Markets Come to Bits: Computation, Evolution and the Future of Economics

Based upon:
Special issue JEBO, 2007
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A Brief History of Neoclassical Economic Ontology

Three Phases of Scientific Models

[1] Pure Mechanical Analog {1870-1940}

Cf.: Mirowski, *More Heat than Light* (1989)

[2] Agent as Information Processor {1930s- }

Cf.: Mirowski, *Machine Dreams* (2002)

[3] Market Structures as Algorithms {now}

Was Neoclassical Economics Ever a Theory of "Markets"?

- Mere synonym for 'exchange'?
- Walras… never described actual market (Walker,2001)
- Arrow & Hahn take markets for granted
- Coase, North, …
- At best, differentiated by commodity identity, or along continuum of 'monopoly… perfect competition'
- Thoroughly ignores computational theory

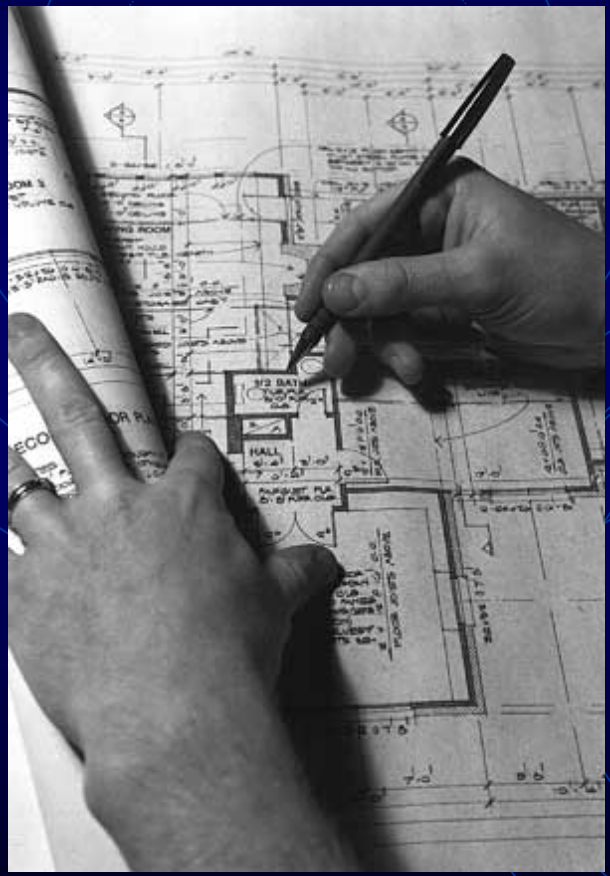
What We Talk about when We Talk about 'Markets'

- Data dissemination, exclusion
- Order routing through time and space
- Order execution
- Price discovery and assignment
- Custody and delivery arrangements
- Clearing and settlement, including property rights assignment
- Record keeping
- Commodity definition and enforcement

Five Indicative Post-1980 Trends
from agency theory to market automata

- Modern ‘Mechanism Design’
- Zero-Intelligence Agent offshoot of Experimental Economics
- ‘Market Microstructure’ in Finance
- ‘Engineering Economics’
- Artificial Intelligence researchers coding markets

Walrasian Mechanism Design



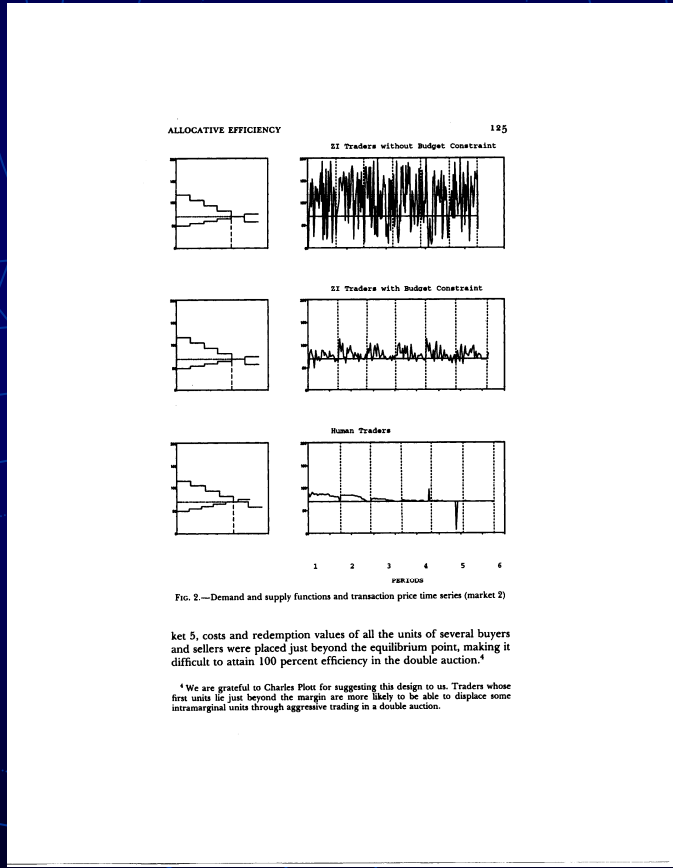
- Begins at Cowles with work of Leonid Hurwicz: What is ‘decentralization’?
- Heavy ‘welfare’ spin: Stan Reiter (1977)
- 1980s shift to Bayes/Nash obsession w/truth-telling or ‘incentive compatibility’
- Ames (1983) translates into automata theory
- Gibbard etc. converges with voting literature

‘Mechanisms’ over time become increasingly algorithmic

- Ledyard describes tradition as concerned with: (a) incentive compatibility, (b) computational capacity, and © political feasibility
- Mount & Reiter (2002): “it is not appropriate to separate the person from the machine… [it] facilitates analysis of computational problems to be solved by a combination of human and machine resources.”
- Still ambiguous if this can be reconciled with cognitive inclinations of neoclassical economics

Gode & Sunder's Zero Intelligence Agents

- Prompted by class in automated trading
- Response Vernon Smith: 'Hayek Hypothesis'
- Restricted to Double Auction format
- Ran market experiments with humans, 'zoids
- Results indistinguishable from humans



ALLOCATIVE EFFICIENCY 125

ZI Traders without Budget Constraint

ZI Traders with Budget Constraint

Human Traders

1 2 3 4 5 6

PERIODS

FIG. 2.—Demand and supply functions and transaction price time series (market 2)

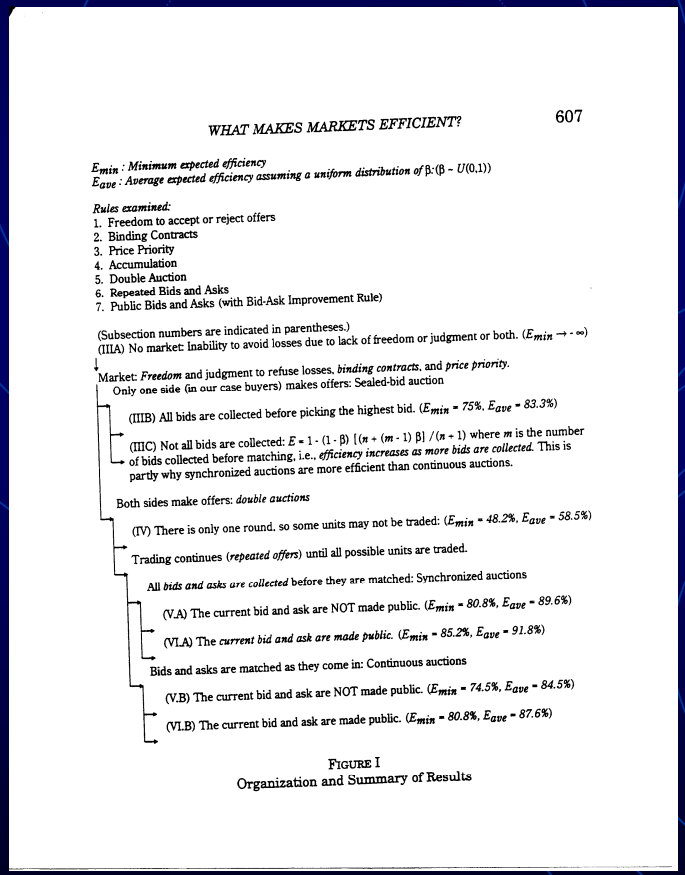
ket 5, costs and redemption values of all the units of several buyers and sellers were placed just beyond the equilibrium point, making it difficult to attain 100 percent efficiency in the double auction.[4]

[4] We are grateful to Charles Plott for suggesting this design to us. Traders whose first units lie just beyond the margin are more likely to be able to displace some intramarginal units through aggressive trading in a double auction.

Sources of Confusion

- ☑ Not about cognitive science: rather, what happens when cognition artificially 'zeroed out'
- ☑ Hence 'welfare measures' are meaningless: fascination with 'efficiency' ill-motivated
- ☑ *Not* about general equilib., but individual market rules and their consequences [not just DAs]
- ☑ Interactions of multiple market forms then a second meta-level research question
- ☑ closest to this interpretation: G&S, *QJE 1997; Sunder, HOPE 2006*

G&S 1997 decompose markets into components



WHAT MAKES MARKETS EFFICIENT? 607

E_{min} : *Minimum expected efficiency*
E_{ave} : *Average expected efficiency assuming a uniform distribution of* β:(β ~ *U*(0,1))

Rules examined:
1. Freedom to accept or reject offers
2. Binding Contracts
3. Price Priority
4. Accumulation
5. Double Auction
6. Repeated Bids and Asks
7. Public Bids and Asks (with Bid-Ask Improvement Rule)

(Subsection numbers are indicated in parentheses.)
(IIIA) No market: Inability to avoid losses due to lack of freedom or judgment or both. ($E_{min} \rightarrow -\infty$)

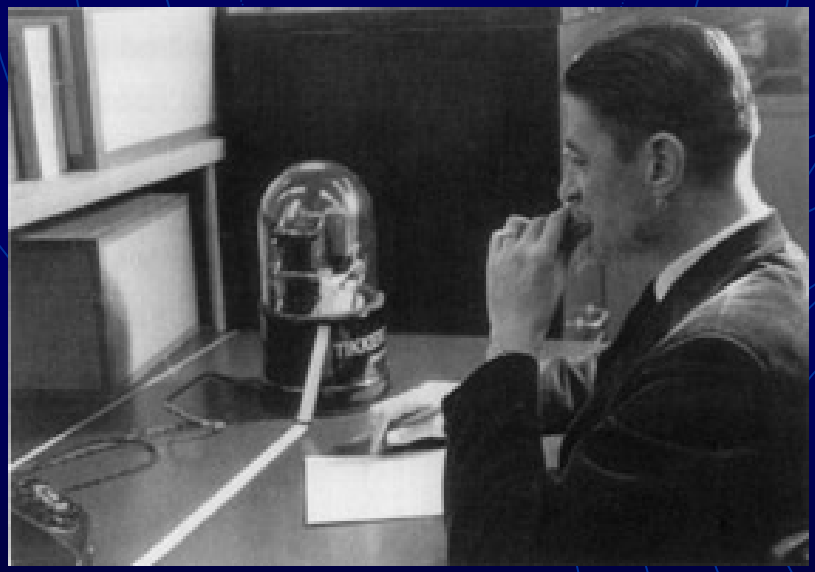
Market: *Freedom* and judgment to refuse losses, *binding contracts*, and *price priority*.
Only one side (in our case buyers) makes offers: Sealed-bid auction
(IIIB) All bids are collected before picking the highest bid. (E_{min} = 75%, E_{ave} = 83.3%)
(IIIC) Not all bids are collected: $E = 1 - (1 - \beta)\ [(n + (m - 1)\ \beta]\ /(n + 1)$ where m is the number of bids collected before matching, i.e., *efficiency increases as more bids are collected.* This is partly why synchronized auctions are more efficient than continuous auctions.

Both sides make offers: *double auctions*
(IV) There is only one round, so some units may not be traded: (E_{min} = 48.2%, E_{ave} = 58.5%)
Trading continues (*repeated offers*) until all possible units are traded.
All *bids and asks are collected* before they are matched: Synchronized auctions
(V.A) The current bid and ask are NOT made public. (E_{min} = 80.8%, E_{ave} = 89.6%)
(VI.A) The *current bid and ask are made public.* (E_{min} = 85.2%, E_{ave} = 91.8%)
Bids and asks are matched as they come in: Continuous auctions
(V.B) The current bid and ask are NOT made public. (E_{min} = 74.5%, E_{ave} = 84.5%)
(VI.B) The current bid and ask are made public. (E_{min} = 80.8%, E_{ave} = 87.6%)

FIGURE I
Organization and Summary of Results

- Map individual rules into exp. Max Marshallian efficiency
- Warn not 'info efficiency'
- Organize rules into cumulative sequential formats
- 'Rules' get specific: freedom to reject, no reneging, bid improvement, public info dissemination

Market Microstructure in Finance



- Stock market automation dates from 1970s
- Crash of 1987 traumatic, foregrounded dangers (cf. MacKenzie, & *Nat.Images*)
- SEC attacks dealers in 90s
- Business-school program, mostly in finance
- Surveys: O'Hara (1995), Madhavan (2000), Harris (2003)

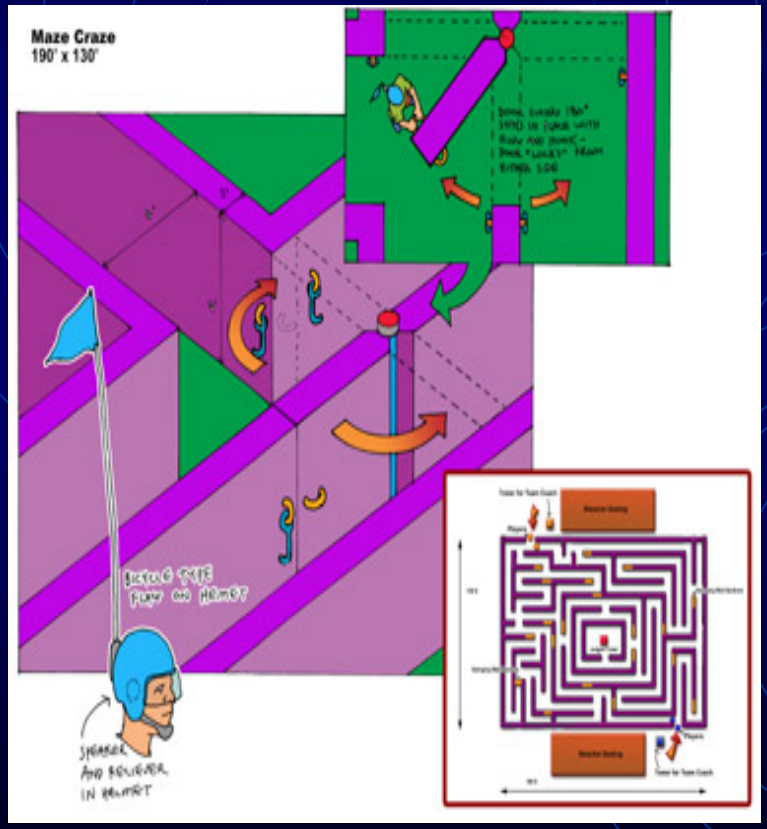
Economic Engineers

- Changed meaning of 'engineer'
- Experimental econ begin to consult on allocation algorithms
- Saga of FCC spectrum auctions (Nik-Khah, 2007)
- Game theorists startup firms to construct auctions
- Manifesto: (Roth, *Econometrica* 2002)

Roth's Revealing Language

- "markets don't always grow like weeds… some of them are hothouse orchids"
- None of the available theory…could be directly applied to the [intern] market….The only parts that applied directly to the medical market were *counterexamples*"
- "experiments were constructed not to test specific hypotheses …but rather as 'proof of concept' demonstrations"
- "The concept of informational efficiency is fraught with difficulty… There is no clear basis in the economic literature for concluding that informational efficiency in markets does obtain, and if so to what extent"

Artificial Intelligence Markets



- AI history passes through many ‘phases’
- 90s hot area: shopbots and ‘autonomous agents’
- Dot-com bust leads to more prosaic coding of markets
- Market design now taught in all major computer science depts.
- Serious treatments of issues of computational complexity
- Undermines ‘generality’ of General Equilibrium Theory

Contradictions of these Trends

- On what grounds can any of these groups claim to successfully "make markets better"?
- All tend to ignore the '*non-constructed markets"*
- Neoc. Welfare benchmarks make little sense for each of the individual traditions
- Oblivious to implications of evolutionary terms used
- Lacking realization that shift to diversity of market forms undermines previous notions of 'lawlike' regularities of a generic 'Market'

Three Repressed Traditions in the History of Economic Thought

1. There is no such thing as a generic 'Market'

   William Thornton (1869); John R. Commons (1936)

2. Markets are conceived as computational algorithms, diverse in character

   John von Neumann, Ross Miller

3. There is no such thing as "commodity space" with a connected topology and/or Euclidean distance metric (Debreu quote)

Possible Destination of Ontological Shift in Economic Theory?

- Economics *per se* has nothing interesting to say about 'human nature', and perhaps about Nature itself [econophysics? Sociobiology?]
- Yet Economics cannot escape making use of and reference to the natural sciences
- It is a science covering both 'naturally occurring' and constructed sets of market relationships
- Markets as diverse algorithmic entities (*markomata)* are the appropriate subject matter of economics
- Machine theory is the sole common denominator of dominant schools in the history of economic thought

General Theory of Market Automata

- Markomata : abstract ‘machines’ that evolve in environment of irreducibly diverse humans
  - Replication: not physical but computational
  - No single generic index of success governs all markomata
  - Complexity index: Chomsky hierarchy
  - Selection: differential use by differing humans
  - Fitness surface: neither welfare nor commodity space
  - Mutation: humans fudging the rules

Individual Market form modeled as some version of finite automaton

- Defined over alphabet $\alpha=\{\alpha_1,\alpha_2 \ldots\alpha_n\}$ and states $\theta=\{\theta_1, \theta_2 \ldots\theta_m\}$
- Transition function **T** that maps $(\theta_i\ \alpha_j) \rightarrow \theta_k$
- Subset **O** = $[\theta_k]$ final accepting states
- May be 'nondeterministic', ie **T** not one to one
- Easiest to see this in 'price assignment' function, but other functions (routing, order execution, prop rights, record-keeping) also can be expressed as automata
- Fixed price markets the simplest: does offer ≥ fixed price? Final state is completed sale

Computational Capacity of Market Forms, Chomsky Hierarchy

TABLE 1: MARKOMATA HIERARCHY

Automaton type	Recognizes lang.	Memory	Markomata
Finite ш	Regular	none	Posted-price
Pushdown	Context-free	Pushdown stack	Sealed bid
Linear bounded	Context sensitive	Finite tape	Double auction
Turing Machine ™	Recursively enumerable	Infinite tape	None

Chomsky is flat hierarchy: resource availability nested within hierarchy

- 'Intractability' gauges rate of speed increase vis-à-vis time/ resource increase *within* Chomsky class: some tasks NP-hard {eg., much linear programming simplex method}
- Some markomata forms *cannot* accomplish task in polynomial time [explains relative scarcity of double auctions in real life?]
- Avoids infinite regress of 'transactions cost' literature: costs of market separate analytical class from market-generated prices
- Obstacles overcome by some markomata simulating operation of other lower-complexity markets

Some Immediate Empirical Implications

- ⇨ All markets operate on rational numbers; nothing occurs with the irrationals
- ⇨ Most 'complex' versions of markomata are not most prevalent forms in human experience: DAs rare outside of finance {Achilles Heel of Hayek Hypothesis}
- ⇨ Market failure looks like inability to 'halt', which cannot be ruled out in advance
- ⇨ No markomata possesses power of Turing Machine: no such thing as generic market capable of simulating operation of any other market

Division of labor applied to markomata formats

- Posted price robust to customer interference, more open to diversity of clientele, but arbitrage opportunities not captured, limits buyer communication; low complexity
- Dutch auction promotes clearing of market in preset time frame, difficult to implement across commods, low levels communication
- Continuous double auction good at arbitrage, promotes liquidity and communication, limits participation, awkward for multiple complimentary commods; high complexity
- Network analysis: Markomata of higher complexity use inputs/ simulate markets of lower complexity, *but not vice versa*
- No such thing as ‘law of supply and demand’

Market graphs and intractability of arbitrage

- Market graph **G:** nodes markomata, edges price/quantity inputs, outputs;let **H** be *k*-clique subset of **G** dealing with single commodity, and **S**(L) be set of all possible cycles in **H** of length L
- Define chain of exchanges $w_t(s) = \mathbf{\Pi}\ w_{jk}$ along any cycle s in S(L). If $w_t(s) \neq \mathbf{1}$, arbitrage opportunities exist
- Decision problem finding arbitrage $w_t(s)$ -1 > c is reducible to well-known travelling salesman problem; hence NP-complete, since set **S**(L) grows exponentially with length L and markomata identities t
- 'Small worlds' network theory also applicable?

An Alternative Evolutionary Economics

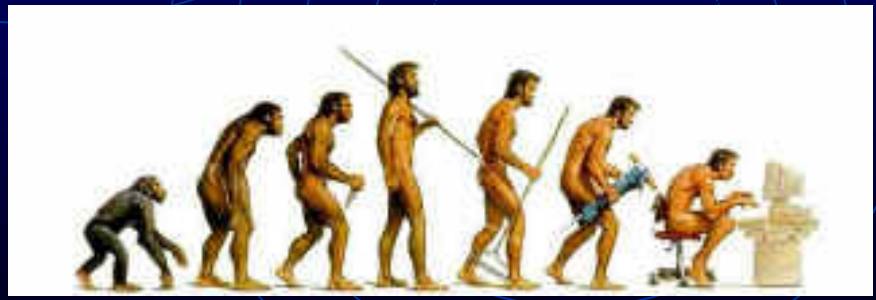
- Individual markomata evolve: ‘mutation’ as tinkering with the rules of specific automata by participants
- Arrow of evolution: higher Chomsky class markomata appear with economic development
- Market graphs **G** also evolve: more complex markomata simulate the operation of lesser markomata, some markets accept inputs from other forms, graphs become more dense
- Fixed independent commodity space unnecessary, since commodity definitions altered with evolution
- This conforms to von Neumann’s original vision of automata theory as formalization of evolution

Evolution *not* optimal search

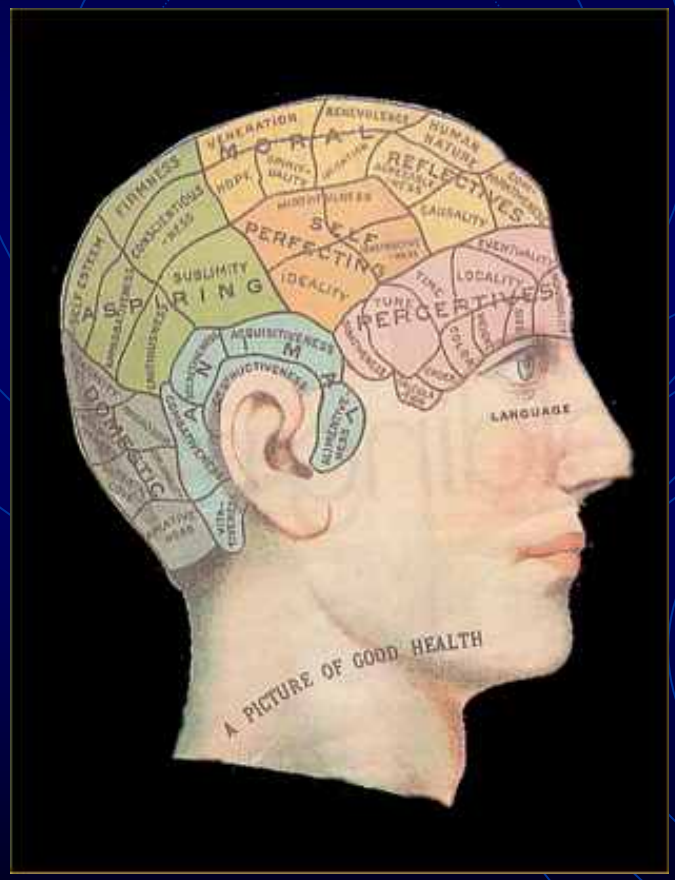
- **Stadler, Wagner& Fontana, *Jour.Theor.Biology* (2001);**
- **Mathematical presumption of Euclidean fitness surface in standard dynamics precludes models of punctuated equilib., developmental constraints ('spandrels'), irreversibility in evolution**
- **Presumption of commodity space blocks progress in econ**
- **Mathematical presumption of Euclidean distance metric in commodity space precludes modeling of irreversible exchange, different markomata trading 'same' commodity in different ways for different purposes; reifies presumption of single monolithic 'Market'**
- **Here 'economic fitness' is suggested to be portrayed as an accessibility pretopology based on asymmetric 'nearness' of various economic objectives**

Future Directions for Markomata Theory

- An explicit natural history of markets from the markomata viewpoint
- Empirical studies on the actual distribution of markomata and empirical market graphs, correlated with their impacts upon realized price distributions
- Exploration of the role of firms in constitution of specific markomata

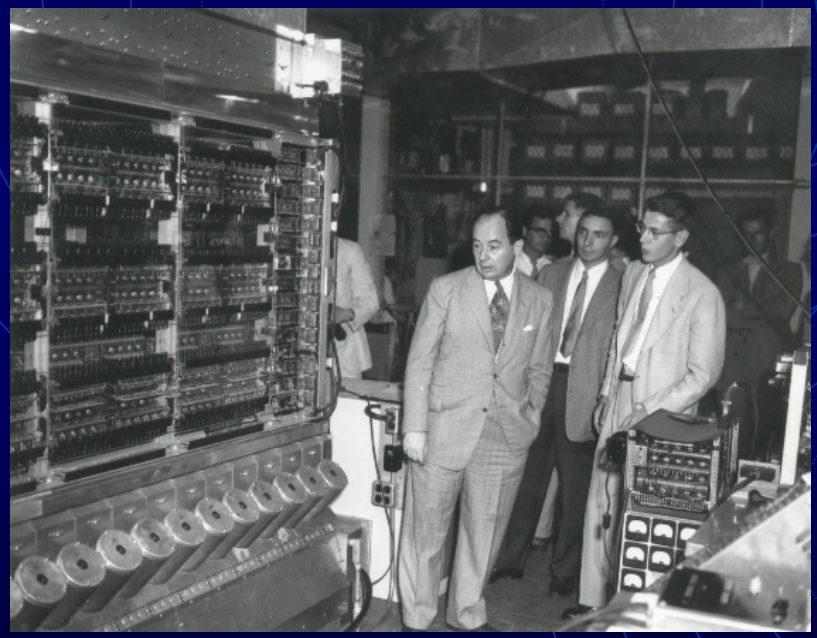


Which Program is more likely to resonate with further scientific research into the nature of mind?



- 'Preferences' are not serious cognitive science
- Much work suggests scads of cognition is sub-conscious, embodied and not even located in the head
- Experimental psych disdains economists & vice versa
- Markomata respects diversity of methodological individualism, neoc does not
- Markomata make no *a priori* theoretical commitments abt nature of human beings

Von Neumann Was Right



- He accused neoclassicals of being mired in 19th C notions of science
- Mechanics long ago gave way to computation as *lingua franca* of science
- Warned against confusing human agency with 'Machines who think'
- Cyborg future blurs boundary human/machine interface