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Systems Philosophy and Engineering Thermodynamics

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Systems Evolution and Engineering Thermodynamics



Terry Bristol, President

Institute for Science, Engineering and Public Policy
Affiliated with Portland State University

Terry Bristol

Institute for Science, Engineering and Public Policy
Linfield College, Portland State University

Philosophy of Science -> Philosophy of Engineering

University of California, Berkeley

University of London



Sir Karl Popper



Thomas Kuhn



Paul Feyerabend



Imre Lakatos

Paul Romer's Paradigm Shift in Economics

FROM

Scientific (Equilibrium) Economics

to

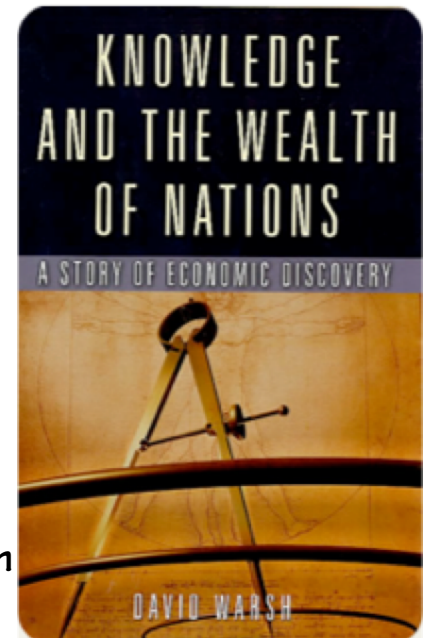
Engineering (Productive) Economics

“Endogenous Technological Change”
(1990)

The homo economicus is an engineer
Problem solver: value actualizer



Paul Romer



David Warsh

Economics as an Engineering Enterprise

Romer's Anti-Malthusian Paradigm Shift:

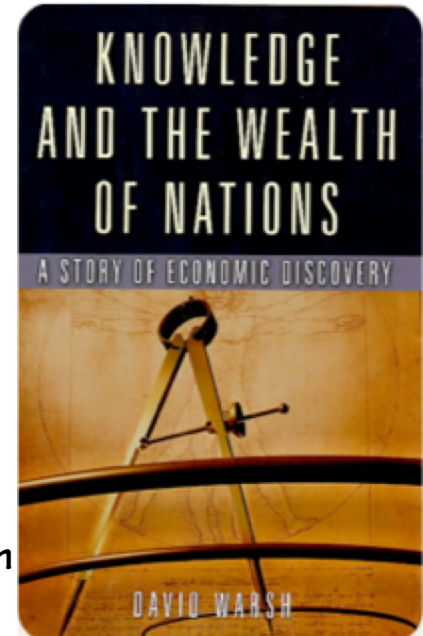
Normally functioning economies
produce a surplus and an abundance of...

'increasing capacity to perform work'

Economies increase activity but also
increase their ability to increase activity



Paul Romer



David Warsh

Economics as an Engineering Enterprise

Romer's Paradigm Shift:

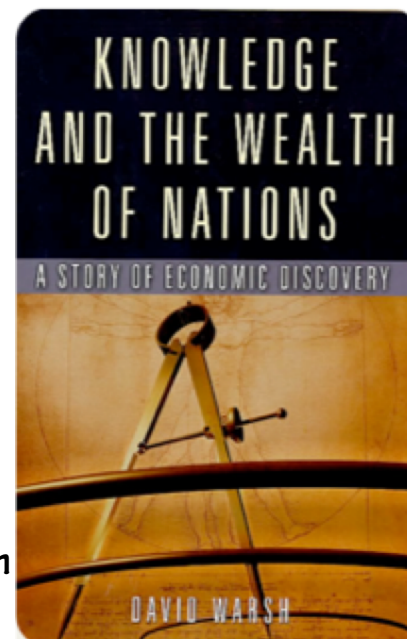
Starbuck's
RAM Chips

It is in my interests that
you succeed!

New Growth Economics
New Growth Politics
New Growth Morality



Paul Romer



David Warsh

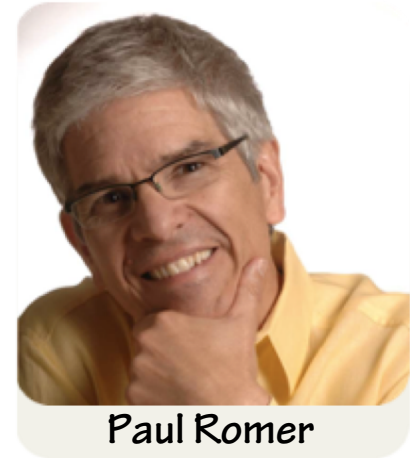
Economics as an Engineering Enterprise

Paul Erhlich (1965): “There will be mass starvation of Earth by 1985 due to population growth”

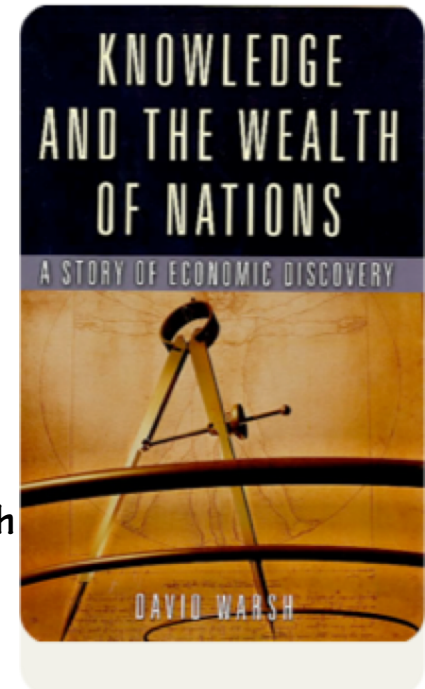
Romer as Post-Scarcity Economist
Post-Malthusian, NGE, NGP, NGM

The product/surplus is what allows
populations to expand

(Later: Economic basis of Evolution)



Paul Romer



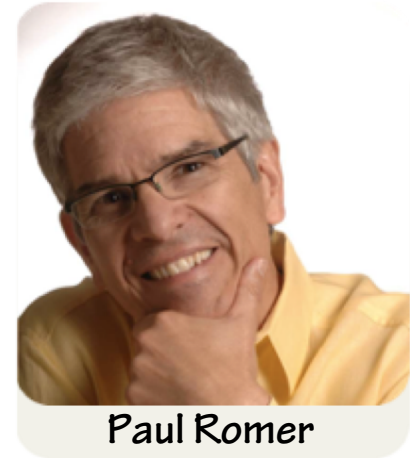
David Warsh

Economics as an Engineering Enterprise

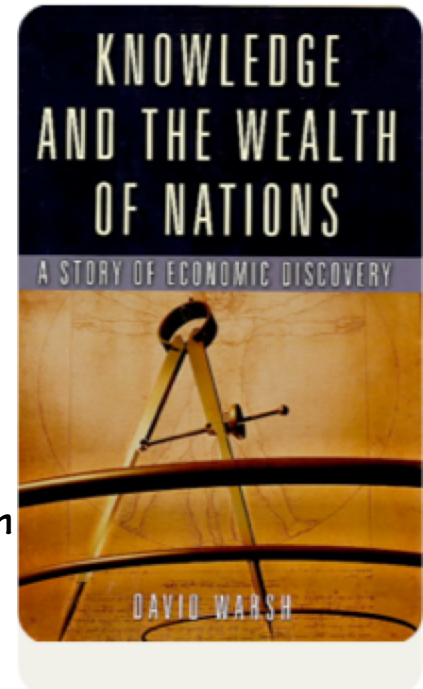
Romer's Paradigm Shift:

Ideas can be shared...
resulting in exponential acceleration

Not how much land, water, gold...
It is what you do with it.



Paul Romer

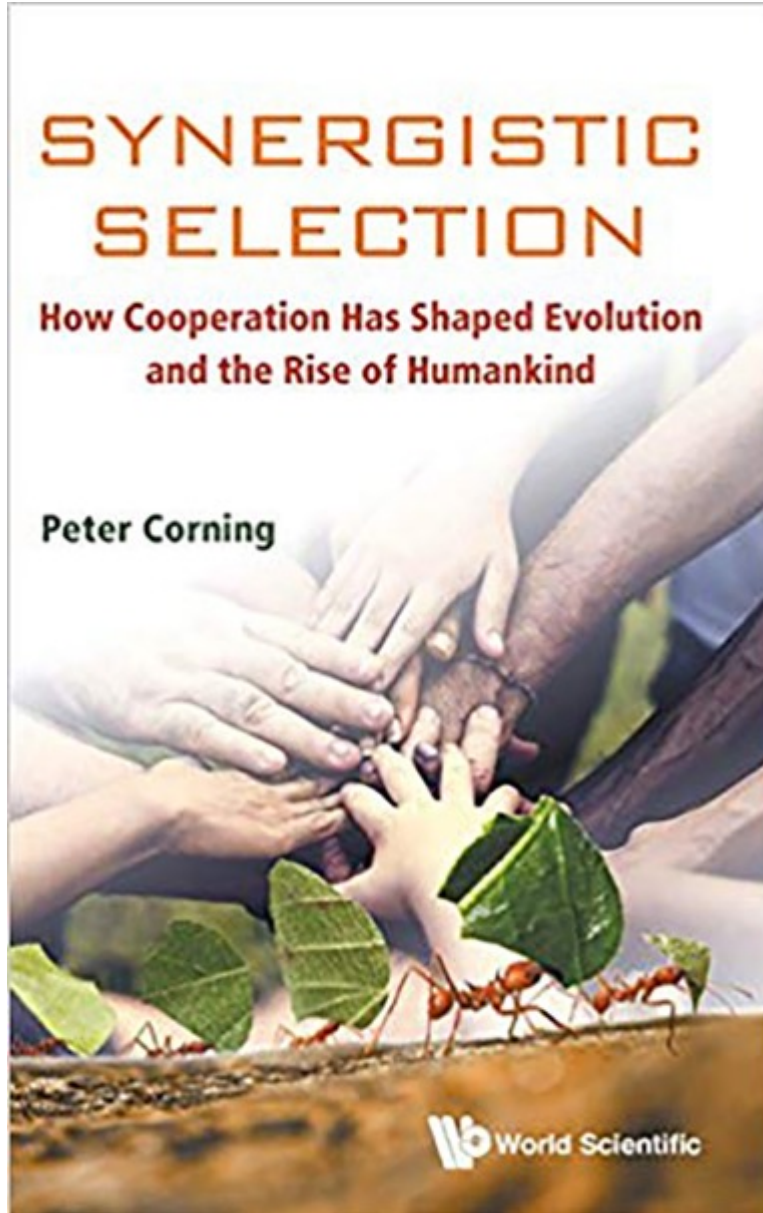


David Warsh

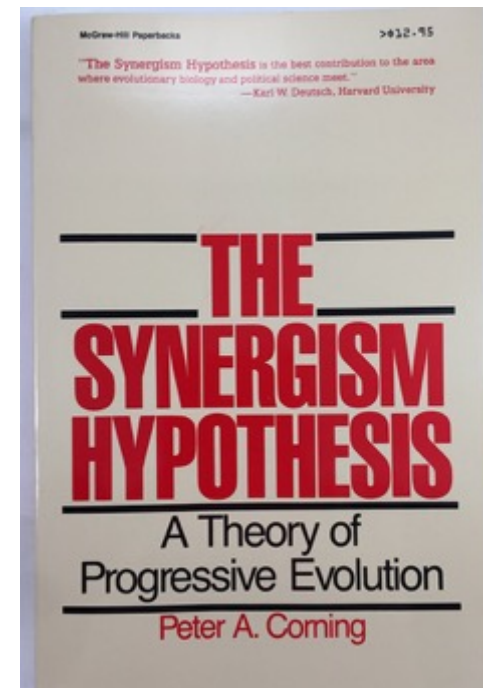


Ramez Naam

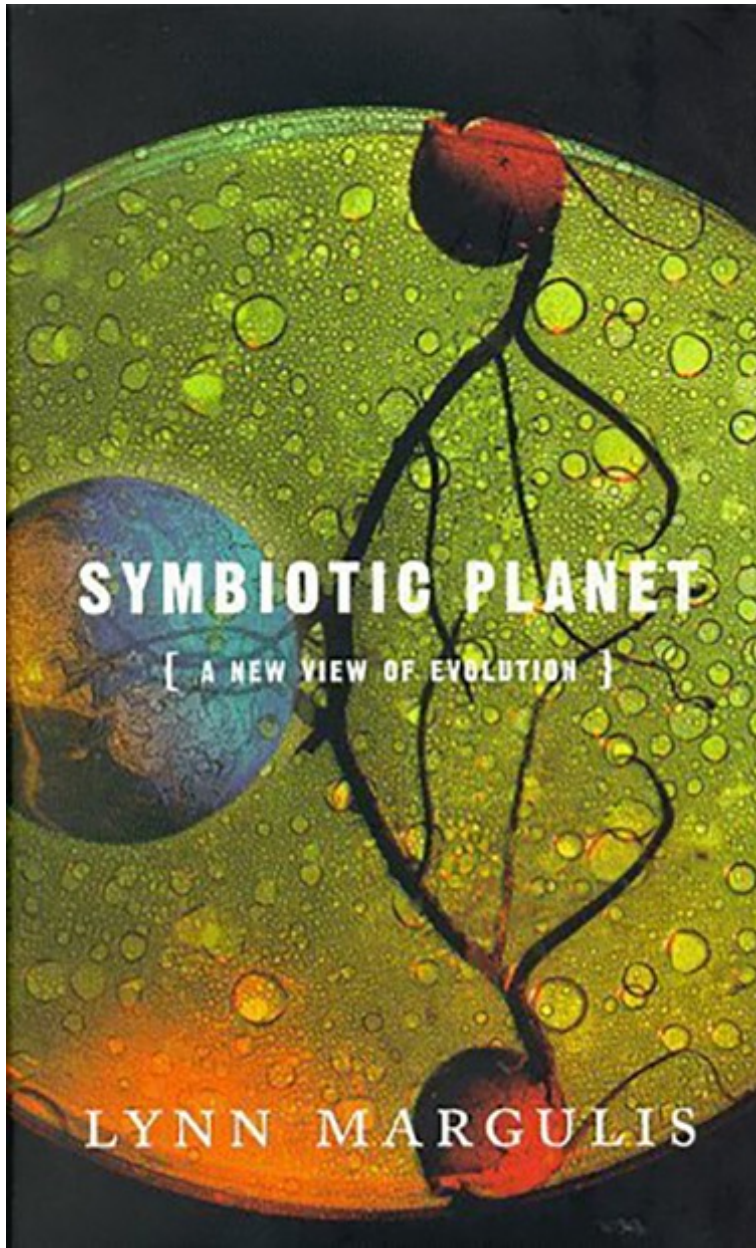
Evolution as Synergetic



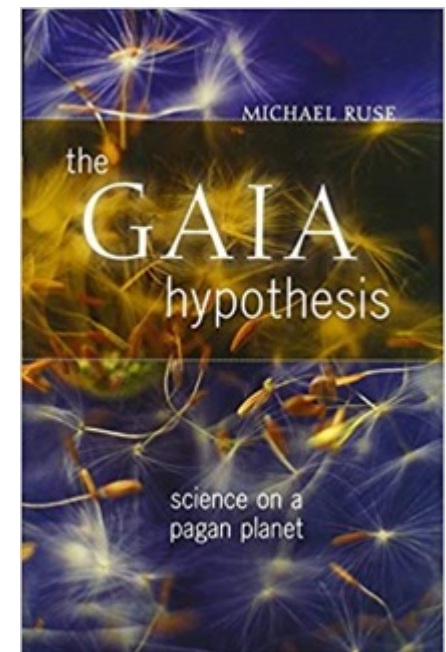
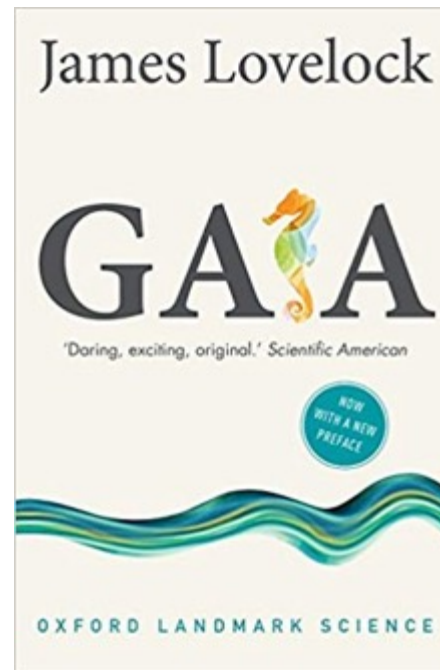
Peter Corning



Evolution as Symbiogenetic



Lynn Margulis



Rethinking Evolution

"The state of affairs on the 150th anniversary of Darwin's Origin of Species is somewhat shocking:

"in the post-genomic era, all major tenets of the Modern Synthesis are, if not outright overturned, replaced by a new and incomparably more complex vision of the key aspects of evolution. So, not to mince words, the Modern Synthesis is gone.

What's Next?"

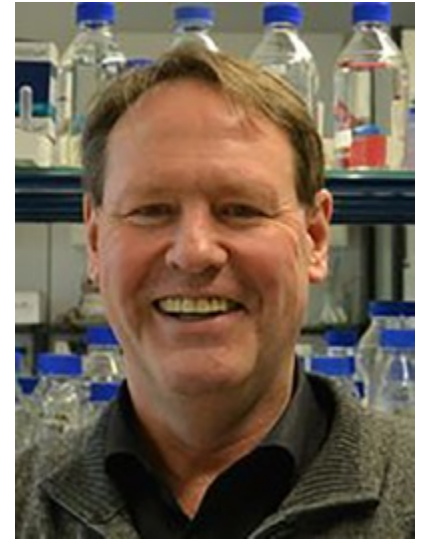
Eugene Koonin



Eugene Koonin

Rethinking Evolution

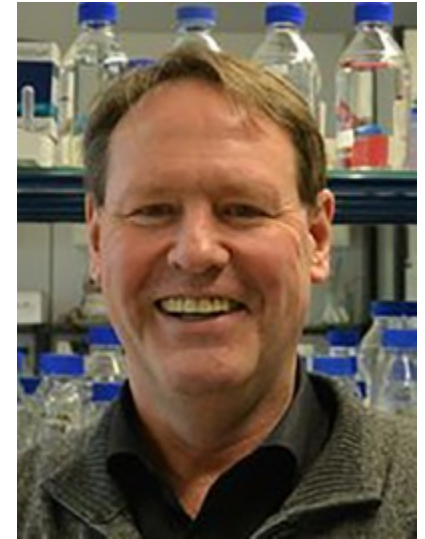
"The transition to complex life hinged on a unique endosymbiotic, bioenergetic jump, rather than on natural selection acting on mutations accumulated gradually among physically isolated prokaryotes."



Bill Martin

Rethinking Evolution

“If [Darwinian] evolution works like a tinkerer, evolution with mitochondria works like a corp of engineers.”



Bill Martin



“Why is life the way it is?”

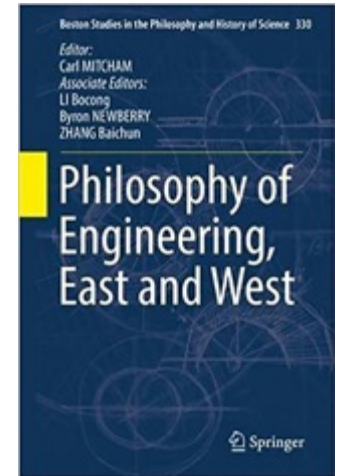
Nick Lane, UCL

Engineering Research Program

“The Philosophy of Engineering
and the Engineering Worldview”

AIM: A more general, post-scientific
engineering framework

– that formally subsumes and
supersedes all possible deterministic
scientific, mechanical theories.



Per hypothesis:

Philosophy of Engineering is Systems Philosophy

The systems engineering framework is
post-scientific, conceptually more
general –

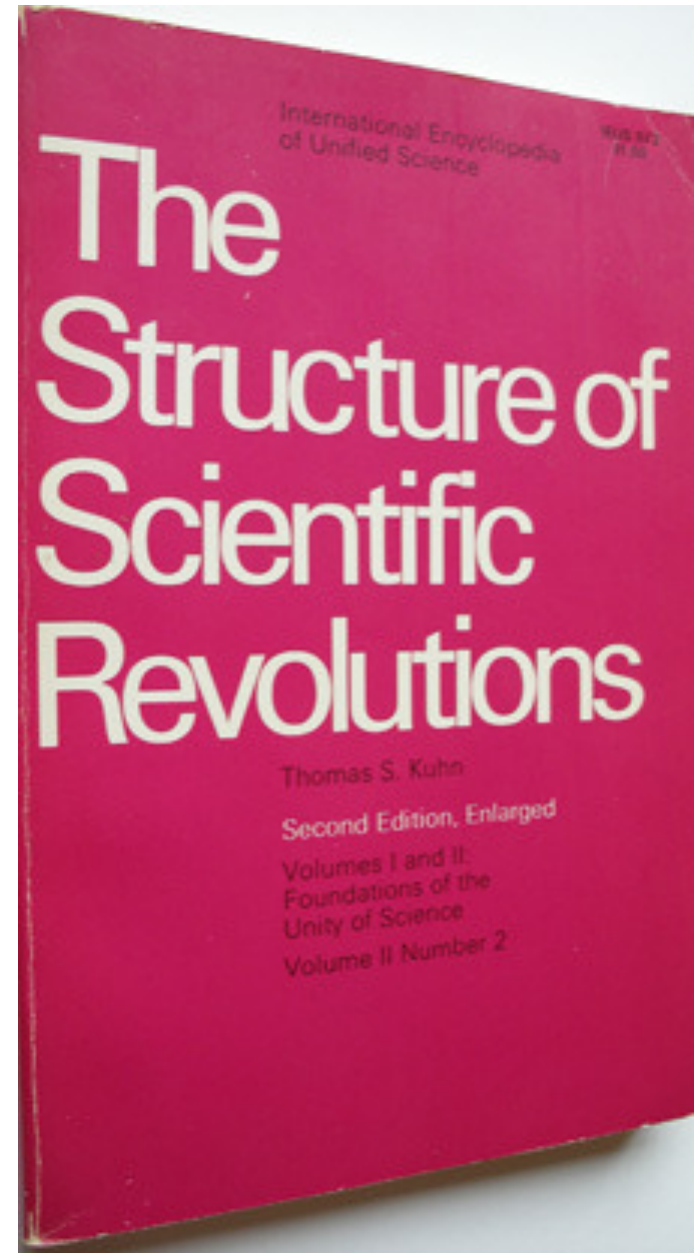
– formally subsuming and
superseding all possible deterministic
scientific, mechanical theories.



Paradigm Shift



Thomas Kuhn



The Correspondence Principle

The later 'better' theory must both subsume and supersede the earlier.



What is the relation between Systems/Engineering and Classical Science



All scientific-mechanical theories are limited special cases within the more general systems engineering worldview.

Per hypothesis:
Philosophy of Engineering and
the Engineering Worldview
is
Systems Philosophy and
the Systems Worldview



Paradigm Shift in Representation of Inquiry

Scientific Spectator and Objective Reality

Embodied Participant and ???

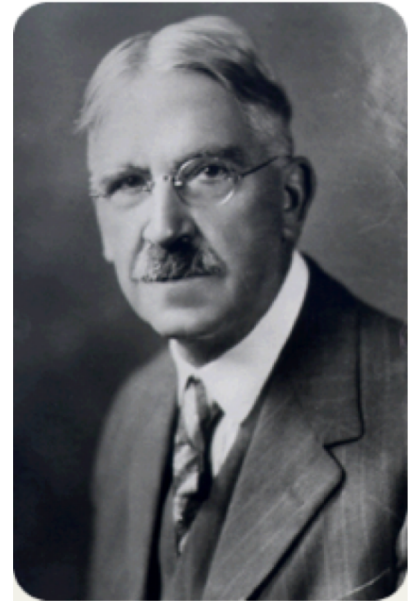
American Pragmatism

Scientific inquirer is a spectator seeking universal laws governing objective reality.

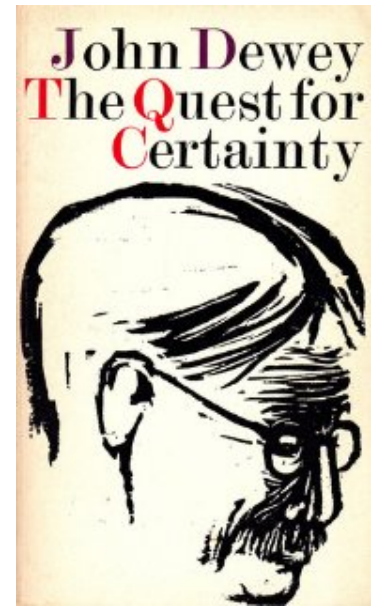
How does the world – ‘out there’ – work?

Participant inquirer is an agent embodied in reality.

How to work in the world?



John Dewey



The Engineering Worldview

Physicists Attitude

“Isn't it quaint that the engineers think that they can change the course of events, since we physicists know that the course of events is uniquely determined by universal laws everywhere from the beginning of time?”

Nobel Laureate Physicist Stephen Weinberg



“I have noticed even people who claim everything is predestined, and that we can do nothing to change it, look before they cross the road.”

Stephen Hawking

“People who are promoting determinism have lost touch with common sense.”

*Stanley Jaki
Physicists, Seton Hall*



Engineering Knowledge

“Modern engineers are seen as taking over their knowledge from scientists and, by some occasionally dramatic but probably intellectually uninteresting process, using this knowledge to fashion material artifacts.

“From this point of view, studying the epistemology of science should automatically subsume the knowledge content of engineering.

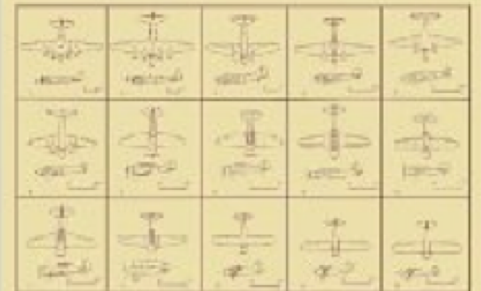
“Engineers know from experience that this view is untrue.”



Walter Vincenti

What Engineers Know and How They Know It

Analytical Studies from
Aeronautical History



WALTER G. VINCENTI

Engineering Knowledge

“[From an engineering perspective], technology appears, not as derivative from science, but as an autonomous body of knowledge.

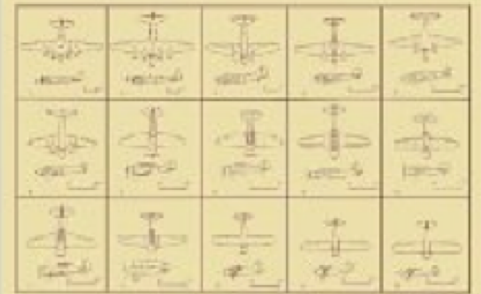
“Aeroplanes are not designed by science, but by art – in spite of some pretense and humbug to the contrary. I do not mean to suggest for one moment that engineering can do without science, on the contrary, it stands on scientific foundations, but there is a big gap between scientific knowledge and the engineering product which has to be bridged by the art of the engineer.”



Walter Vincenti

What Engineers Know and How They Know It

Analytical Studies from
Aeronautical History



WALTER G. VINCENTI

Knowledge according to Systems Engineering

“The creative, constructive knowledge of the engineer is the knowledge needed to implement that art.”

Systems engineering knowledge is about how to do things – methods.

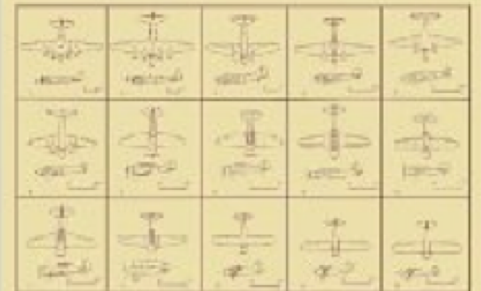
Systems engineering knowledge is about how to change the course of events and evolve the structure of reality.



Walter Vincenti

What Engineers Know and How They Know It

Analytical Studies from
Aeronautical History



WALTER G. VINCENTI

Engineering Research Program

Systems engineering knowledge is about how to do things – methods.

Systems engineering knowledge is about how to change the course of events and develop the structures and functions of reality.



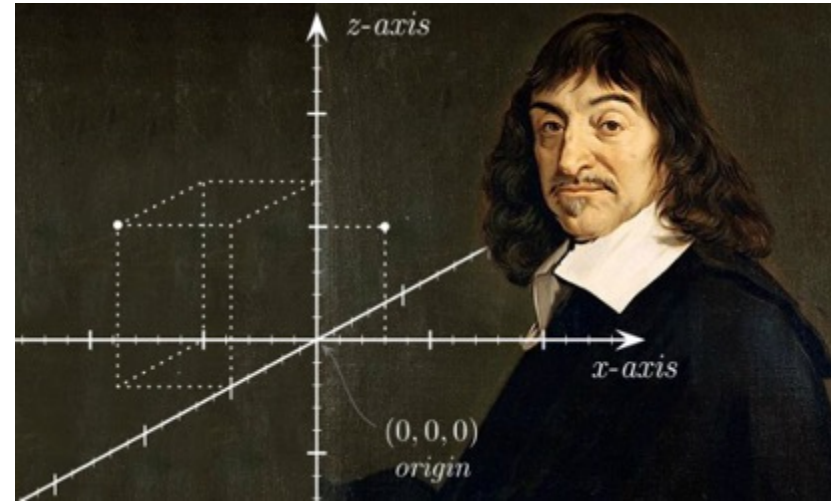
Strong link to
American
Pragmatism:
Peirce, James,
Royce, Lewis,
Dewey, Rorty

...

What is a question in the scientific worldview?

Inquiry doesn't make sense in fully
deterministic scientific worldviews.

If you don't have the freedom to test
your theory then you can have no
confidence.



Rene Descartes

Descartes' Nightmare

God might be a deceiver.

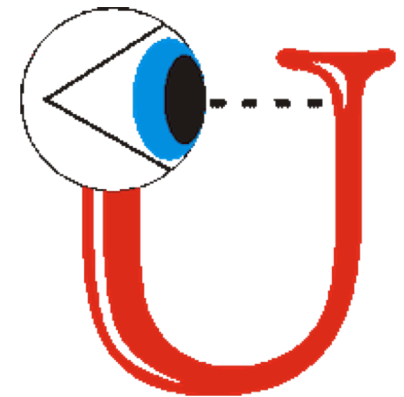
What is Inquiry in Quantum Theory?

The actualizing choices, the
questions are now internal to reality.

Inquiry itself is an irreducible,
embedded, embodied feature of
the nature of reality.



Dr. John A. Wheeler



How do systems evolve according to quantum theory?

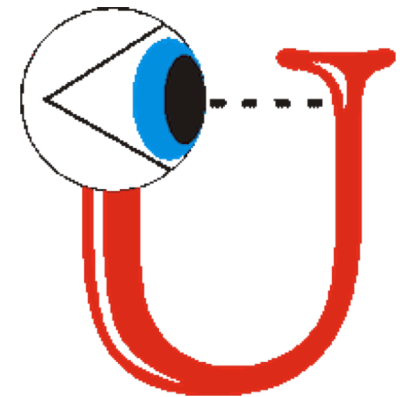
“Observership as Genesis”

The participant's choices actualize one future rather than another.

Per hypothesis: The inquirer is no longer a 'detached' observer – a spectator. He is an active agent involved in the construction of reality.



Dr. John A. Wheeler



How do Quantum Systems Evolve?

Wolfgang Pauli:

“In the new pattern of thought we do not assume any longer the detached observer, occurring in the idealizations of this classical type of theory, but an observer who by his indeterminable effects creates a new situation, theoretically described as a new state of the observed system.”



Wolfgang Pauli



Niels Bohr

“There is no quantum reality. Get over it.”

“Contraries are Complementary”

Participant inquiry as part of reality

Royce's Criterion of Self-referential Coherence

Questions and learning must be
essential irreducible aspects of the
nature of reality.

Problem solving – and agent problem
solvers – must be essential irreducible
aspects of the nature of reality.



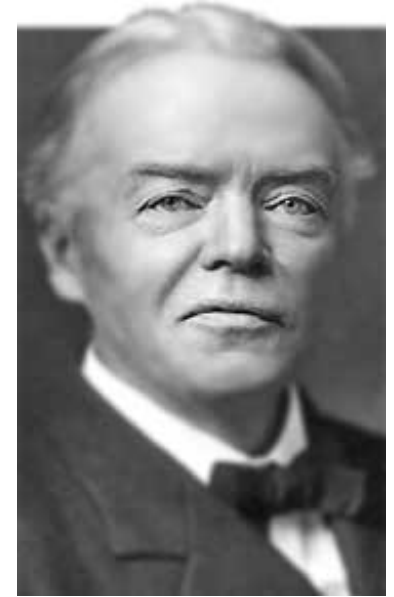
Dr. Josiah Royce

Royce's Criterion of Self-referential Coherence

Subsume and Supersede

*What is the engineering/systems
understanding of 'science'?*

'Science' as engineering research.



Dr. Josiah Royce

Engineering Knowledge

Engineering knowledge subsumes and supersedes scientific knowledge.

Everything you thought of a 'detached' (spectator) scientific research can only be made sense of as participant engineering research and development.



Henry Petroski



Participant RD&D

Choice is not just about actualizing some potential.

In the Paradigm Shift
the basic question changes.

Detached Spectator Question:

How does the world (out there) work? Facts

Participant Engineer Question:

How to act in the world? Methods, Policies



What is the participant engineering design problem solving?

The attempt to move from a current state of affairs to more desirable future state of affairs (design).

To move from a current system design to BETTER system design.

Progressive, innovative designs require experimentation, exploration – discovery.



Herb Simon

Sciences of the
Artificial (1969)

The Existential Engineer

We find ourselves instantiated in reality with the ability to act – to perform work.

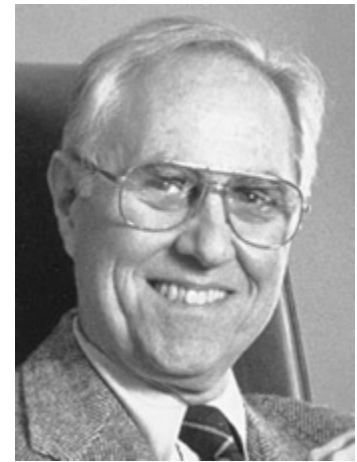
But we have no script.

And yet choice is not an option.

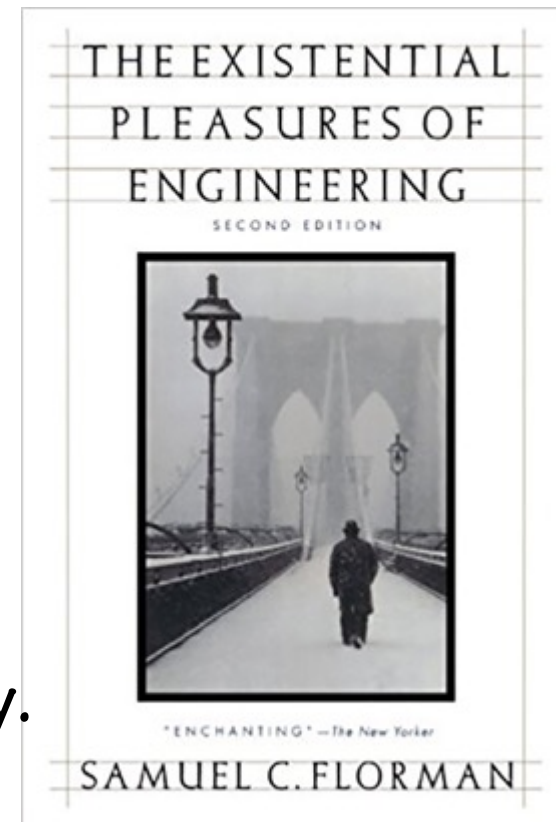
Freewill:

Our abilities and opportunities are constrained. (as in Gibbs free-energy.)

Progressive, innovative design requires experimentation, exploration – discovery.



Samuel Florman



The Problem of Design?

The problem of systems engineering is the design problem.

How to design agriculture, houses, neighborhoods, cities, economies, political systems.



HBR.ORG

Harvard Business Review



SEPTEMBER 2015

44 The Big Idea
The Organizational
“I’m Sorry”
Maurice E. Schweitzer et al.

86 Risk Management
Cybersecurity: Lessons
from the Pentagon
James A. “Sandy” Winnefeld Jr. et al.

108 Managing Yourself
How to Embrace
Complex Change
Linda Brimm

THE EVOLUTION OF DESIGN THINKING

IT’S NO LONGER JUST FOR
PRODUCTS. EXECUTIVES ARE
USING THIS APPROACH
TO DEVISE STRATEGY
AND MANAGE
CHANGE.

PAGE 55

Thinking like a
designer can
transform the
way you develop
products,
services,
processes—and
even strategy.

Tim Brown, IDEO

How engineers understand created systems

Engineers understand – have
knowledge of – created systems
that is not reducible to scientific
(mechanical) knowledge.

Airplanes, cell phones, cars, circuits, the
internet, machines in general ...

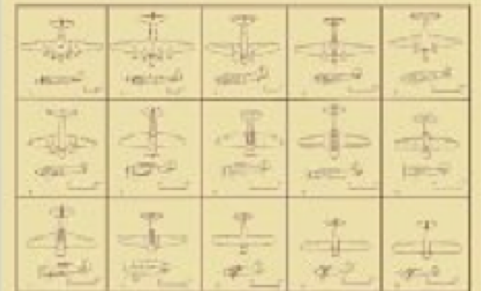
Edwin T. Layton Jr.



Walter Vincenti

What Engineers Know and How They Know It

Analytical Studies from
Aeronautical History



WALTER G. VINCENTI

Policy Questions Make Sense in the Engineering Systems Worldview

Churchman's Meta Question:

The Design of
**INQUIRING
SYSTEMS:**
Basic Concepts
of Systems and
Organization

BY

C. WES CHURCHMAN



C. Wes Churchman

Evolvability:
Recursive enabling

How do systems evolve?

Per hypothesis:

Systems Evolve Thermodynamically

Unexpected (?) link between: Systems Theory,
Engineering Thermodynamics and Quantum Theory.

Bold Hypothesis:

Systems Engineering is thermodynamics.

Note: Quantum theory is a thermodynamic theory, not a mechanical theory.

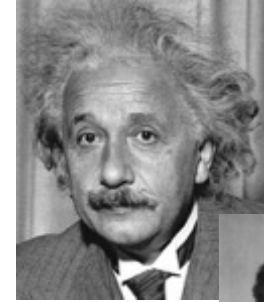


How do systems evolve according to quantum theory?

Quantum Theory entails that systems do not evolve mechanically.

QT requires paradigm shift to a post-scientific, post-mechanical framework to answer this question.

To a New Participant Framework –
Observer/Participant Choice
“actualizes the future”



Engineering Thermodynamic Framework

Two Versions of Thermodynamics?

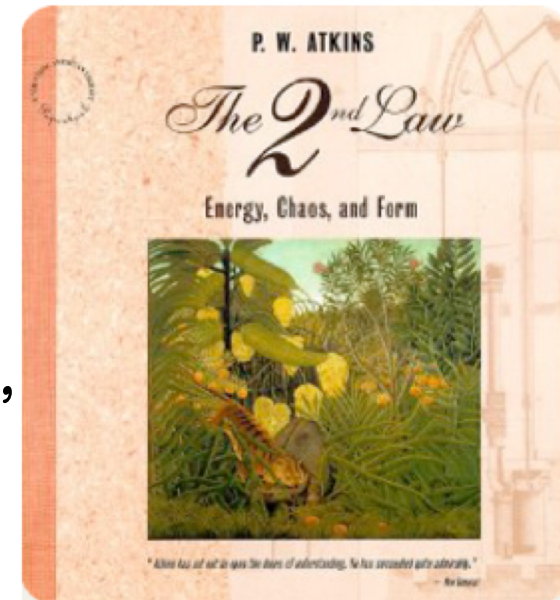
“Carnot and Boltzmann epitomize thermodynamics. Carnot traveled toward thermodynamics from the engine, then the symbol of industrial society.



Peter Atkins, Oxford

“Boltzmann traveled to thermodynamics from the atom, the symbol of emerging scientific fundamentalism.”

“Thermodynamics still has both aspects.”



The 2nd Law

Engineering Thermodynamic Framework

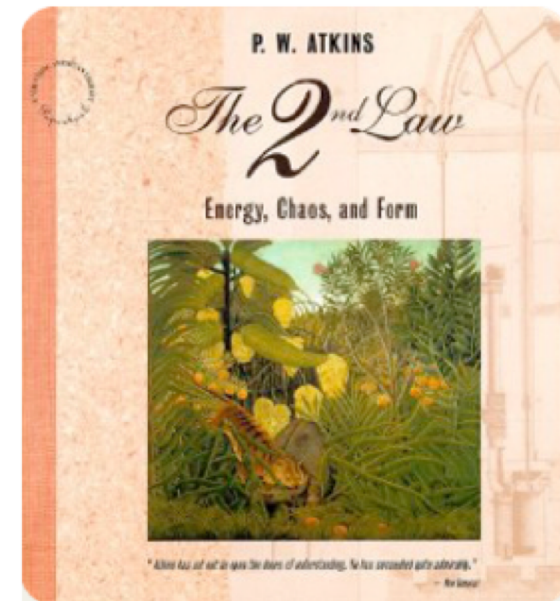
Yet these are NOT compatible.

One thermodynamics must be a special case within the other more general thermodynamics.

Hypothesis: Engineering thermodynamics is more general, subsuming and superseding all mechanical formulations.



Peter Atkins



The 2nd Law

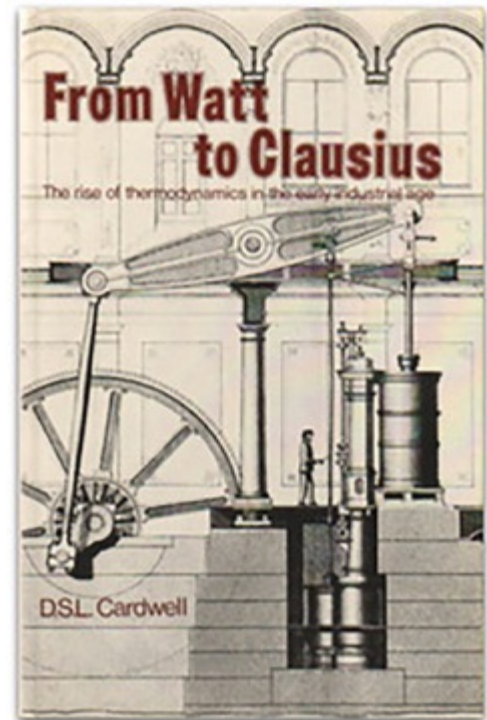
Cardwell's Insight/Hypothesis

“ALMOST traditionally, it seems, accounts of the development of the concepts of work and energy have tended to describe them within the classical framework of Newtonian mechanics.”

“I would like to suggest that this may be to take too narrow a view of the case. It is to project backwards our present specialist arrangement of scientific knowledge, our present divisions between the sciences, and to assume that past development was strictly guided by these divisions. And this is to make questionable historical and sociological assumptions.”



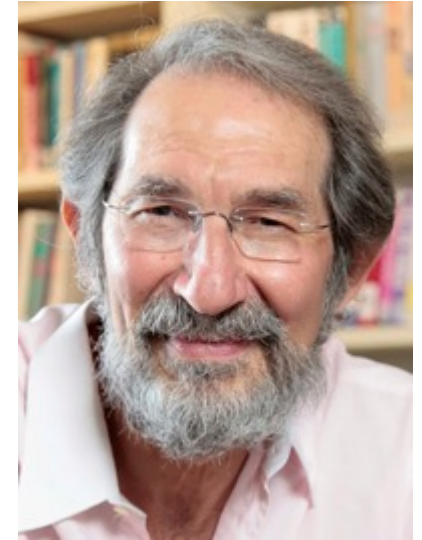
Don Cardwell



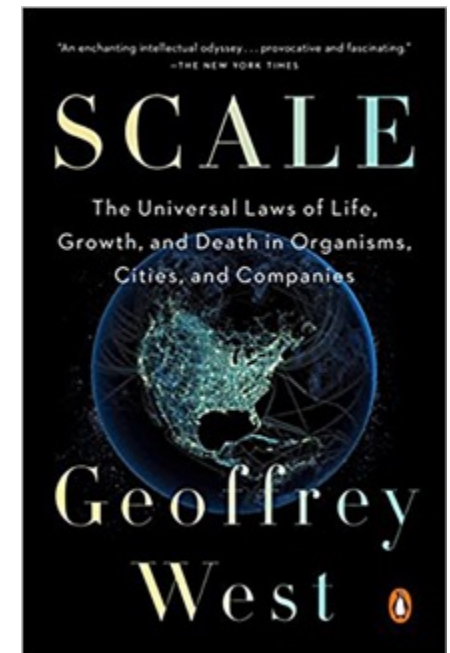
Principle of Least Action

“All the laws of physics can be derived from the principle of least action.

“Consequently, the dynamics, structure, and time evolution of the universe since the Big Bang, everything from black holes and the satellites transmitting your cell phone messages to the cell phones and messages themselves, all electrons, photons, Higgs particles, and pretty much everything else that is physical, are determined from such an optimization principle.”



Geoffrey West



Pierre Maupertuis (1698-1758)



Principle of Least Action
Vis-viva controversy

What is conserved in
motion?

mv or mv^2

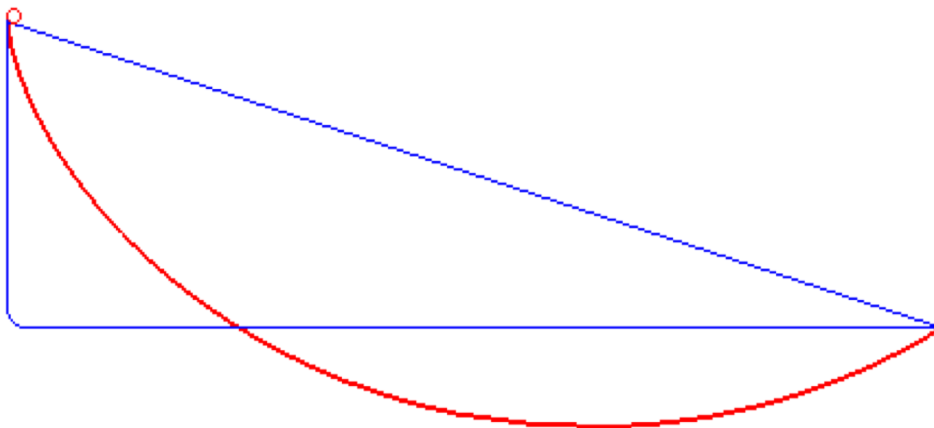
Answer: "Both."

Best depends on choice
of frame of reference

Pierre Maupertuis

All change is an 'action' optimizing two complementary components.

Prior to choice the action framework is dualistic and indeterminate – more general than any one mechanics.



The solution to the brachistochrone problem is not a straight line or some combination thereof but a cycloid.

Maupertuis's Ontology

All structures and functions in the universe are optimizations of complementary components.

Reality is middle ground.

Optimization entails some teleos – for some purpose.



History of Action

Two paths from Maupertuis's Action

Leonard Euler (1707-1783): Euler confirms application of PLA to orbits of the planets.

“Maupertuis is correct but it is not very ‘useful’.” ???

Lagrange develops a ‘useful’ mechanical version of ‘action’ and PLA.
 $L = T - V$

**Deterministic: Conservation/Symmetry



Lazare Carnot

(The path less traveled)

Research Program: to develop a post-mechanical, Engineering Worldview.

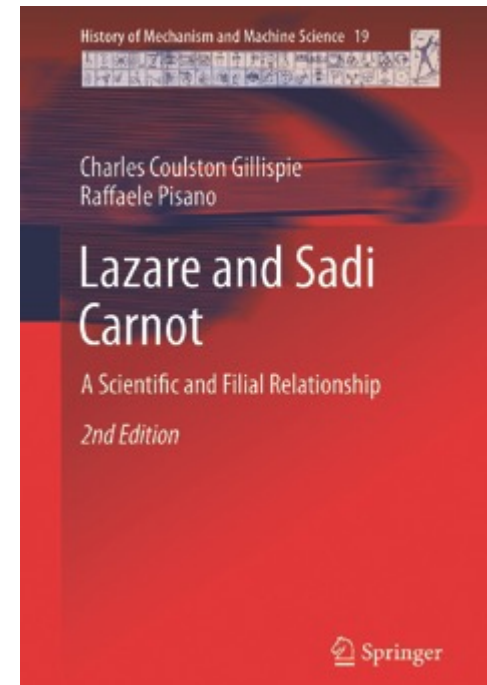
“Everybody knows that there is a tradeoff of velocity/time and power.”

“No mechanics accounts for or can even make sense of this.”

Reality (the future) is indeterminate until the engineer make a choice of how to approach a situation.



Lazare Carnot



Lazere Carnot: Engineering Worldview



Lazere Carnot

“On Machines
in General”

“Equilibrium
and Motion”

“Geometry of
Position”



Sadi Carnot

My Immediate Current Project

Lazare Carnot

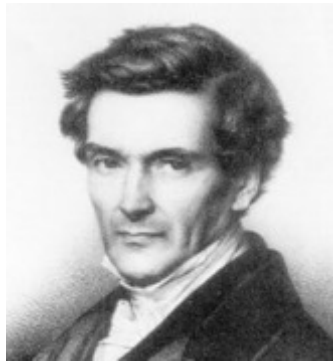
Colleagues at Ecole Polytechnique



Lagrange



Fourier



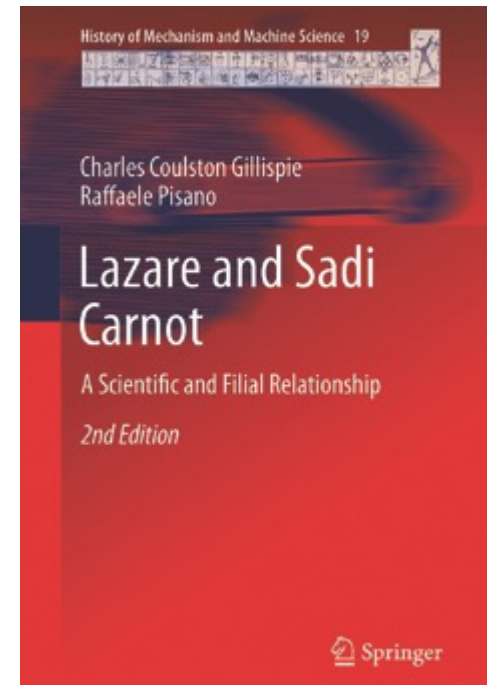
Coriolis



Cauchy



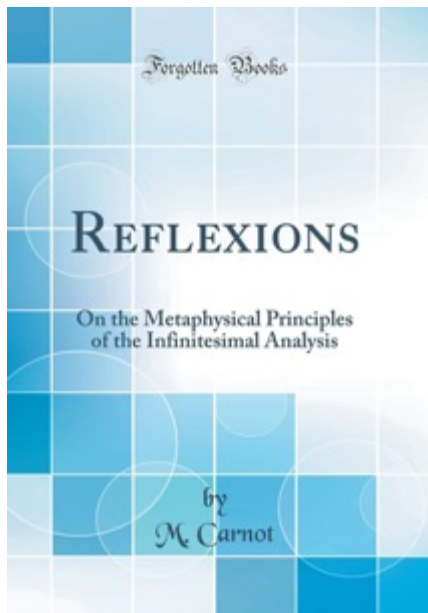
Lazare Carnot



History of Action

Empirical inquiry requires
boundary conditions.

Justification of the calculus.



Reflexions on the
Metaphysical
Principles of the
Infinitesimal
Analysis



Lazare Carnot
1753-1823

History of Action

Classical mechanical relations are valid within boundary conditions and methods.

These cannot be derived but must be learned/discovered through empirical inquiry.

Within a domain of validity you presuppose uniformity (symmetry, conservation) and induction, derivations, and calculus are applicable (continuous functions).

Any domain of mechanical validity requires that the complementary aspect must be in equilibrium (static); Lagrange's variational calculus or Newton's differential calculus.



Lazare Carnot
1753-1823

History of Action

Euler's "Not very 'useful'." Why?
BECAUSE – Reality is Middle Ground.

Wolfgang Pauli to Heisenberg:
'You can observe (act/investigate) in the p-
way or the q-way, but if you try to observe
in a p-q-way it will make you crazy.'

Implication for Understanding Inquiry:

Doing 'science' requires a choice of frame
of reference (boundary conditions) that
idealize.



Wolfgang Pauli



Werner Heisenberg

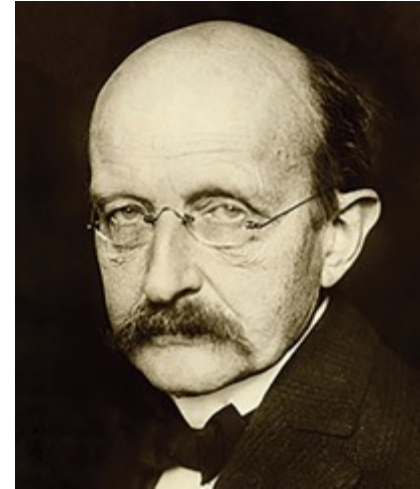
Maupertuis's Original Dualistic, Indeterminate Action Re-Emerges

Planck's Quantum of Action

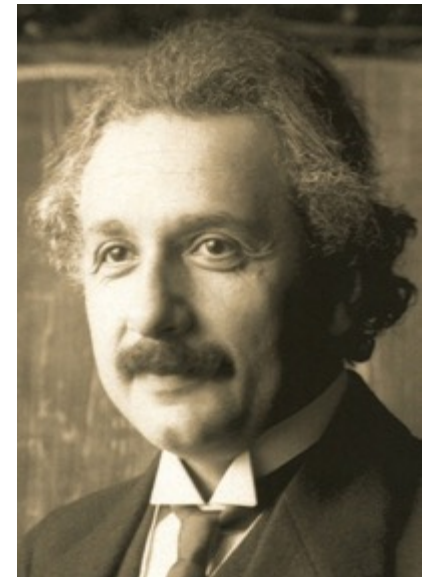
Post-mechanical, dualistic and
indeterminate (requires choice)

Einstein develops the insight:

Leading to major contributions to Quantum
theory and Relativity.



Max Planck



Maupertuis and Evolution

If systems evolve thermodynamically – their evolution is time asymmetric, non-conservative.

In mechanics evolution is always symmetric, conservative (zero-sum).

In engineering, 'work' always involves two incommensurable (complementary) optimized aspects.

Systems evolution has a net product:

The Evolving Universe

Recursively Enabling Cumulative history.



Maupertuis's
Theories of
Evolution

1. Cosmology
2. Venus Earth

Maupertuis's Optimization

Optimization involves a solution.

Least Energy; Stable Structure/Function.

Optimization as 'solution' suggests problem solving
Suggests purpose – final causality

Optimization is unique to engineering.

In single-valued mechanical system with conservation of energy, you just calculate.

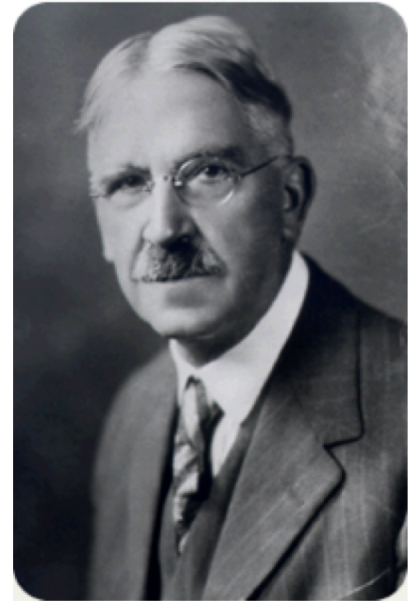


Engineering Knowledge

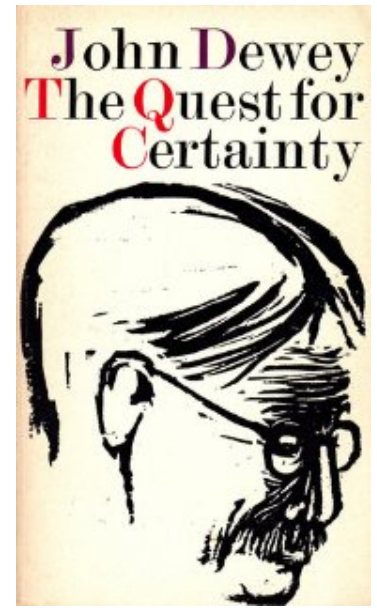
Knowledge is [participant] embodied method.
Not [spectator] detached theory.

Reality is an *evolving, embodied method* –
Recursively Developing – how to live better?

“[Engineering] Evolution is the
construction of the good.”



John Dewey

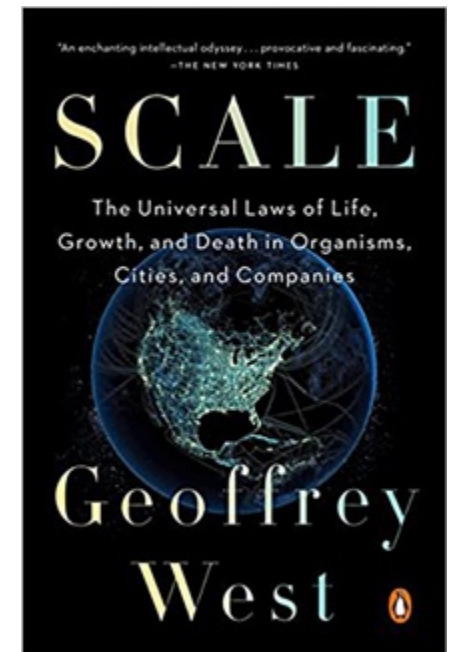


Principle of Least Action

“Optimization principles lie at the very heart of all of the fundamental laws of nature, whether Newton’s laws, Maxwell’s electromagnetic theory, quantum mechanics, Einstein’s theory of relativity, or the grand unified theories of the elementary particles.”



Geoffrey West



Lagrange Analytic Mechanics

Invents Variation Calculus

$$L = T - V$$

(L = total energy)

(T = kinetic energy)

(V = potential)



Joseph-Louis Lagrange

Insisting on Symmetry and Conservation

Lagrange introduces the Mechanical
Conceptions of Action and Principle of
Least Action

Hamiltonian Mechanics

Hamilton's Principle

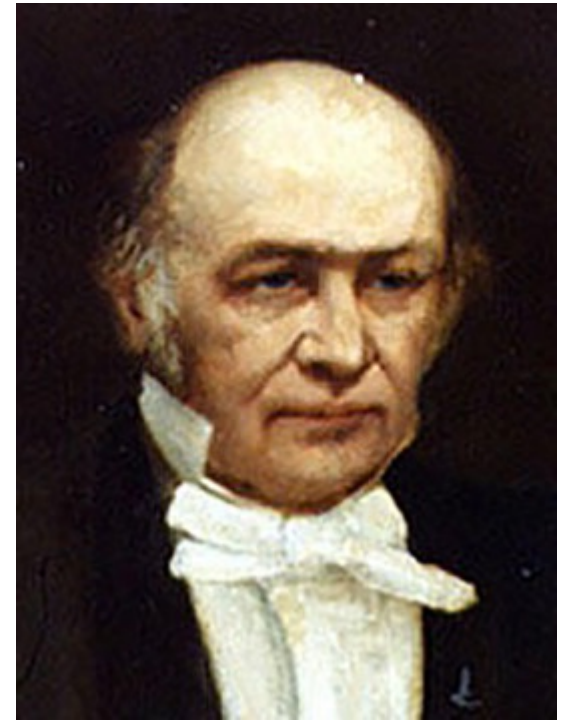
$$H = T + V$$

(H = total energy)

($T = p^2/2m$) (p is the momentum coordinate)

($V = V(q)$) (q is the space coordinate)

T is a function of p alone. V is a function of q alone.



William Rowan Hamilton

At least in practice Hamilton's methods presupposes a framework defined by symmetry and conservation of energy .

Mechanical Conceptions of Action and Principle of Least Action

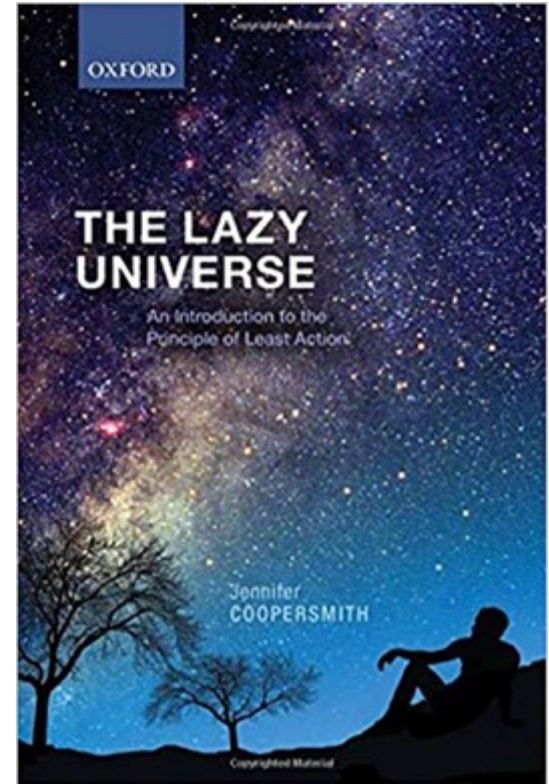
The Problem of Dissipation

If the mechanical worldview were correct Hamilton's Principle would be the basis for a Systems Science.

However ...

'Lagrangian and Hamiltonian mechanics are very 'useful' except in systems where there is significant dissipation.'

The dissipation is incommensurable.
Per hypothesis, Complementary.



The Lazy Universe: An Introduction to the Principle of Least Action
By Jennifer Coopersmith

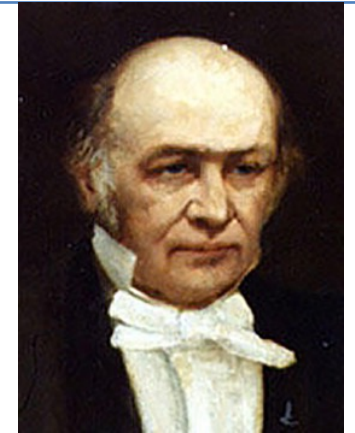
Two Paths for Action



Pierre Maupertuis



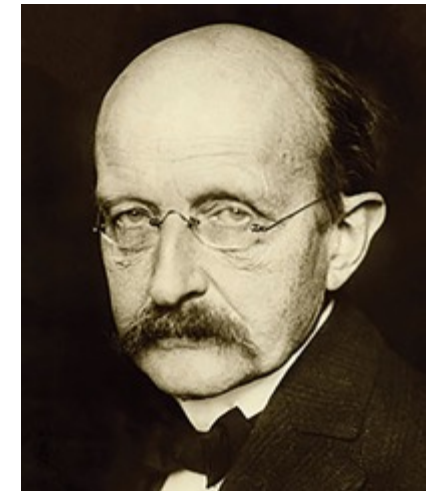
Joseph-Louis Lagrange



William Rowan Hamilton



Lazare Carnot



Max Planck

Conclusions

1. *Systems Theory is Engineering (not science).*
2. *Systems engineering is thermodynamics. (SET)*
3. *SET constitutes a more general framework that subsumes and supersedes all possible scientific/mechanical worldviews.*
4. *SET is self-referentially coherent.*
5. *SET has a strong supportive connection to QT.*



Conclusions

6. SET worldview has inherent structure and function – agents involved in its evolution.
7. SET provides a 'new' more general framework for understanding evolution: cosmology, biological evolution, socio-economics. Reality has a history.
8. SET offers novel, post-scientific paths of inquiry, research and development, new ways of understanding growth and innovation.
9. SET is naturally value-oriented. Toward 'better' world.
10. SET enlightens engineering practice. (Optimization)



General Implications

So What? –

For Systems Thinking

In Cosmology

In Biological Evolution

In Socio-Economics

