

Title: Agent - Based Computational Modeling and Macroeconomics

Date: May 02, 2009 01:00 PM

URL: <http://pirsa.org/09050021>

Abstract: TBA

Agent-Based Computational Modeling and Macroeconomics

Perimeter Institute Conference, May 1-4, 2009

The Economic Crisis and Its Implications
for the Science of Economics

Presenter:

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Presentation Outline

- ❑ Complexity of real-world macroeconomic systems
- ❑ What is *A*gent-based *C*omputational *E*conomics ?
- ❑ *Illustration:* From Walrasian general equilibrium to an ACE Trading World
- ❑ ACE test beds for the systematic experimental study of macroeconomic systems

Complexity of Real-World Macroeconomic Systems

- ❑ Macro regularities arise from local interactions among micro entities (producers, consumers, banks, public agencies,...).
- ❑ Interactions are channeled and constrained by current
 - **Structural conditions** (physical/biological limits, resource distribution, infrastructure, technology, weather patterns,...);
 - **Institutional arrangements** (legal system, credit system, business practices, regulations, social norms,...);
 - **Behavioral dispositions** (risk aversion, responsiveness to incentives, learning capabilities, foresight, strategic planning, time-inconsistent preferences, irrational exuberance,...).
- ❑ Structure, institutions, and behavior can in turn evolve.

Can ACE Help?

- ◆ **Agent-Based Computational Economics (ACE)** is designed to handle this level of complexity.
- ◆ ACE = Computational study of economic processes as dynamical systems of interacting agents.
- ◆ **Goal:** Development of empirically-grounded dynamical economic theories in which equilibrium is a possible outcome rather than a constraint imposed *a priori*.

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ACE Culture-Dish Analogy

- ◆ ACE modeler constructs a virtual economic world populated by various **agent types**.
- ◆ Modeler sets **initial agent attributes**.
- ◆ Modeler then steps back to observe how the **world develops in real (CPU) time without further external intervention** (no imposed market clearing, no assumed perfect foresight,...).
- ◆ World events **driven by agent interactions**.

ACE Agent Types

Agent = Encapsulated bundle of data and methods acting within a computationally constructed world.

- Agents can represent:
 - Individuals (consumers, entrepreneurs,...)
 - Social groupings (families, communities,...)
 - Biological entities (crops, livestock, forests,...)
 - Physical entities (roads, weather, landscapes,...)

ACE Agent Types...

Cognitive agents are capable (in various degrees) of

- Behavioral adaptation;
- Goal-directed learning;
- Social communication (talking with each other!);
- Endogenous formation of interaction networks;
- Autonomy (self-activation and self-determination based on *private* internal data and methods).

Importance of Agent Encapsulation

- Real-world economies consist of distributed entities with limited info & computational capabilities.
- **ACE forces adherence to this constraint.**
 - An ACE model is a collection of data and methods encapsulated into separate bundles ("agents").
 - Procedures encapsulated in the methods of particular agents can only be implemented using the particular resources (data, money, CPU time, reasoning powers, ...) available to these agents.

Four Main Strands of ACE Research

- **Empirical Understanding**
(possible explanations for empirical regularities)
- **Normative Understanding**
(market design, policy selection,...)
- **Methodological Advancement**
(representation, visualization, empirical validation,...)
- **Theory Generation/Qualitative Insight**
(self-organization of decentralized market economies,...)

ACE and Theory Generation

Illustrative Issue: What are the performance capabilities of decentralized market economies?
(*Adam Smith, F. von Hayek, J.M.Keynes, J. Schumpeter, ...*)

ACE Approach:

- ◆ *Construct an agent-based world* qualitatively capturing salient aspects of actual decentralized market economies.
- ◆ *Systematically vary key treatment factors* (learning capabilities, size distribution of firms,...).
- ◆ *For each treatment, let the world evolve* for multiple runs and observe the degree of coordination that results.

Illustration: From Walrasian General Equilibrium to an ACE Trading World

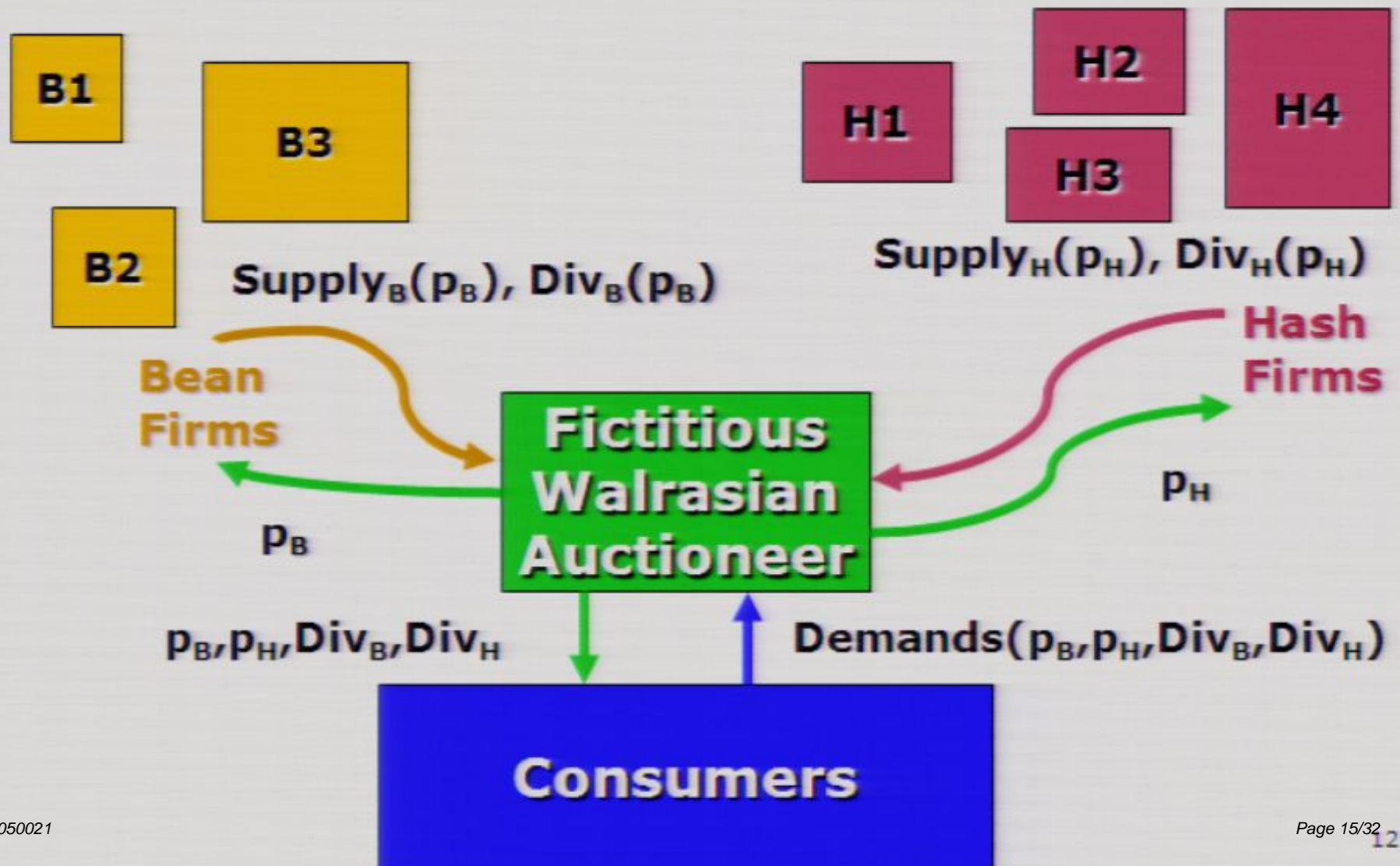
Starting Point:

Standard Walrasian General Equilibrium Economy

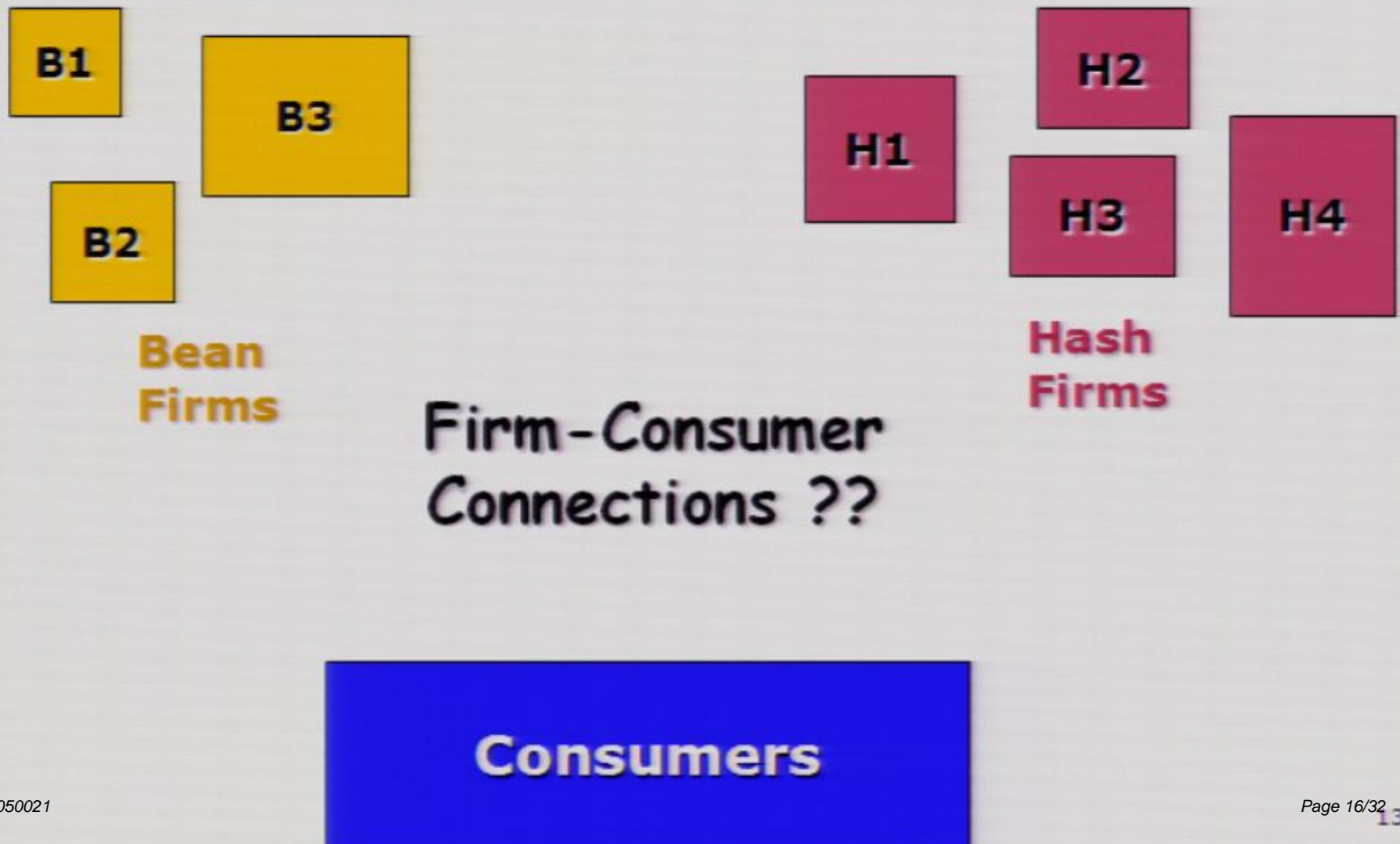
Exercise:

- **Remove** all imposed *equilibrium* conditions (e.g., market clearing, correct expectations,...).
- **Introduce** minimal *agent-driven* production, pricing, and trade processes needed to re-establish sustained circular flow among firms and consumers.
- **Analyze** the resulting economy to see if/when it is able to attain some form of equilibrium state over time.

Start from a Standard Walrasian GE Economy (Price-Taking Firms & Consumers, Auctioneer, ...)



Pluck Out the Fictitious Auctioneer!



How to Construct a Self-Sustaining Economy without the Fictitious Walrasian Auctioneer ?

Attention must now shift FROM firms & consumers who

- maximize profits and utility in social isolation;
- condition decisions on publicly given -- or correctly expected -- equilibrium (market clearing) prices,

TO the trade interaction patterns among profit-seeking firms and utility-seeking consumers who

- recognize that trade is essential for survival as well as for prosperity;
- have individualized endowments and good-for-good "reservation prices" --i.e., marginal rates of (technical) substitution--that constrain their trades.

Construction of a Self-Sustaining Economy...

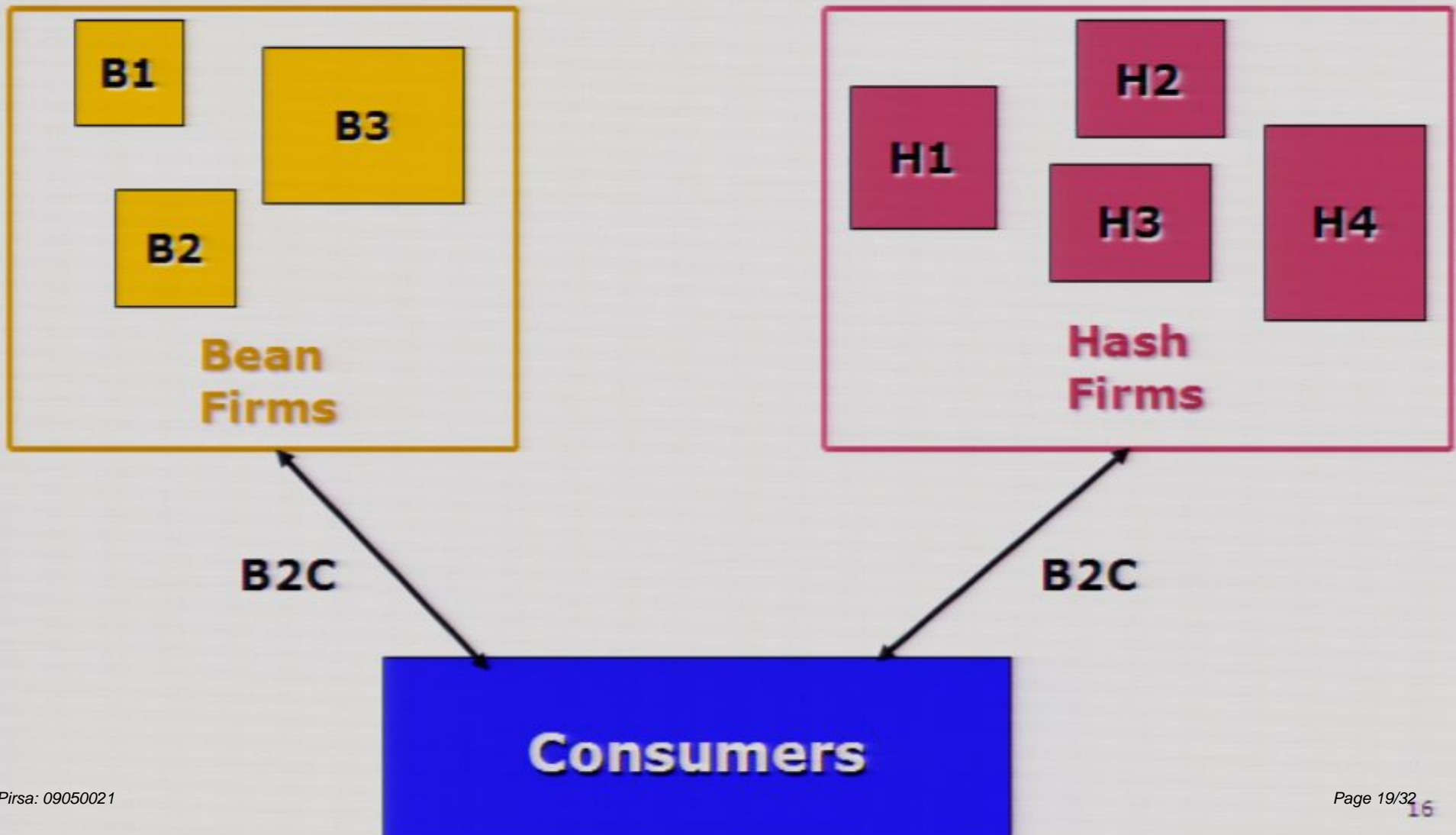
In particular, careful attention must be paid to:

□ Market Organization

- Who is able to trade with whom, and how often?
- Under what types of rules and regulations does trading take place ?
 - Bilateral trade ?
 - Trade mediated by brokers or dealers ?
 - Seller or buyer one-sided posted auctions?
 - Double auctions ?

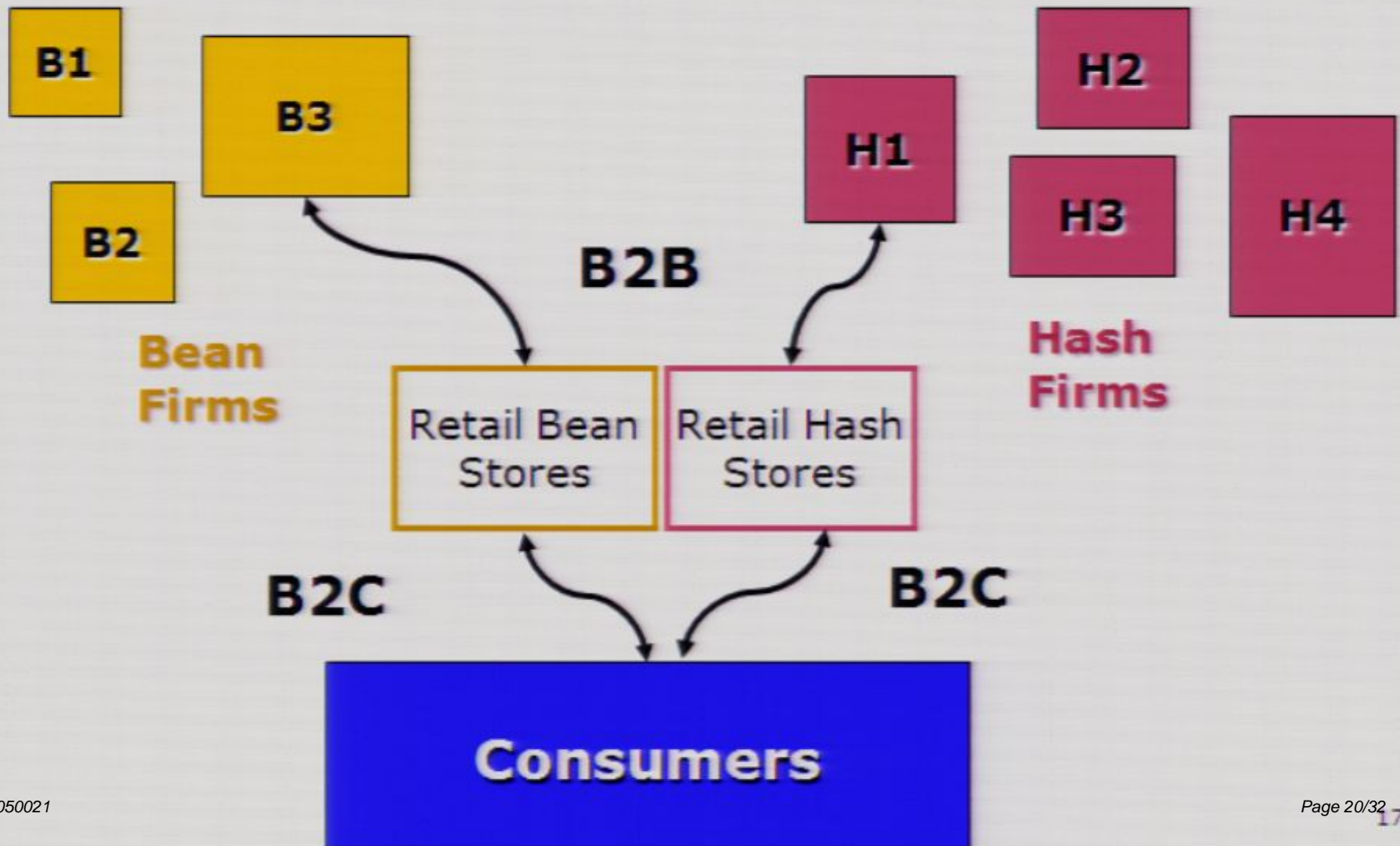
Ex.1: Bilateral Trade

(Business-To-Consumer = B2C)

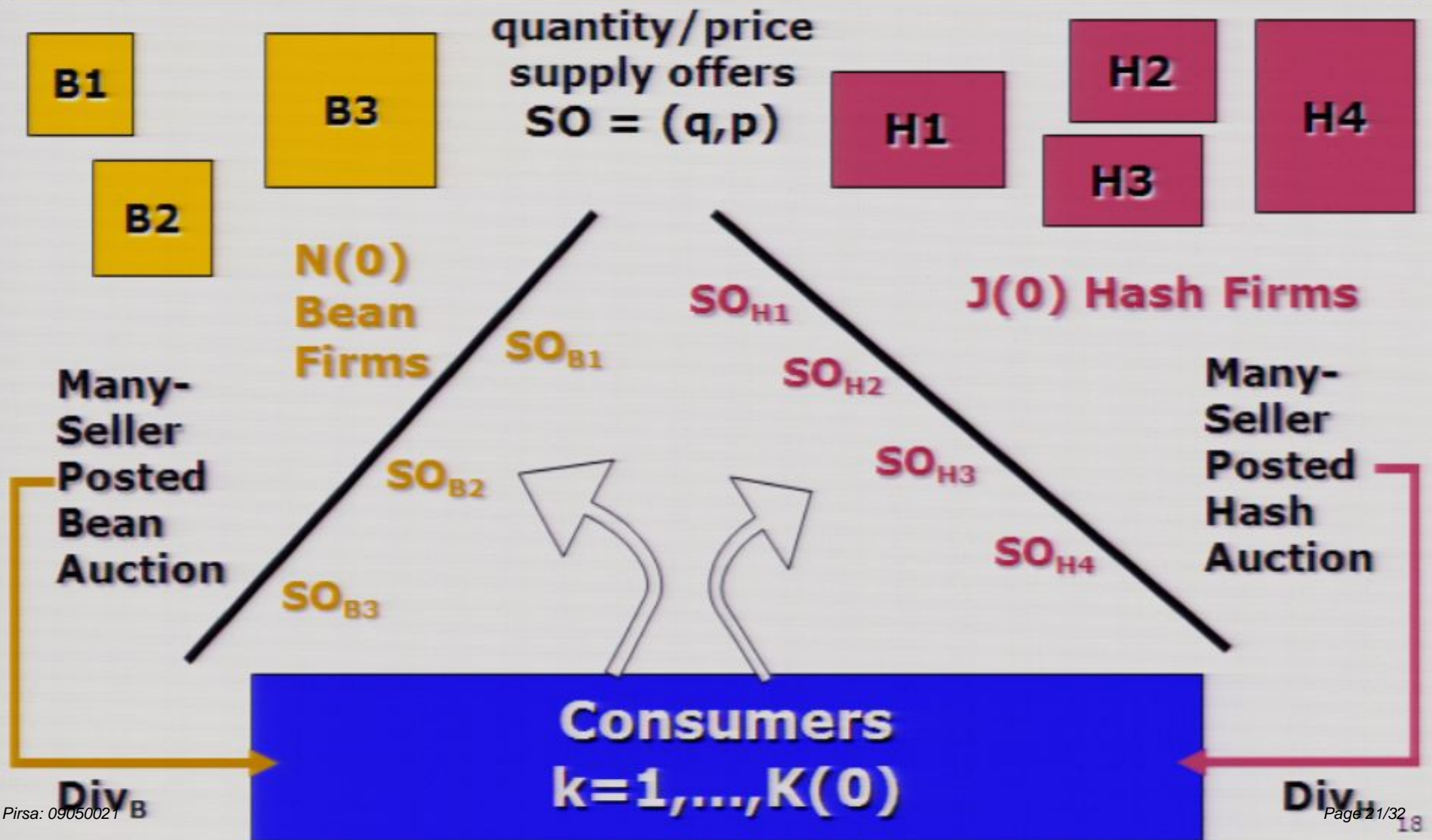


Ex.2: Store-Mediated Trade

(Producers → Retail Stores → Consumers)



Example 3: Trade Through Many-Seller Posted Auctions



Construction of a Self-Sustaining Economy...

Careful attention must also be paid to:

□ Market-making activities

- Seller price/quantity offers?
- Buyer price/quantity bids?
- Seller-buyer matching?
- Price determination from seller/buyer interactions?

□ What happens when things go wrong

- Excess demand (inventory run down or stock-outs)
- Excess supply (inventory pile-up or waste)
- Insolvency (firm negative net worth)
- Starvation (consumer subsistence needs not met)

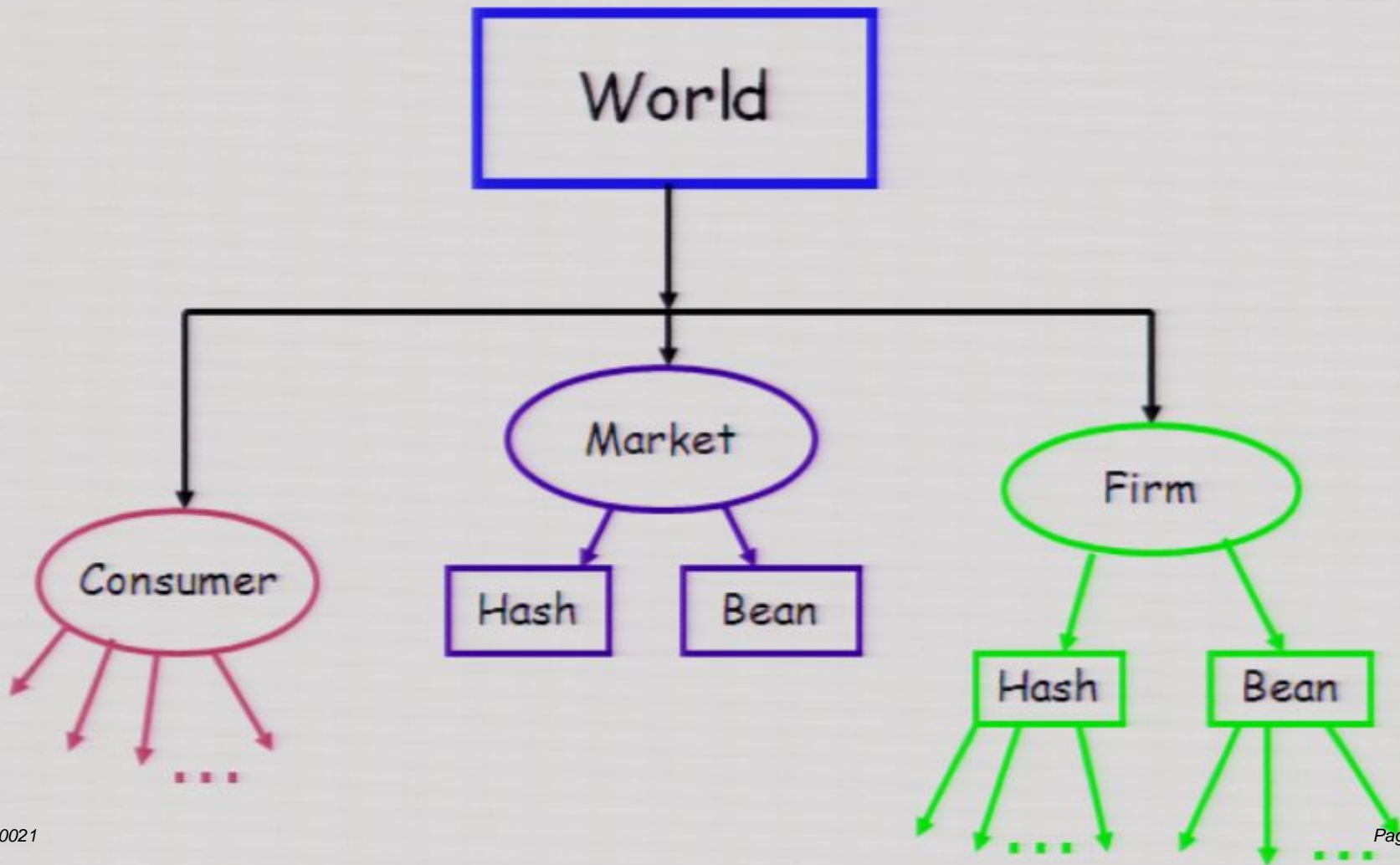
Complex Set of Market Processes Routinely Engaged in By Real-World Traders

- ◆ *Terms of Trade*: Set production and price levels
- ◆ *Seller-Buyer Matching*:
 - Identify potential suppliers/customers
 - Compare/evaluate opportunities
 - Make demand bids/supply offers
 - Select specific suppliers/customers
 - Negotiate supplier/customer contracts
- ◆ *Trade*: Transactions carried out (or contracts broken)
- ◆ *Settlement*: Payments carried out (or default occurs)
- ◆ *Learning*: Strategy revisions, exit/entry decisions
- ◆ *Management*: Long-term supplier/customer relations

Dynamic Activity Flow for Firms Over Time Periods $T \geq 1$

- ◆ Each firm f starts out with positive *net worth* $NW_f(0)$ and *plant production capacity* $Cap_f(0)$.
- ◆ Firm f 's *sunk cost* $SC_f(T)$ for $T \geq 1$ is proportional to its plant production capacity, $Cap_f(T-1)$.
- ◆ At beginning of each $T \geq 1$, firm f selects a *supply offer* = (production level, unit price).
- ◆ At end of $T \geq 1$, firm f is *solvent* if it has positive net worth: $NW_f(T) = [Profits_f(T) + ValueCap_f(T)] > 0$
- ◆ If solvent, firm f *allocates its profits* (+ or -) between retained earnings, dividends, and/or capacity purchase/sale; otherwise it exits world.

ACE H&B Trading World: Agent Hierarchy



Market Agent (Institutional)

Public Access:

Public Methods

```
// getWorldEventSchedule(clock time);  
getWorldProtocols (collusion, insolvency);  
getMarketProtocols (posting, matching, trade, settlement)  
Methods for receiving data;  
Methods for retrieving Firm data;  
Methods for retrieving Market data;
```

Private Access:

Private Methods

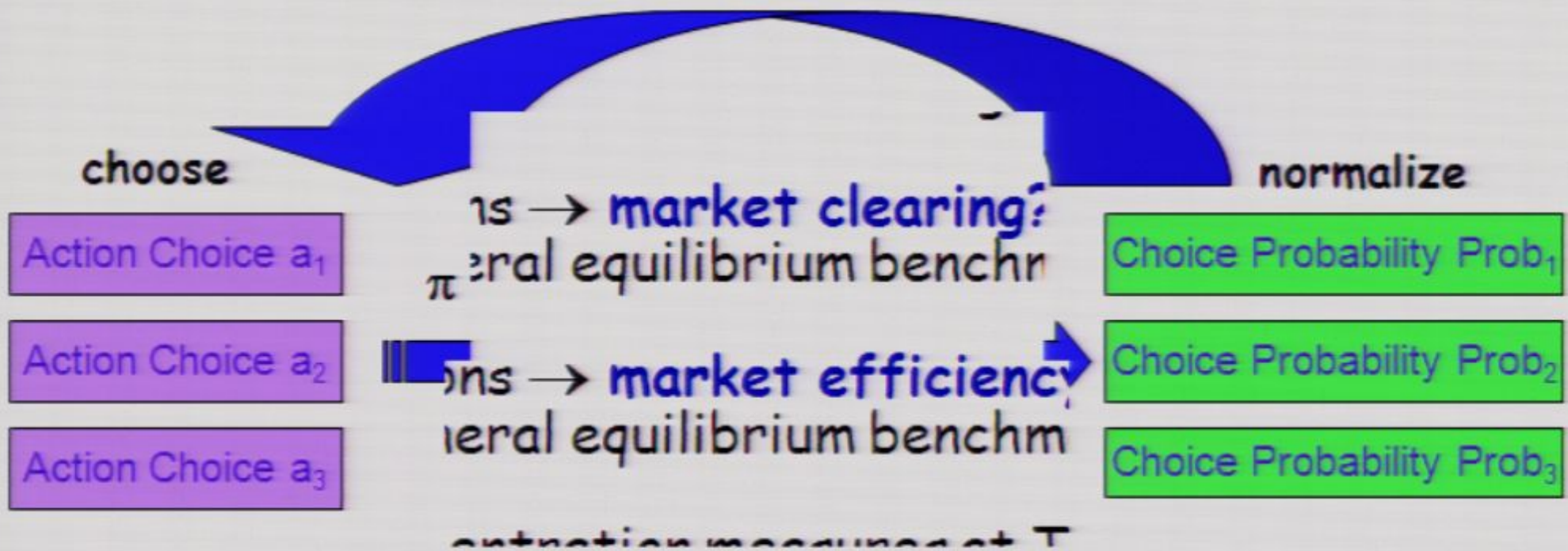
```
// Methods for getting, storing, processing, & sending data;  
Methods for calculating expected & actual profit outcomes  
// Methods for supply offer selection, profit allocation...;  
Methods for updating my methods (PLASTICITY);
```

Private Data

Data about me (history, capacity, cost function, net worth)
Data about external world (rivals' supply offers. ...):

Firm & Consumer Learning?

Illustration: Stochastic Reinforcement Learning



- Action choice a' leads to earnings/utility π' , followed by updating of action choice propensities q based on this reward, followed by normalization of these propensities into action choice probabilities $Prob$.

Interesting Issues for Exploration

- ◆ Initial conditions → **carrying capacity?**
(Survival of firms/consumers in long run)
- ◆ Initial conditions → **market clearing?**
(Walrasian general equilibrium benchmark)
- ◆ Initial conditions → **market efficiency?**
(Walrasian general equilibrium benchmark)
- ◆ Standard concentration measures at $T=1$ →
good predictors of long-run market power?
- ◆ Importance of **learning vs. market structure**
for market performance? (*Gode/Sunder, JPE, 1993*)

ACE H&B Trading World as a Test Bed ? (Cook & Tesfatsion, 2009)

Form1
File Tools Window Help

Untitled 1 (Empty Lab)

Hash & Bean Multi-Market Economy Model

CONSUMERS	Group	Count	Consumer Details		
	Cons Type 1	100	Group Name:	Consumption Needs:	Endowment Schedule:
	Cons Type 2	100	Cons Type 2	Hash: 3	Lifecycle [edit]
Total:		200	Count: 100	Beans: 3	Initial: 25
			Add	Preference: [edit]	$\alpha = 0.505$ Slightly Prefers Hash

FIRMS	Group	Count	Firm Details			
	Large	1	1	Group Name:	Initial Assets:	Cost Function:
	Small	20	20	Small	Money: 50	Default [edit]
Total:		21	21	Hash Firms: 20	Capacity: 10	Capacity: 1.0
			Add	Bean Firms: 20	Profit Distribution:	Learning Strategy:
				Money: 0.5	Random P & O (Det) [edit]	Dividends: 0.5

Experiment Number: 1 Trial Count: 5 Trial Length (TMax): 100

START

Recommended Tasks

- Develop ACE test beds that permit systematic study of macroeconomic systems.
 - Test beds can be tailored to specific issues (agent scale, agent taxonomy, agent plasticity, ...).
 - Test beds should be open source to permit replication.
 - Findings should be replicated using multiple software & hardware platforms (*model verification*).

- Evaluate test-bed generated theories against actual data to the fullest extent possible. (*empirical validation*).

Firm Agent (Cognitive)

Public Access:

// **Public Methods**

getWorldEventSchedule(clock time);
getWorldProtocols (collusion, insolvency);
getMarketProtocols (posting, matching, trade, settlement);
Methods for receiving data;
Methods for retrieving Firm data;

Private Access:

// **Private Methods**

Methods for getting, storing, processing, & sending data;
Methods for calculating expected & actual profit outcomes;
Methods for supply offer selection, profit allocation...;
Methods for updating my methods (**PLASTICITY**);

// **Private Data**

Data about me (history, capacity, cost function, net worth,...);
Data about external world (rivals' supply offers, ...);
Address book (communication links);

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