Agent-Based Computational Economics

A Constructive Approach to Economic Theory

Presenter (Spring 2005):

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Basic References

- Leigh Tesfatsion, **"Agent-Based Computational Economics: A Constructive Approach to Economic Theory"**

  Chapter 1 in Leigh Tesfatsion and Kenneth L. Judd, Editors, *Handbook of Computational Economics, Volume 2: Agent-Based Computational Economics*, Handbooks in Economics Series, North-Holland, Amsterdam, to appear.

  http://www.econ.iastate.edu/tesfatsi/hbace.htm

- **ACE Website**

  http://www.econ.iastate.edu/tesfatsi/ace.htm

Outline

- The Complexity of Decentralized Market Economies
- What is Agent-Based Computational Economics (ACE)?
- An Illustrative ACE Model of a Decentralized Market Economy
- Computational Laboratory Implementation

  (joint work with C. Cook)

The Complexity of Decentralized Market Economies

- Large numbers of economic agents involved in ***distributed local interactions***
- ***Two-way feedback*** between microstructure and macro regularities mediated by agent interactions
- Potential for ***strategic behaviour***
- Pervasive ***behavioural uncertainty***
- Possible existence of ***multiple equilibria***
- Critical role of ***institutional arrangements***

What is Agent-Based Computational Economics (ACE)?

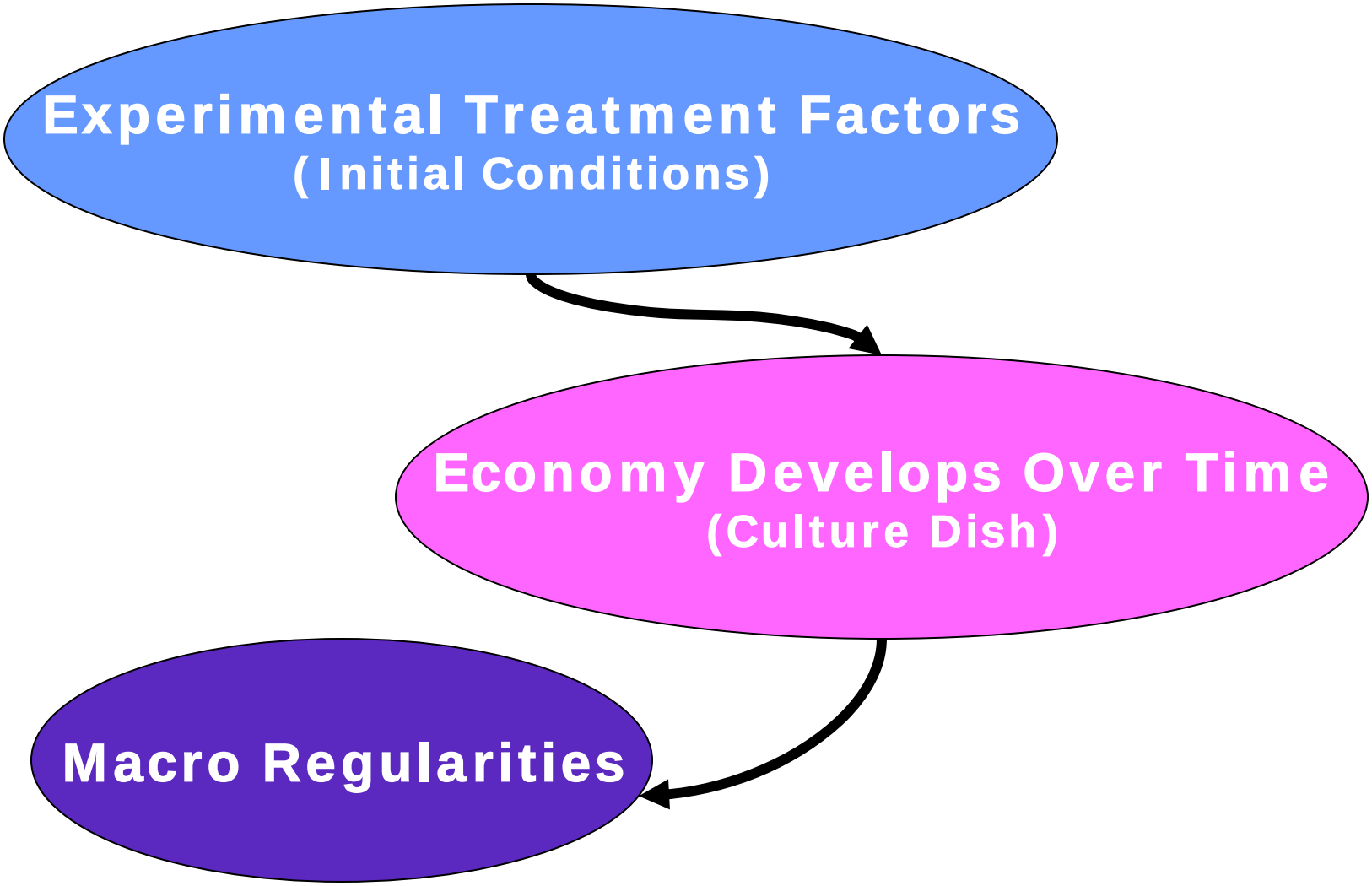
- **Culture-dish approach** to the study of decentralized market processes
- **Experimental study** of economies computationally modeled as evolving systems of autonomous interacting agents with learning capabilities
- **ACE Website**

www.econ.iastate.edu/tesfatsi/ace.htm

ACE Modeling: Culture Dish Analogy

- Modeler constructs a **virtual economic world** populated by various agent types (economic, social, biological, physical)
- Modeler sets **initial conditions**
- The world then **develops over time** without further outside intervention
- World driven solely by **agent interactions**

ACE Modelling: Culture Dish Analogy



Key Characteristics of ACE Models

- **Agents** are encapsulated software programs capable of
  - ***Adaptation*** to environmental conditions
  - ***Social communication*** with other agents
  - ***Goal-directed learning***
  - ***Autonomy*** (self-activation and self-determinism based on private internal processes)
- Agents can be situated in **realistically rendered problem environments**
- **Behaviour / interaction patterns can evolve over time**

Increased facility for modeling autonomous agents

- ***Distributed agent control***, not just distributed agent actions.
- Agents can decide for themselves which actions they perform, and when, based on ***private internal processes***.
- ***Implication:*** Major source of uncertainty for agents in ACE models is not knowing what other agents will do (unpredictable endogenous heterogeneity!)

TradeBot: A Virtual Trader

Public Access:

// **Public Methods**

Protocols governing communication with other traders;
Protocols governing search for trade partners;
Protocols governing the conduct of trades;
Methods for receiving data (e.g., a “telephone”);
Methods for retrieving Trader data.

Private Access:

// **Private Methods**

Methods for gathering, storing, and sending data;
Method for calculating my expected utility assessments;
Method for calculating my actual utility outcomes;
Method for updating my trade strategy (learning);
Methods for updating my methods (learning to learn).

// **Private Data**

Data about myself (my history, utility fct., current wealth…);
Data recorded about external world (rivals’ bids/asks…);
Addresses (e.g., a “telephone book”).

ACE and Macro Regularities

Key Issue: Is there a causal explanation for a **persistently observed macro regularity?**

ACE Approach:

- Construct an ***agent-based world*** capturing salient aspects of the empirical situation.
- Investigate whether the observed macro regularity can be ***reliably generated*** "from the bottom up" in this agent-based world.
- **Generative Science** (Epstein/Axtell,1996)

ACE and Market Design

Key Issue: Does a proposed or actual market design ensure **efficient, fair, and orderly market outcomes over time** despite repeated attempts by traders to game the design for their own personal advantage?

ACE Approach:

- Construct an ***agent-based world*** capturing salient aspects of the market design.
- ***Introduce self-interested traders with learning capabilities.*** Let the world develop over time. Observe/evaluate resulting market outcomes.

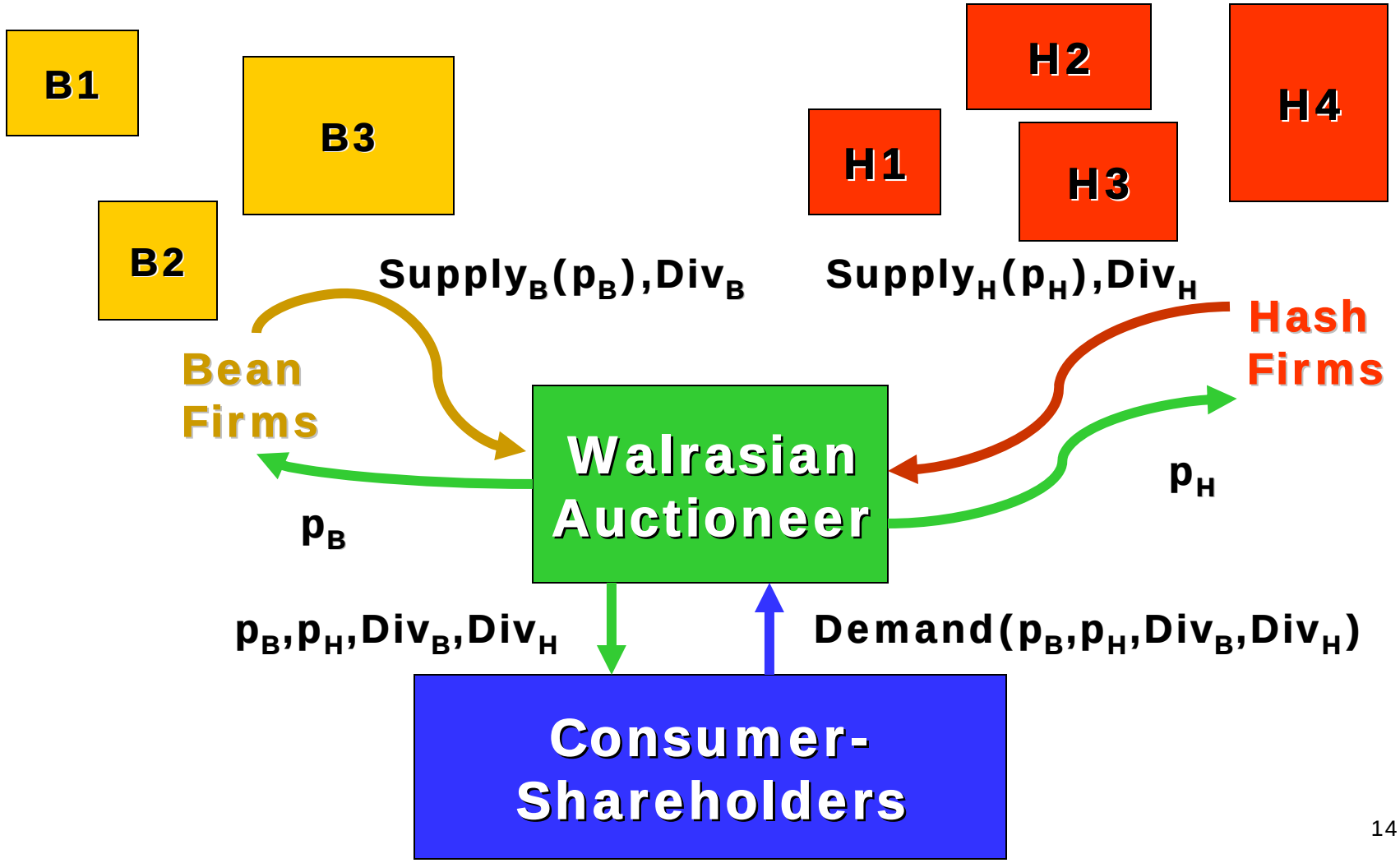
ACE and Qualitative Analysis

Key Issue: Constructive Understanding

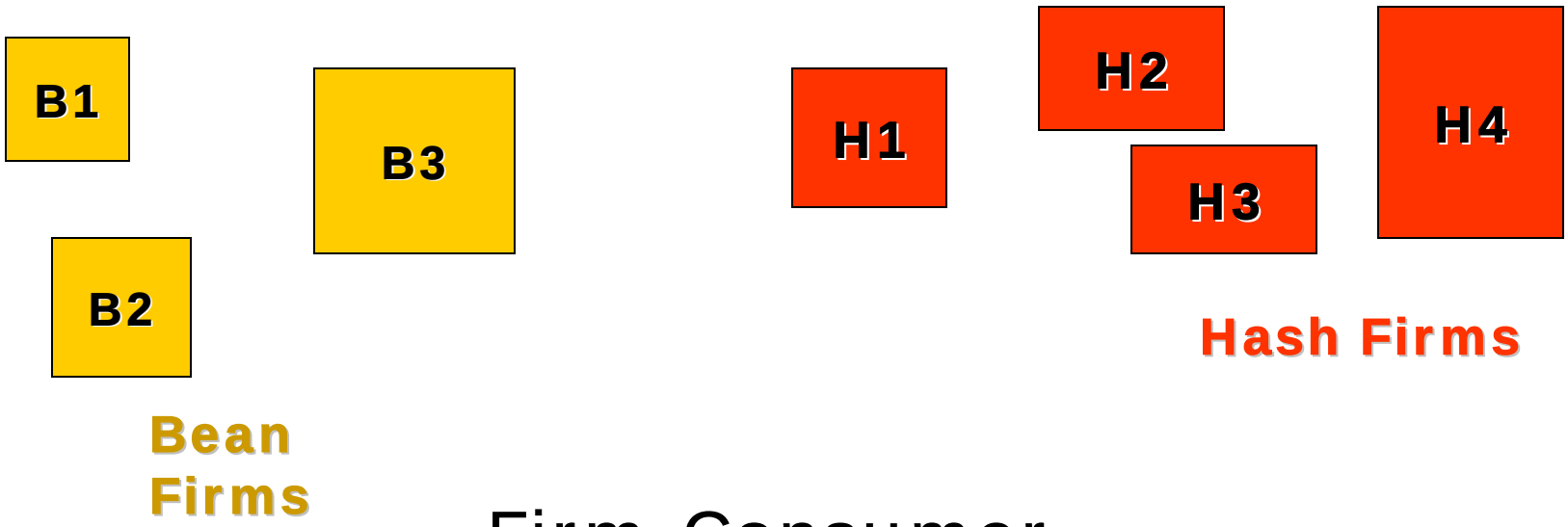
Example: If you had to construct a profit-seeking firm capable of surviving and even prospering in a realistically rendered decentralized market economy, how would you go about it?

Question: If economists are not capable of rising to this constructive challenge, to what extent can we be said to have a ***scientific*** understanding of real-world decentralized market economies?

Illustration: Start with a Traditional Walrasian Economy



Plucking Out the Walrasian Auctioneer



Firm-Consumer Connections??

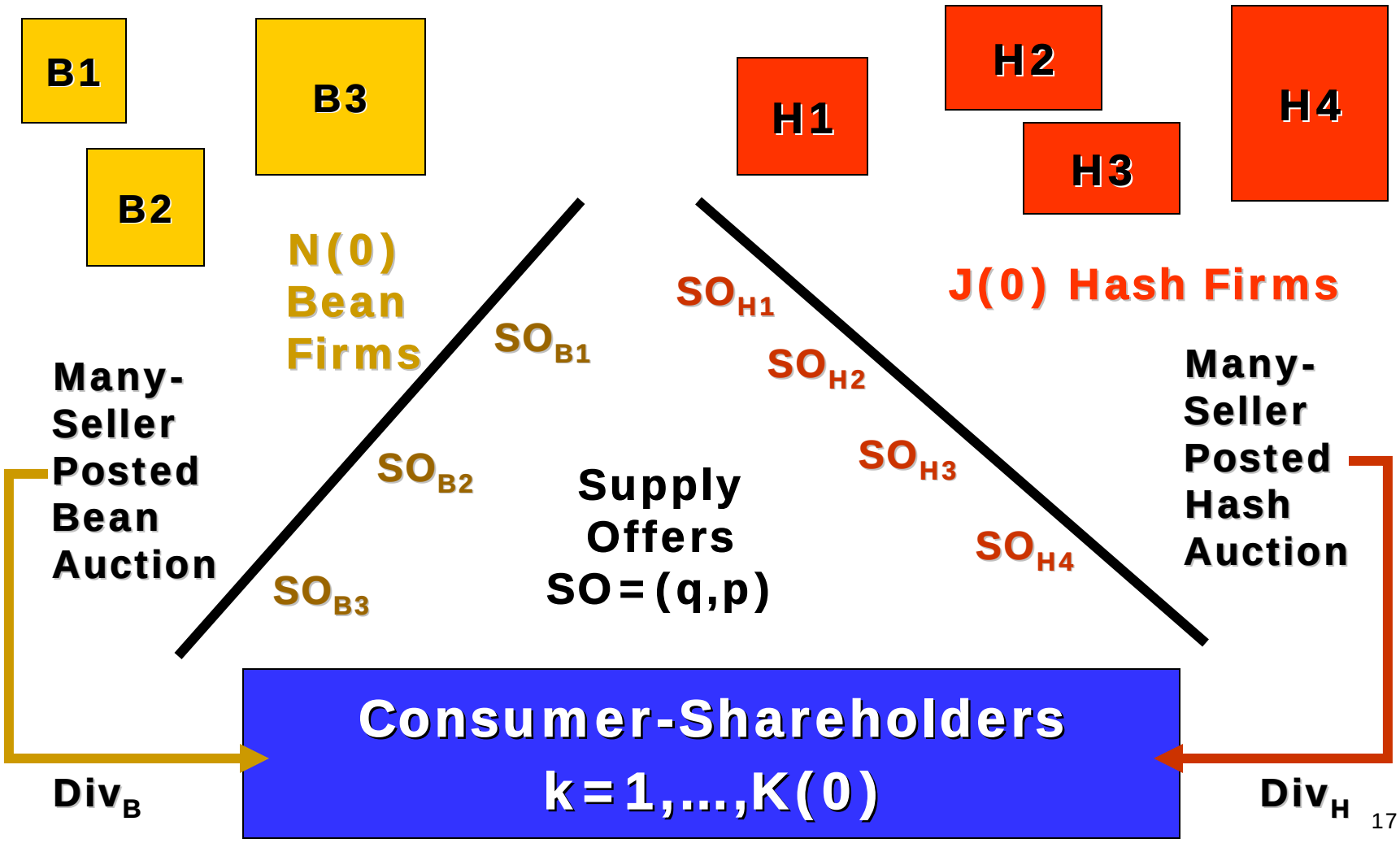
Consumer-Shareholders

Plucking Out the Walrasian Auctioneer

Focus must now be procurement processes

- Deciding on production levels and unit prices
- Potential supplier/customer identification
- Submission of supply offers/demand bids
- Comparison/evaluation of opportunities
- Supplier/customer selection
- Negotiation among suppliers/customers
- Transaction and payment processing
- Managing supplier/customer relationships

Example of an ACE Trading World



ACE Firms

- Each firm f starts out (T=0) with ***Money$_f$(0)*** and a production capacity ***Cap$_f$(0)***.
- Firm f's ***FixedCost$_f$(0)*** in each period $T \geq 0$ is proportional to its current capacity.
- At beginning of each period $T \geq 0$, firm f posts a ***SupplyOffer$_f$ = (production level, unit price)***
- At end of $T \geq 0$, firm f is **insolvent** if it has

  $NetWorth_f(T) = [Profit_f(T) + M_f(T) + ValCap_f(T)] \leq 0$
- If **solvent**, firm f ***allocates profits*** (+ or -) between $Money_f$, Cap_f, and dividend payments.

ACE Consumer-Shareholders

- Each consumer k starts out (T=0) with a ***lifetime money endowment profile***

  ($Money_{youth}$, $Money_{middle}$, $Money_{old}$)

- Consumer k has a **utility function** of the form

  $U_k(T) = (bean(T) - b_k^*) \bullet (hash(T) - h_k^*)^{\theta k}$

- In each $T \geq 0$, consumer k attempts to ensure her survival/happiness by ***searching*** for bean and hash to buy at ***lowest possible prices***.

- At end of each $T \geq 0$, consumer k **dies** if she fails to consume at least (b_k^*, h_k^*).

Experimental Design Treatment Factors

- **Initial size of consumer sector** [K(0)]
- **Initial firm concentration** [N(0), J(0), Cap(0)]
- **Learning** (supply offer/profit allocation decisions)
- **Firm cost functions**
- **Firm initial money holdings** [$Money_f(0)$]
- **Firm rationing method** (for excess demand)
- **Consumer search process**
- **Consumer money endowment profiles**
  (rich, poor, ↗ , ↘ , life cycle u-shape)
- **Consumer preferences** (θ values)
- **Consumer subsistence needs** (b*,h*)

Interesting Issues to be Explored

- Initial conditions → **Market efficiency**
  (Walrasian equilibrium benchmark)
- Initial conditions → **Market power**
  (Walrasian equilibrium benchmark)
- Initial conditions → **Carrying capacity**
  (Survival of firms/consumers in long run)
- **Standard concentration measures at T=0**
  (Good predictors of long-run market power?)
- Importance of **learning vs. market structure**
  for market performance *(Gode/Sunder, JPE, 1993)*

Possible Structural Extensions

- **Introduce Other Coordination Mechanisms:**
  Let traders engage in direct social communication (evolution of trust, implicit contracts, loyalty,...); Introduce retail stores, insurance companies,...
- **Co-Evolution of Behaviours and Institutions:**
  Let trading behaviours (supply offers, profit allocation rules) and institutional arrangements (market protocols, consumer search process,...) *co-evolve* together.
- **Demographics/Biological Reproduction:**
  Consumers can be modelled as having genotypes as well as phenotypes, permitting haploidy or diploidy reproduction (parent(s) $\rightarrow$ children)

ACE Trading World: Implementation

C. Cook and L. Tesfatsion, **"Agent-Based Computational Laboratories for the Experimental Study of Complex Economic Systems,"** Working Paper, ISU Department of Economics, ***in progress***.

- Computational laboratory implementation
- Programming language C#/.Net (WinDesktops)
- Under development for Econ 308 (ACE course)

www.econ.iastate.edu/classes/econ308/tesfatsion/

What is a Computational Laboratory?

- ***Computational framework***
  for the study of complex system behaviors by means of controlled and replicable experiments
- ***Graphical user interface (GUI)***
  permits experimentation by users with no background in programming
- ***Modular/extensible software support***
  permits CL capabilities to be changed/extended by users who have programming skills
- **ACE Comp Lab Sites**

www.econ.iastate.edu/tesfatsi/acedemos.htm

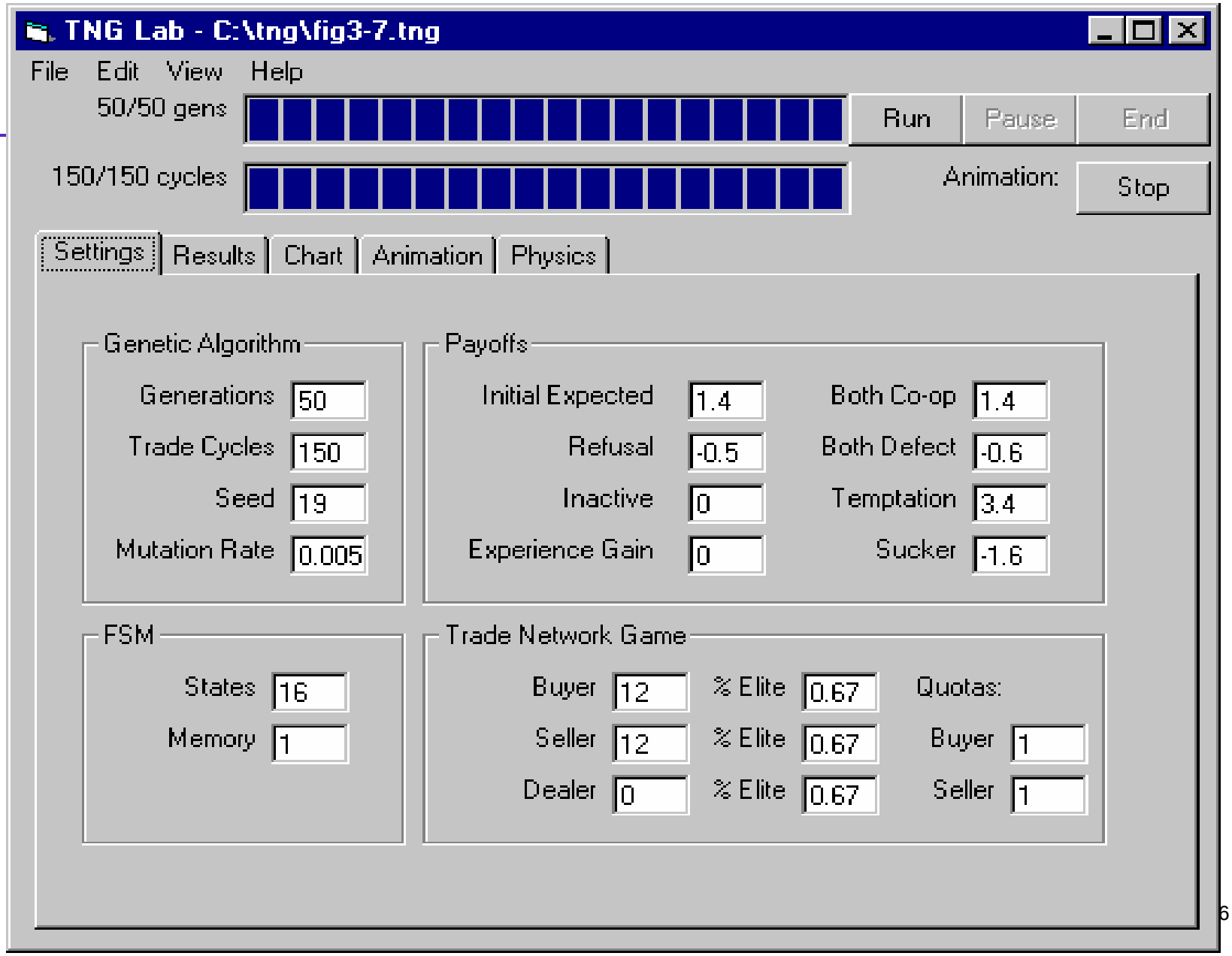
www.econ.iastate.edu/tesfatsi/acomplab.htm

Finished Example: The Trade Network Game (TNG) Lab

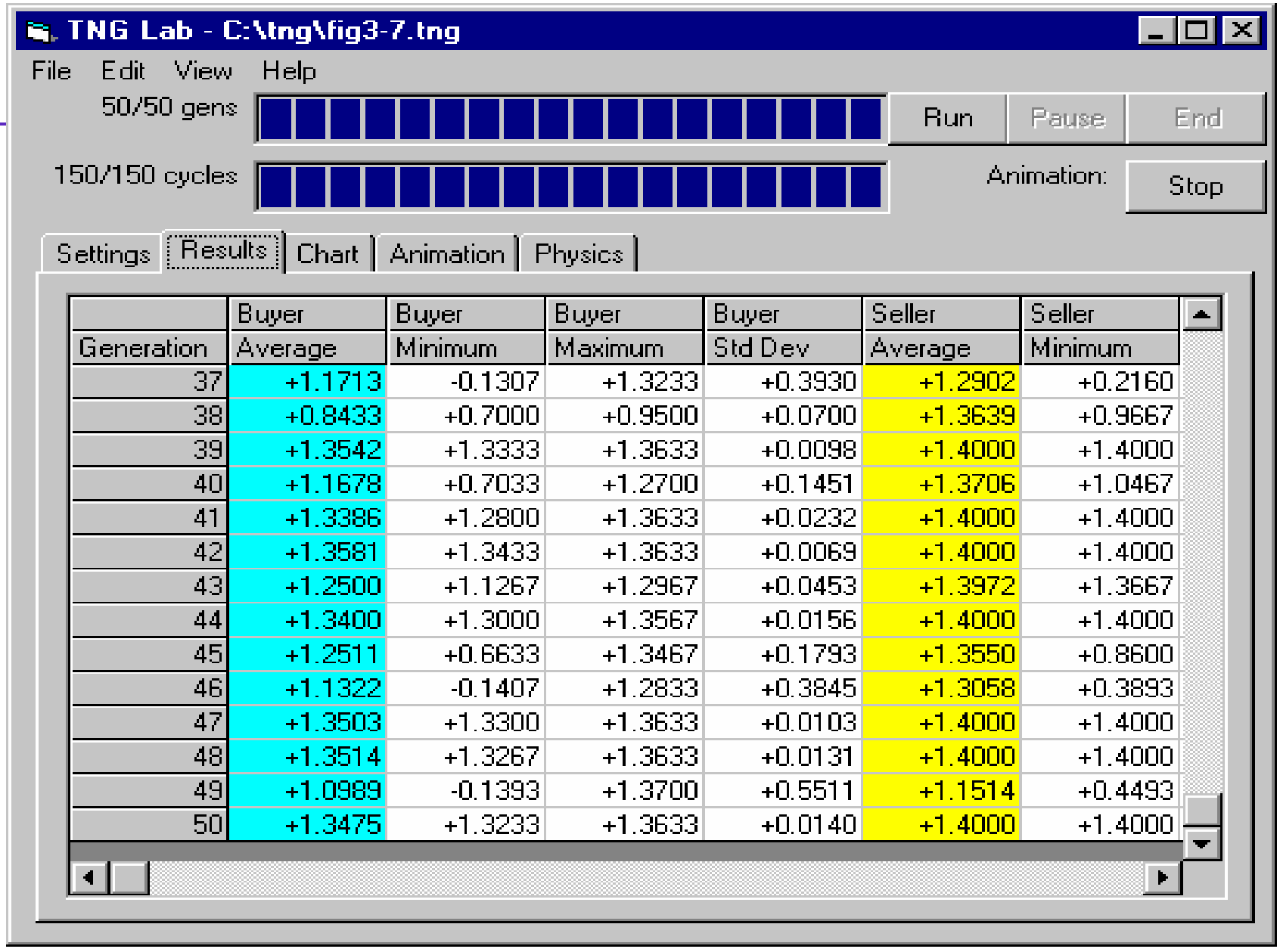
- **Evolution of trade networks**
  among strategically interacting traders (buyers, sellers, dealers) with trades=PD games
- **Traders instantiated as "tradebots"**
  (autonomous software entities)
- **Event-driven communication**
  among traders to determine their trade partners
- **Tradebots evolve trade strategies**
  starting from *initially random* strategies

* **http://www.econ.iastate.edu/tesfatsi/tnghome.htm**

TNG Settings Screen

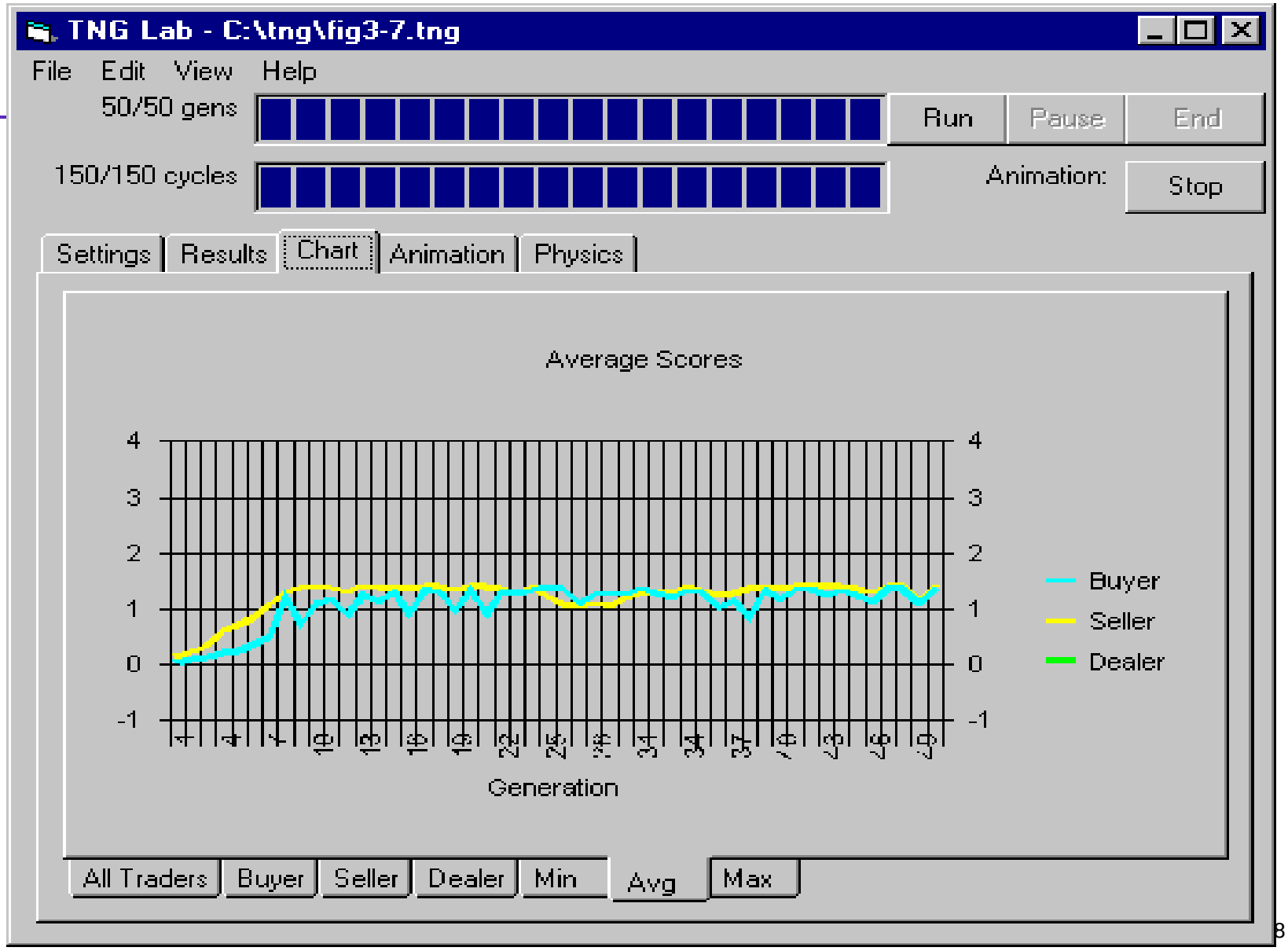


TNG Results Screen

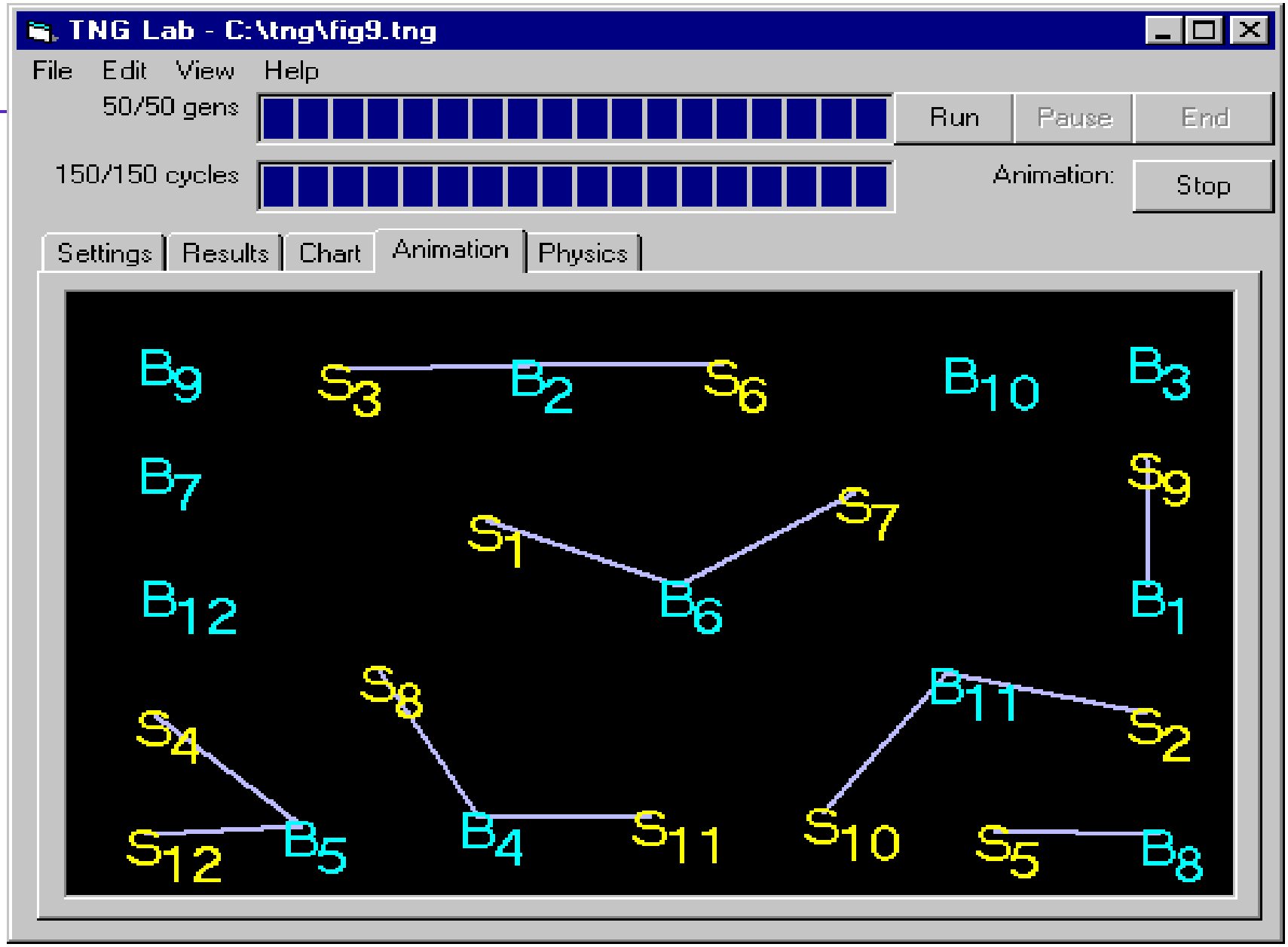


Generation	Buyer Average	Buyer Minimum	Buyer Maximum	Buyer Std Dev	Seller Average	Seller Minimum
37	+1.1713	-0.1307	+1.3233	+0.3930	+1.2902	+0.2160
38	+0.8433	+0.7000	+0.9500	+0.0700	+1.3639	+0.9667
39	+1.3542	+1.3333	+1.3633	+0.0098	+1.4000	+1.4000
40	+1.1678	+0.7033	+1.2700	+0.1451	+1.3706	+1.0467
41	+1.3386	+1.2800	+1.3633	+0.0232	+1.4000	+1.4000
42	+1.3581	+1.3433	+1.3633	+0.0069	+1.4000	+1.4000
43	+1.2500	+1.1267	+1.2967	+0.0453	+1.3972	+1.3667
44	+1.3400	+1.3000	+1.3567	+0.0156	+1.4000	+1.4000
45	+1.2511	+0.6633	+1.3467	+0.1793	+1.3550	+0.8600
46	+1.1322	-0.1407	+1.2833	+0.3845	+1.3058	+0.3893
47	+1.3503	+1.3300	+1.3633	+0.0103	+1.4000	+1.4000
48	+1.3514	+1.3267	+1.3633	+0.0131	+1.4000	+1.4000
49	+1.0989	-0.1393	+1.3700	+0.5511	+1.1514	+0.4493
50	+1.3475	+1.3233	+1.3633	+0.0140	+1.4000	+1.4000

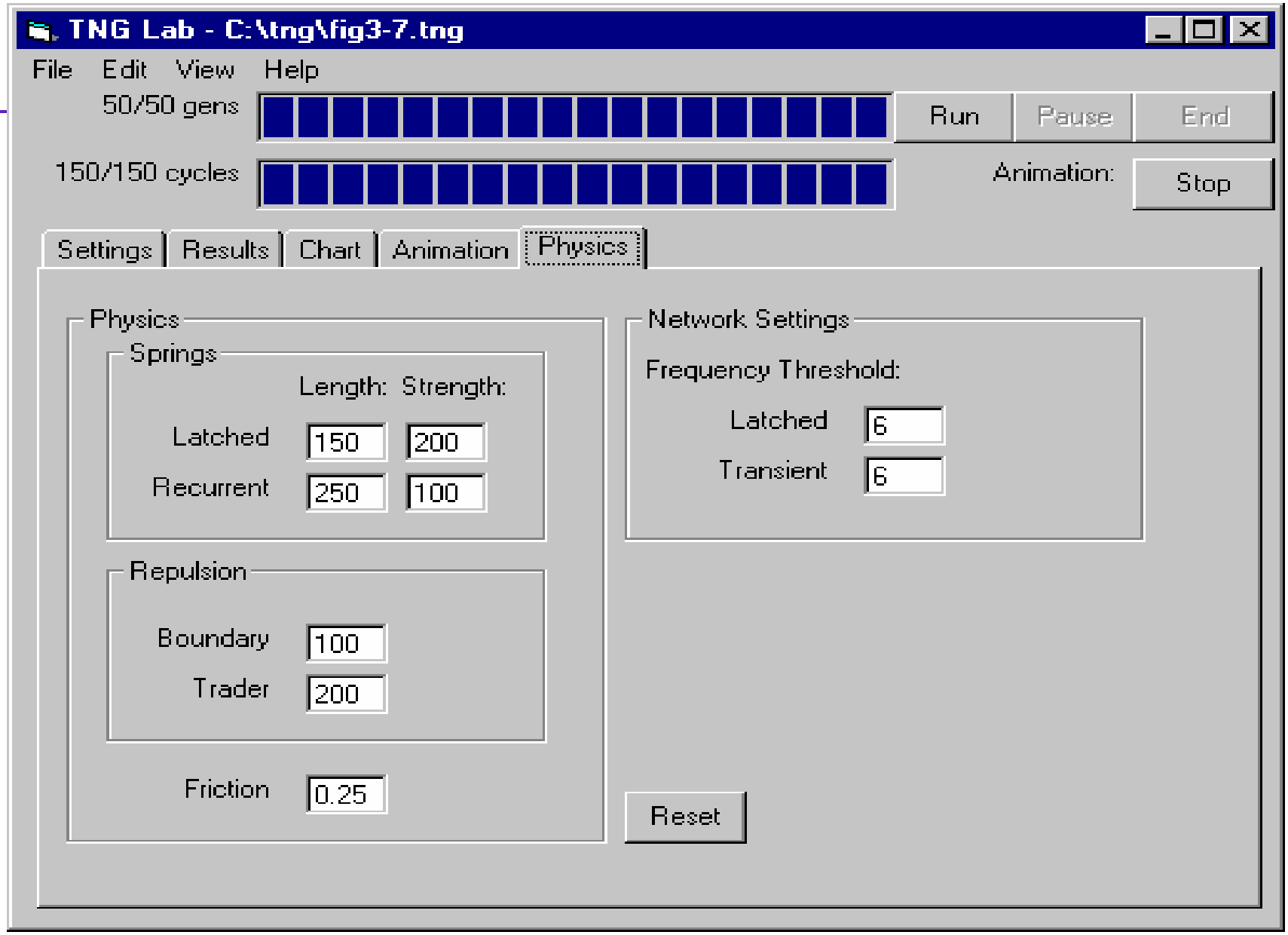
TNG Chart Screen



TNG Network Animation Screen



TNG Physics Screen



In Conclusion: ACE as a Research/Teaching Tool

- ACE permits the **systematic experimental study** of decentralized market processes (descriptive, normative, qualitative…)
- ACE computational laboratories facilitate and encourage **creative exploration and discovery**.
- Researchers/students can test interesting hypotheses of their own devising, with immediate feedback and no original programming required.
- Modular form of software permits **relatively easy modification/extension of model features**.

Resource Sites for ACE Research Areas

(http://www.econ.iastate.edu/tesfatsi/aapplic.htm)

- Embodied cognition
- Network formation
- Evolution of norms
- Specific market case studies
- Industrial organization
- Market design
- Multiple-market modelling
- Automated markets and software agents
- Development of computational laboratories
- Parallel experiments (real and computational agents)
- Empirical validation
- Many others...