

Institutional scalability and a complex systems view of sustainability

Ryan Taylor

REU, Summer 2017
and Summer 2018



[audience]

Roughly 75 people

- Rich alumni and maybe even science board members
- Postdoc and summer school alumni, wanting to reconnect
- Bonus: staff and some faculty

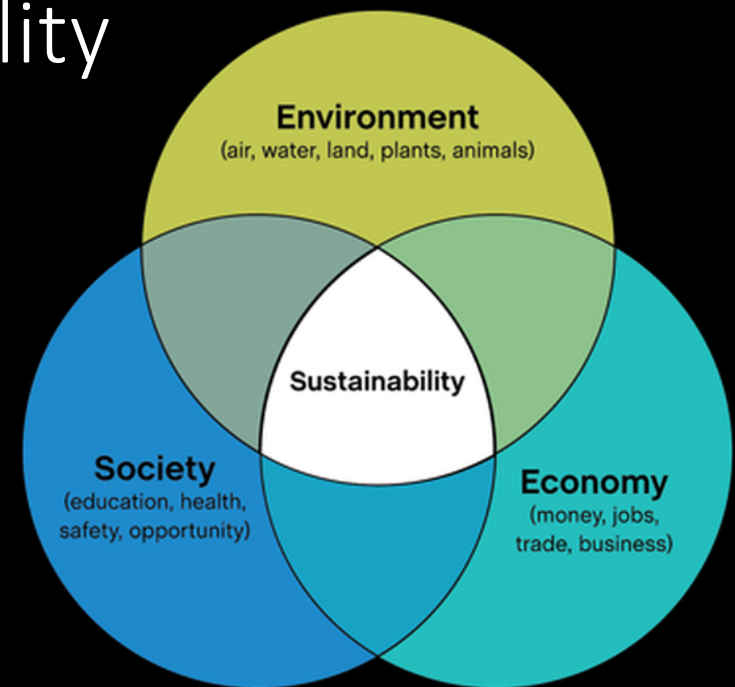
[purposes]

- Explain appreciation for Santa Fe Institute, in a way that is interesting
 - Personal perspective
 - A story. Collaboration, out of field | meeting tons of people
 - Concluding with my impression of SFI community and culture
- Share my passion for complex systems science
 - our work on institutional scaling, story?
 - Our scaling method: examining the effect of scale, crossing levels
 - Our main results: fundamentally different institutional types, unique roles
 - Connecting sustainability, complex systems, evolutionary political economy
 - application to sustainability challenges

My background in sustainability

UN Brundtland Commission 1987

UN Sustainable Development Goals 2015




- Goal and solution oriented
- Builds on many other frameworks

My background in sustainability ...how to approach solutions?

- Technological innovation
- Markets – let private sector coordinate
- Policy – administered by public institutions
- Social movements – individual behavior change
- Historical / transformational – cultural shifts



My background in sustainability ...how to approach solutions?


- 
- Technological innovation
 - Markets – let private sector coordinate
 - Policy – administered by public institutions
 - Social movements – individual behavior change
 - Historical / transformational – cultural shifts



(1) exists on a political
spectrum

(2) intervention at different
levels of complexity

BUT DOES IT SCALE???

- 
- Technological innovation
 - Markets – let private sector coordinate
 - Policy – administered by public institutions
 - Social movements – individual behavior change
 - Historical / transformational – cultural shifts



(1) exists on a political
spectrum

(2) intervention at different
levels of complexity

Sustainability! Complexity!

A few related concepts:

- Multiple scales, hierarchy
- Nonlinearity, feedbacks, dynamics
- Self-organization: collective action problems → game theory
- Markets and institutions as information processors...

Summer 2017 REU!!!



Project team



Xiaofan Liang
Minerva Schools



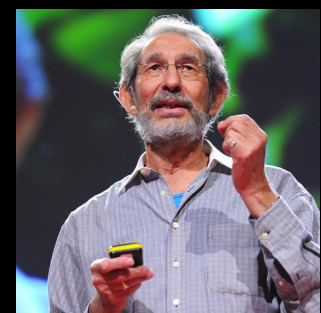
Marion Dumas
SFI, LSE



Chris Kempes
SFI-ASU



Manfred Laubichler
ASU-SFI



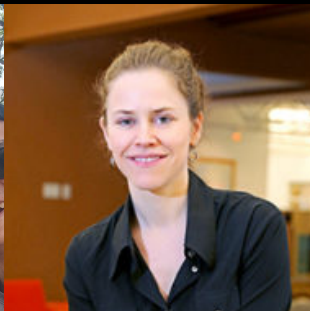
Geoffrey West
SFI

The Scalability, Efficiency and Complexity of Universities and Colleges:
A New Lens for Assessing Tradeoffs in Higher Education

Project team



Xiaofan Liang
Minerva Schools



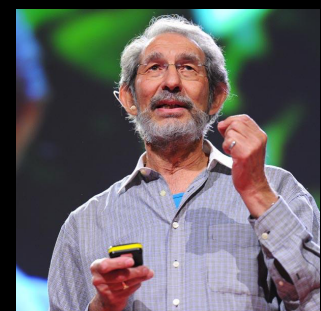
Marion Dumas
SFI, LSE



Chris Kempes
SFI-ASU



Manfred Laubichler
ASU-SFI



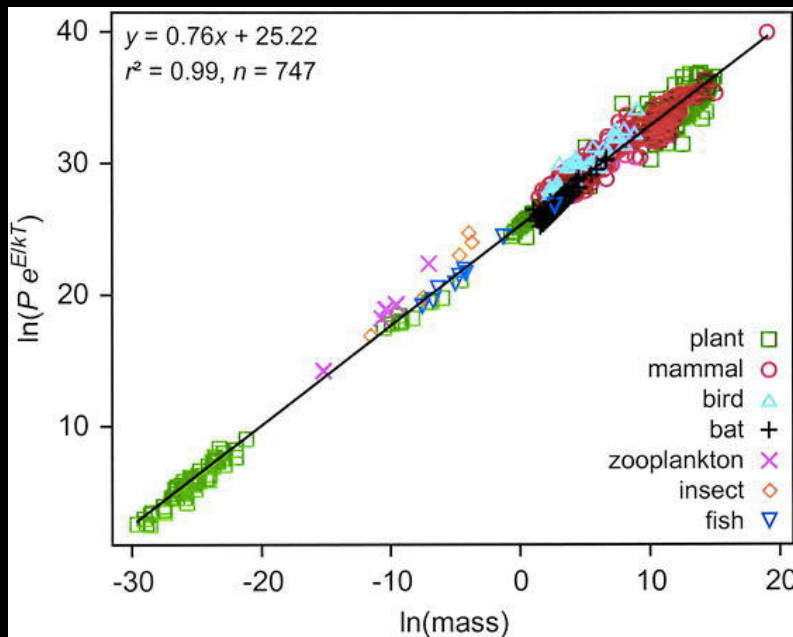
Geoffrey West
SFI

The Scalability, Efficiency and Complexity of Universities and Colleges:
A New Lens for Assessing Tradeoffs in Higher Education

Size and function – scaling framework

Metabolic rate
vs mass

$$\alpha \approx 3/4$$



Brown et al., *Ecology*, 2004

$$Y = aX^\alpha$$



α is the **slope** of the fitline and scaling exponent

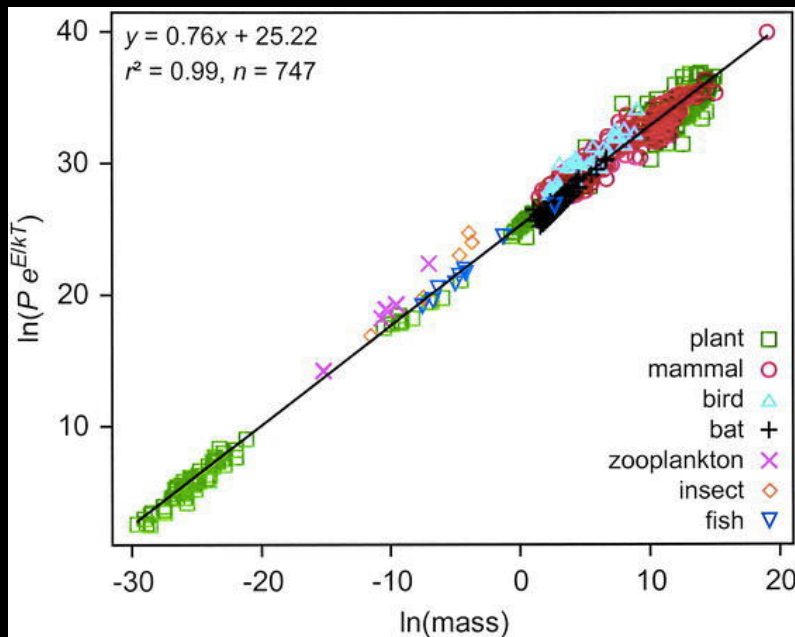
$\alpha > 1.05$: increasing (superlinear)

$\alpha = 1$: constant (linear)

$\alpha < 0.95$: decreasing (sublinear)

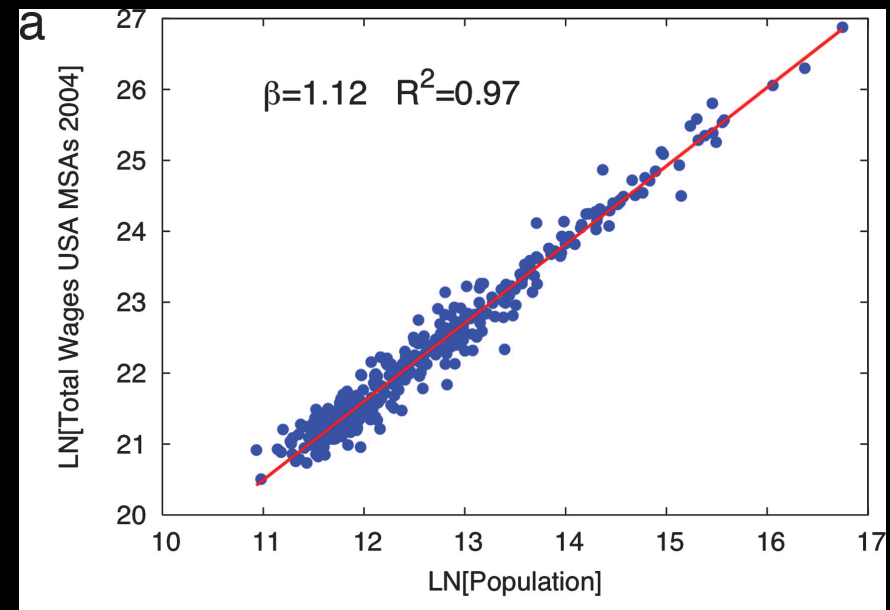
Size and function – scaling framework

Metabolic rate
vs mass $\alpha \approx 3/4$



Brown et al., *Ecology*, 2004

Total Income
vs population $\alpha \approx 7/6$



Bettencourt et al., *PNAS*, 2007

Size and function – scaling framework

- Reveals underlying mechanisms, e.g. network optimization.



West, Brown and Enquist, *Science*, 1997

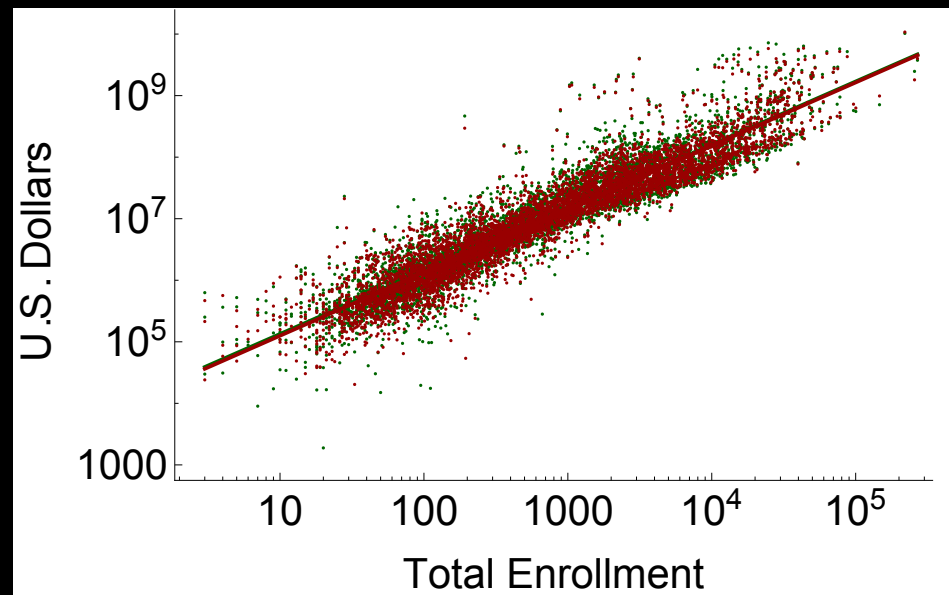


Bettencourt, *Science*, 2013

Size and function – university scaling






Revenues and expenditures
versus total enrollment

$$\alpha \approx 1$$



Total Revenue	Total Expenditure
1.03 ± 0.01	1.03 ± 0.01

University sectors

Sector name	Control	Level	N schools	Selected examples
Public Research Universities	Public	4yr+, Doc	160	
Private Research Universities	Private N-P	4yr+, Doc	103	
State Colleges	Public	4yr+	394	 The California State University
Community Colleges	Public	2yr	912	
Non-Profit Private Colleges	Private N-P	4yr+	1,389	Seminaries, liberal arts (St. Johns)
For-Profit Colleges	For-Profit	4yr+	669	
Professional Schools	For-Profit	2yr, 2yr-	2,225	Beauty schools, nursing programs

University scaling: financial flows

Sector name	Total Revenue	Total Expenditure
Public Research Universities	1.29 ± 0.14	1.27 ± 0.13
Private Research Universities	1.22 ± 0.24	1.19 ± 0.23
State Colleges	0.80 ± 0.05	0.79 ± 0.05
Community Colleges	0.81 ± 0.02	0.83 ± 0.02
Non-Profit Private Colleges	0.98 ± 0.03	0.95 ± 0.02
For-Profit Colleges	0.98 ± 0.03	0.87 ± 0.03
Professional Schools	1.02 ± 0.02	1.05 ± 0.02

Interpreting the scaling exponent:

$\alpha > 1.05$: increasing (superlinear)

$\alpha \sim 1$: constant (linear)

$\alpha < 0.95$: decreasing (sublinear)

University scaling: financial flows

Sector name	Total Revenue	Total Expenditure
Public Research Universities	2	2
Private Research Universities	2	2
State Colleges	0	0
Community Colleges	0	0
Non-Profit Private Colleges	1	1
For-Profit Colleges	1	0
Professional Schools	1	1

Coarse coding for scaling exponent:

2: increasing (superlinear)

1: constant (linear)

0: decreasing (sublinear)

University scaling: outcomes

Coarse coding:
 0 decreasing (sublinear)
 1 constant (linear)
 2 increasing (superlinear)

Purpose area	Level of education	Educational Performance	Affordability	Non-educational functions	Financial Performance
Outcome scaling measure	Level (up to Doctoral)	Completions	Net tuition	<i>No outcome variables. Research exp. shown</i>	Profit margin (rev. scaling – exp. scaling)
Public research universities	4yr+, Doc.	2	0	2	1
Private research universities	4yr+, Doc.	2	0	2	1
State colleges	4yr+	2	1	-	1
Community colleges	2yr	1	2	-	1
Non-profit private colleges	4yr+	1	0	-	1
For-profit colleges	4yr+	-	1	-	2
Professional schools	2yr, 2yr-	1	0 or 1	-	1

Relevance at multiple levels of complexity

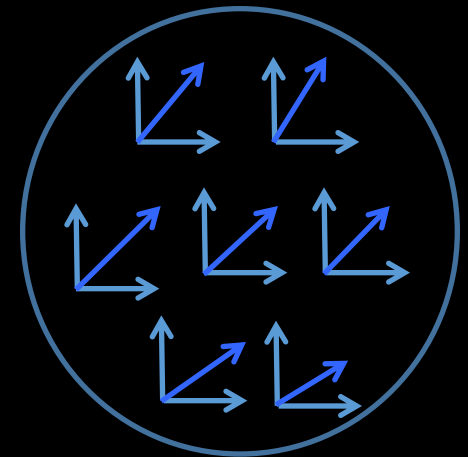
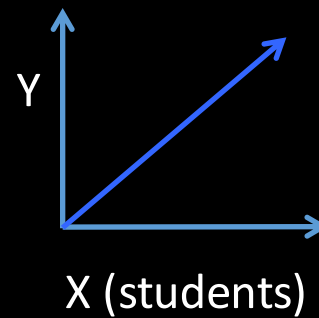
I. Students:
college search



II. Institutions:
growth strategies



III. Sector and IV. System-wide:
policy for scaling up



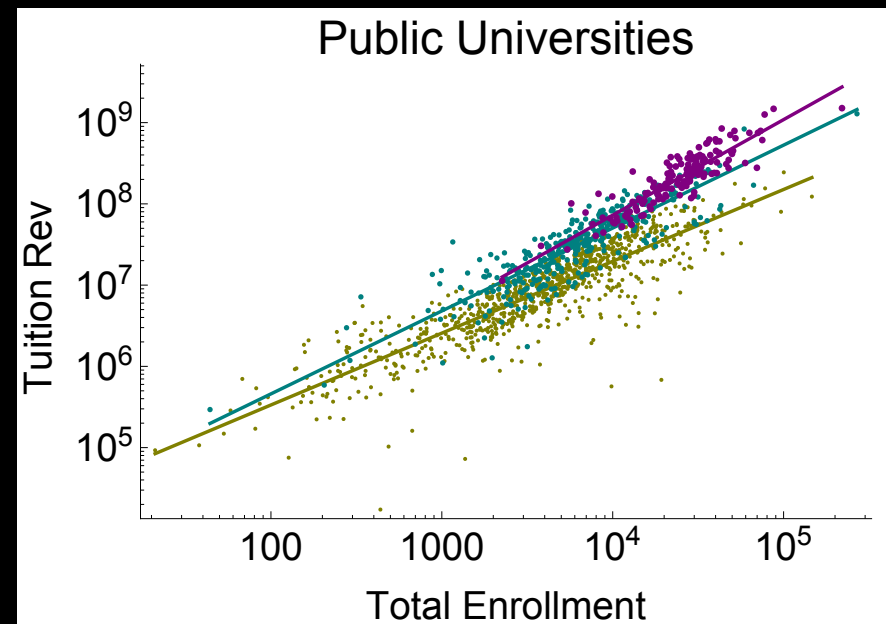
... toward a science of institutional scaling

1. Universities exhibit scaling
2. Diverse ecology of institutions
Institutional design can change the scaling.

— Community Colleges $b: 0.88 \pm 0.03$

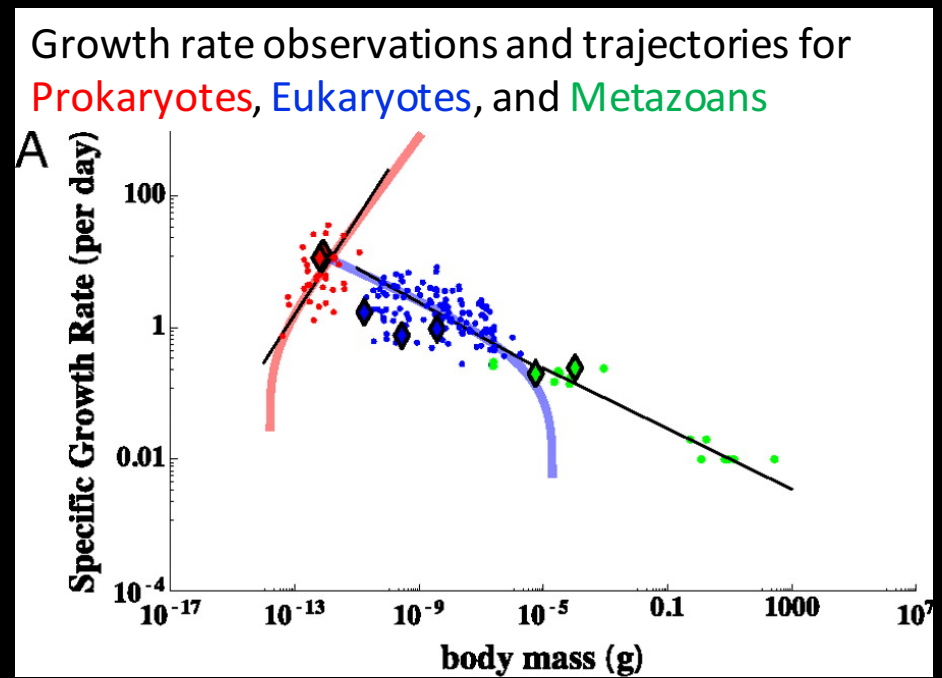
— State Colleges $b: 1.02 \pm 0.06$

— Public Research Universities $b: 1.18 \pm 0.09$



... toward a science of institutional scaling

1. Universities exhibit scaling
2. Diverse ecology of institutions
Institutional design can change the scaling.
3. Suggests evolutionary constraints



Kempes et al, *PNAS*, 2012

... toward a science of institutional scaling

1. Universities exhibit scaling
2. Diverse ecology of institutions
Institutional design can change the scaling.
3. Suggests evolutionary constraints

Development as the process by which we evolve our institutions (or organizations)

What more can we learn about the physiology of institutions to help sustainable development?

Thank you!

Special acknowledgments:

Xiaofan Liang

Paul Hooper

Chris Kempes

Carla Shedy

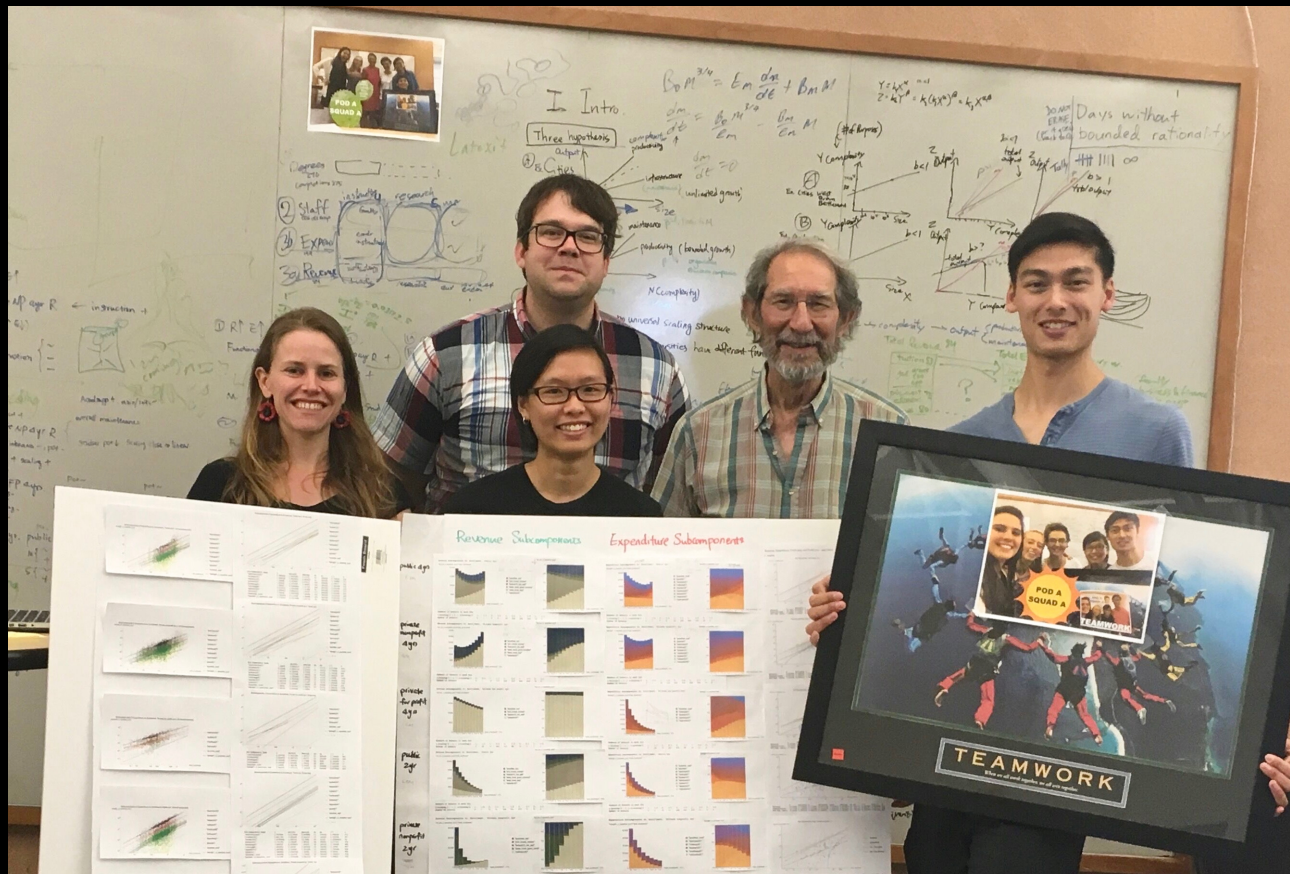
Marion Dumas

JP Gonzales

Manfred Laubichler

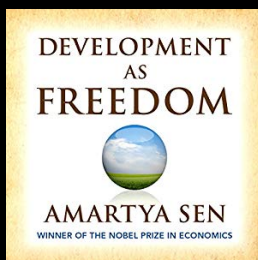
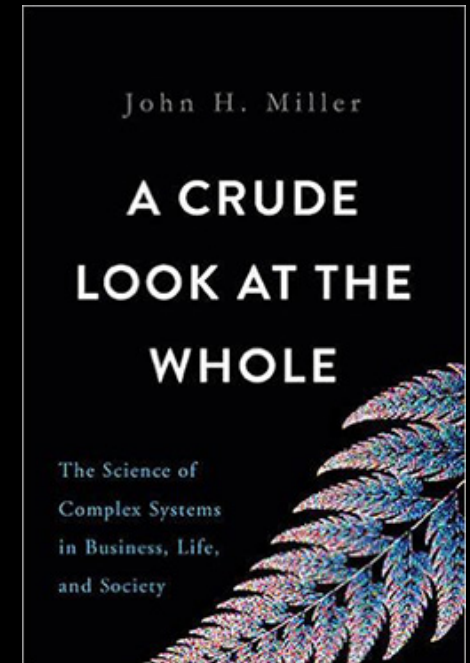
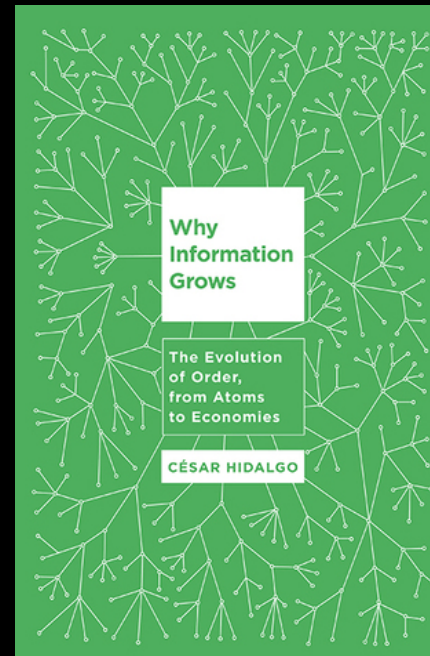
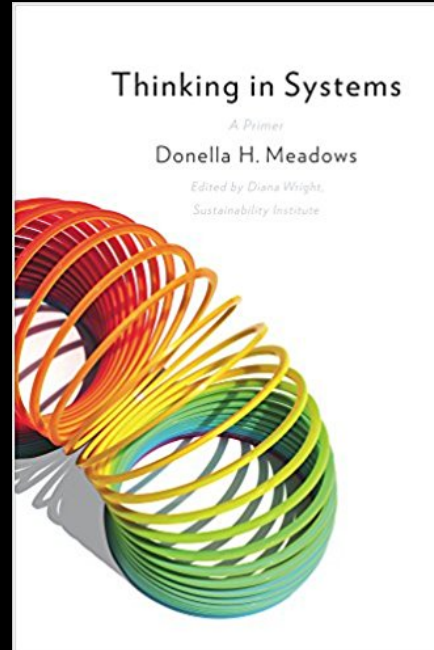
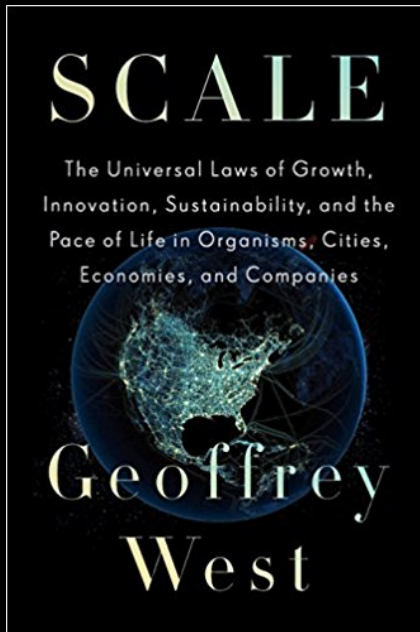
Geoffrey West

Cate Heine



Teamwork | When we all work together, we all win together

Books



+ COMPLEXITY by Melanie Mitchell!!!

+ THE ORIGIN OF WEALTH by Eric Beinhocker