# Framing Complexity

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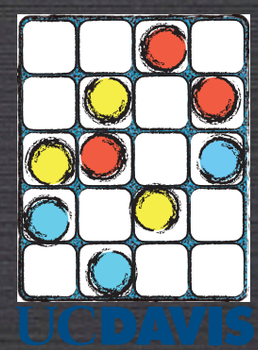
International Conference on
Morphological computation
ICMC2011
Venice, Italy
12-14 September 2011



# Learning Arbitrary Dynamical Systems & their Intrinsic Computing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Lesson: How Nature is Structured
is
How Nature Computes

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Computational Mechanics Archive: http://cse.ucdavis.edu/~cmg/

# What's the Question?

# What's the Question?

- **Fundamental challenges**:
  - Nature is unpredictable
  - Nature spontaneously organizes
  - Perception is fickle

# What's the Question?

- **Goal**: Find underlying mechanism ...
  - Understanding
  - Prediction
  - Design

# What's the Question?

- **Answer:**
  - Pattern discovery

# Nature is Predictable!

**Determinism**:

The present state of the system of nature is evidently a consequence of what it was in the preceding moment, and if we conceive of an intelligence which at a given instant comprehends all the relations of the entities of this universe, it could state the respective positions, motions, and general affects of all these entities at any time in the past or future.

Pierre Simon de Laplace (1776)

# Nature is Unpredictable!

**But** ignorance of the different causes involved in the production of events, as well as their complexity, taken together with the imperfection of analysis, prevents our reaching the same certainty about the vast majority of phenomena. Thus there are things that are uncertain for us, things more or less probable, and we seek to compensate for the impossibility of knowing them by determining their different degrees of likelihood. So it is that we owe to **the weakness of the human mind** one of the most delicate and ingenious of mathematical theories, the science of chance or probability.

Pierre Simon de Laplace
*Calculus of Probabilities* (1776)

# Nature is Unpredictable!

**But** even if it were the case that natural laws had no longer any secret for us, we could still only know the initial situation approximately. If that enabled us to predict the succeeding situation with the same approximation, that is all we require, and we should say that the phenomenon had been predicted, that it is governed by laws. But it is not always so; it may happen that **small differences in the initial conditions produce very great ones in the final phenomena**. A small error in the former will produce an enormous error in the latter. Prediction becomes impossible, and we have the fortuitous phenomenon.

Henri Poincaré
*Les Methodes Nouvelles de la Mecanique Celeste* (1892)

# Nature is Unpredictable

Poincaré: Randomness is endogenous.

# Nature Spontaneously Organizes

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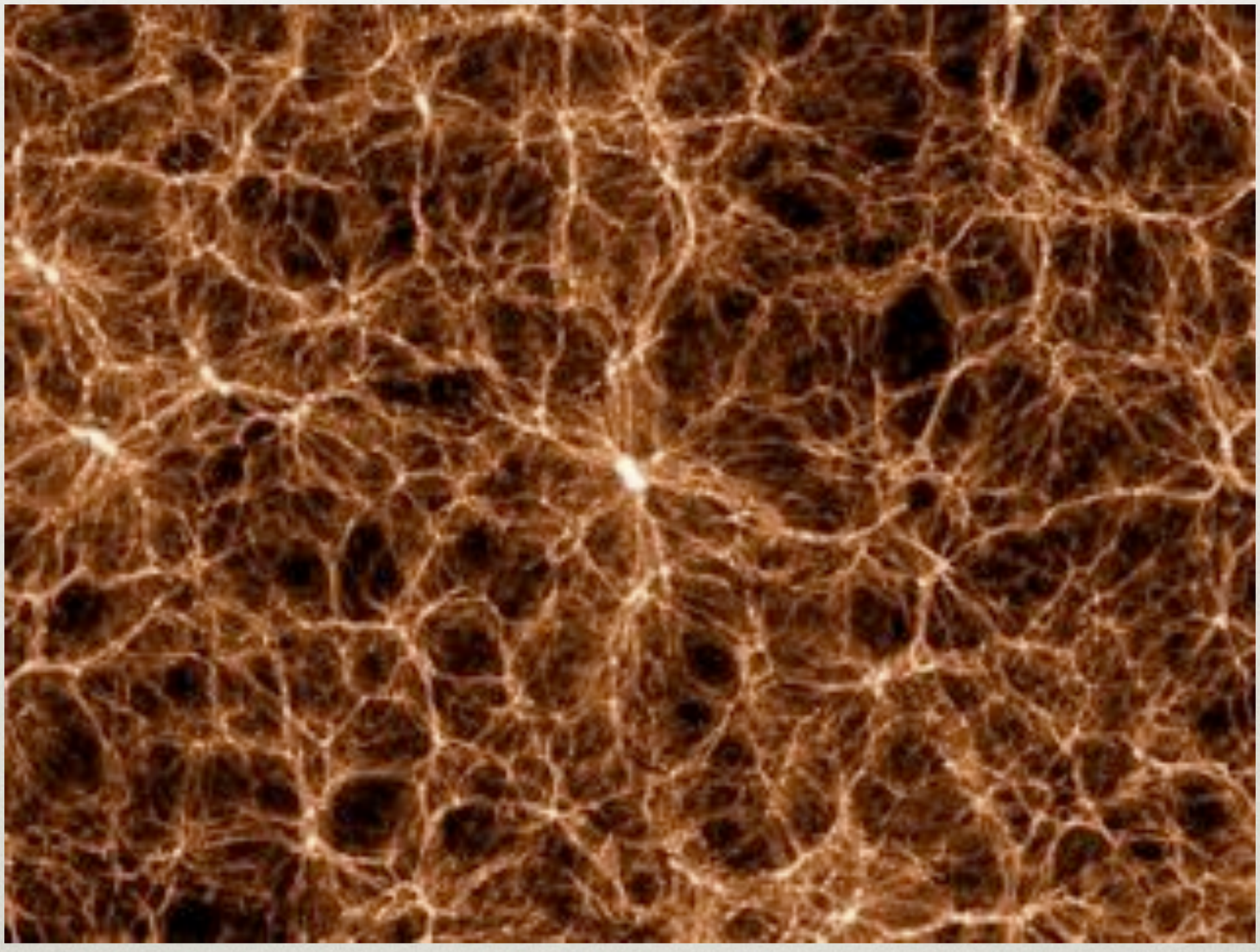

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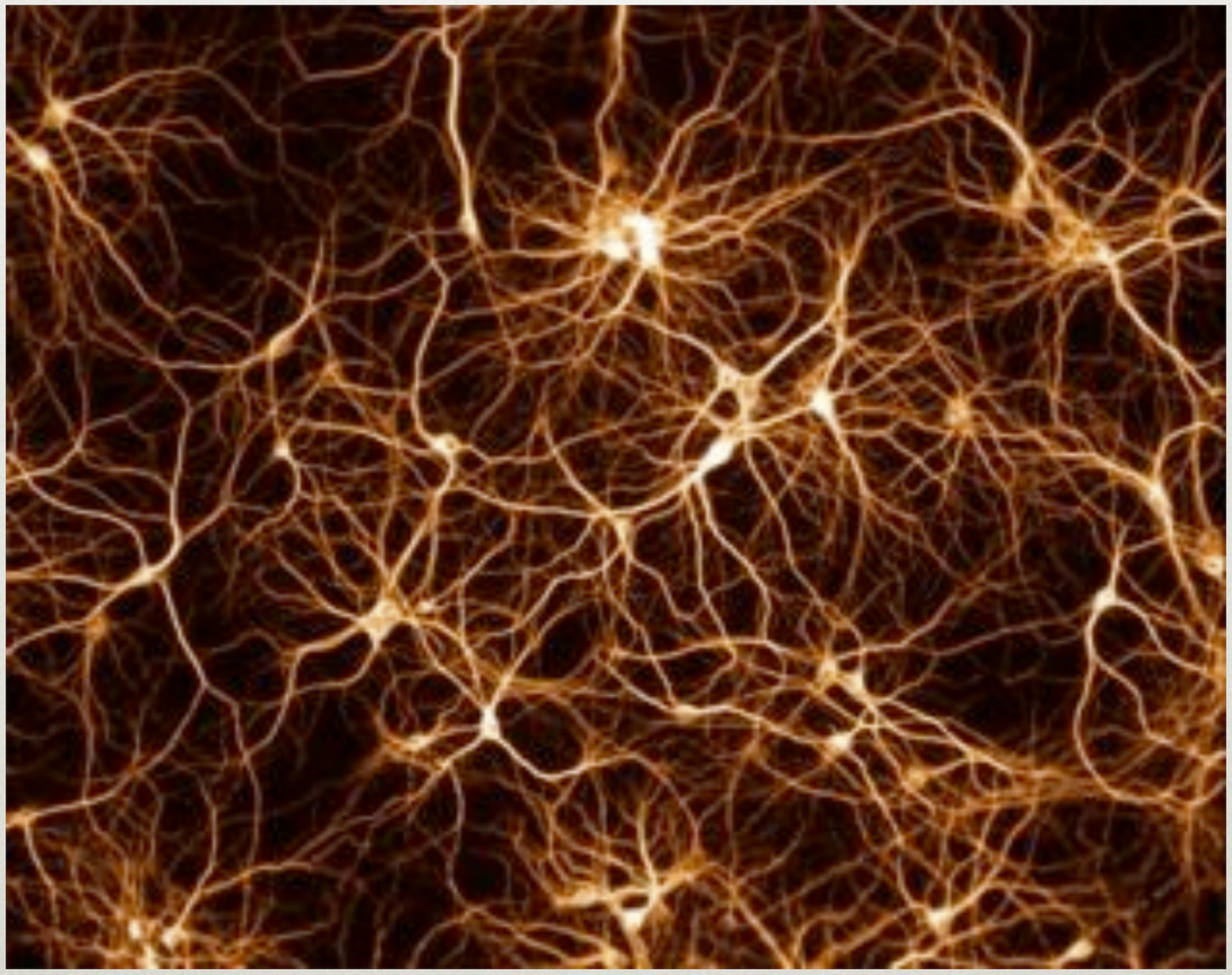

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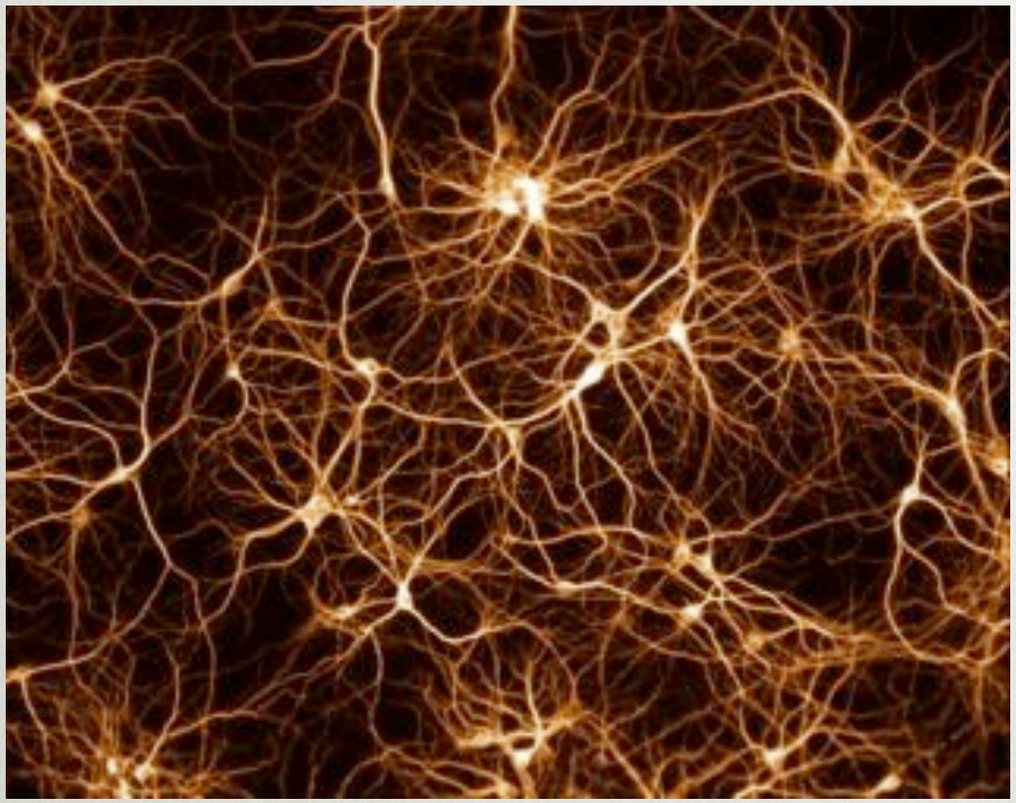

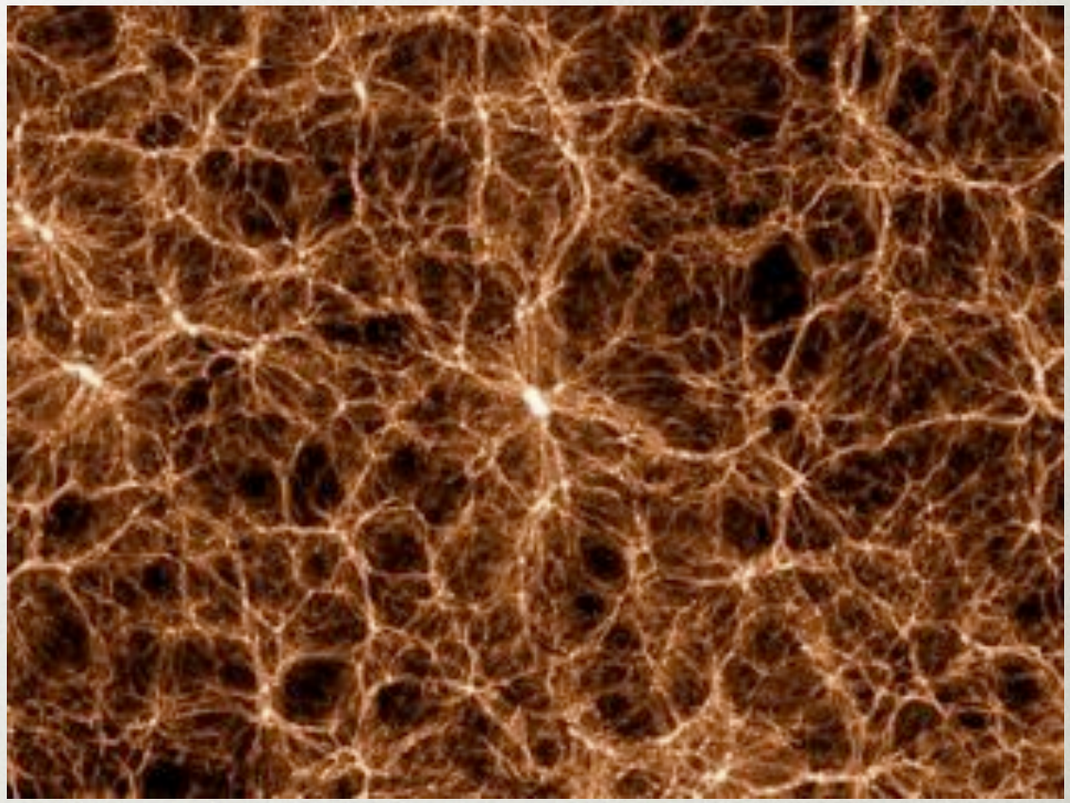

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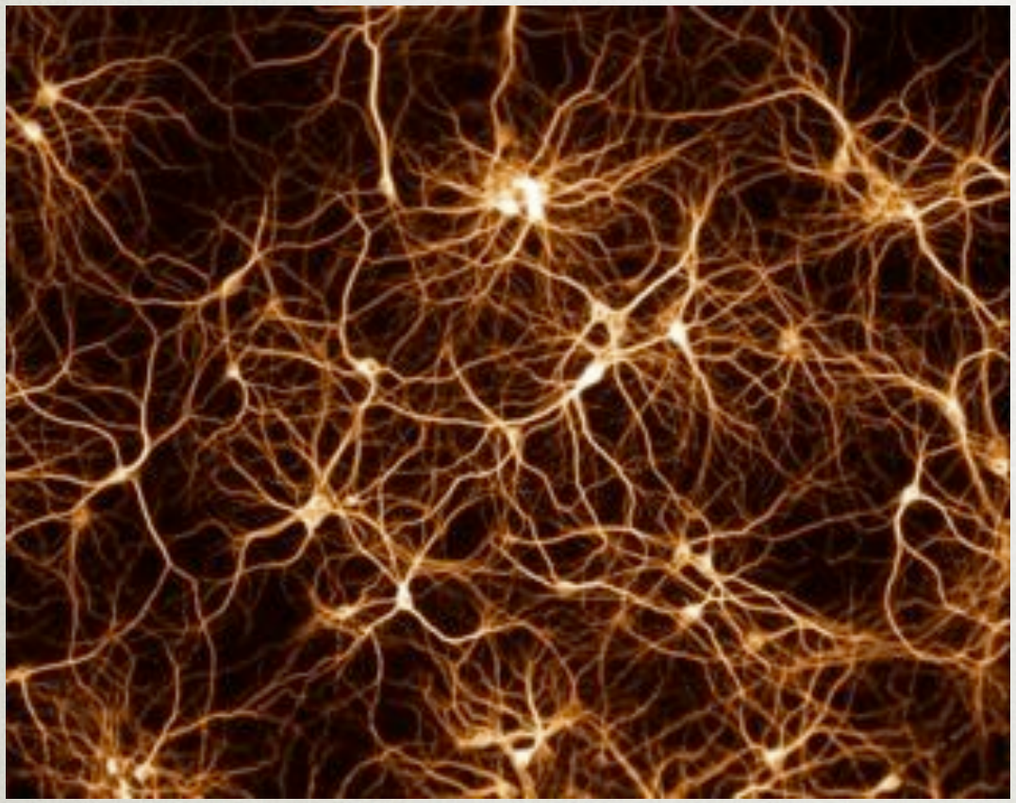

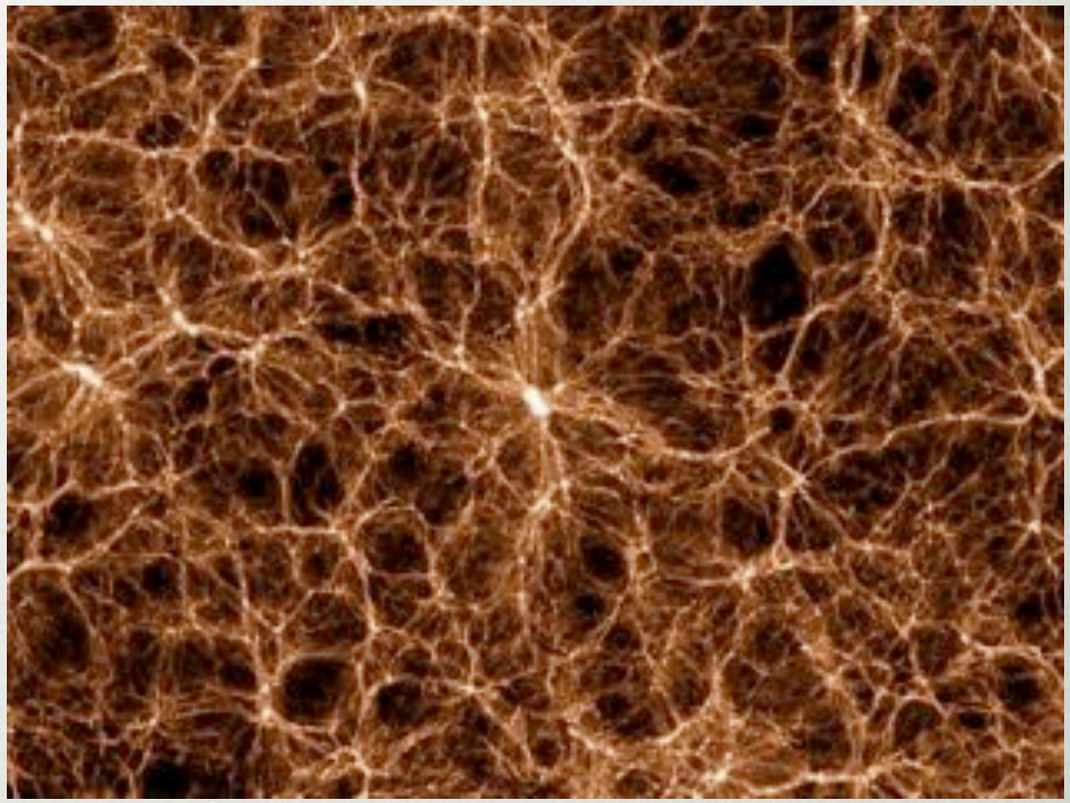

Structure of the brain:
Neurons and synapses, 2 mm across

http://www.visualcomplexity.com/vc/project.cfm?id=146

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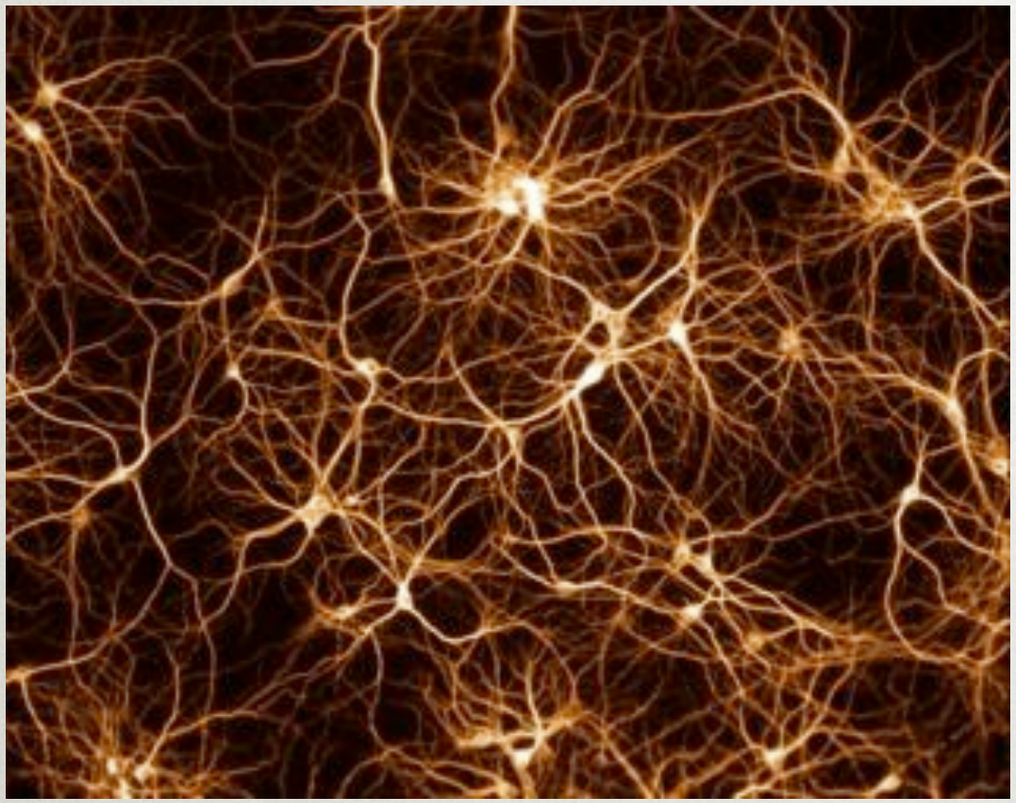

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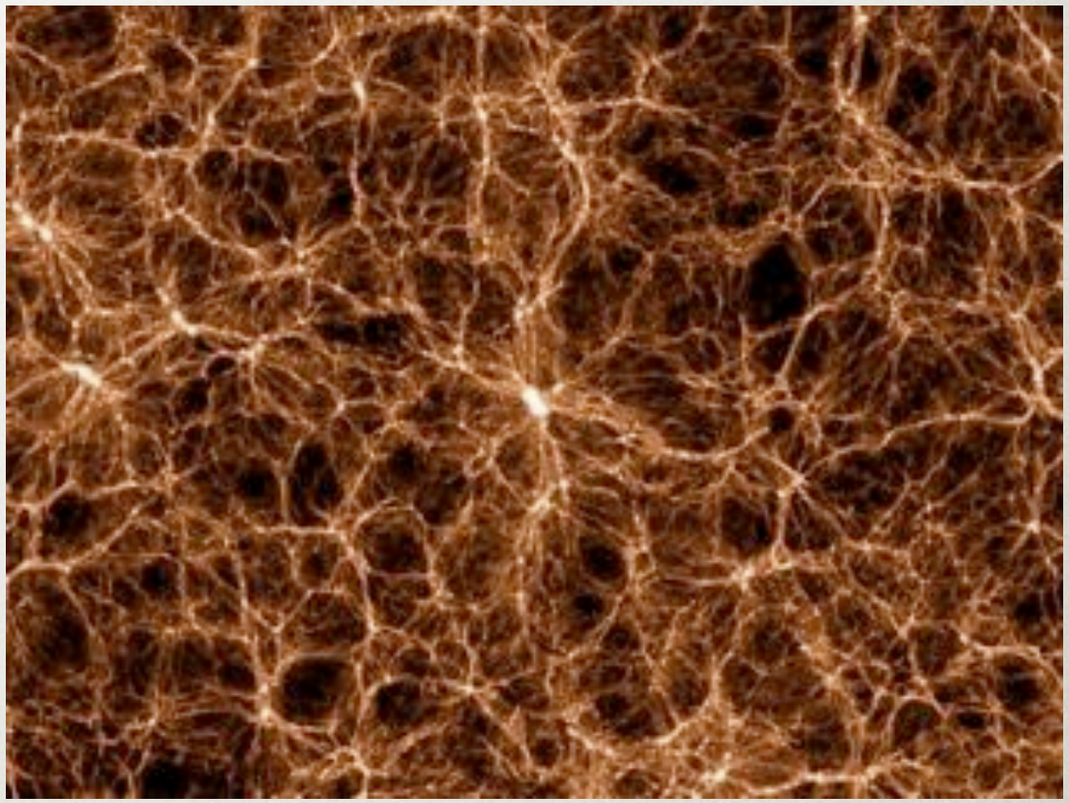
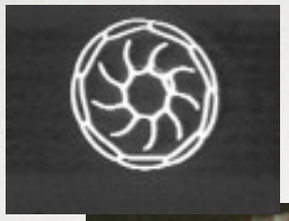
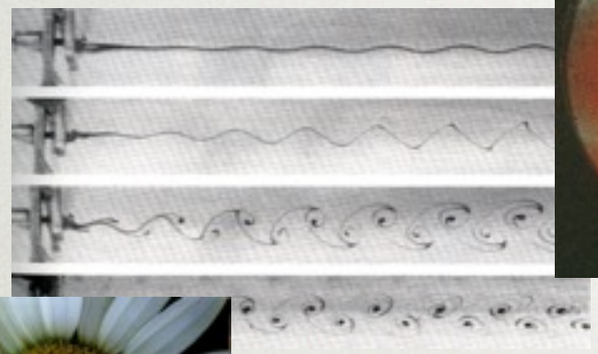


Structure of the Universe:
1 billion light years across

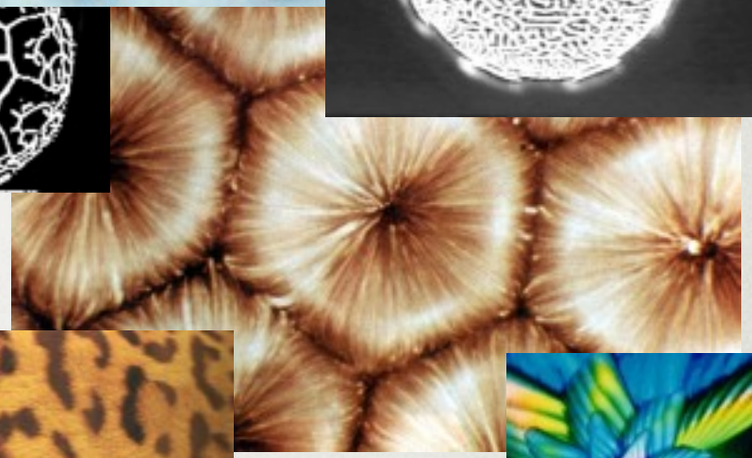
http://www.mpa-garching.mpg.de/galform/virgo/millennium/

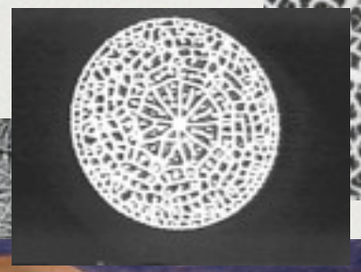
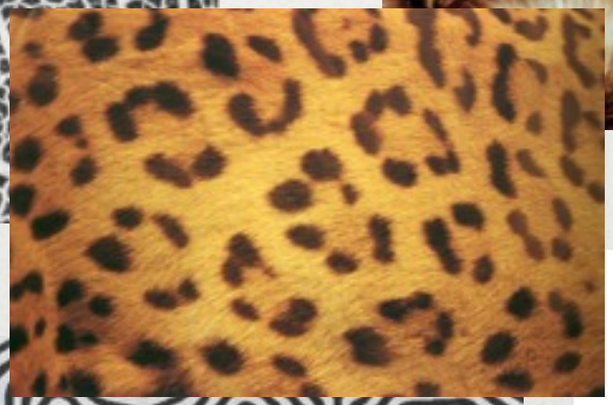
# Patterns!

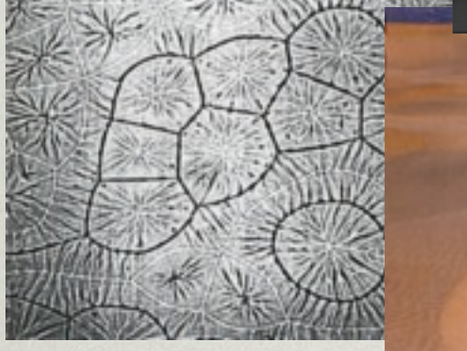
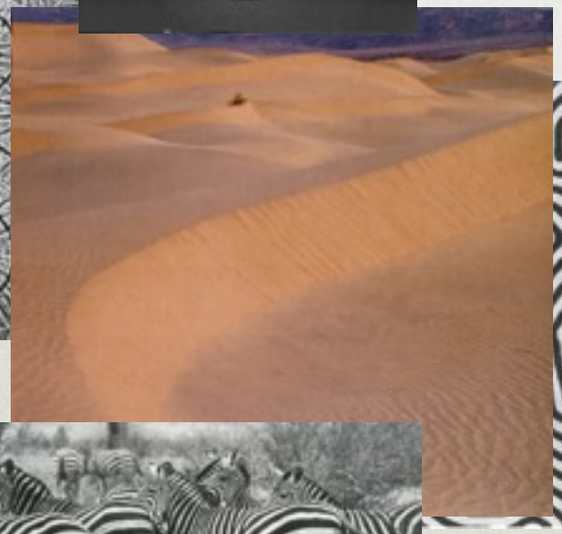
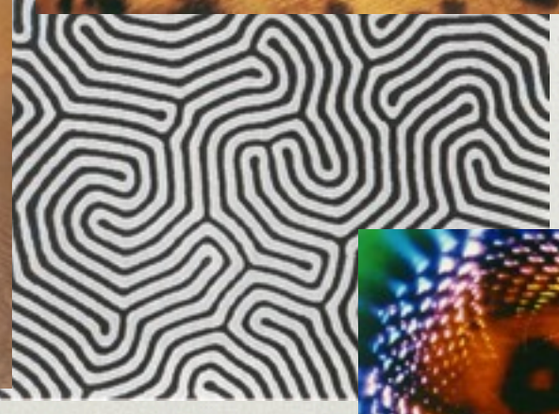


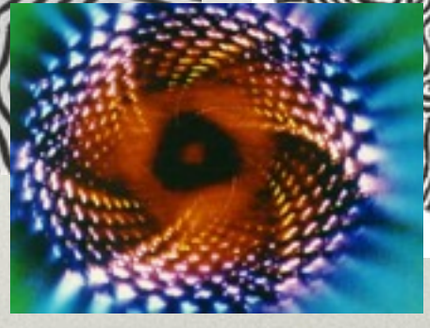







# Emergent structures

- Engineered systems also spontaneously organize
  - Internet route flapping
  - Power-law Internet organization
  - Financial markets crash
  - Power grids fail spectacularly
  - Social pattern formation on the web
  - ...

# What is a Pattern, anyway?

# Animals!

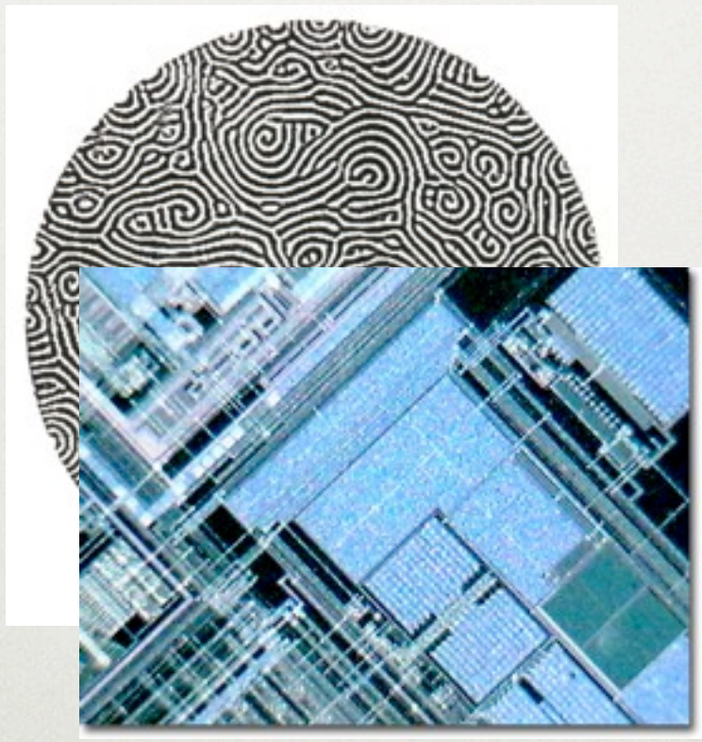
These ambiguities, redundances, and deficiencies recall those attributed by Dr. Franz Kuhn to a certain Chinese encyclopedia entitled Celestial Emporium of Benevolent Knowledge. On those remote pages it is written that animals are divided into (a) those that belong to the Emperor, (b) embalmed ones, (c) those that are trained, (d) suckling pigs, (e) mermaids, (f) fabulous ones, (g) stray dogs, (h) those that are included in this classification, (i) those that tremble as if they were mad, (j) innumerable ones, (k) those drawn with a very fine camel's brush hair, (l) others, (m) those that have just broken a flower vase, (n) those that resemble flies from a distance.

J. L. Borges, "The Analytical Language of John Wilkins", in Other Inquisitions 1937-1952 (1964) 103.

# Pattern?
# The Fundamental Problem

# Randomness versus Structure?

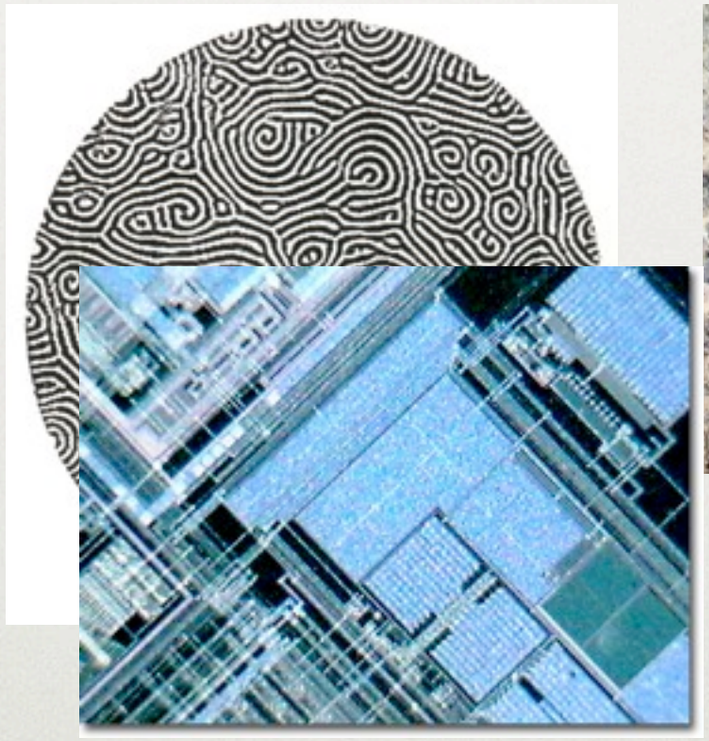

# Randomness versus Structure?

# Randomness versus Structure?

Boredom

Variatio Delectat



Confusion

# Randomness versus Structure?

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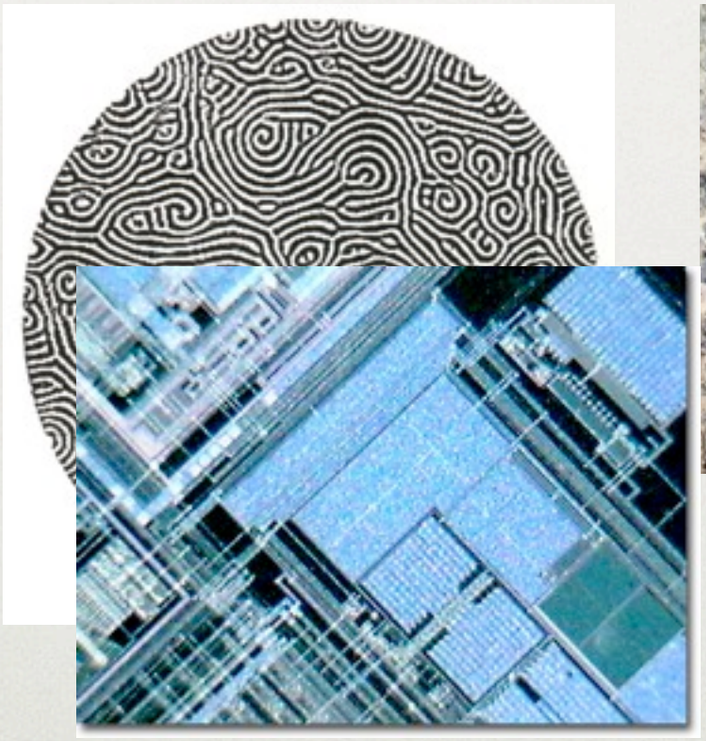

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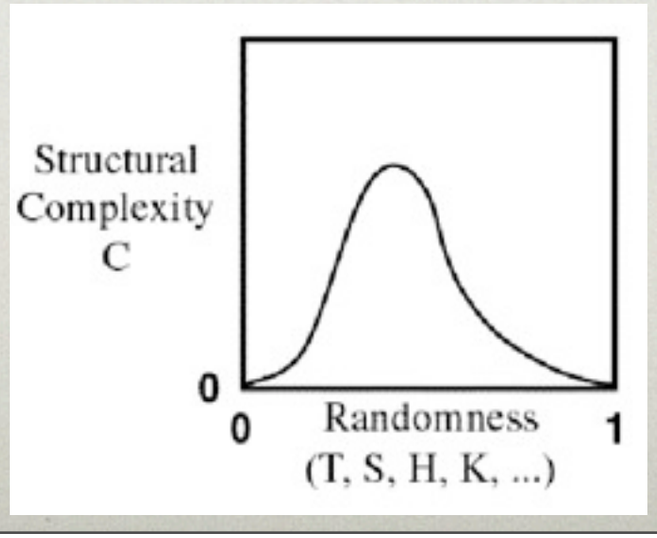

# Pattern as the Middle Ground

The social history of mankind exhibits great organizations in their alternating functions of conditions for progress, and of contrivances for stunting humanity. The history of the Mediterranean lands, and of western Europe, is the history of the blessing and the curse of political organizations, of religious organizations, of schemes of thought, of social agencies for large purposes. The moment of dominance, prayed for, worked for, sacrificed for, by generations of the noblest spirits, marks the turning point where the blessing passes into the curse. Some new principle of refreshment is required. **The art of progress is to preserve order amid change, and to preserve change amid order.** Life refuses to be embalmed alive. The more prolonged the halt in some unrelieved system of order, the greater the crash of the dead society.

Alfred North Whitehead
"Ideal Opposites"
in *Process and Reality* (1920)

# Pattern as the Middle Ground ...

The same principle is exhibited by the tedium arising from the unrelieved dominance of fashion in art. Europe, having covered itself with treasures of Gothic architecture, entered upon generations of satiation. These jaded epochs seem to have lost all sense of that particular form of loveliness. It seems as though the last delicacies of feeling require some element of novelty to relieve their massive inheritance from bygone system. Order is not sufficient. **What is required, is something much more complex. It is order entering upon novelty; so that the massiveness of order does not degenerate into mere repetition; and so that the novelty is always reflected upon a background of system.**

Alfred North Whitehead
"Ideal Opposites"
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# Natural Lessons

- Simple systems can be complicated
- Complicated systems can be structured
- Organization arises from the interplay of order and randomness

# Pattern Perception

- But, we have an impoverished view of a hidden world:

  Our sensorium gives only indirect evidence of nature's organization.

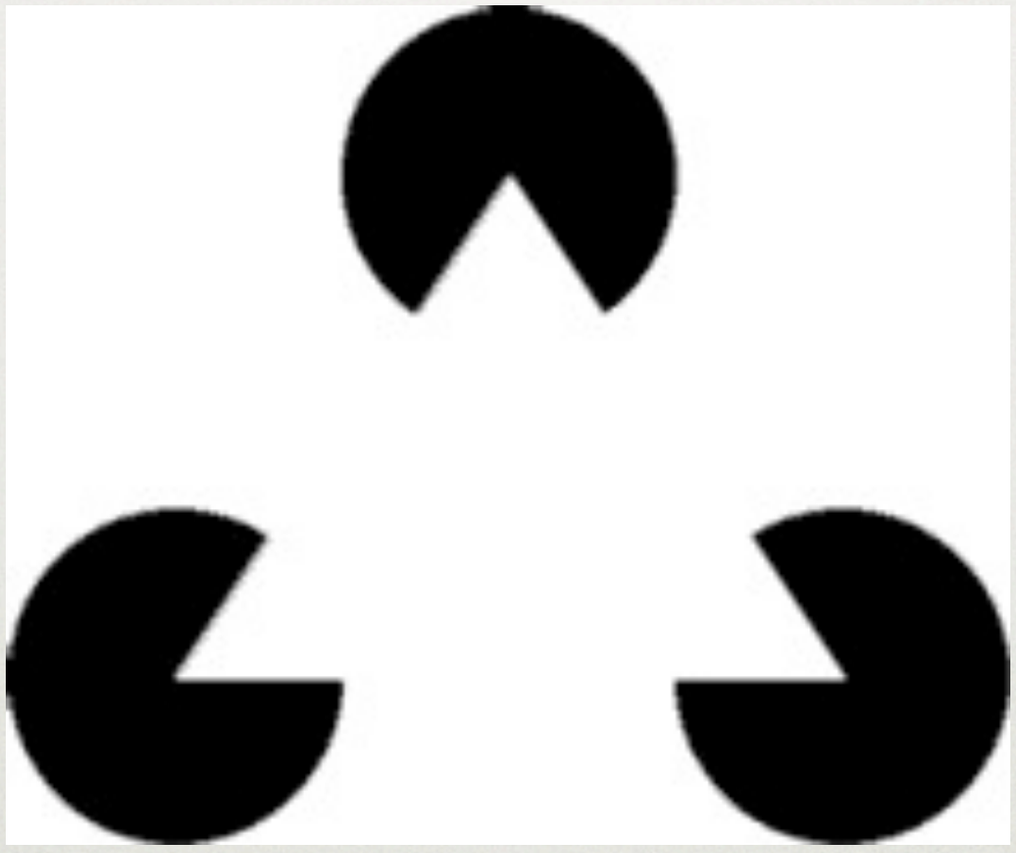
"If the doors of perception were cleansed, every thing would appear to man as it is, infinite. For man has closed himself up, till he sees all things through narrow chinks of his cavern."

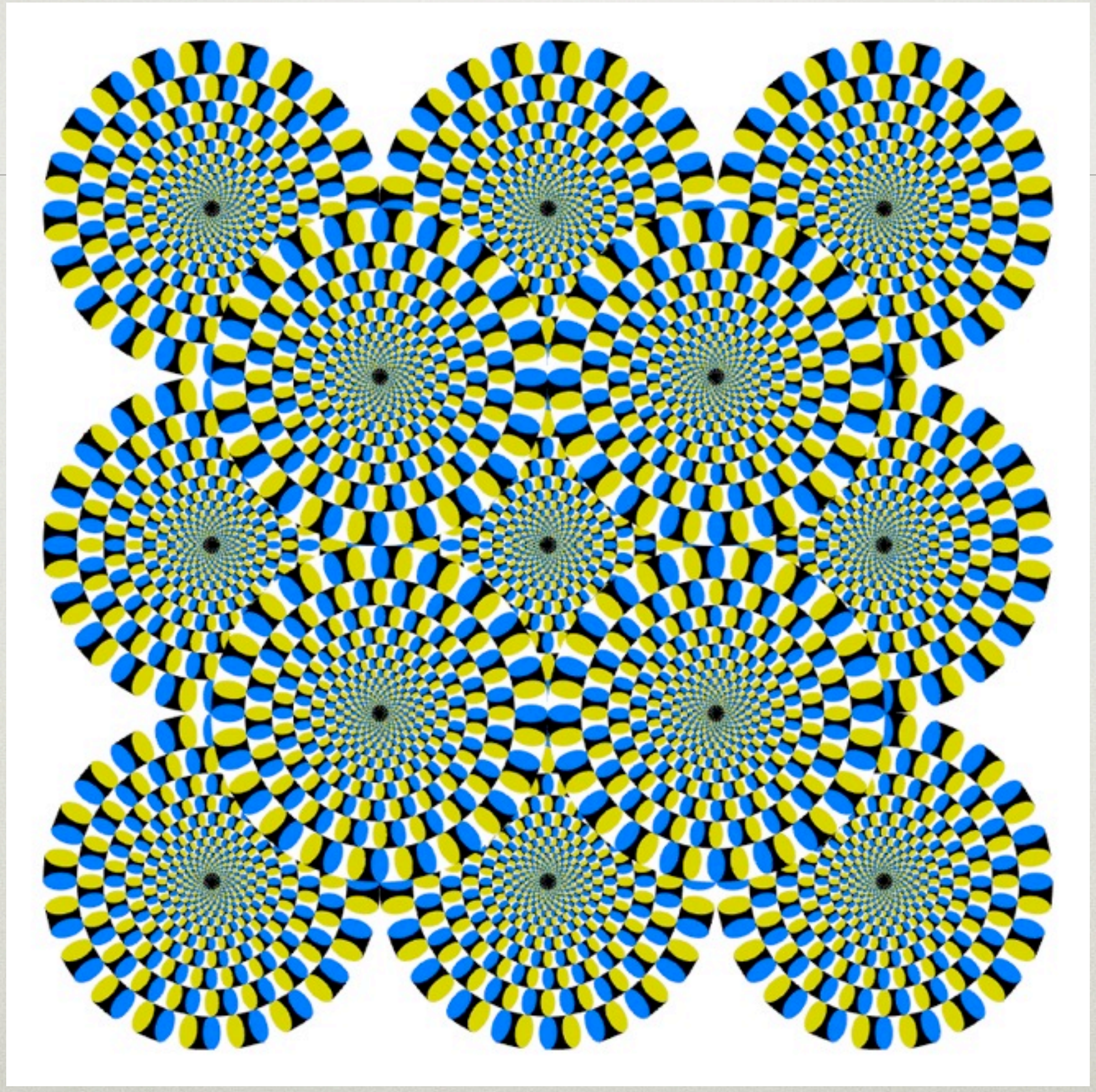
William Blake, The Marriage of Heaven & Hell (1793)

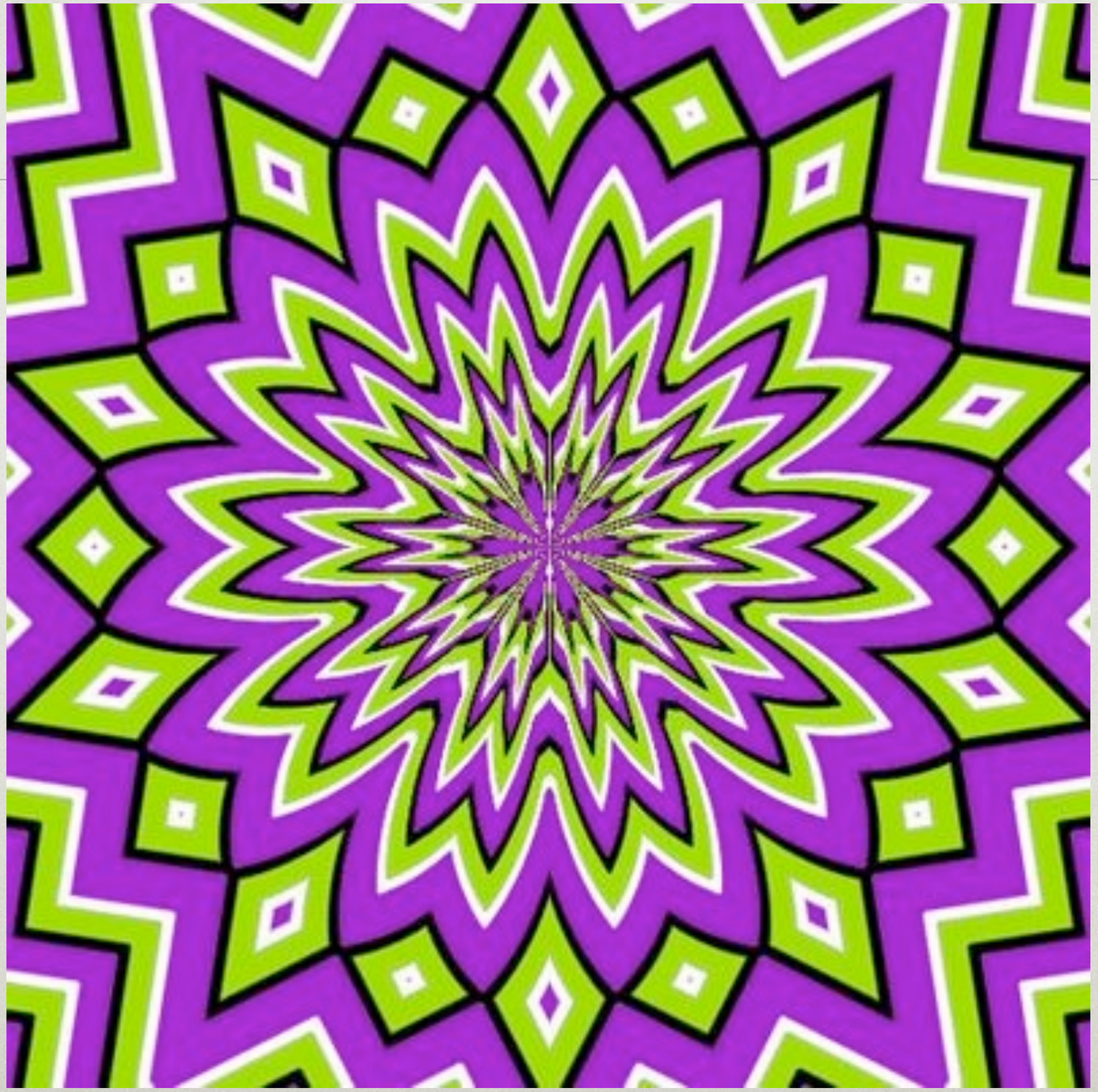
# Pattern Perception

In addition,

our sensorium actively interprets the world.







# Patterns in Time

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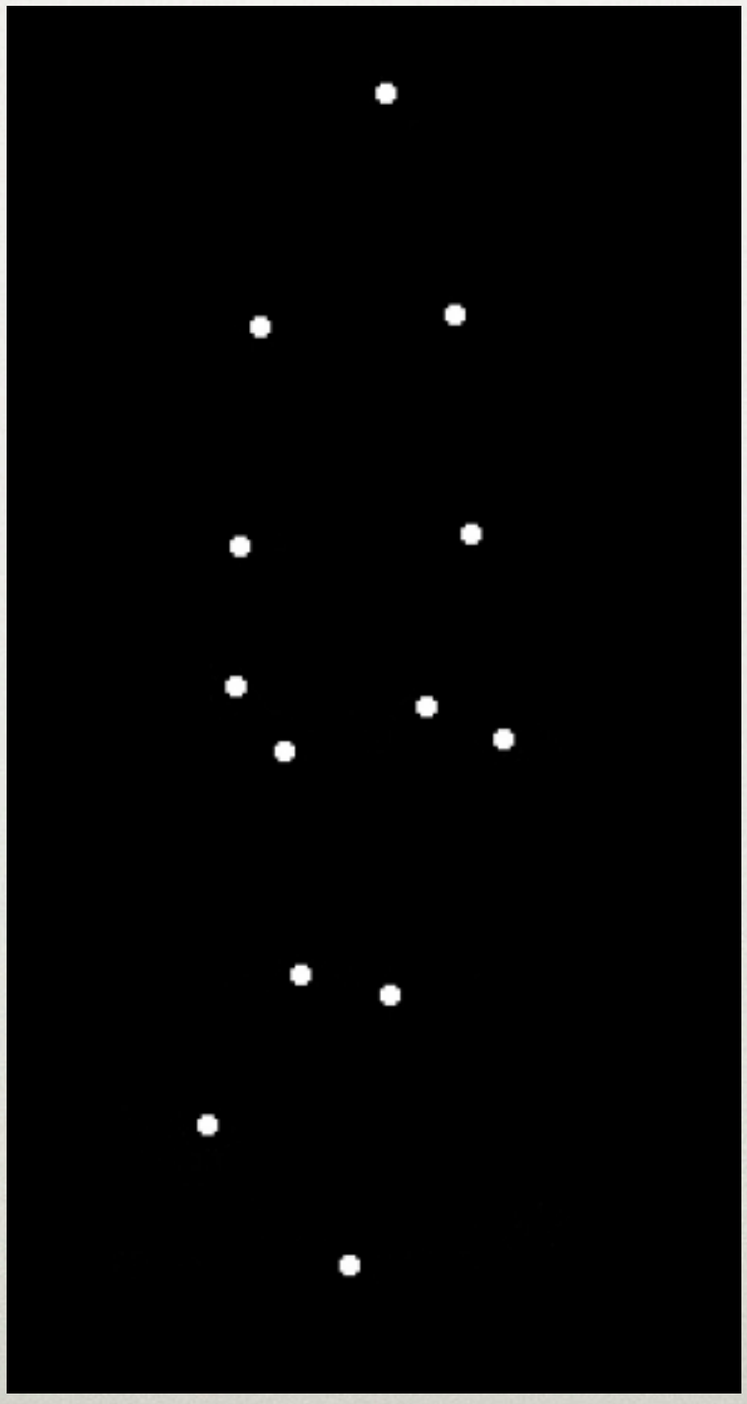


# Reprise

- **Fundamental challenges**:
  - Nature is unpredictable
  - Nature spontaneously organizes
  - Perception is fickle

# Fundamental in Nonlinear Dynamics

- Deterministic chaos ⇒ Probabilistic description
- Structures are not given directly by the governing equations of motion: They are emergent.
- Each nonlinear system requires its own representation
- Selecting balance between ascribing structure or noise to a measurement depends on representation
- Fundamental issue: Theory building

# Theory?

The grammar of a language can be viewed as a theory of the structure of this language. **Any scientific theory is based on a certain finite set of observations and, by establishing general laws stated in terms of certain hypothetical constructs, it attempts to account for these observations, to show how they are interrelated, and to predict an indefinite number of new phenomena. A mathematical theory has the additional property that predictions follow rigorously from the body of the theory.** Similarly, a grammar is based on a finite number of observed sentences (the linguist's corpus) and it "projects" this set to an infinite set of grammatical sentences by establishing general "laws" (grammatical rules) .... A properly formulated grammar should determine unambiguously the set of grammatical sentences.

Noam Chomsky,
Three Models for the Description of Language.
IRE Transactions (1956) 113-124.

# Discovery: What is Nature's Grammar?

- But what are the right representations?
  - Depends on how nature is patterned.
  - Even our perception of nature's randomness, depends on the structures that we can detect.

# The Problem of Discovery

If a Martian scientist sitting before his radio in Mars accidentally received from Earth the broadcast of an extensive speech [...], what criteria would he have to determine whether the reception represented the effect of an animate process on Earth, or merely the latest thunderstorm on Earth? It seems that the only criteria would be the arrangement of occurrences of the elements, and **the only clue to the animate origin would be this: the arrangement of the occurrences would be neither of rigidly fixed regularity such as frequently found in wave emissions of purely physical origin nor yet a completely random scattering of the same.**

George K. Zipf,
The Psycho-Biology of Language:
An Introduction to Dynamic Philology,
2nd ed. The MIT Press (1965) p. 187.

# Pattern Discovery?

- All we can express is given in the language of our current understanding.

- How do we extend our vocabularies?
- How to find patterns that we have not seen before?

# Pattern Discovery?

- Empirically:

  We do this!

- Claim:

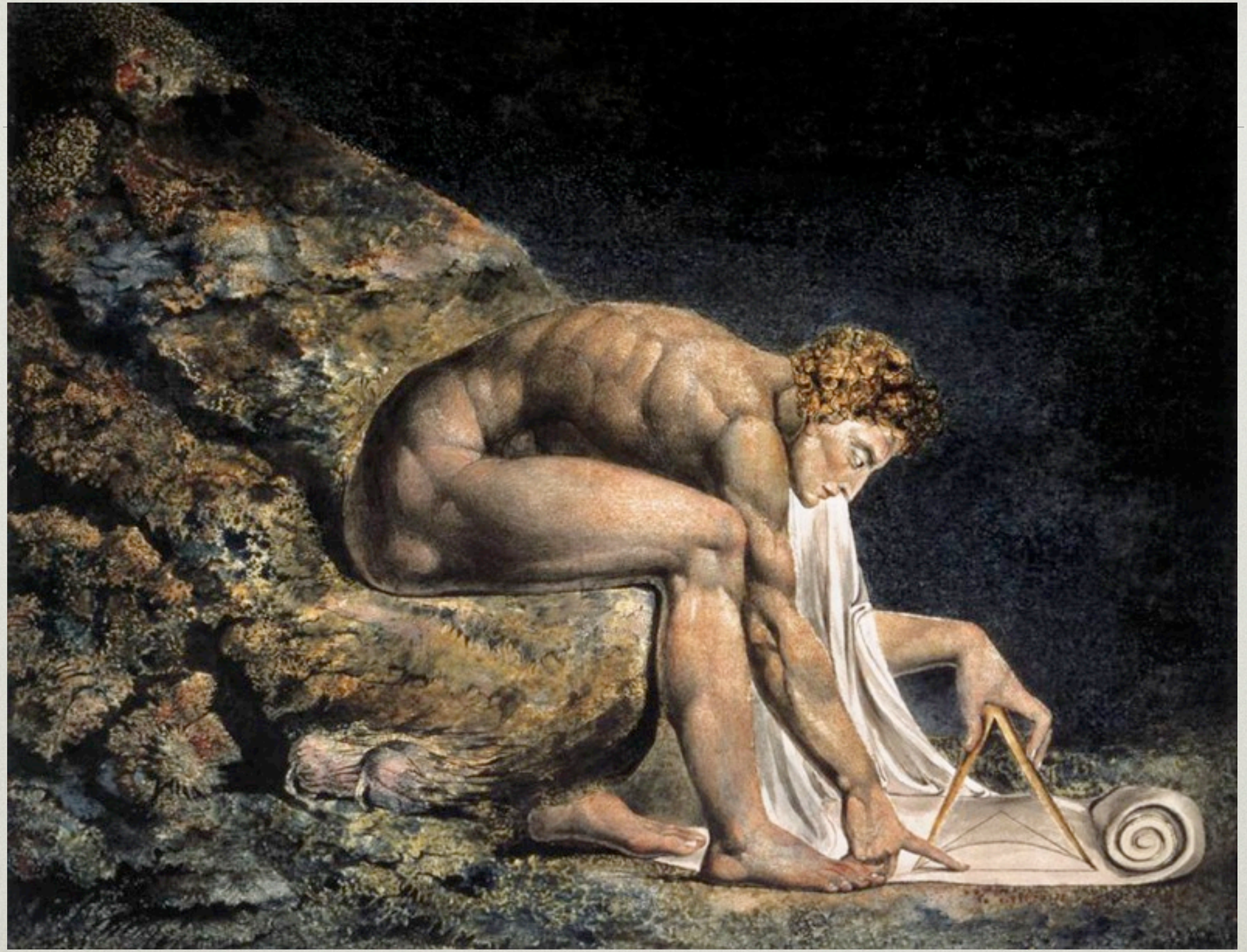
We are Pattern Discovery Engines.

# A Paradigm of Discovery

Seen from the outside, the Amazonian forest seems like a mass of congealed bubbles, a vertical accumulation of green swellings; it is as if some pathological disorder had attacked the riverscape over its whole extent. But once you break through the surface-skin and go inside, everything changes: seen from within, the chaotic mass becomes a monumental universe. The forest ceases to be a terrestrial distemper; it could be taken for a new planetary world, as rich as our world, and replacing it.

As soon as the eye becomes accustomed to recognizing the forest's various closely adjacent planes, and the mind has overcome its first impression of being overwhelmed, a complex system can be perceived.

Claude Levi-Strauss,
Triste Tropiques,
(1955).



Newton (1795), William Blake (Tate Museum)

# Simplicity Sciences

Everything should be made as simple as possible,

but not simpler.

A. Einstein, On the Method of Theoretical Physics.
Philosophy of Science **1**:2 (1934) 163–169.

# Thanks!

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