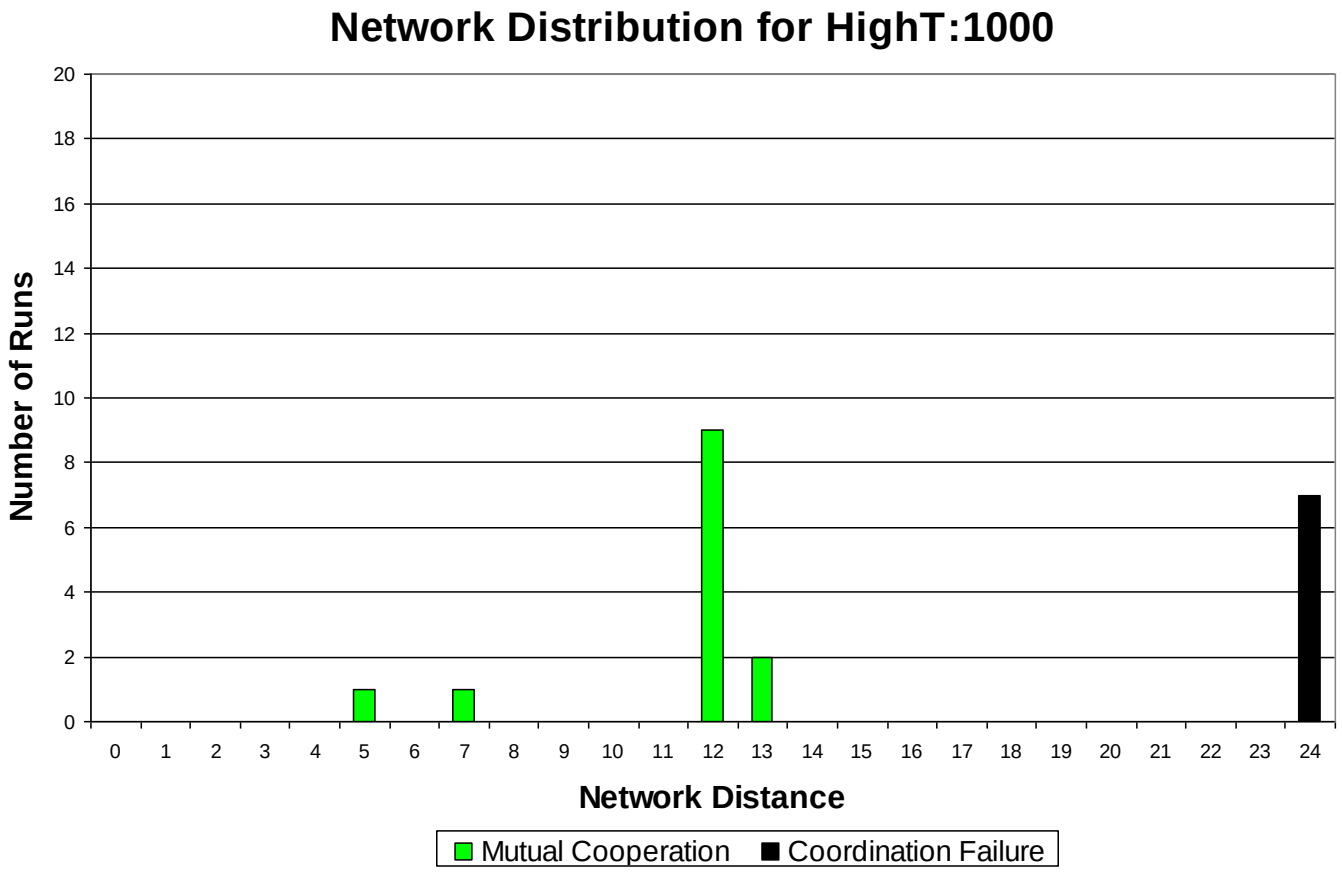
# Network Distribution for UB=30

## (Sampled at End of Generation 50)



# Network Distribution for UB=30

## (Sampled at End of Generation 1000)



# 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, …)
- **Method/Tool 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/afinance.htm

# ACE and Qualitative Analysis

**Illustrative Issue:** What are the performance capabilities of decentralized markets? *(Adam Smith, Ludwig von Mises, Friedrich von Hayek, John Maynard Keynes, Joseph 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 computational modeling, not simply the use of pre-existing models/programs, requires good computer programming knowledge)

# Potential Advantages of ACE for Economic Modeling

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

- **Facilitates creative experimentation** with realistically rendered economic systems:

  - 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 modifications and/or major extensions of system features.

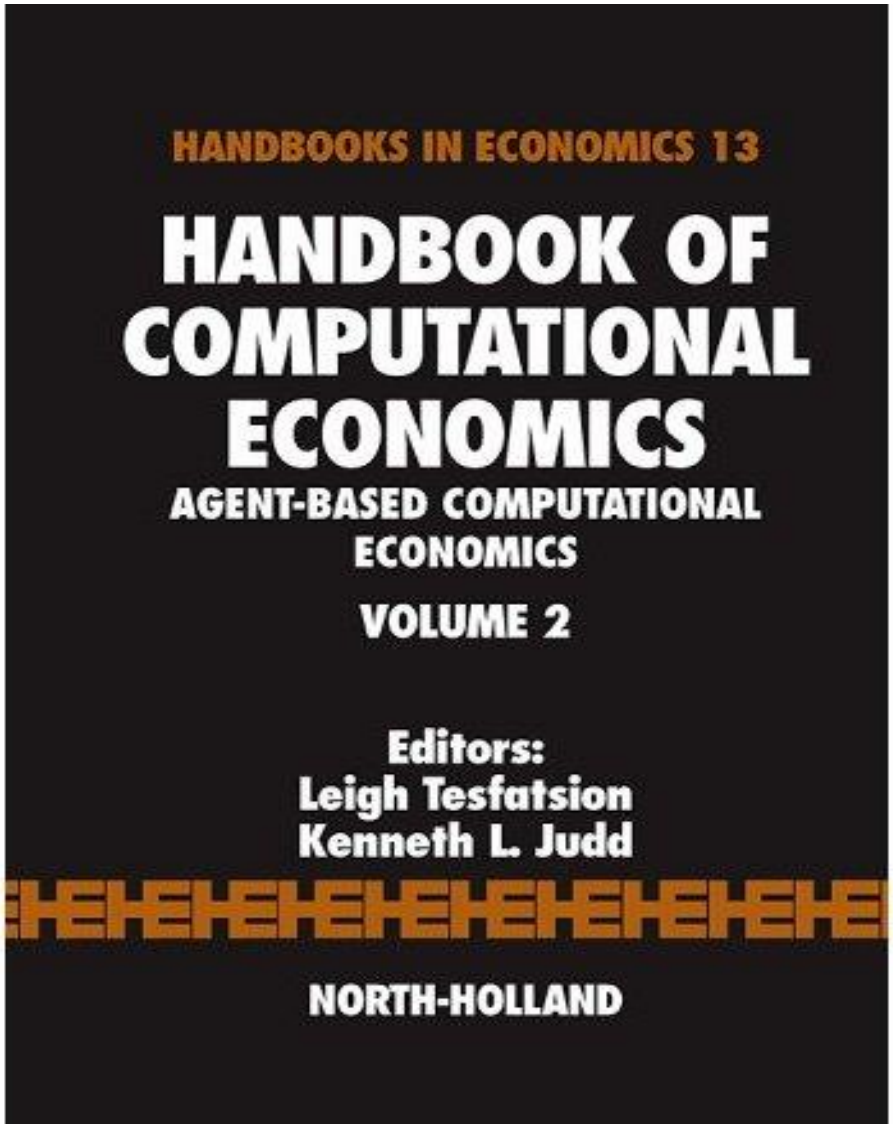
# ACE Resources

- **ACE Website**

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

- **ACE Handbook** (Tesfatsion & Judd, Handbooks in Economics Series, North-Holland, 2006, 904pp)

  https://www2.econ.iastate.edu/tesfatsi/hbace.htm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HANDBOOK OF COMPUTATIONAL ECONOMICS
AGENT-BASED COMPUTATIONAL ECONOMICS
VOLUME 2
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# Current ACE Research Areas

https://www2.econ.iastate.edu/tesfatsi/aapplic.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!***