

# Beyond Thermodynamics: the Physics of Matter, Life, and Intelligence

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# **3 BIG questions:**

- **the Origin of the Universe**
- **the Origin of Life**
- **the Origin of Intelligence**

# 3 BIG questions:

- **the Origin of the Universe**
- **the Origin of Life**
- **the Origin of being able to ask: what is**
  - the Origin of the Universe**
  - the Origin of Life**
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    - the Origin of the Universe**
    - the Origin of Life**
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      - the Origin of the Universe**
      - the Origin of Life**
      - the Origin of being able to ask: what is**

# The 3 BIG questions:

- the Origin of the Universe
- the Origin of Life
- the Origin of Intelligence

Mathematics



Physics



Biology



Cognitive Science

# The 3 BIG questions:

- the Origin of the Universe
- the Origin of Life
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Information



Matter



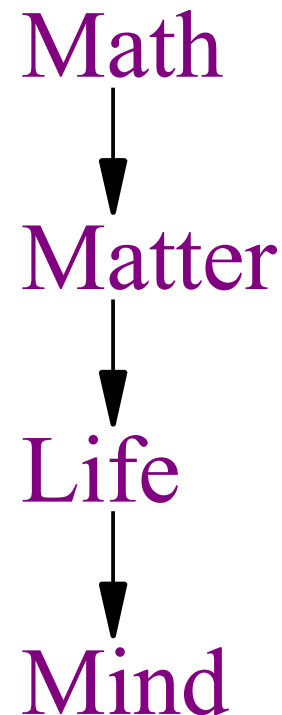
Autonomous Agents



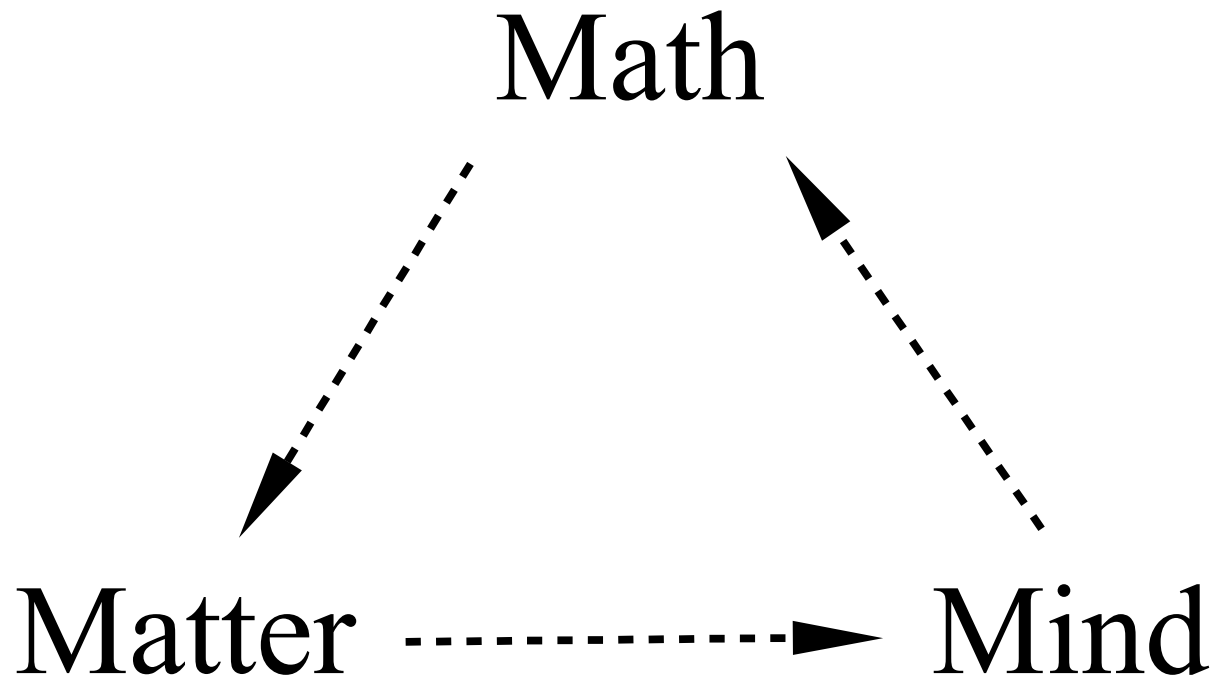
Awareness

# The 3 BIG questions:

- the Origin of the Universe
- the Origin of Life
- the Origin of Intelligence

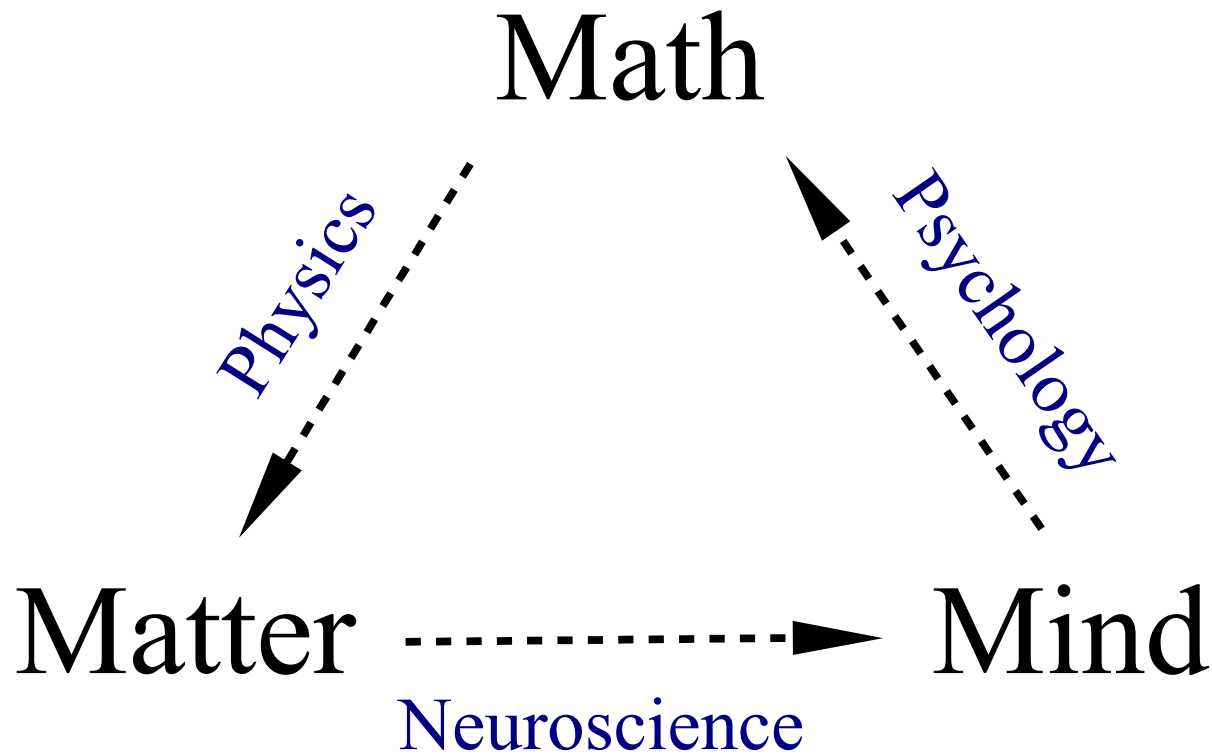


and . . . 3 other BIG questions:



*What underlies what?*

and . . . 3 other BIG questions:



*What underlies what?*





## Let us look at the middle question:

- **the Origin of Life**

In 2012, a new institute was started at Tokyo Tech, *ELSI*, short for *Earth-Life Science Institute*, to study the origin of life, in the context of the origin of the Earth and of other planets, with room for chemists, biologists, geophysicists, astrophysicists, physicists, computer scientists, mathematicians, ..... a paradise for broadly interdisciplinary collaborations.

# The success of science rest on:

- Reductionism -- look for building blocks
- Complexity -- look for emergent features

Quarks, gluons, electrons

Protons, neutrons, electrons

Atomic nuclei, electrons

Atoms

Molecules

Quarks, gluons, electrons

Protons, neutrons, electrons

Atomic nuclei, electrons

Atoms

Molecules

Organic Molecules

... ??? ...

Life

Quarks, gluons, electrons

Protons, neutrons, electrons

Atomic nuclei, electrons

Atoms

Molecules

Organic Molecules

... ??? ...

Life

*Physics*

*Chemistry*

*Biology*



Quarks, gluons, electrons

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... ???...

Life

*Physics*

*Chemistry*

*Geology*

*Biology*



Quarks, gluons, electrons

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... ???...

Life

*Physics*

*Chemistry*

*Biology*

*Astronomy*

*Geology*

Quarks, gluons, electrons

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Organic Molecules

... ??? ...

Life

*Physics*

*Chemistry*

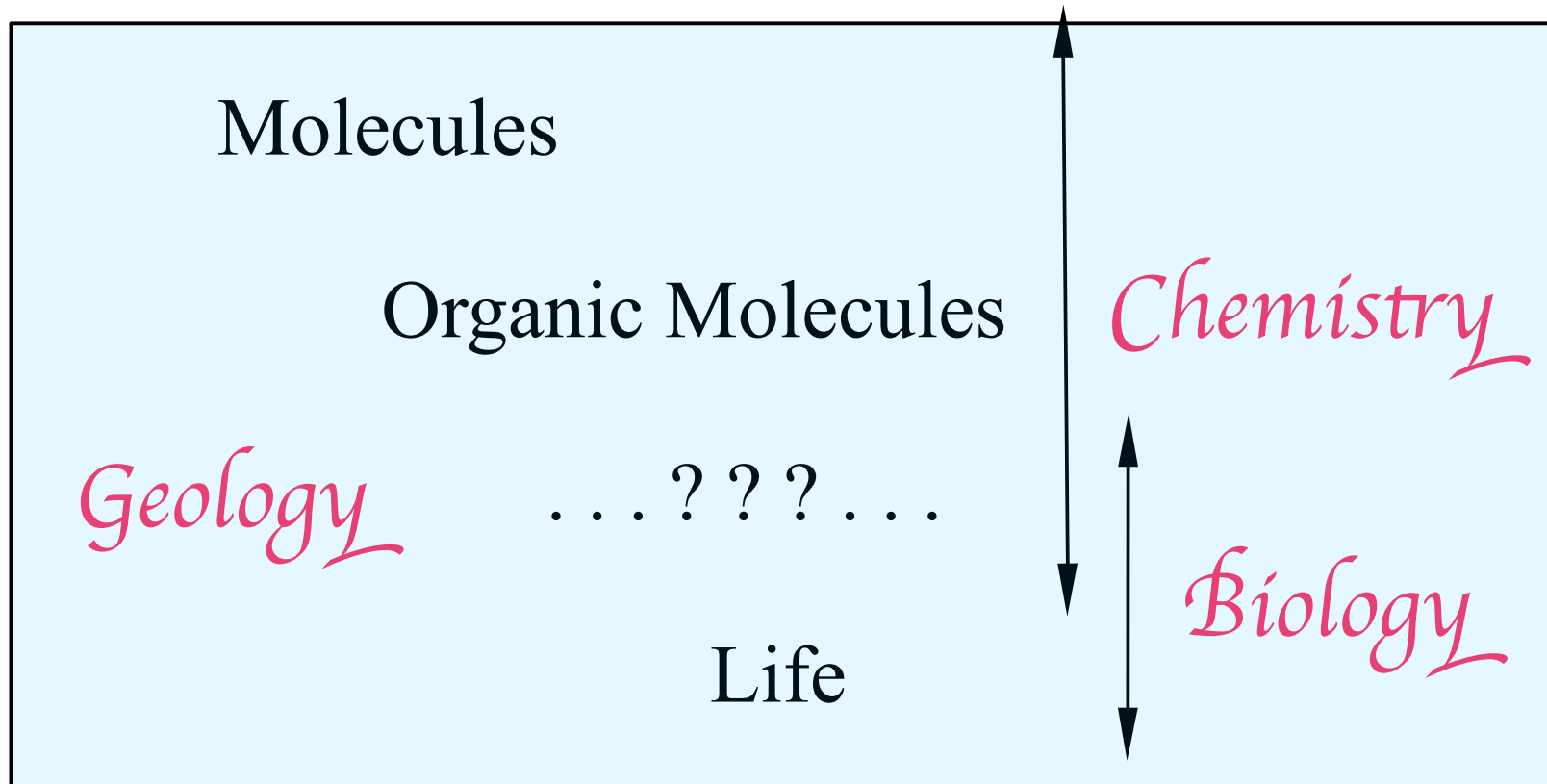
*Biology*

*Complexity theory*

*Astronomy*

*Geology*

But . . . this picture is misleading: the question marks are presented on the level of *structure*



. . . whereas the answers must surely be found in terms of *process*



# The success of science rest on:

- Reductionism -- look for building blocks
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Quarks, gluons, electrons

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Molecules

Quarks: elementary particles (as far as we know)

Protons: we cannot liberate the quarks !

Atomic nuclei: we can transmute (nuclear energy)

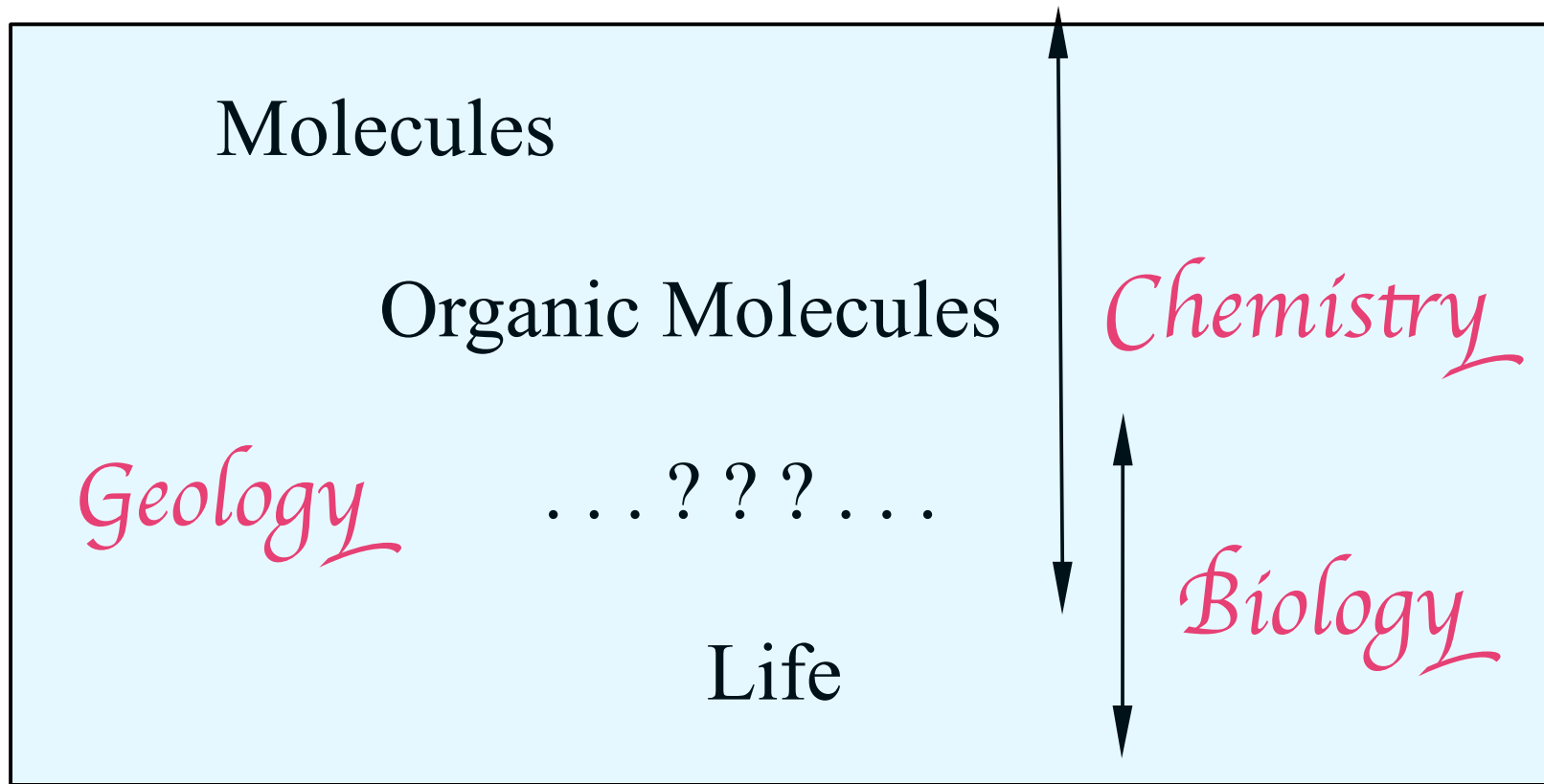
Atoms: we can strip electrons (in a candle)

Molecules: we can rearrange (chemistry!)

The more complex, the more brittle, so . . .

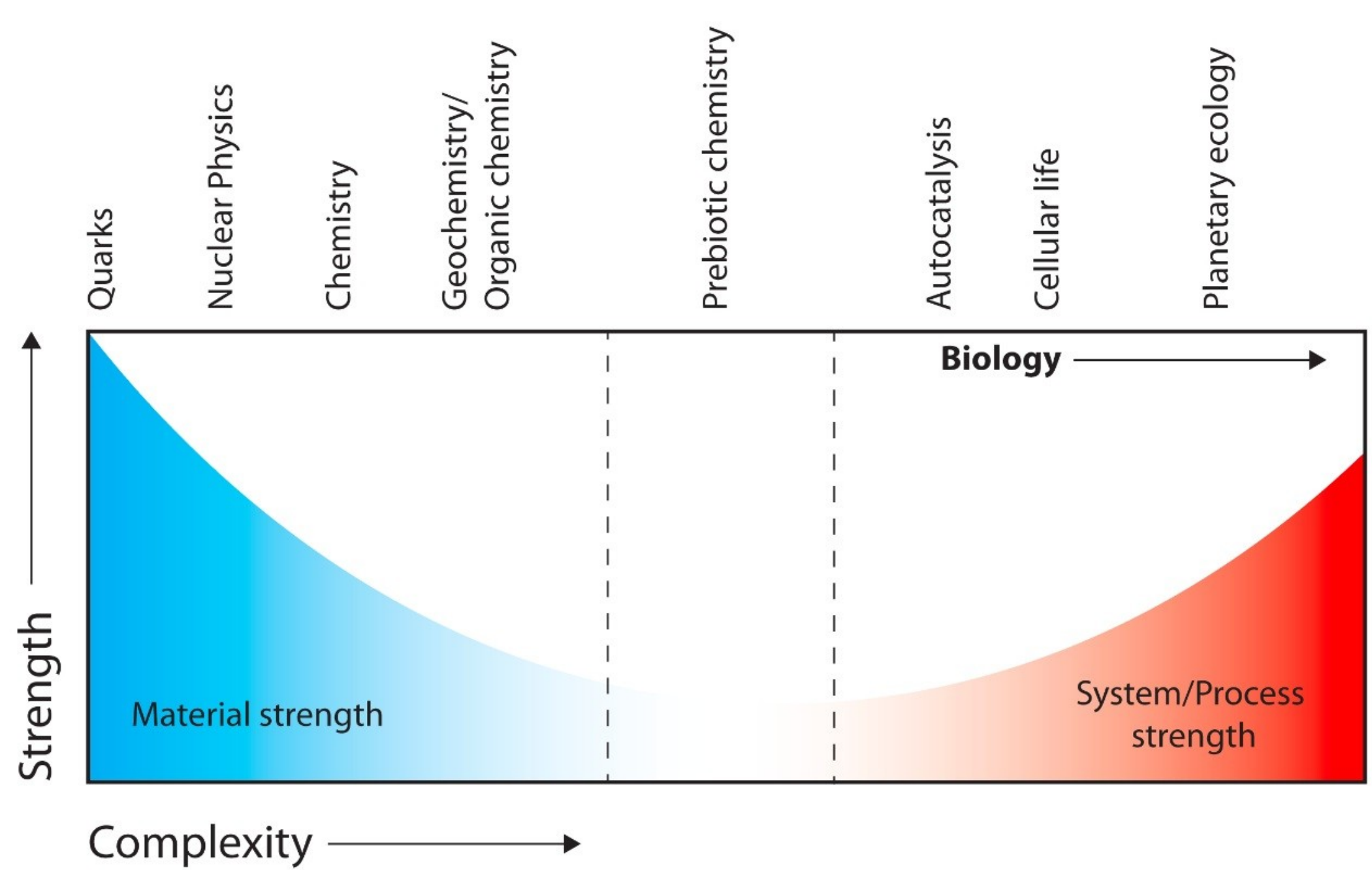
molecules that are more and more complex are  
unlikely to survive in a natural environment

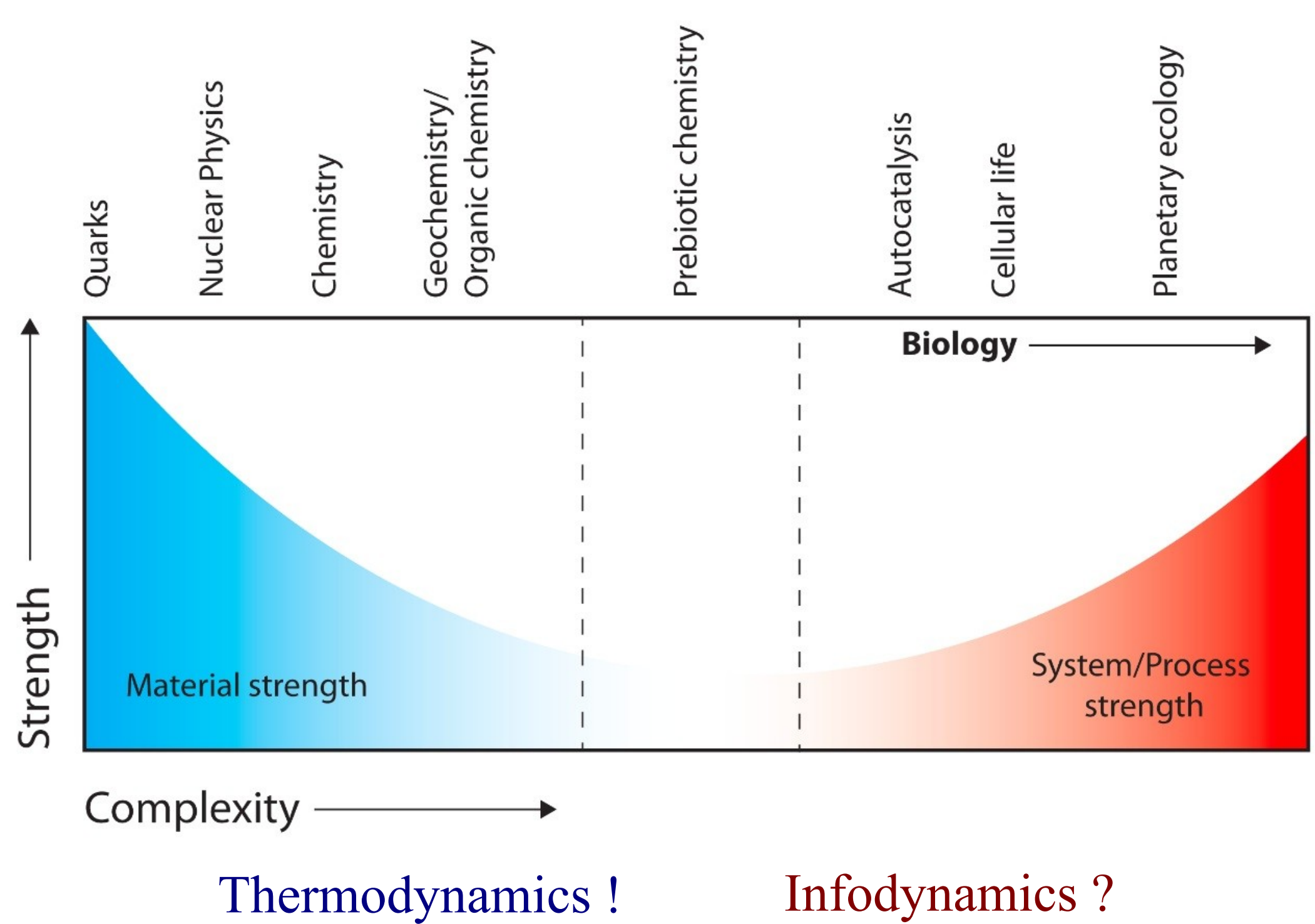
So . . . how come nature could add further complexity ???



The trick is the invention of repair, maintenance, resilience.

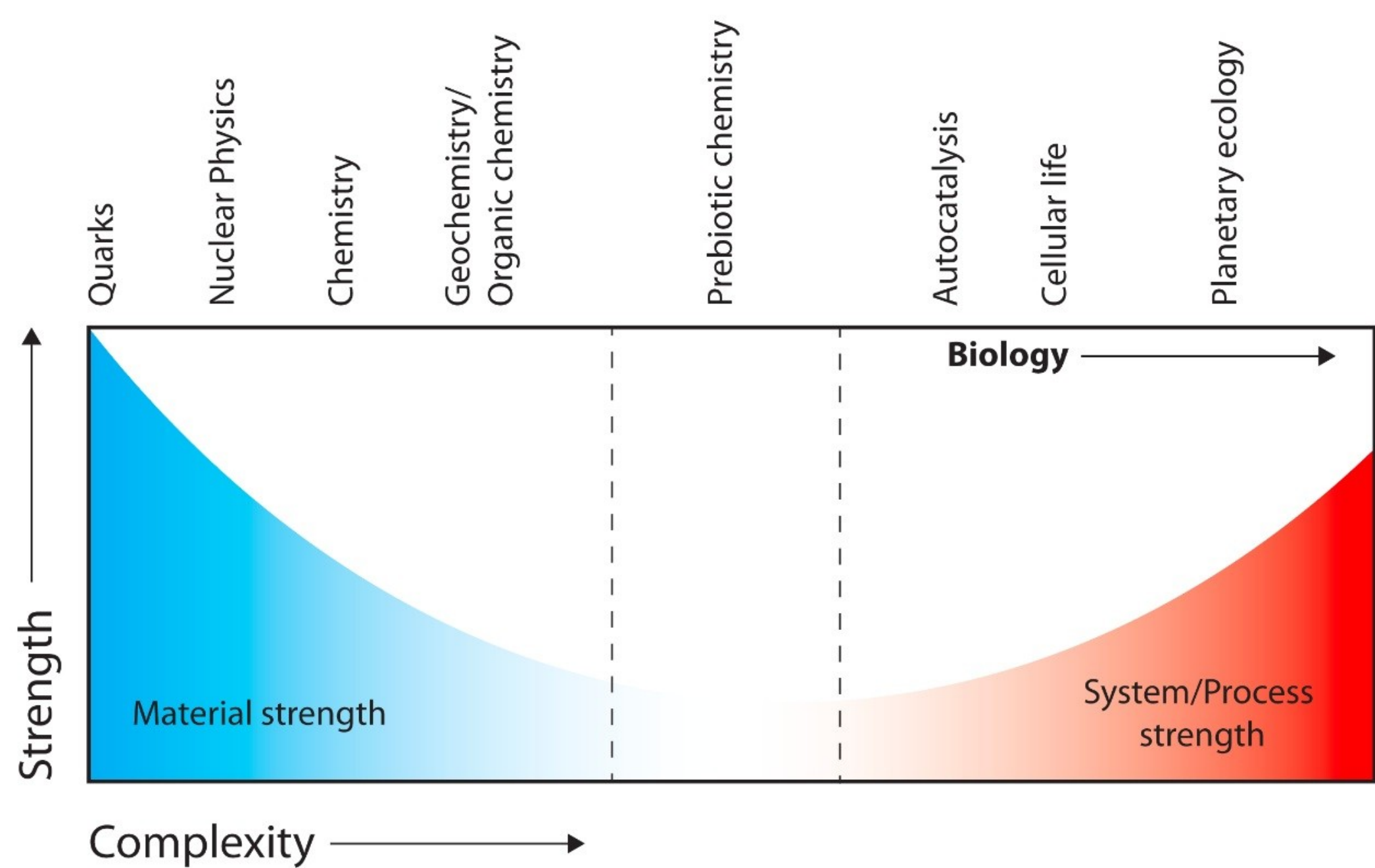
Make many copies, tinker, let most fail but keep the best:  
this is evolution, and evolution produced resilience.





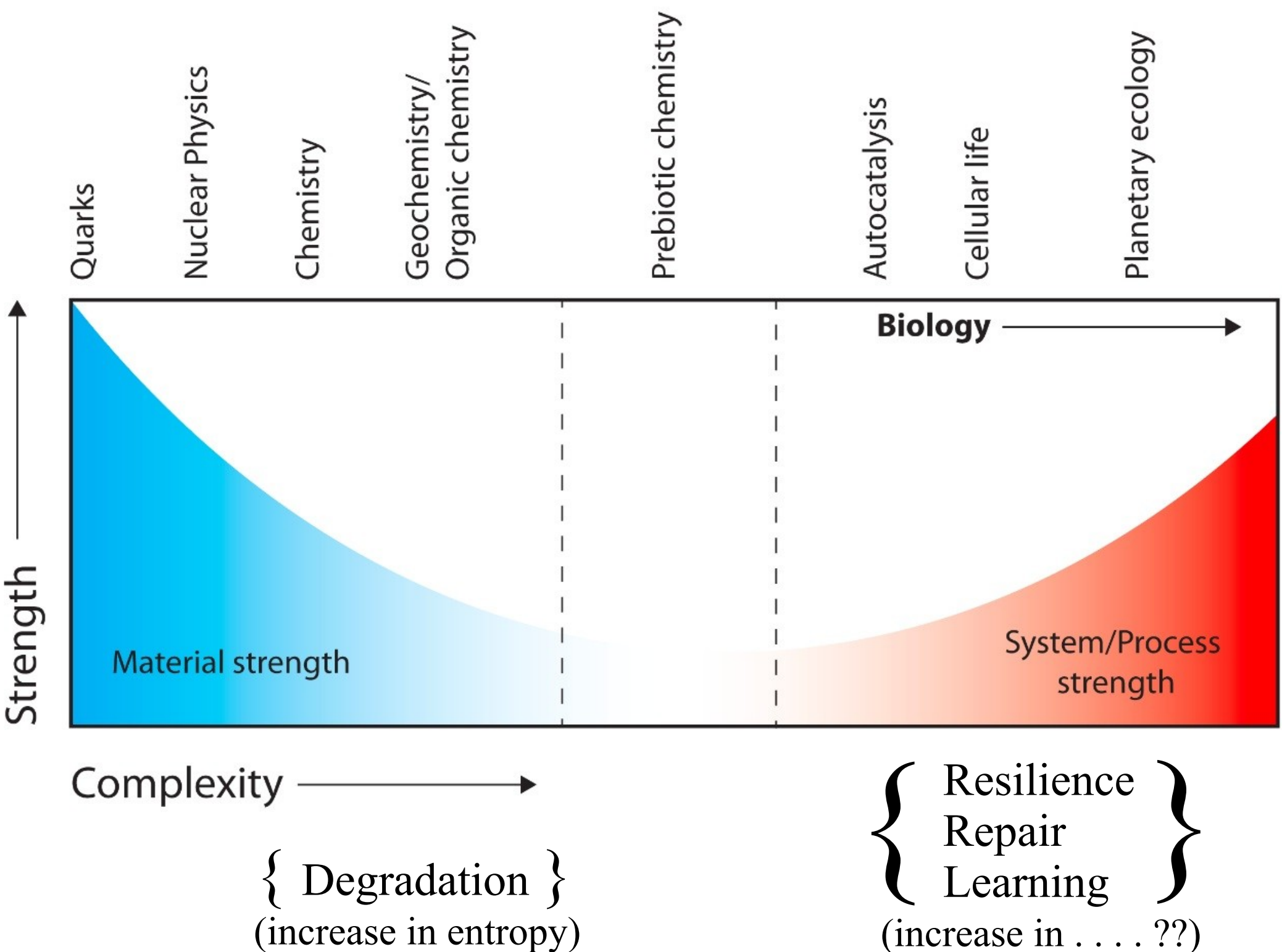
# A Brief History of Thermodynamics

- 1775: James Watt: Steam Engine
- 1800: Richard Trevithick: Steam Locomotive
- 1825: Sadi Carnot: Carnot diagram
- 1850: Rudolf Clausius: 2<sup>nd</sup> Law of Thermodynamics
- 1875: Ludwig Boltzmann: entropy from molecular motion

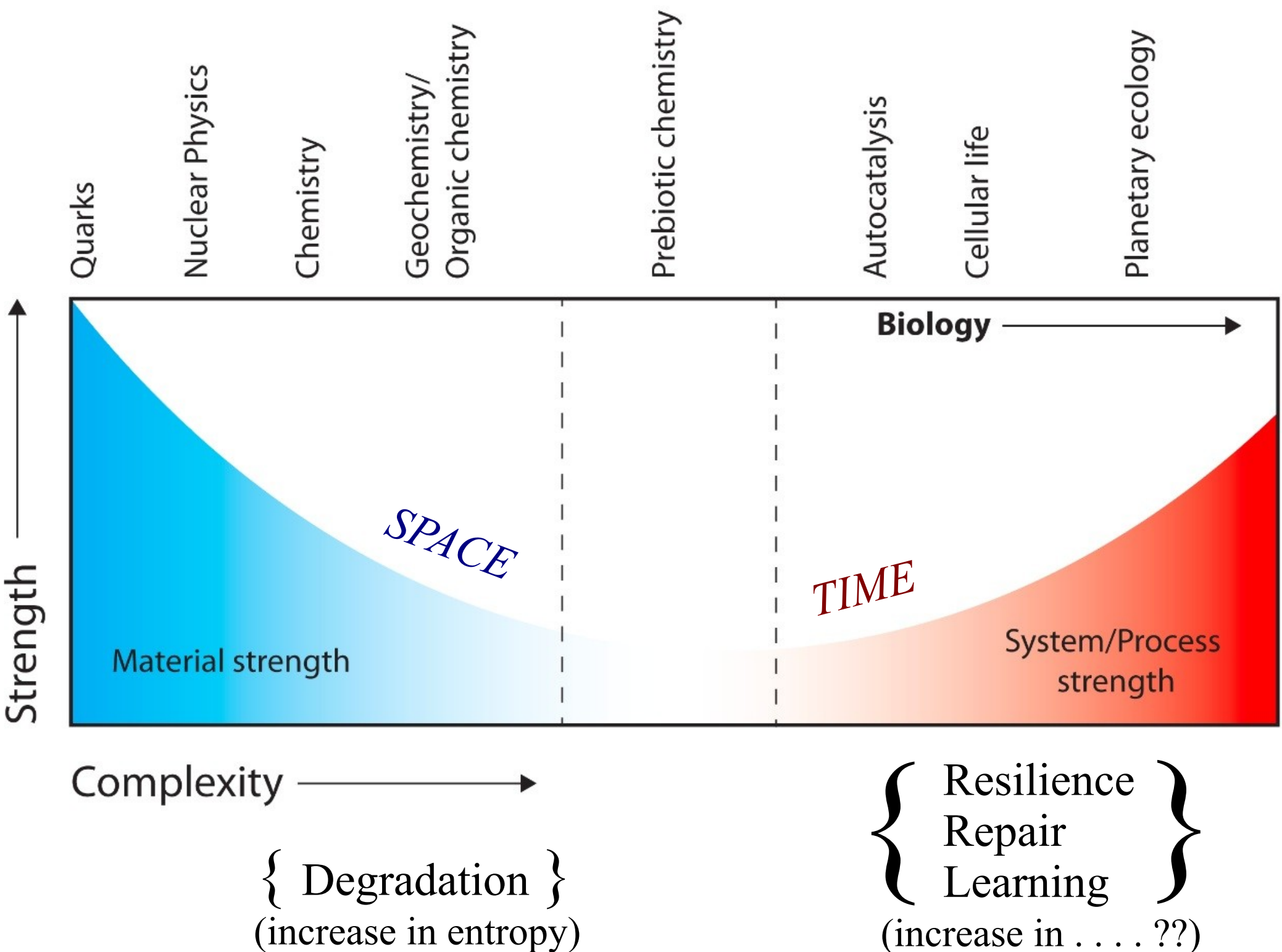


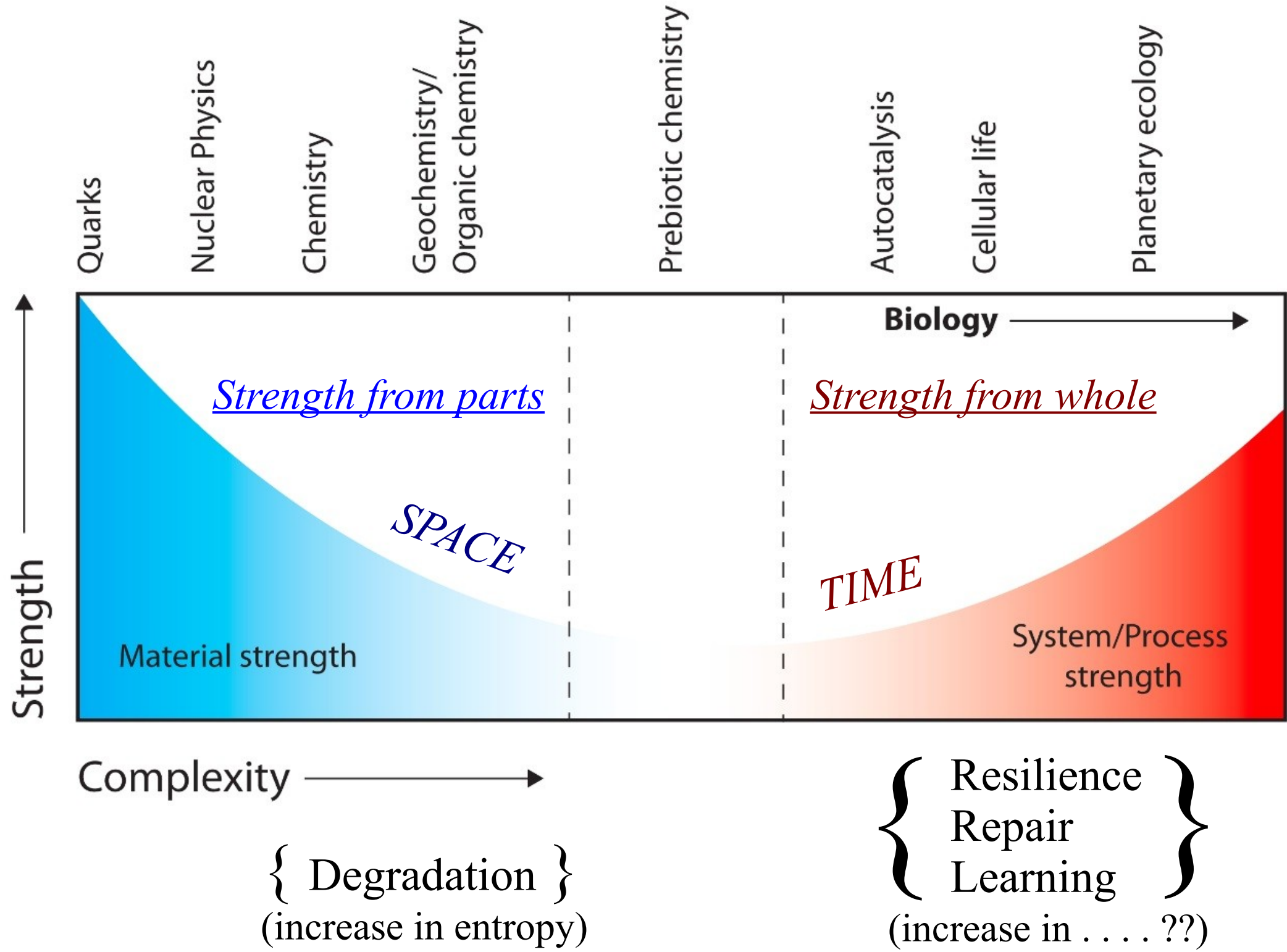
**Thermodynamics !**  
(1775 - 1875)

**Infodynamics ?**  
(1953 - 2053?)









# The success of science rest on:

- Reductionism -- look for building blocks
- Complexity -- look for emergent features

A single water molecule is not wet, nor are two or three.

Yet a thousand molecules are starting to become wet . . . .

A few molecules don't exhibit thermodynamics, but . . . .  
 $10^{23}$  molecules certainly do so, as an *emergent* property.

Yet physicists consider the 2<sup>nd</sup> law of thermodynamics to be more *fundamental* than any particular law of motion.

Why? It's a mystery . . . . (Freeman Dyson)

A major 19<sup>th</sup> century *mystery*:

Physicists consider the 2<sup>nd</sup> law of thermodynamics to be more *fundamental* than any particular law of motion.

(a major 20<sup>th</sup> century *mystery*: unify qm & gravity)

What next? My prediction:

A major 21<sup>th</sup> century *mystery*:

Biologists may consider laws of infodynamics to be more *fundamental* than any particular laws of physics.

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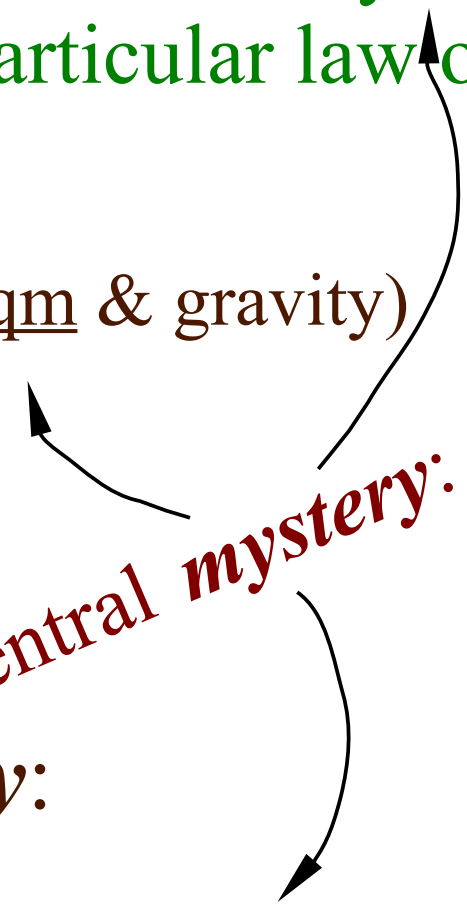
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central *mystery*: statistics!



Aristotle: causality & teleology

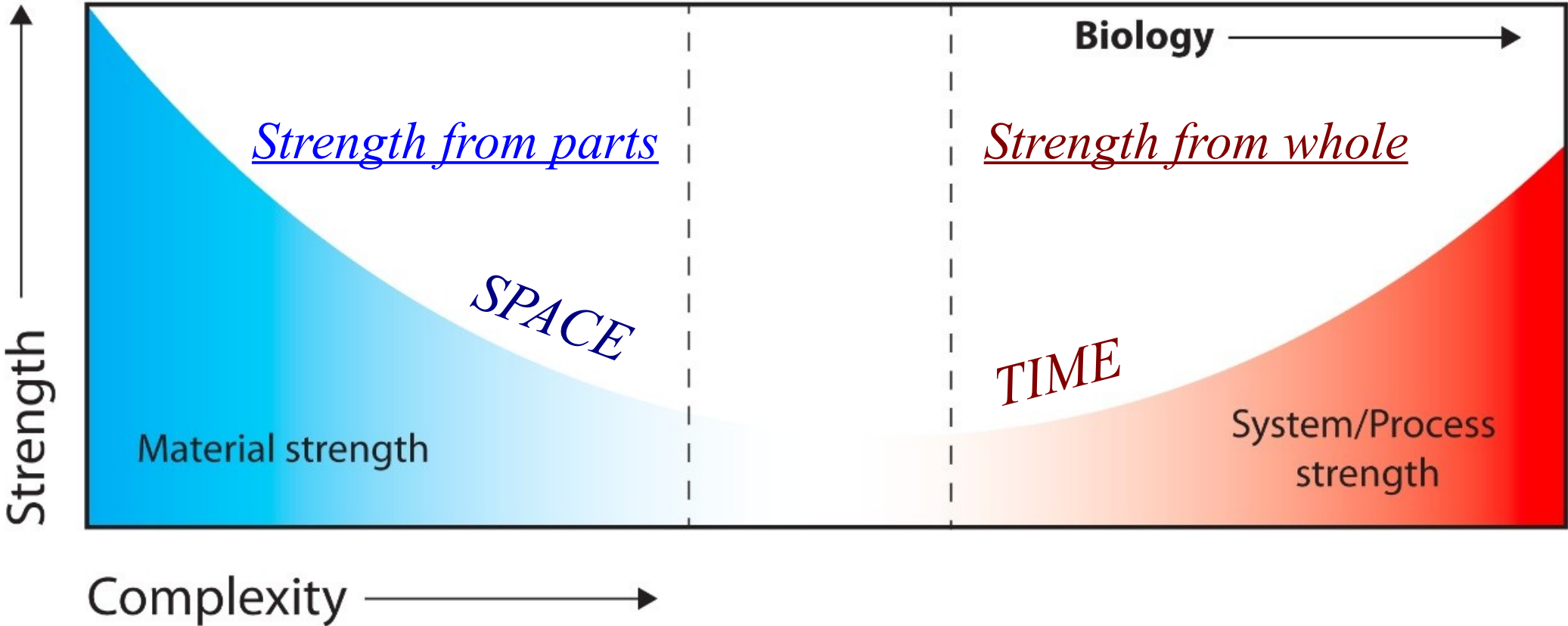
Newton: causality

Darwin: *evolution* as emergent adaptation:  
statistical teleology from causality

Gibbs, Maxwell, Boltzmann: statistical causality:  
*Thermodynamics*

???: emerging autonomous agents, statistically  
arising in complex systems: *Infodynamics*  
origin of life(-like processes)

???: emerging learning leading to intelligence.  
origin of intelligence



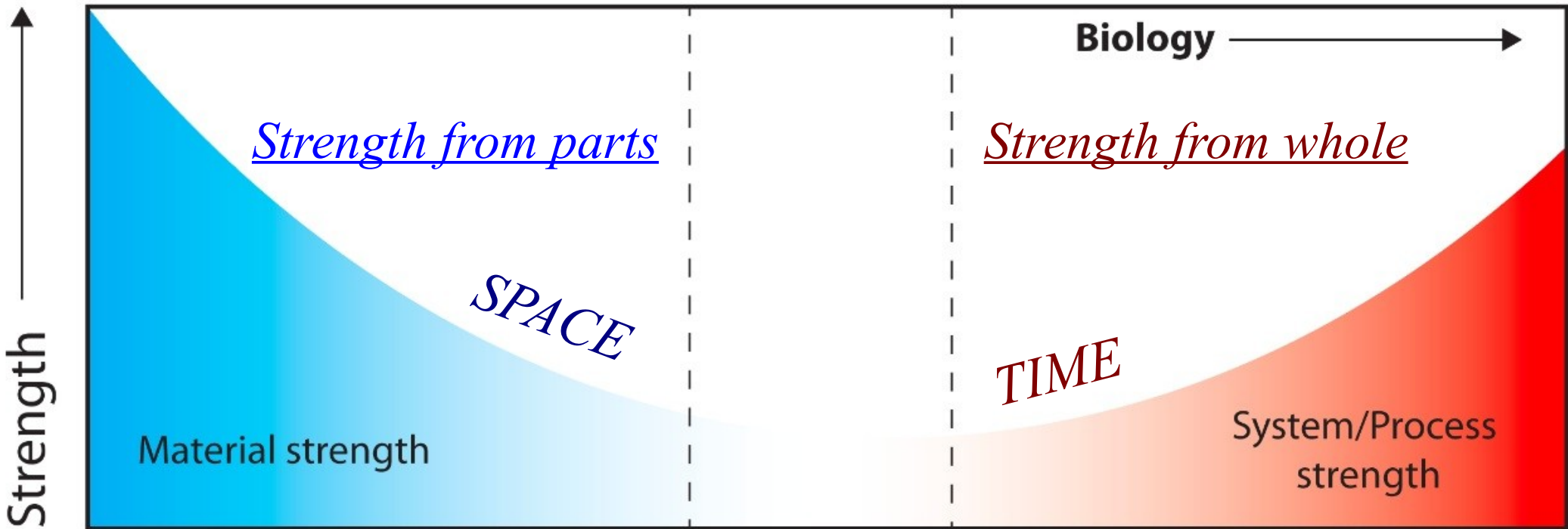
{ Degradation }  
 (increase in entropy)

{ Resilience  
 Repair  
 Learning }  
 (increase in . . . . ??)

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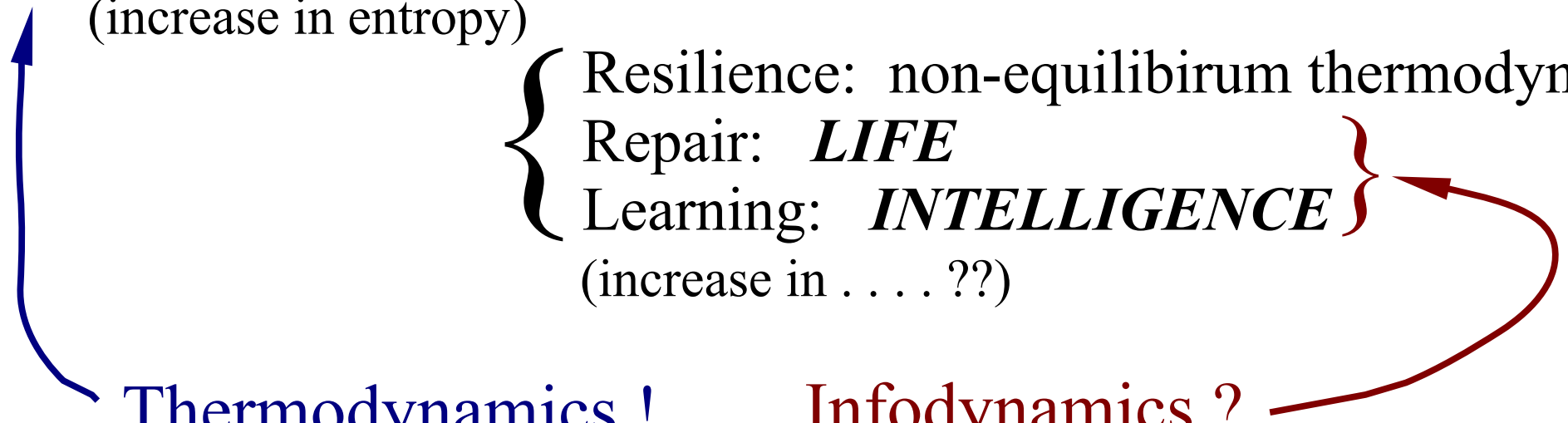
Complexity →

{ Degradation: equilibrium thermodynamics  
(increase in entropy)

{ Resilience: non-equilibrium thermodynamics  
Repair: *LIFE*  
Learning: *INTELLIGENCE*  
(increase in . . . ??)

Thermodynamics !  
(1775 - 1875)

Infodynamics ?  
(1953 - 2053?)



# Five centuries of fundamental modern science:

## Popular view:

- 17<sup>th</sup> century: Galileo, Kepler, Newton: building up
- 18<sup>th</sup> century: Newton: classical mechanics
- 19<sup>th</sup> century: Maxwell: electromagnetism
- 20<sup>th</sup> century: Einstein + ... : relativity + qm
- 21<sup>th</sup> century: ??? : unified theory

## Deeper view:

- 17<sup>th</sup> century: Differential equations
  - 18<sup>th</sup> century: Variational calculus
  - 19<sup>th</sup> century: Thermodynamics
  - 20<sup>th</sup> century: Quantum mechanics
  - 21<sup>th</sup> century: Infodynamics ?
- } *infinitesimals*
- } *statistical nature*

## Five centuries of fundamental modern science:

- 17<sup>th</sup> century: Differential equations
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- } *infinitesimals*
- } *statistical nature*

The main challenge for 21<sup>th</sup> century fundamental science:  
to invent a *statistical theory of self-organizing information*

Advice for young (at heart) people:

while working in chemistry, biology, neuroscience,  
computational science of complex systems in general:  
keep an eye open for an *info* equivalent of *thermo*-dynamics

