Adaptive complex systems, economics,finance, ...

or

Why is a complex systems guy studying markets?

SFI Summer School

Summer Solstice, 2007

J. Doyne Farmer

Santa Fe Institute

Science and technology will shift from a past emphasis on motion, force, and energy to communication, organization, programming, and control.

John von Neumann, 1950

Add: Complexity, structure, form, function, information, computation, emergence, evolution, …

THESAURUS

OF WORDS AND PHRASES

BY

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PLAN OF CLASSIFICATION

Class	Section		Nos.
I. ABSTRACT RELATIONS	I.	Existence	1 to 8
	II.	Relation	9— 24
	III.	Quantity	25— 57
	IV.	Order	58— 83
	V.	Number	84— 105
	VI.	Time	106— 139
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II. SPACE	I.	Generally	180— 191
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	II.	Inorganic	321— 356
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	Division		
IV. INTELLECT	(I.)	Formation of Ideas	450— 515
	(II.)	Communication of Ideas	516— 599
V. VOLITION	(I.)	Individual	600— 736
	(II.)	Intersocial	737— 819
	Section		
VI. AFFECTIONS	I.	Generally	820— 826
	II.	Personal	827— 887
	III.	Sympathetic	888— 921
	IV.	Moral	922— 975
	V.	Religious	976—1000

Properties of adaptive complex systems

- Bottom-up/top down hierarchical structure.
- Distributed information processing.
- Interacting parts (not necessarily reflecting whole)
- Emergent properties (whole greater than sum of parts)
- Diversity of specialized roles and functions.
- Evolution based on opportunistic innovation.
- Frozen accidents (lock in, path dependence)
  - history is an important determinant of details, but may or may not be important for broad principles of behavior
- Resilience, robustness?

Examples

- Living systems and subsystems
  – Nervous system, ecology, immune system, hormonal system, metabolic network, ant colony…
- Social systems and subsystems
  – Economy, social networks, internet, evolution of language, …
- Study of adaptive complex systems focuses on trying to discover the common principles of organization, structure, function, and ontogeny underlying these systems.

Complex vs. not complex

- Celestial mechanics not adaptively complex
  - Interactions are all on same level
- Turbulence is complex, but not adaptive
- Chemistry has some of both
  - Belousov-Zhabotinsky reaction
- Biology is adaptively complex
- Social science even more so

Complexity (the discipline)

- Complex systems is continually reinventing itself: cybernetics, synergetics, self-organization, plectics, complexity, emergence, evolution broadly construed, …
- Interdisciplinary, but with a focus.

What characterizes complex systems as a discipline?

- Not yet a novel, but rather a collection of anecdotes and short stories seeking a coherent plot.
- Tractable models illustrating aspects of emergence
  - Steam engine governor, logistic map, perceptron, game of life, von Neumann's self-reproducing automaton, iterated prisoner's dilemma, El Farol, Tierra, sandpile, epsilon machine, autocatalytic set, small world network, …
- Dead heros
  - Smith, Darwin, Butler, Spencer, Wiener, Shannon, Ulam, von Neumann, Monod, Varela, Simon, …
- Central topic is itself a nonmaterial abstraction.

Just a few open problems

- Develop a theory for the emergence of hierarchies, e.g. demonstrate emergence across more than one level of a hierarchy.
- Develop a taxonomy of machines.
- Develop a theory of automated design for complex systems.
  - Self-programming computer programs
  - Evolvable self-reproduction
  - Understanding of principles behind thinking machines

More than any other field, complex systems has the potential to give insight into deep philosophical questions

Three ideas about the universe

- **Animism.** All natural objects are animate, ensouled, or spirit-directed.
- **Vitalism.** The nature of life is due to a force peculiar to living organisms and different from all other forces found outside living things.
- **Mechanism.** All natural phenomena, including life, has a material explanation in terms of physical laws. Living organisms are "just machines".

All modern scientists are mechanists.

Vitalism

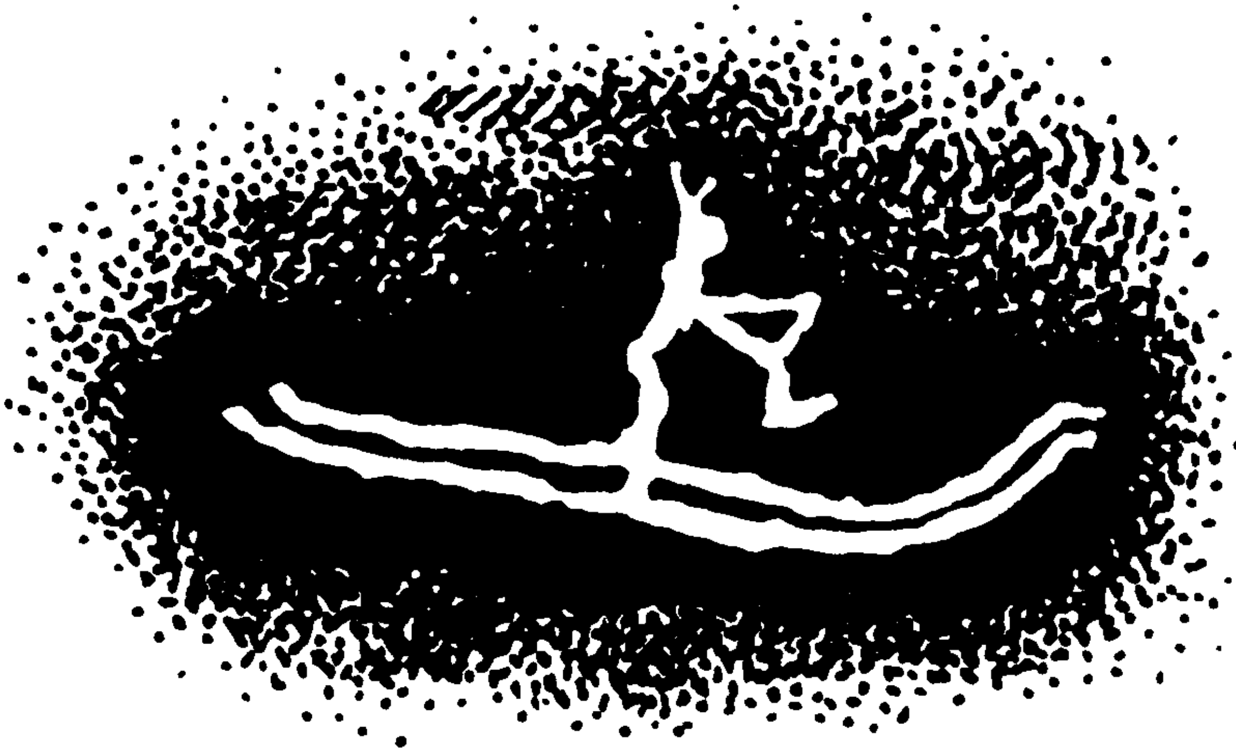
Vitalism amounted to the assertion that living things do not behave as though they were nothing but mechanisms, constructed of mere material components; but this presupposes that one knows what mere material components are, and what kind of mechanisms they can be built into.

C.H. Waddington

How are complex properties like life and intelligence compatible with the mechanistic view?

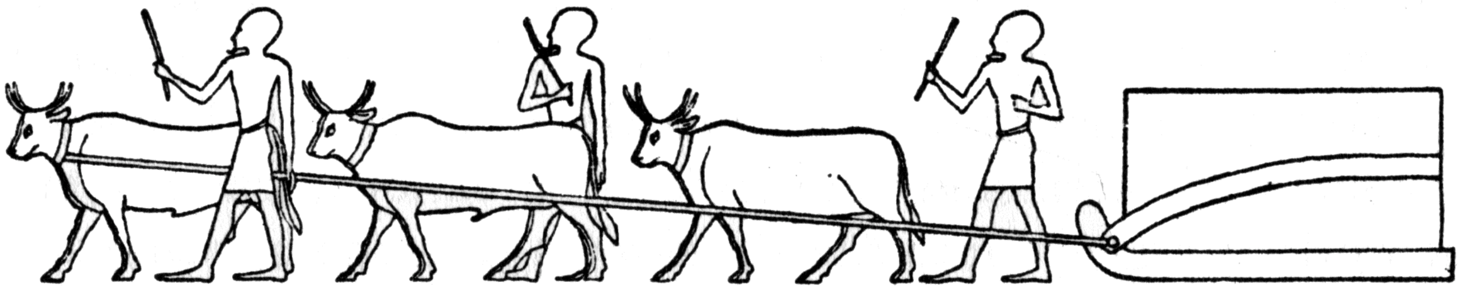
- Modern hypothesis is **emergence.**
  - Systems have properties not present in components (Behavior is not obvious from parts alone).
  - No contradiction with mechanism, rather, emergent properties coming from mechanistic parts are far richer than previously imagined.
- Understanding emergence is the central task of complex systems theory.

The emergence of the mechanistic view as the dominant paradigm of science



Man on skis. Stone Age rock carv-
ing, north Norway

Machines have always been associated with humans.

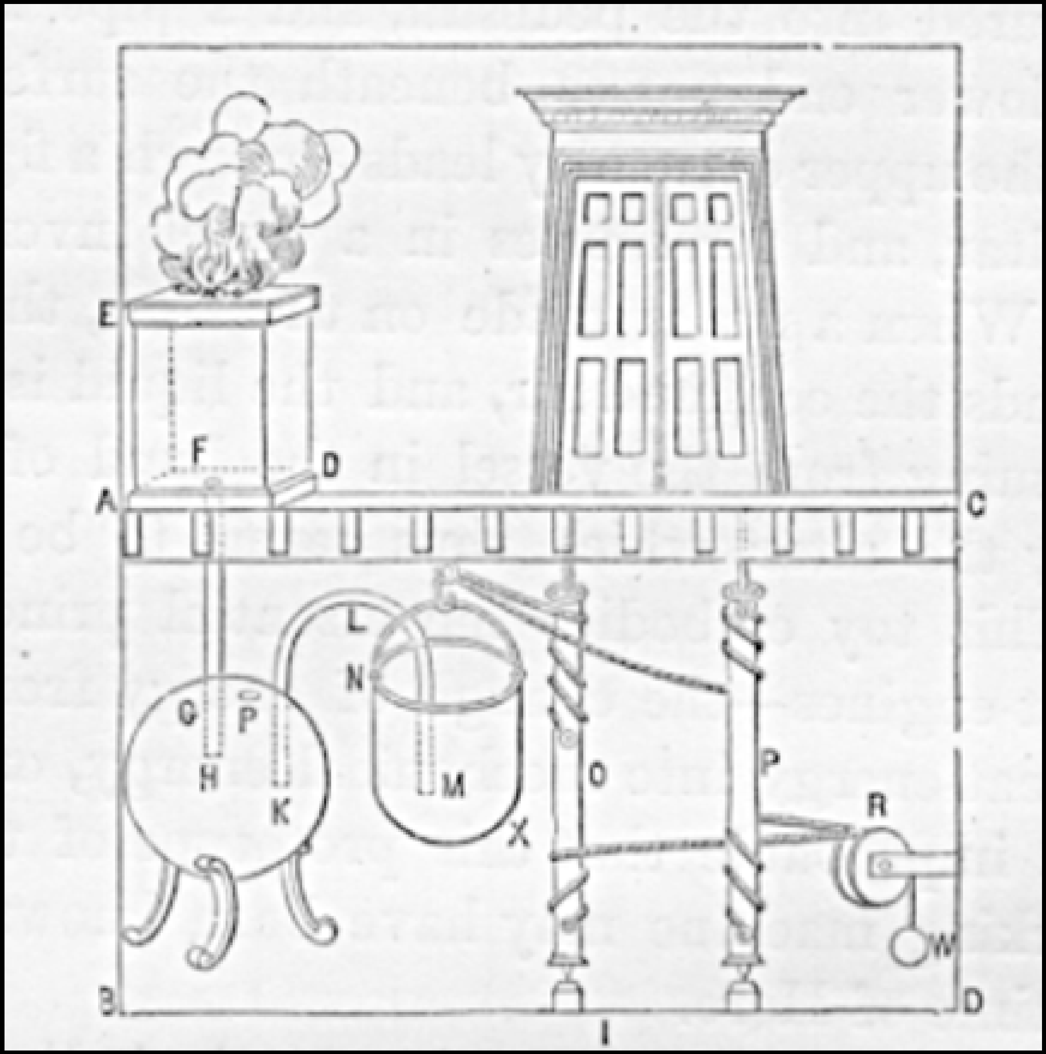


TRANSPORT OF A BLOCK DESTINED FOR THE BUILDING OF A TEMPLE AT MEMPHIS, IN THE 22ND YEAR OF A'HMOSE (18TH DYN.).

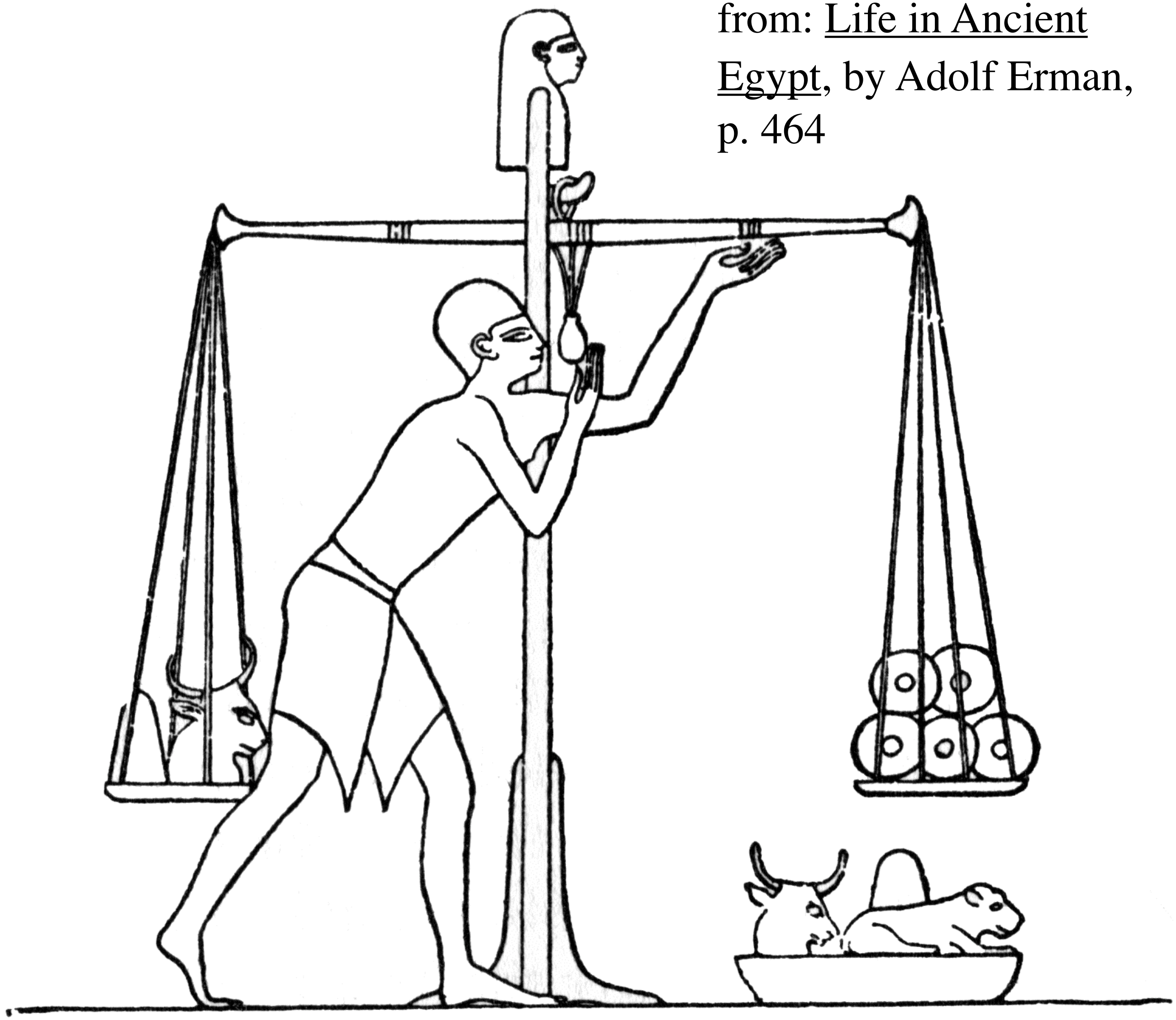
According to the inscription the bearded workmen are Phœnicians (L. D., iii. 3).

from: Life in Ancient Egypt, by Adolf Erman, p. 476

Hero’s steam engine (200 BC).

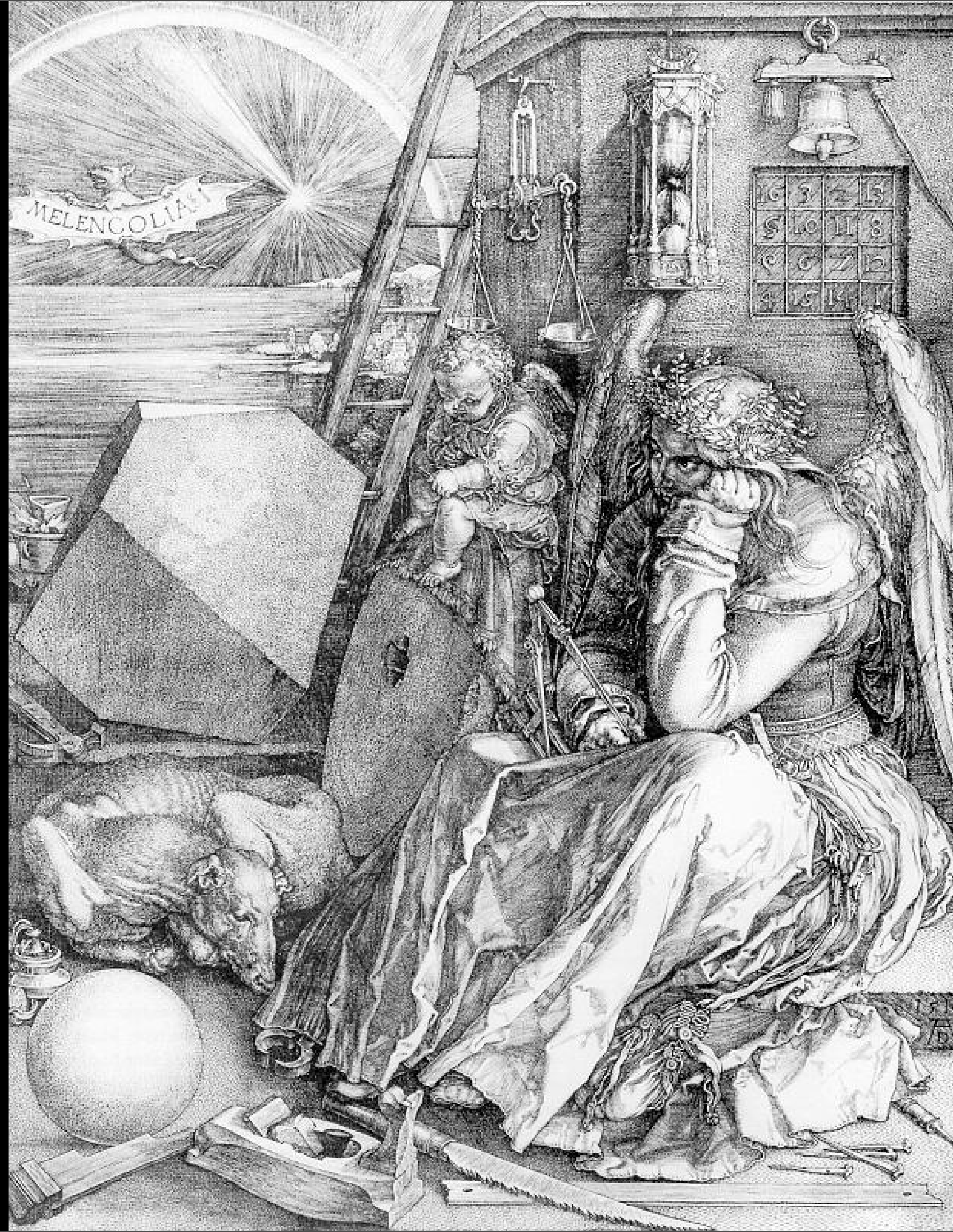


from: <u>Life in Ancient Egypt</u>, by Adolf Erman, p. 464



THE WEIGHING OF GOLD RINGS.

The weights are in the shape of a cow's head, of a lion, and of a cone (after L. D., iii. 39 a).

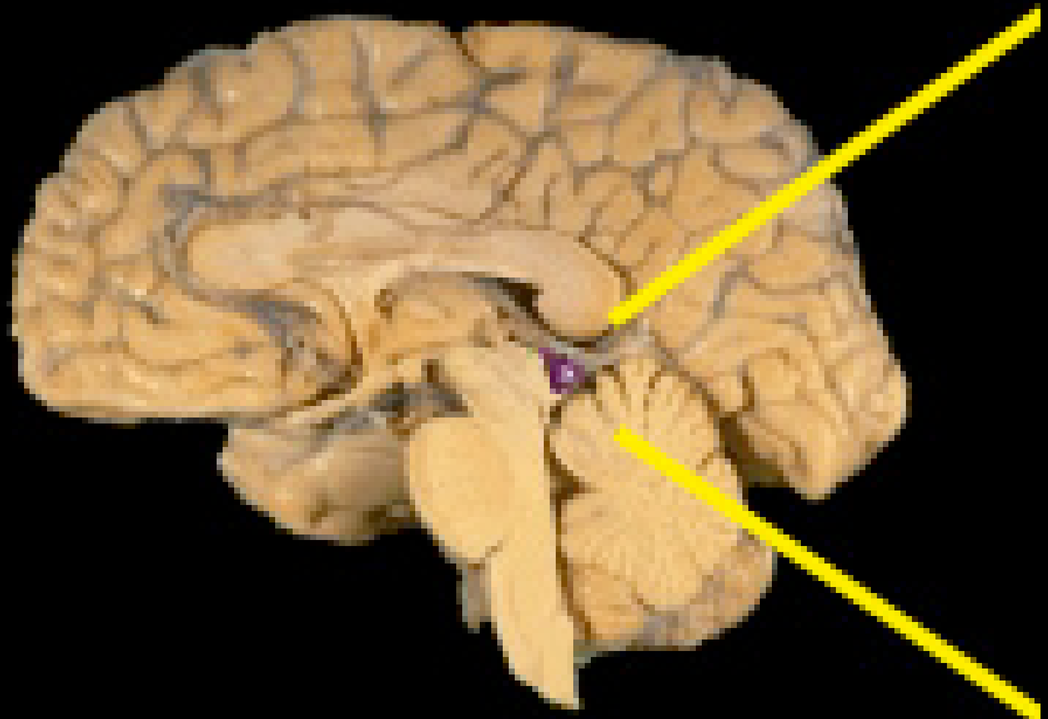

MELENCOLIA I

Rene Descartes (1596 – 1650)

Rene’s world

- Principia Philosophiae: “Explains” almost everything in purely mechanical terms.
  - Origin and mechanism of the Solar system, transmission of light, ebb and flow of the sea, powers in magnet, fire in the heart, sensations of the mind, volcanos, …
  - Three types of matter, only one with weight, vortices and eddies, …
  - Blood was vaporized in the heart, recondensed in the lungs
- Exempted God and the human soul.
  - The soul was located in the pineal gland.
  - Set up a dichotomy between mind and body that has persisted for centuries
- Mechanistic, mathematical, but not science

Pineal gland – the seat of the soul?



Final propositions

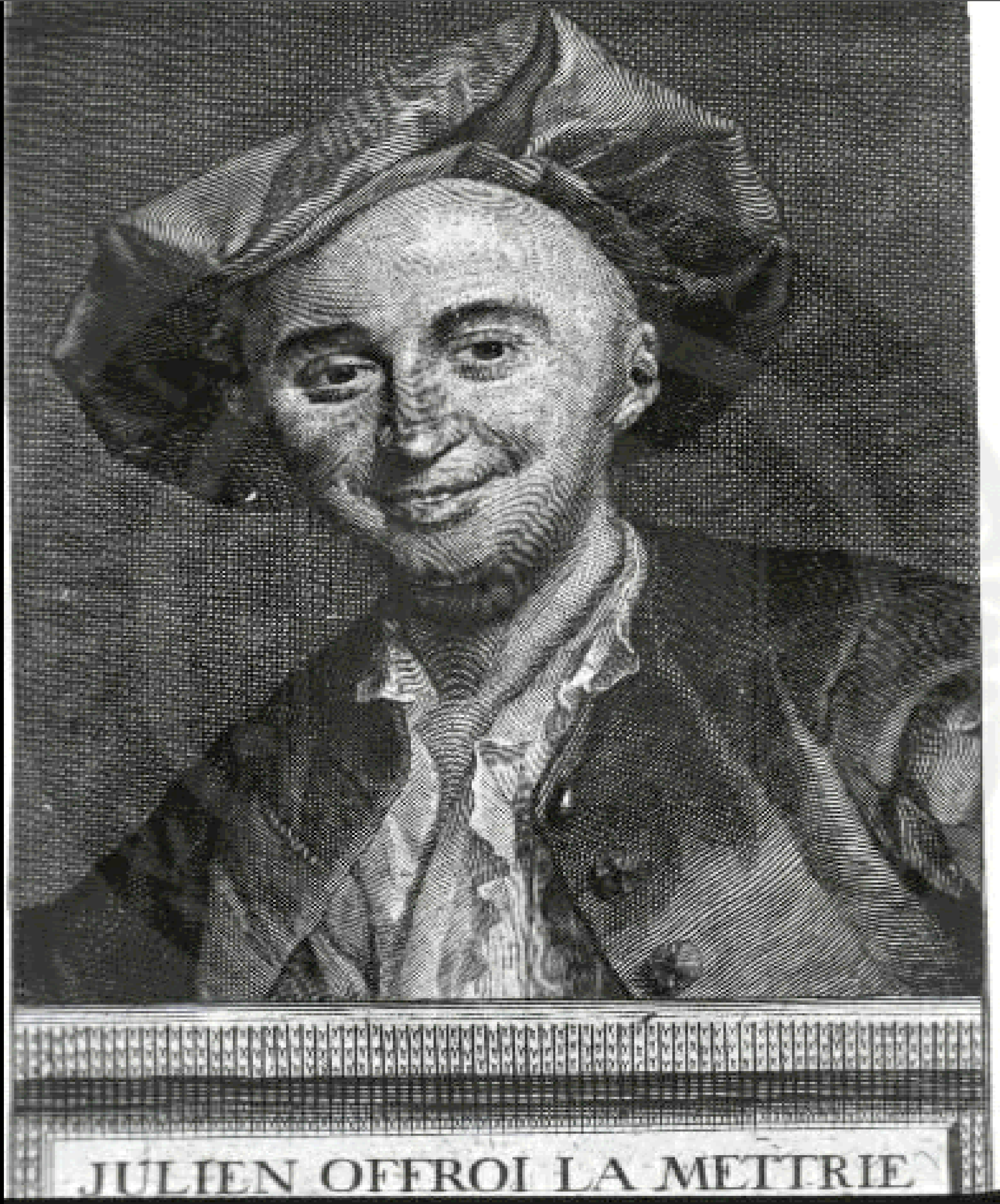
- 199. That no phenomena of nature have been omitted in this treatise.
- 205. That those things which I have explained here do seem at least morally certain, however.
- 206. That on the contrary they seem more than morally certain.
- 207. But that I submit all my opinions to the authority of the church.

But vitalism persisted

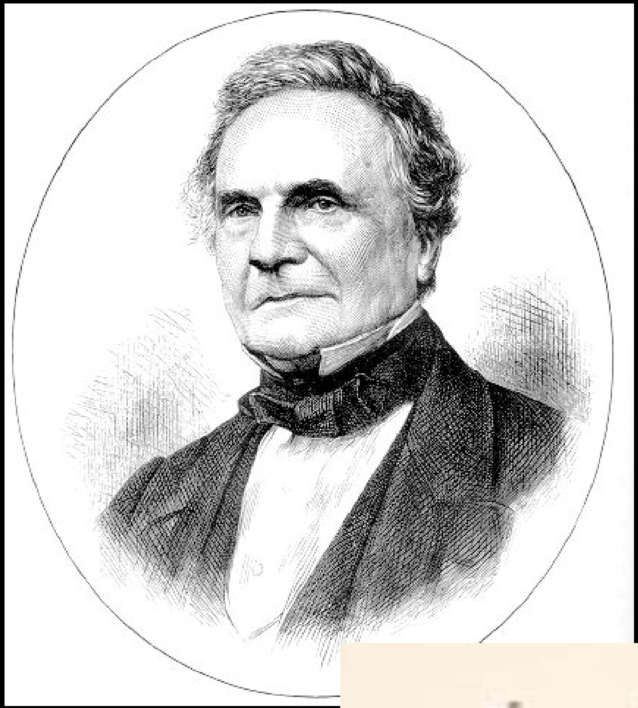
- Well into the 20th century, many if not most scientists continued to think that the “essence of life” and thought could not be explained without resorting to some form of vitalism.

The earliest known dissenter

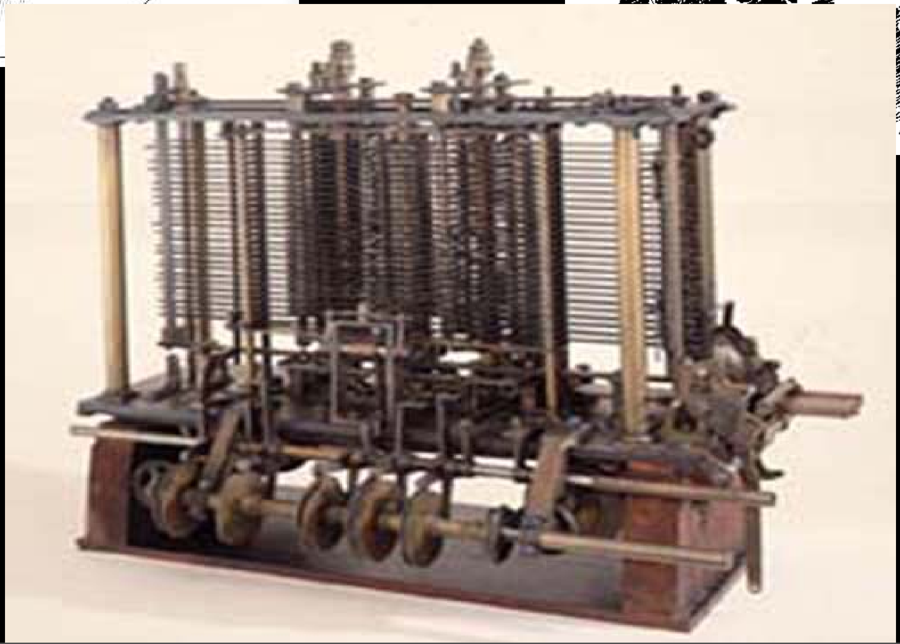
1709 - 1751



Charles Babbage



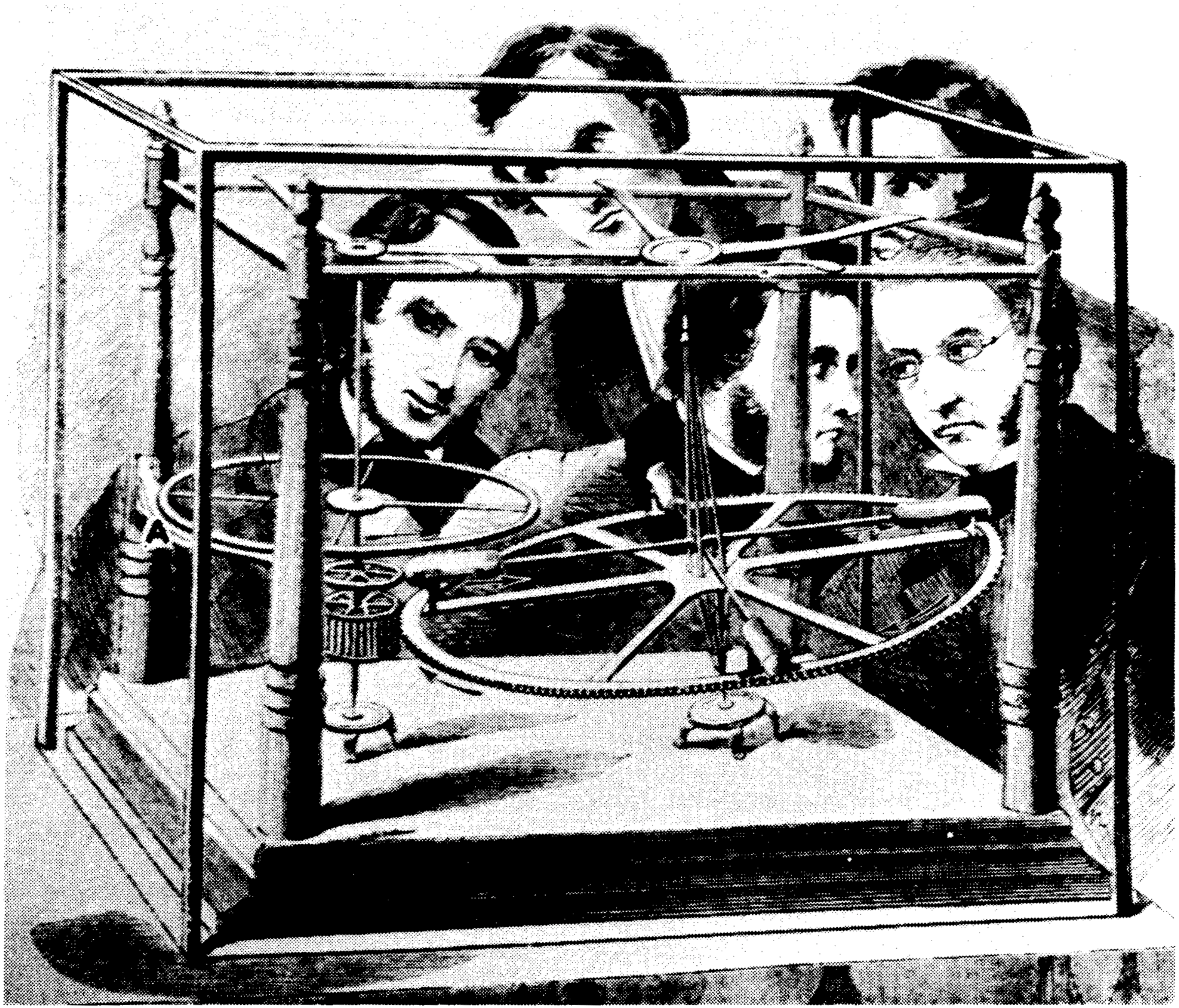
Lady Augusta Ada Byron,
Countess of Lovelace



Of men and machines

When asked by a student how he could assert that a machine could think, Claude Shannon is reputed to have replied as follows:

"I'm a machine. You're a machine. I can think, you can think. So how can you think that a machine can't think?"



from: Perpetual Motion, by A.W.J.G. Ord-Hume (1977), p.

Thermodynamics led to

- 1st Law: Energy is conserved.
- 2nd Law: Entropy of closed systems (defined as ratio of heat flow to temperature) does not decrease, and tends to increase.

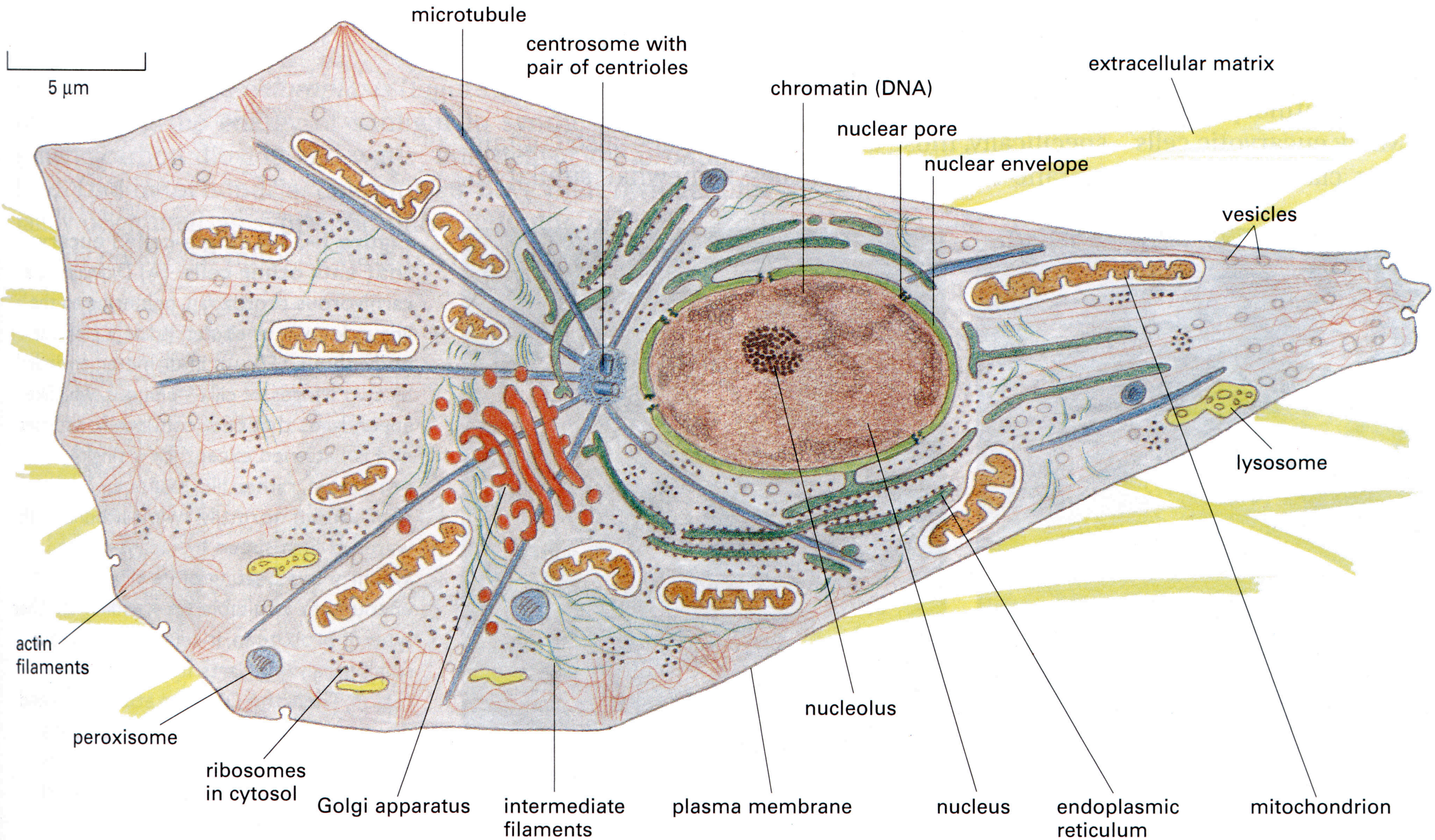
With the atomic theory, this led to statistical mechanics and information theory.

- Entropy becomes a measure of disorder.
- Information is the opposite of entropy. It provides an indiscriminate measure of knowledge. (No notion of quality).
- The discovery of the second law of thermodynamics and its implications

In the 20th century, the view of matter and machines expanded

- Mechanistic view of the ether emerged, but in terms of “machines” of a quite different kind.
  - quantum vs. classical machines
- Biological processes increasingly understood in mechanistic terms.
- Vitalism has not explained anything
- Only debate is role of quantum effects.

A very ancient machine



The Cell as a Machine Factory

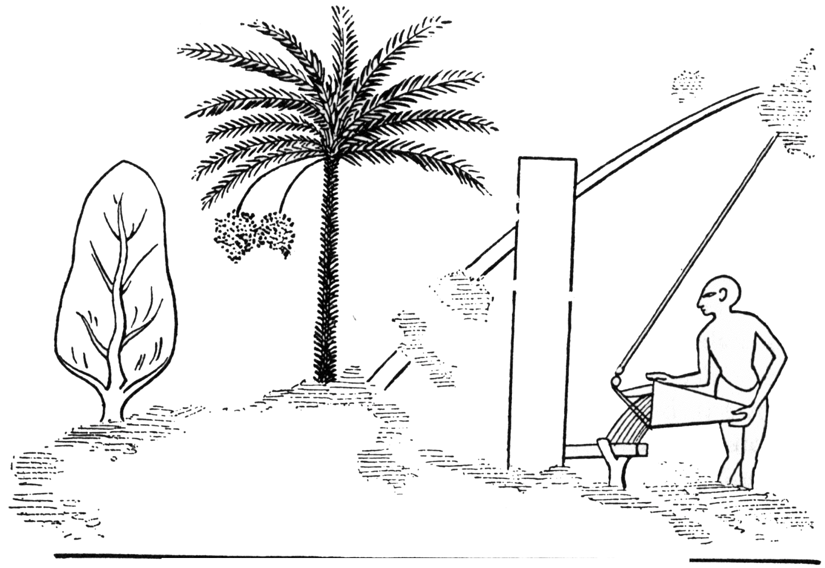
Proteins	Machines	Messenger RNA	Pattern Templates
Nucleus	Machine Pattern Archive	Endoplasmic Reticulum	Machine Assembly Shop
Ribosomes	Assembly Machines	Golgi Body	Machine Dispatch Office
Microtubules	Girders, Cranes, Tracks	Lysosomes	Disassemblers, Recyclers
Mitochondria	Power Generators	Kenesin, Dynein	Tractors, Motors

Role of machines

- Modern science is fully mechanistic, but it is not clear exactly what a machine is.
- Machines (properly defined) are the bridge that connects physics to information.
  - They make order possible (complexity, organization, complexity, structure, function, …

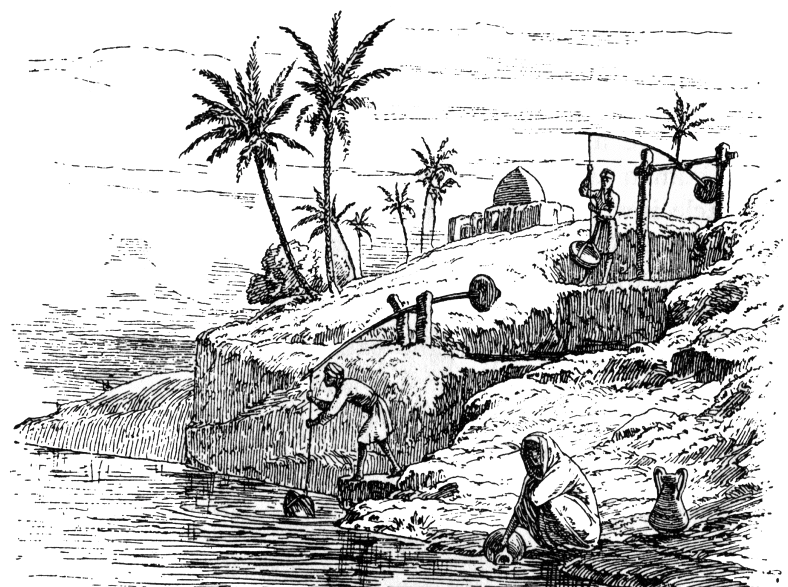
What is a machine?

- Aristotle:
  - “A means of altering nature’s course”
- Early treatises on machines
  - Philo of Byzantium, 200 BC.
  - Hero of Alexandria, 62 AD., “Mechanics”, or “Book on the raising of heavy weights”
- Five simple machines known to Archimedes
  - Lever, wedge, screw, wheel and axle, pulley



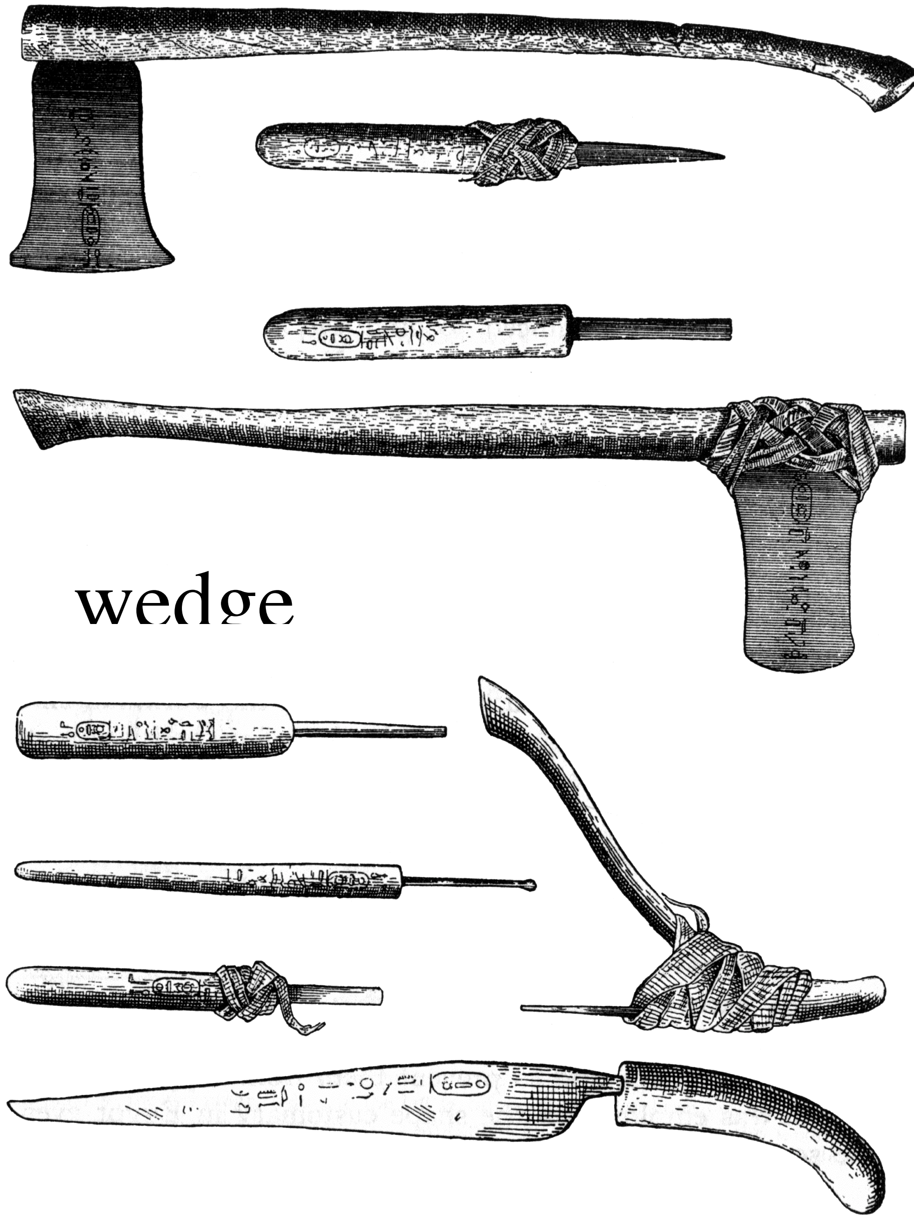
ANCIENT SHADUF. (Thebes. After W., I. 281.)

above: ancient shaduf (draw well)
below: modern shaduf



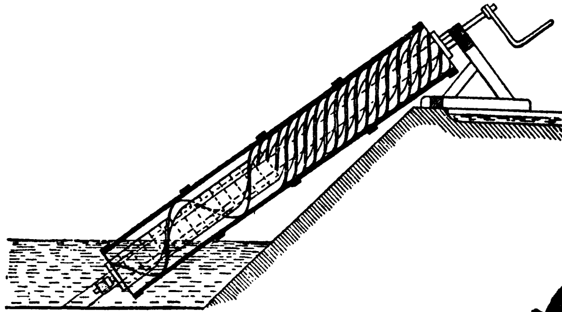
MODERN SHADUF.

from: Life in Ancient Egypt, by Adolf Erman wedge

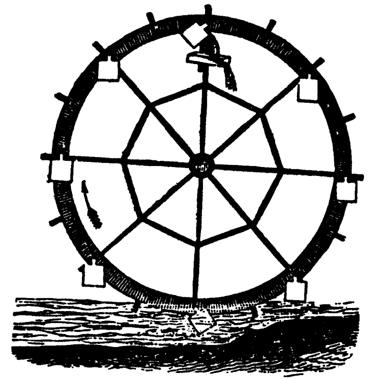


EXAMPLES OF THE TOOLS USED BY THOTHMES III.: 2 AXES, 5 CHISELS, AN ADZE, AND A SAW.
(From the collections at Leyden and at Alnwick Castle.)

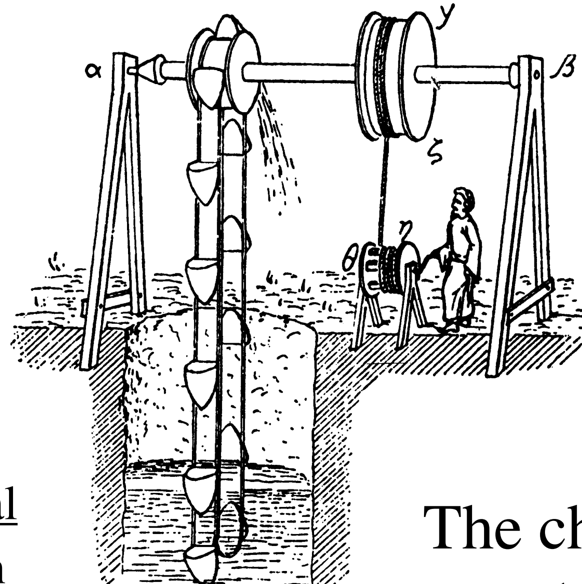
from
Egy
p. 4



The water screw



Developed noria
(wheel)



The chain of pots
(pulley)

from: <u>A History of Mechanical Inventions</u>, by Abbott Peyson Usher (1929), p. 130.

19th century

- Theory of machines was an active field of research in 19th century.
  - Hachette, Whewall, Willis, Reuleaux, …
- Classified possible mechanisms, different functions of classical machines.
- Does not encompass 20th century machines

What is a "machine"?

- A machine is an assembly of matter capable of selectively altering other assemblies of matter.
- The key property of a machine is its ability to implement a *functional constraint*, restricting the possible motions of matter.
- Not a definition of a machine, but rather of the "machineness" of matter.

Sieve

- Sorts sand into piles (reducing macroscopic entropy) while producing heat (increasing microscopic entropy).
- Requires energy to run (shaking sand).
- Creates up to one bit of information per grain of sand.

Functional constraint

- Specifies what machine does in topological, geometric, or probabilistic terms.
- E.g. for sieve: "Particles of size $x < x_c$ will remain on the same side of the sieve.
- Probability of passage in any given shake of sieve depends on fraction of small vs. large particles.

Taxonomy of machines?

- Can potentially classify machines based on their constraint functions.
- General classification of functions is an unsolved mathematical problem.
- All I can do is identify a few examples.
- Such a taxonomy would be based on function, not form, ancestry, or material composition.
- Different, more useful, more universal way to think about evolution.

Key developments enabling and encouraging complex systems in 20th century

- Computers
  - Ability to simulate nonlinear systems
  - Gathering of complex data sets
- Nonlinear mathematics
- Information theory
- Discovery of DNA, gene sequencing
- Recognition that human society and human artifacts are increasingly complex, and increasingly self-organized.

Why complex systems are so important

- Practical importance
  - The world is increasingly complex
  - Ultimately, adaptive complex systems is about engineering of living and thinking systems:
  - Organisms, brains, societies, internet, planet, ...
  - Also about evolution of systems through time
- Metaphysical importance
  - What are we and why are we here?
  - Only get little hints -- averted vision

Social science from a complex systems perspective


Non est potestas Super Terram quæ Comparetur ei Iob. 41. 24.
LEVIATHAN
Or
THE MATTER, FORME
and POWER of A COMMON-
WEALTH ECCLESIASTICALL
and CIVIL.
By THOMAS HOBBES
of MALMESBURY.

What is an economy?

- In an analogy with biological systems (immune system, nervous, system, etc.) what is analogous to an economy?
- If you think about things from a machine learning point of view, what function does the financial system play for society?

What is theoretical motivation for studying financial markets?

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- Because they provide a perfect laboratory in which to study social evolution.

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  - Descent, variation, selection

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- Because they provide a perfect laboratory in which to study social evolution.
- Just like biology:
  - Descent, variation, selection
- Of course, comparison should not be taken literally: Important to understand both similarities and differences.

What is biggest difference between social and biological evolution?

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People can think.

What is biggest difference between social and biological evolution?

People can think.

- In this respect, biology is easier: Accurately modeling thinking humans is very difficult.
  - Innovation
  - Strategic anticipation
- Limiting cases (tractable but far-fetched):
  - Perfect rationality
  - Zero Intelligence
- ZI provides a foundation for modeling evolution.

In some respects finance is an easier to study evolution that biology

- Interactions are tightly constrained and more easily measurable.
  - Financial transactions vs. organism interactions
  - Money vs. energy
- Institutions that mediate financial interactions are simple and essentially mechanical.

Advantages of economics as a medium to study evolution

- Fitness may be easier to understand a priori
  - (e.g. fitness in engineering as given in design requirements is stated a priori)
  - Is there a notion of quality that can be defined without reference to reproductive success?
  - Does "survival of the fittest" make sense?
- Money is a more transparent mediator of evolution than free energy

Not like biology -- need to cope with agent intelligence

Financial economics motivation for social evolutionary models

- Quantitatively resolve (numerous) failures of equilibrium theory
  - Fat tails, clustered volatility, disagreement of price and fundamental value, low influence of news, excess trading, predict profits of financial sector, rate of strategy evolution, …
- Huge practical/social importance: Design markets that minimize risk and transaction costs.
- Proof of principle: Blake Lebaron, “Calibrating an agent-based model”

Biology-like evolutionary theory

- Species -> agents with given strategies
- Population -> capital of agents
- Selection -> accumulation of capital
- Innovation -> creation of new strategies
- Environment -> factors driving price formation (which determines profits).
  - Lots of niche construction!

Market force, ecology, evolution

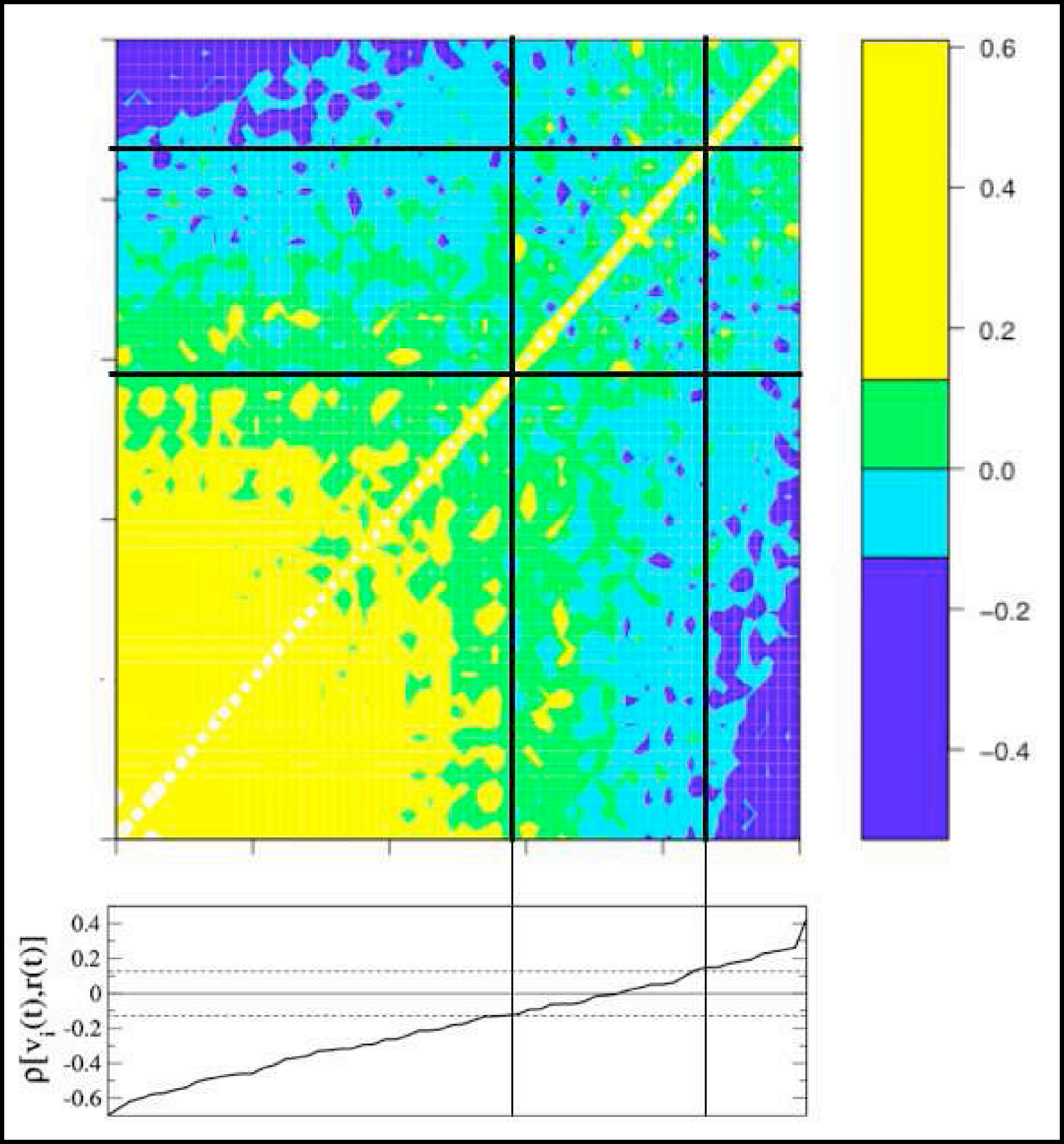
- Key principle is market impact.

$$\Delta p_t = \sum_i f_I(\Delta x_i(p_t, p_{t-1}, \ldots, I')) + n_t$$

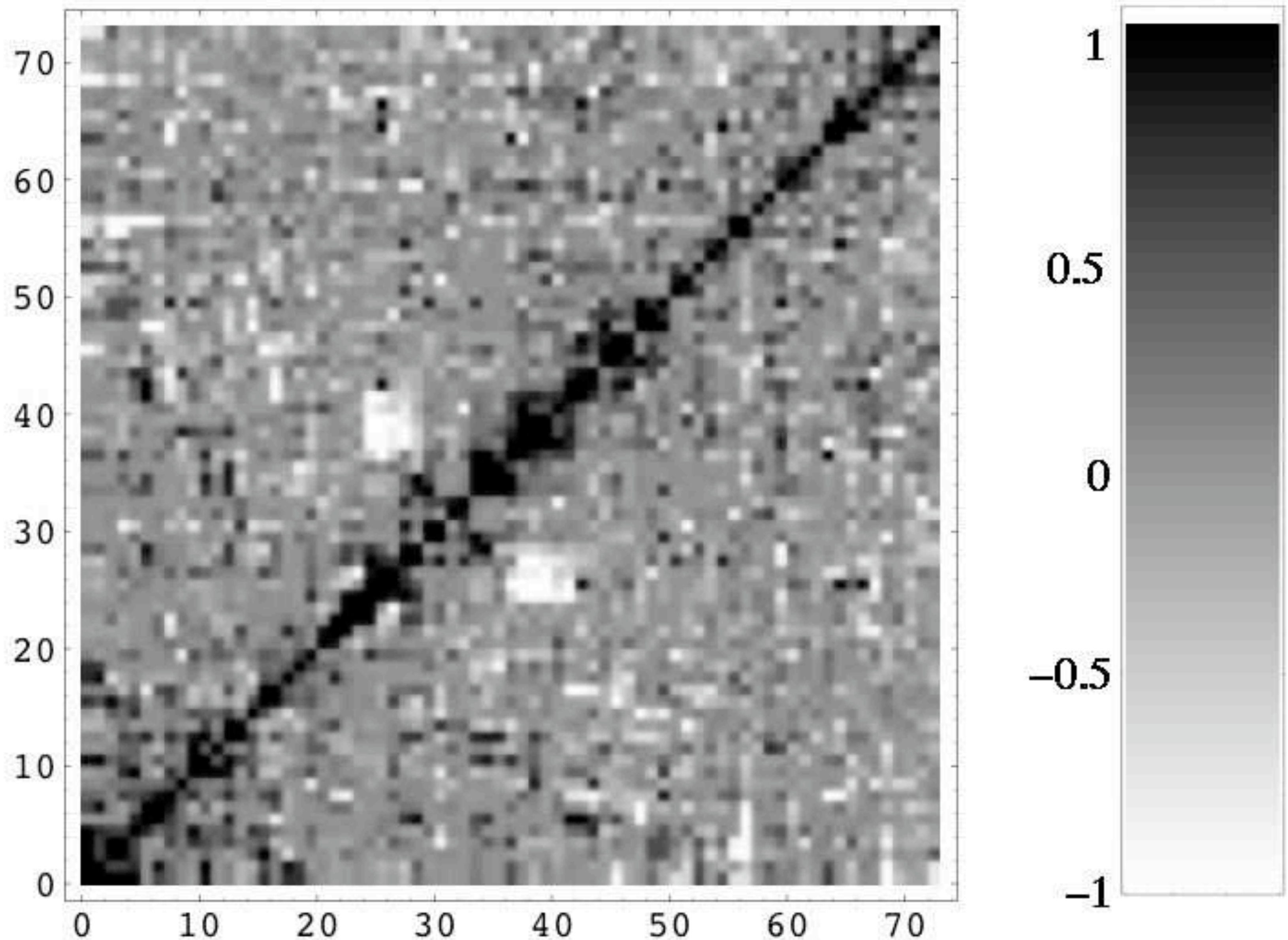
- Trading orders change the price.
- Agents observe price and place trading orders.
- Agents are specialized and form a diverse, evolving ecology.

Building a model from first principles: Market ecology

- Economic need is "food" for arbitrageurs.
- Agents in ecology (nice case study of specialization)
  - Market makers
  - Fundamentalists
  - Technical traders
  - …
- Agent construction
  - Hand constructed stylized models
  - Machine learning
  - Taxonomy via data analysis of real markets



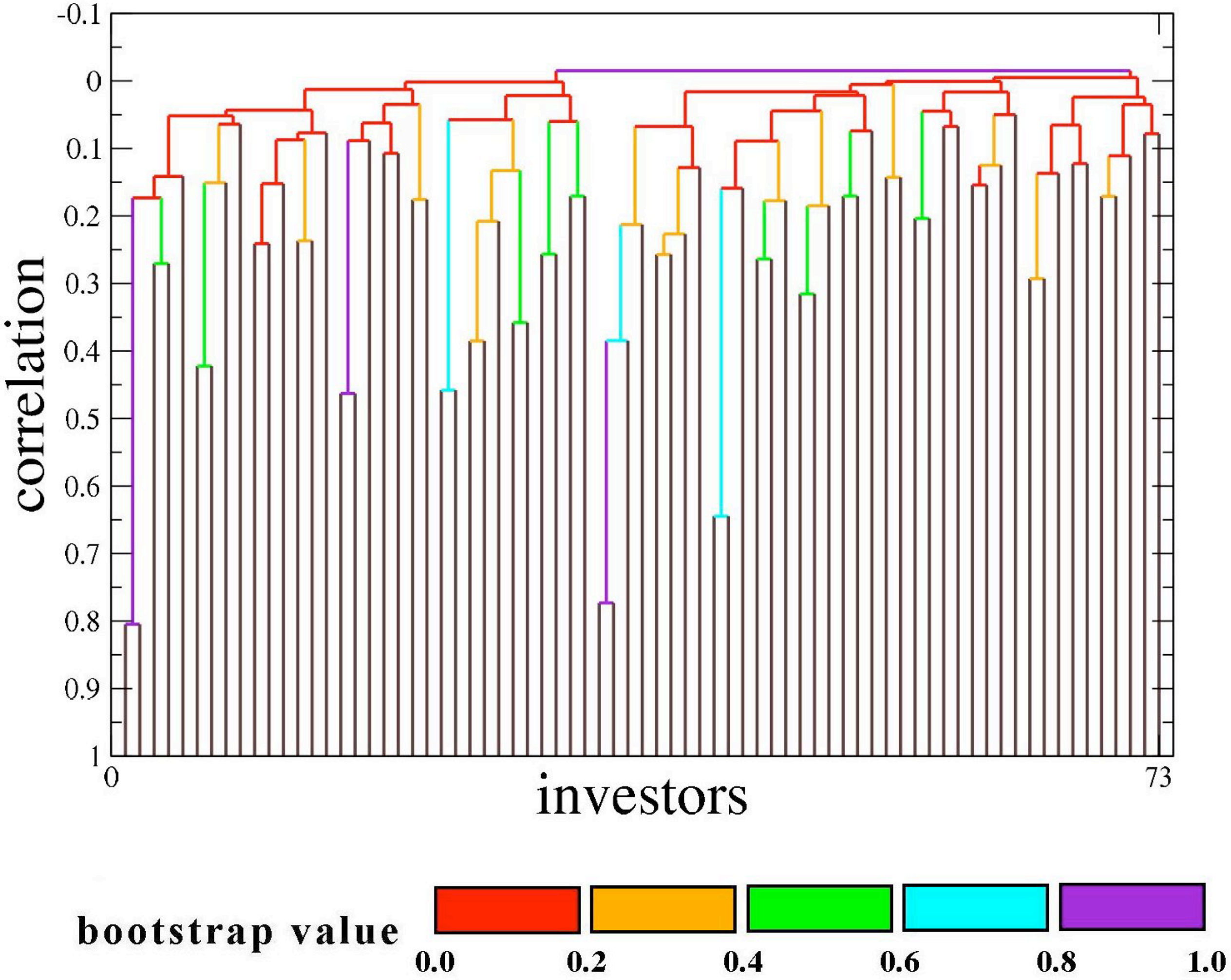
Vaglica, Lillo, Mantegna, Moro, ?



With Michele Tuminello and Neda Zamani

Average Linkage Cluster Analysis

(73 investors; daily inventory variation)



ECOLOGICAL FOOD CHAIN

- Market impact is interaction rule.
  - players made trades, trades alter prices, prices alter trades
- Can use this to study ecological interactions of players and relation to market evolution.
  - Profits of each player depend on interactions with others
  - If A gains capital, do B's profits go up or down? (competitive, predator-prey, mutualist)
  - Relation between ecology and long-term evolution?

Achievements of theory

- Can predict how different types of strategies will affect price dynamics
- Can predict fitness of strategies in a given environment a priori
  - Which strategies can invade?
- Predictions are still only qualitative -- but new data sets offer hope to make it quantitative.