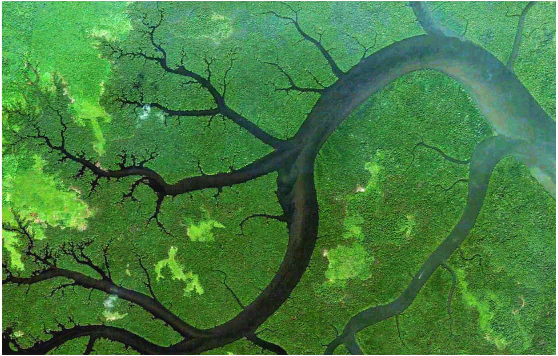
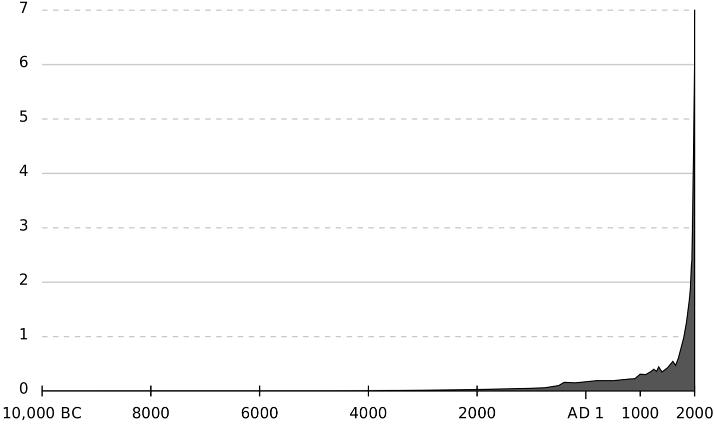
THE MATHEMATICS OF PLANET EARTH

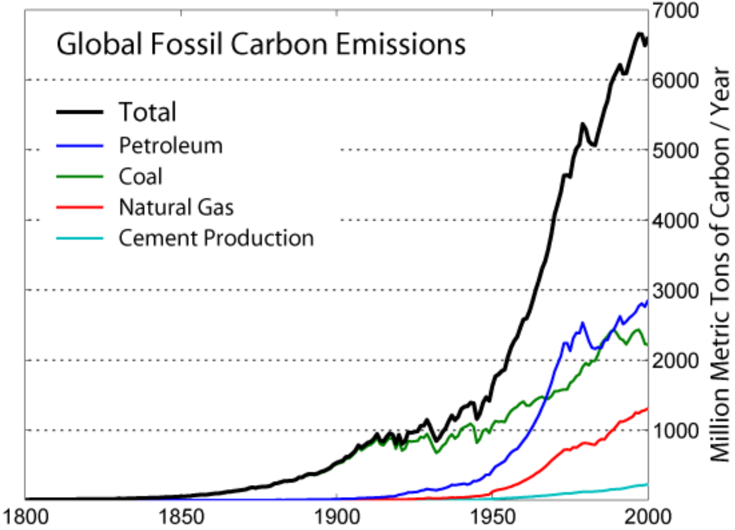


John Baez
Institute of Fundamental Sciences, Massey University
2 September 2014

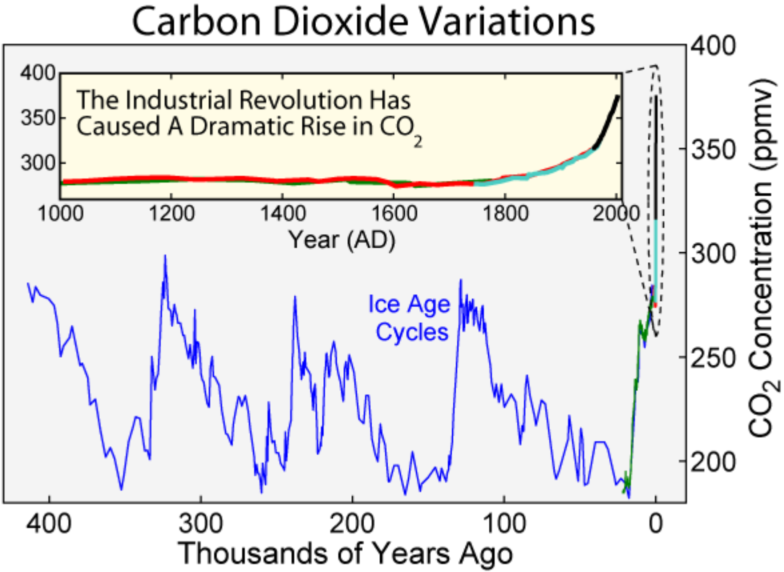
We have left the Holocene and entered a new epoch, the Anthropocene, when the biosphere is rapidly changing due to human activities. Global warming is just *part* of this process.



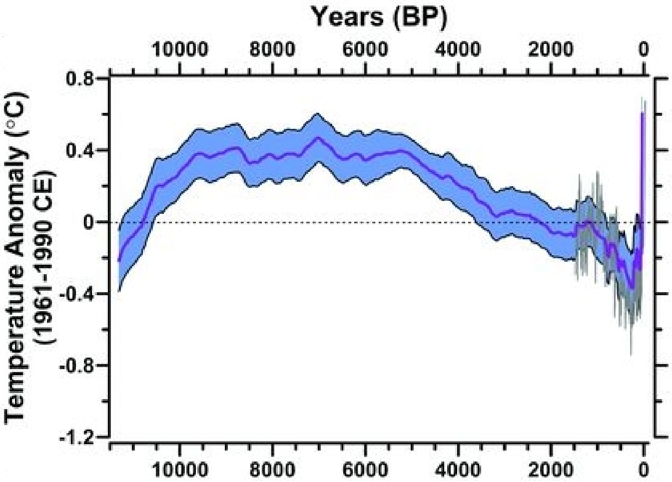
HUMAN POPULATION, IN BILLIONS



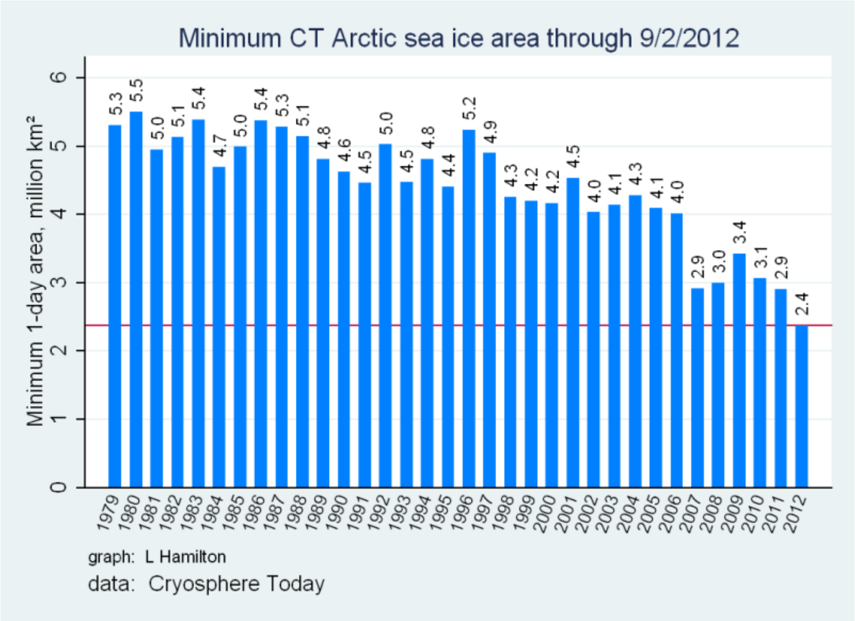
Global Warming Art



Antarctic ice cores and other data — Global Warming Art



Reconstruction of temperature from 73 different records —
Marcott *et al.*


Minimum CT Arctic sea ice area through 9/2/2012
Minimum 1-day area, million km²
0
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4
5
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5.5
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graph: L Hamilton
data: Cryosphere Today

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- In oceans, eutrophication has created about 400 dead zones, from 1 to 70,000 km^2 in area.
- Populations of large ocean fish have declined 90% since 1950.
- The rate of species going extinct is 100-1000 times the usual background rate.

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Institutions and attitudes will change dramatically, like it or not:

- *Before*, we could treat ‘nature’ as distinct from ‘civilization’. *Now*, there is no nature separate from civilization.
- *Before*, ‘economic growth’ could be our main goal, with many side-effects ignored. *Now*, many forms of growth are pushing the biosphere toward tipping points.

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One hard thing:

Invent the math we need for life on a finite planet.

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During this revolution, from 10,000 to 5,000 BC, we began to systematically exploit solar power by planting crops.

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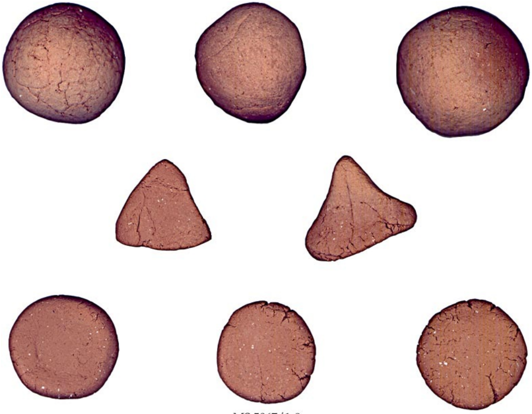
- *geometry* for measuring fields and storage containers.
- *written numbers* for commerce.

Consider the last...

Starting around 8000 BC, in the Near East, people started using 'tokens' for contracts: little geometric clay figures that represented things like sheep, jars of oil, and amounts of grain.



MS 5067/1-8
Neolithic plain counting tokens. Near East, ca. 8000--3500 BC

The Schøyen Collection

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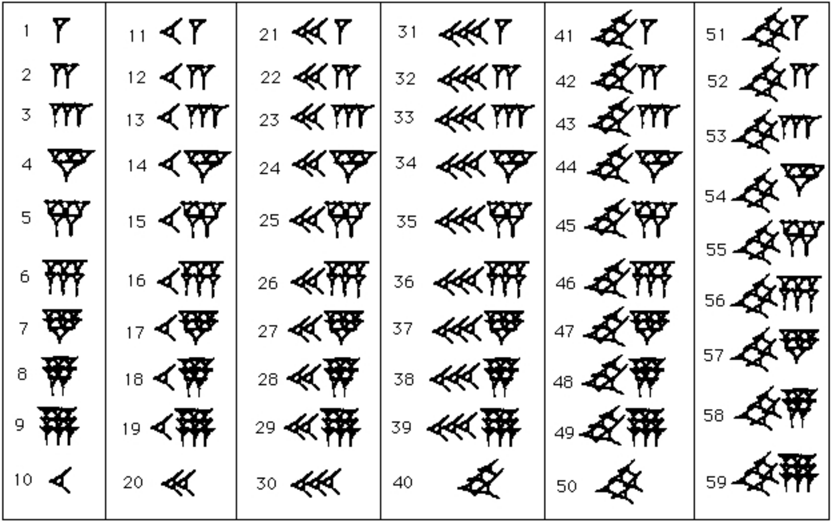
Eventually they gave up on the tokens. The marks on tablets then developed into the Babylonian number system! The transformation was complete by 3000 BC.



J. J. O'Connor and E. F. Robertson, Babylonian Numerals

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By 1700 BC the Babylonians could compute $\sqrt{2}$ to 6 decimals:

$$1 + \frac{24}{60} + \frac{51}{60^2} + \frac{10}{60^3} \approx 1.414213...$$

Yale Babylonian Collection, YBC7289

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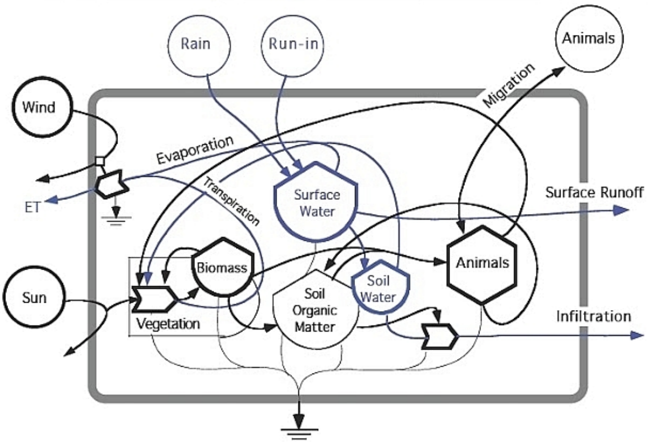
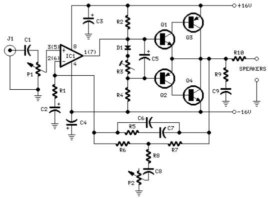
Math may undergo a transformation just as big as it did in the Agricultural Revolution.

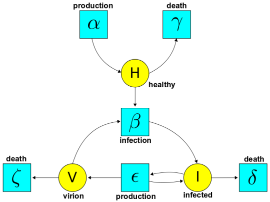
To understand ecosystems, ultimately will be to understand networks. — B. C. Patten and M. Witkamp

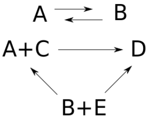


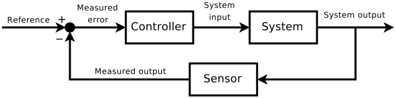
In the 1950's, Howard Odum introduced an Energy Systems Language to describe these networks.

Engineers, chemists, biologists and others now use *many* diagram languages to describe complex systems:



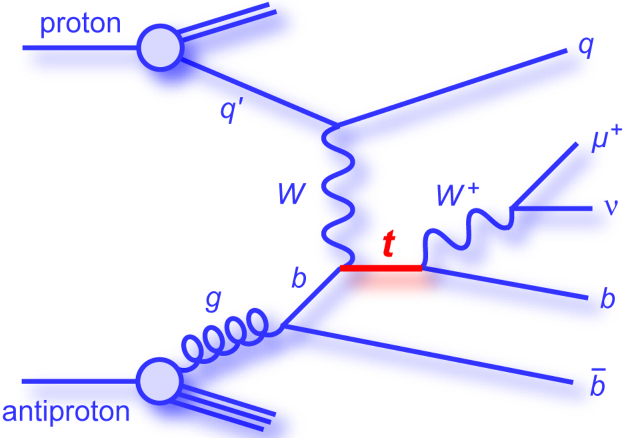






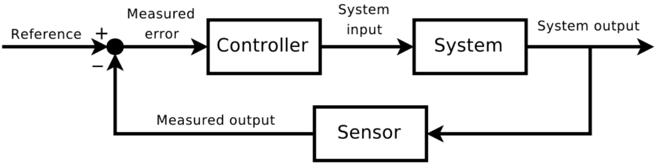
We need a good mathematical theory of these!

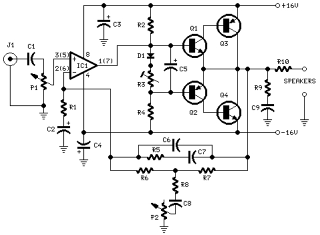
The mathematics of particle physics, and category theory, can help!



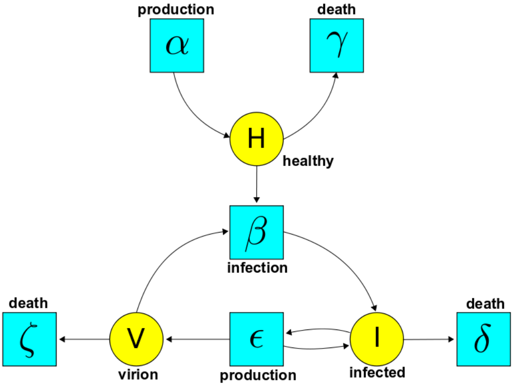
Together with colleagues and students I have been using category theory to update and synthesize the mathematics of:

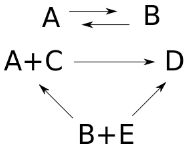
1) signal-flow graphs and electrical circuit diagrams:



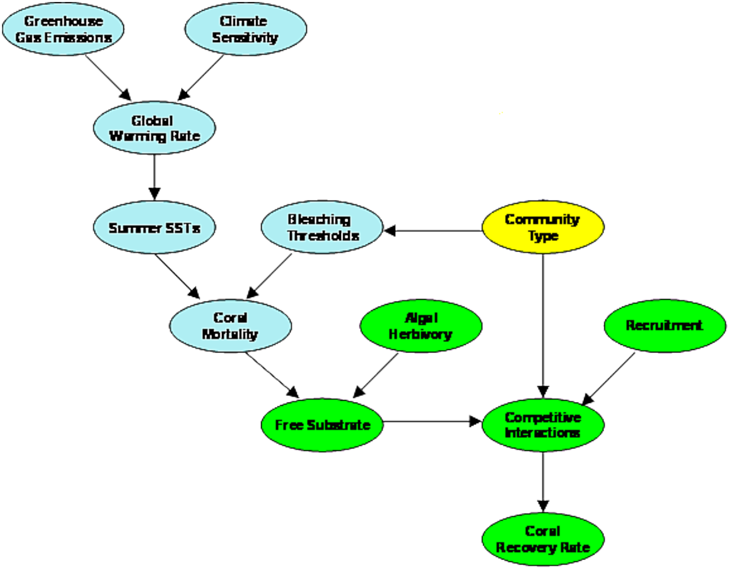


2) stochastic Petri nets, chemical reaction networks and Feynman diagrams:





3) Bayesian networks and information theory:



Network theory is just a small part of the mathematics we'll need to invent. We can't predict most of it.

However, I expect the mathematics of this century will draw inspiration from *biology*, *ecology* and *sociology*, much as the math of the industrial revolution was inspired by physics.

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It's just beginning to be born. I hope you can help out. Check out the Azimuth Project!