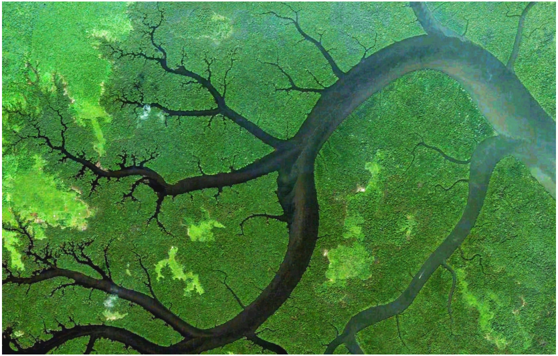
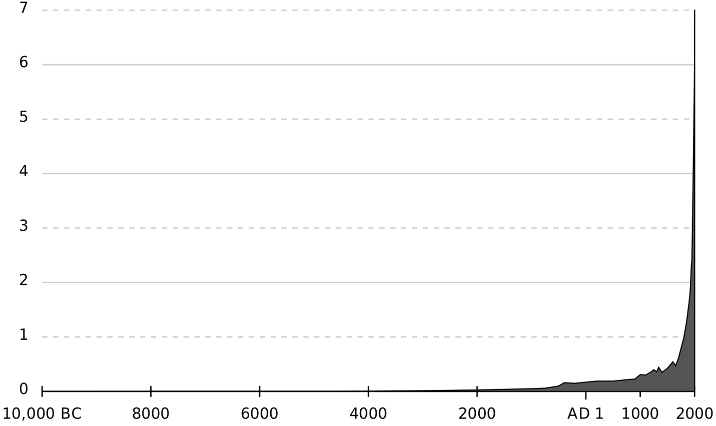
THE MATHEMATICS OF THE 21ST CENTURY

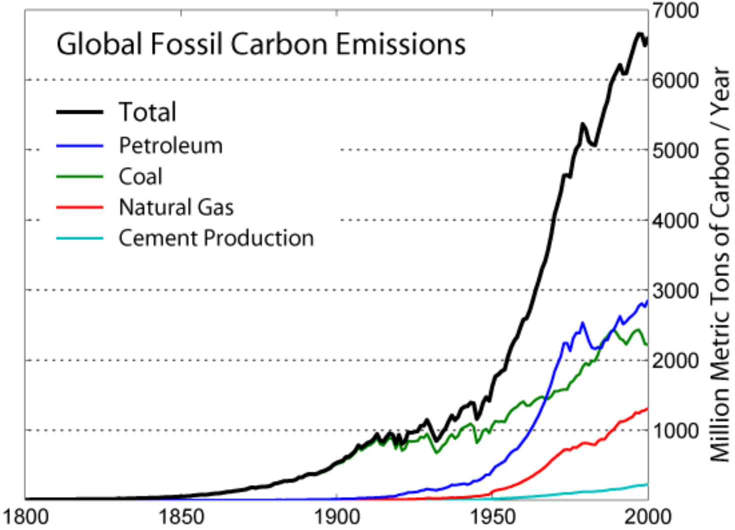


John Baez
Department of Mathematics, U.C. Riverside
8 February 2019

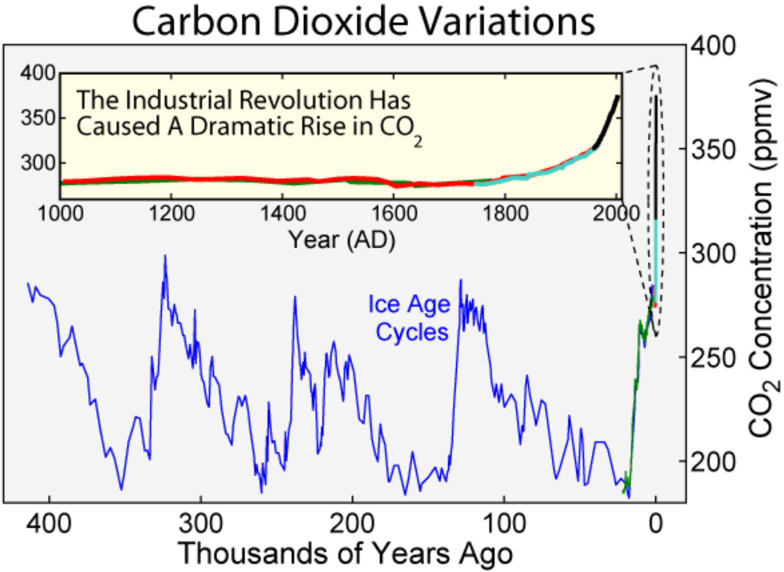
We have left the Holocene and entered a new epoch, the Anthropocene, when the biosphere is rapidly changing due to human activities. Global warming is just *part* of this process.



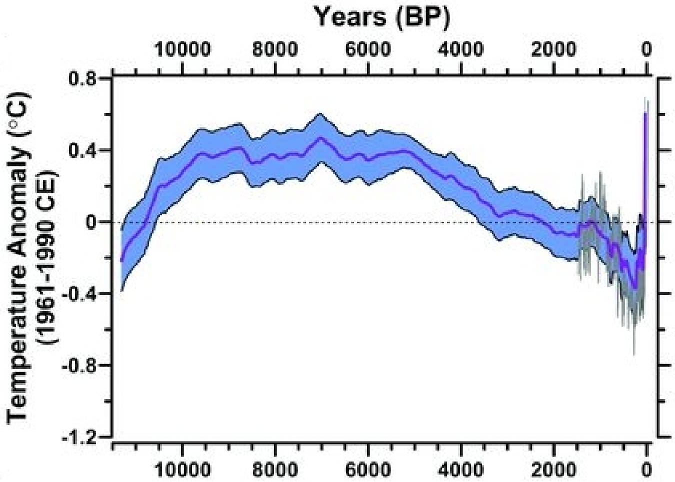
HUMAN POPULATION, IN BILLIONS



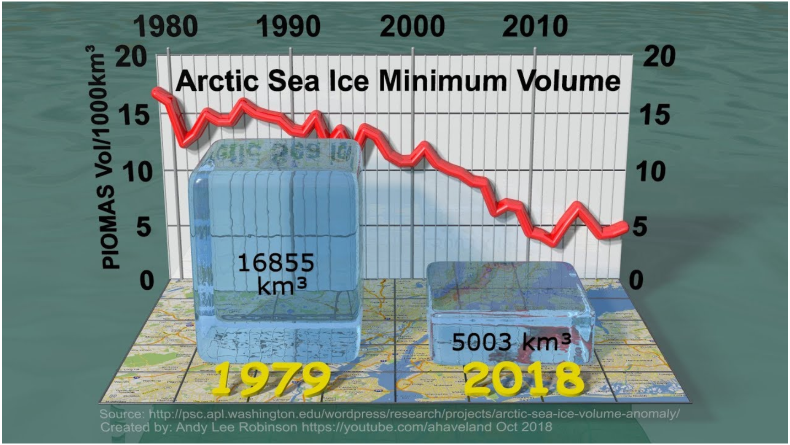
Carbon Dioxide Information Analysis Center



Antarctic ice cores and other data — Global Warming Art



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



PIOMAS data, art by Andy Lee Robinson

- About 1/4 of all chemical energy produced by plants is now used by humans.
- Humans now take more nitrogen from the atmosphere and convert it into nitrates than all other processes combined.
- 8-9 times as much phosphorus is flowing into oceans than the natural background rate.
- The rate of species going extinct is 100-1000 times the usual background rate.
- Populations of large ocean fish have declined 90% since 1950.

Vertebrate populations worldwide are dropping fast:

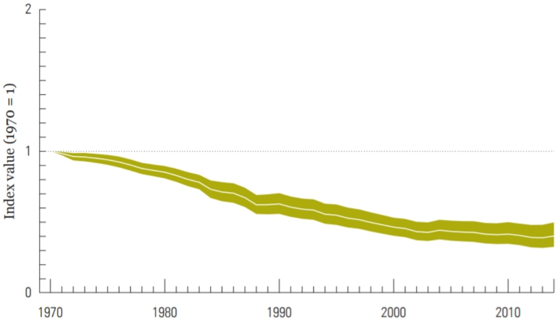


Figure 20: The Global Living Planet Index: 1970 to 2014
Average abundance of 16,704 populations representing 4,005 species monitored across the globe declined by 60%. The white line shows the index values and the shaded areas represent the statistical certainty surrounding the trend (range: -50% to -67%)[1].

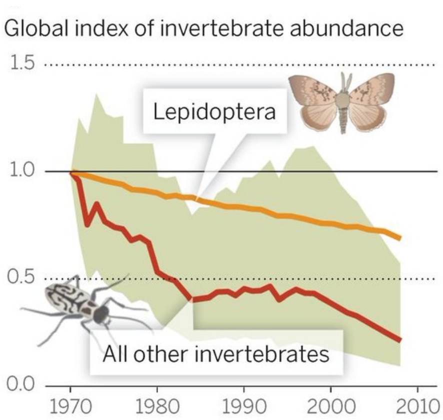
Key

Global Living Planet Index

Confidence limits

World Wildlife Fund, Living Planet Report 2018

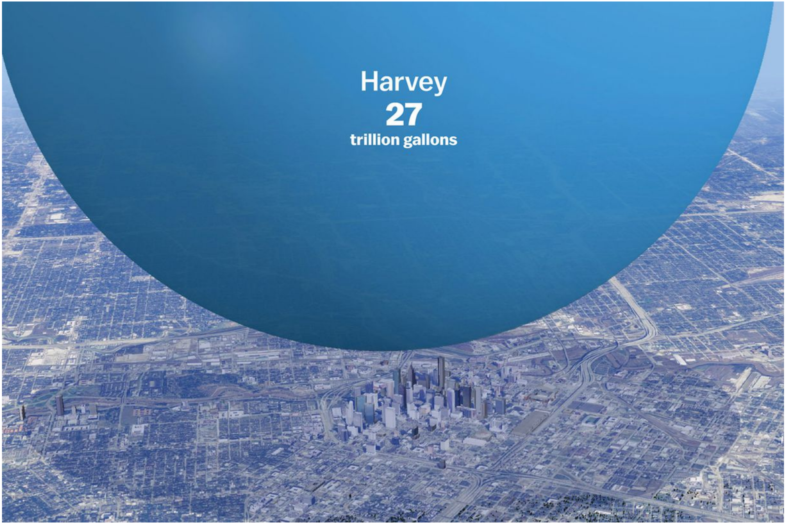
Invertebrate populations are dropping even more:



Dirzo *et al.*, Defaunation in the Anthropocene

Santa Rosa in 2017: second most destructive fire in California

Hurricane Harvey, August 2017: costliest hurricane on record.



Camp Fire, November 2018:
deadliest fire in the US since 1918.

These changes are not isolated ‘problems’ of the sort routinely ‘solved’ by existing human institutions.

They are part of a shift from the exponential growth phase of human impact on the biosphere to a new, uncharted phase.

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.

What can *everyone* do about this?

1. Study the environmental consequences of your actions. Adjust them accordingly.
For example: compute your carbon footprint.

2. Work with groups and politicians who are taking action. For example, in the US: the Green New Deal.

3. Tilt every activity toward dealing with the Anthropocene. You've got special skills and talents that can help! You can do a lot as part of your existing job!

What can *mathematicians* do?

Two easy things:

1. Teach math better.

You can instill a love of math without letting students get lost in its dream world. You can use real-world examples to illustrate important lessons: for example, no growth is forever exponential.

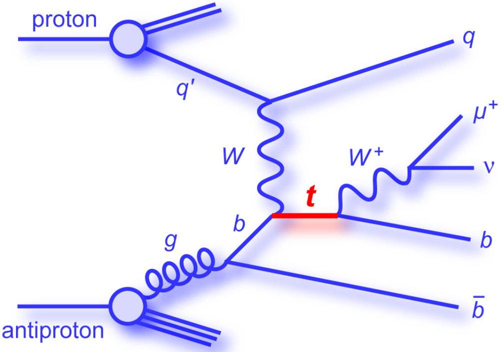
2. For academics: fly less.

A round-trip flight from LAX to Heathrow emits 1.5 tonnes of CO_2. On average, people worldwide put out 4.8 tonnes of CO_2 per capita. The jet set is killing the planet.

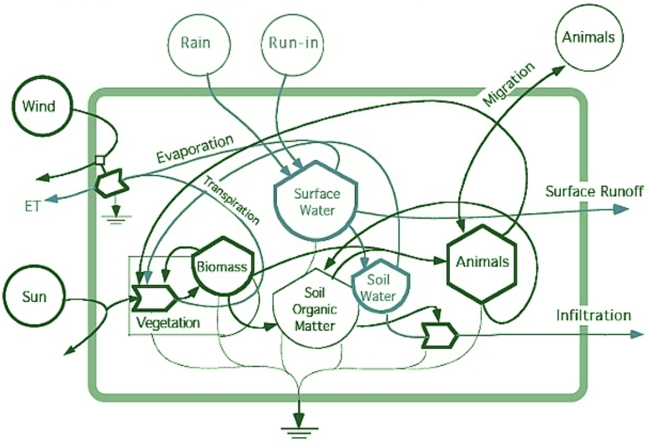
One hard thing:

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

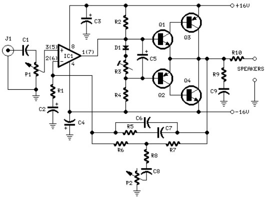
We can draw mathematical inspiration from ecosystems just as well as from particle physics... and what we discover may be more useful!

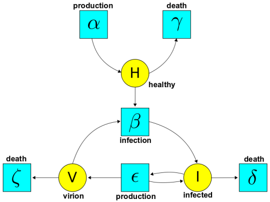


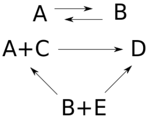
To understand ecosystems, ultimately will be to understand networks. — B. C. Patten and M. Witkamp

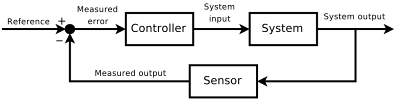


Engineers, chemists, biologists and others use many different diagram languages to describe networks:





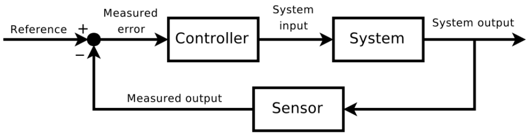


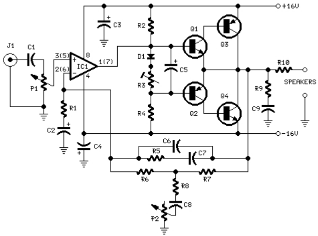


We are now unifying these with category theory!

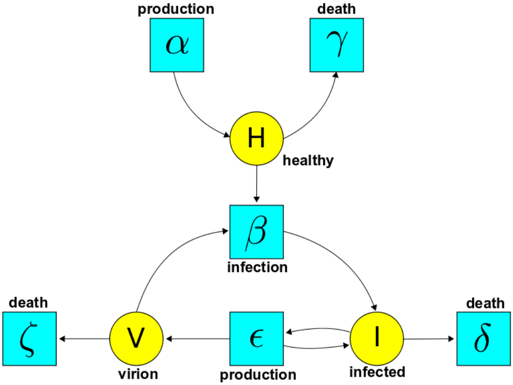
In the last 7 years we've been working on:

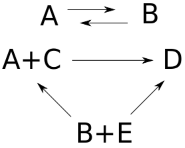
1. signal-flow graphs and electrical circuit diagrams:



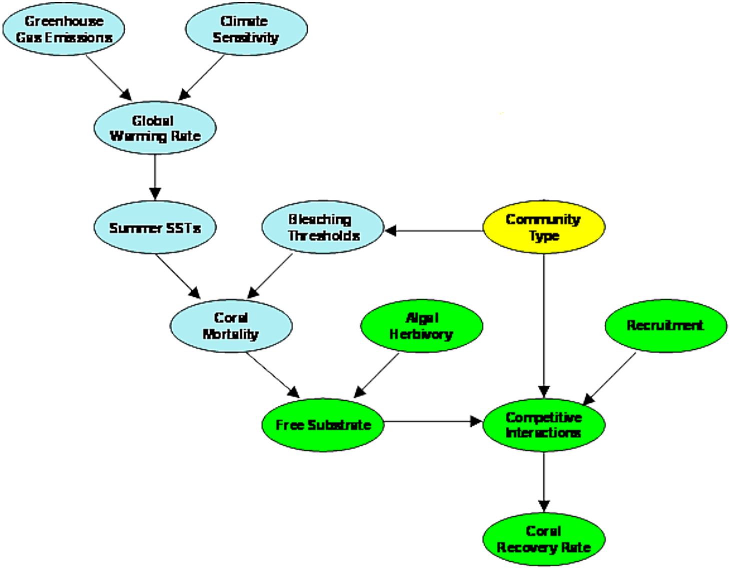


2) Petri nets and chemical reaction networks:





3) Bayesian networks and information theory:



But this is just the tip of the iceberg called “applied category theory”...

... which in turn is just a small bit of the math we need to understand biology, ecosystems, and social systems.

In this seminar we want to expand the scope of questions studied by our research group. Here are some topics we’ll discuss.

January 15: Jonathan Lorand, **Problems in symplectic linear algebra**.

Reading material:

- J. Lorand, Classifying linear canonical relations.
- J. Lorand and A. Weinstein, Decomposition of (co)isotropic relations.

January 22: Christina Vasilakopoulou, **Systems as wiring diagram algebras**.

Reading material:

- P. Schultz, D. Spivak and C. Vasilakopoulou, Dynamical systems and sheaves.
- D. I. Spivak, The operad of wiring diagrams: formalizing a graphical language for databases, recursion, and plug-and-play circuits.
- D. Vagner, D. Spivak and E. Lerman, Algebras of open dynamical systems on the operad of wiring diagrams.

January 29: Daniel Cicala, **Social contagion modeled on random networks**.

Reading material:

- M. Porter and J. Gleeson, Dynamical systems on networks: a tutorial.
- D. Watts, A simple model of global cascades on random networks.

February 5, 2019: Jade Master, **Backprop as functor: a compositional perspective on supervised learning**.

Reading material:

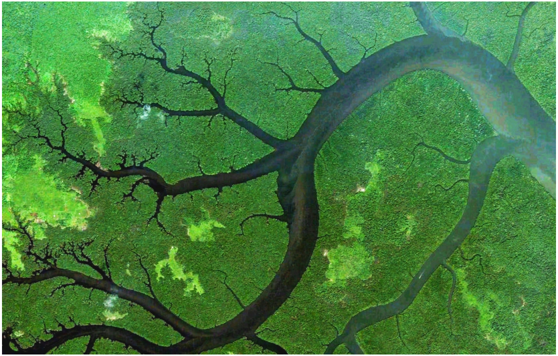
- B. Fong, D. Spivak and R. Tuyéras, Backprop as functor: a compositional perspective on supervised learning.

February 5, 2019: Christian Williams, **The pi calculus: towards global computing**

Reading material:

- Robin Milner, The polyadic pi calculus: a tutorial.
- Robin Milner, *Communicating and Mobile Systems*.
- Joachim Parrow, An introduction to the pi calculus.

I hope you attend and help us figure things out!



For more details, click on links in green in these slides, which you can get here:

http://tinyurl.com/planet-ucr