

Welcome to our opening day of
Japan(JSPS)-Korea(NRF)
bilateral project
on

*“Self-organization and robustness of
evolving many-body systems”*
(2016-17, mutual visit every year)

The road to this bilateral project

mid-winter of 2013



The road to this bilateral project

2014: SMSEC & AICS symp.



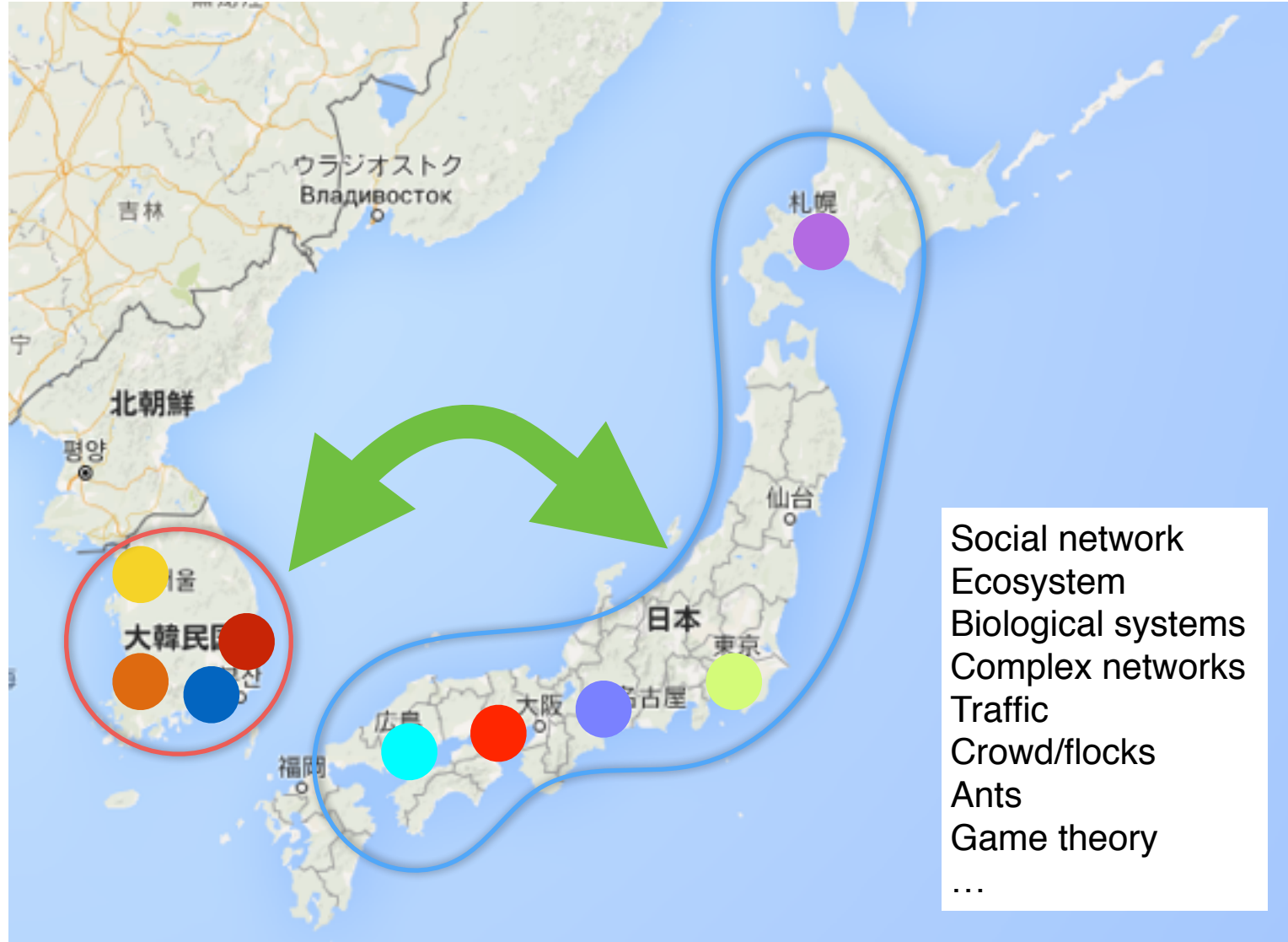
The road to this bilateral project

2015: PoSCo



The road to this bilateral project

2016-17: mutual visit on Physics of Social&Non-Social Complexity



So let the meeting open,
and spare time for
questions, discussions, & chats!

It's a ***workshop***,
not a ***talkshop***!



prof. D. P. Landau

On the Robustness of Evolving Open Systems

Takashi Shimada

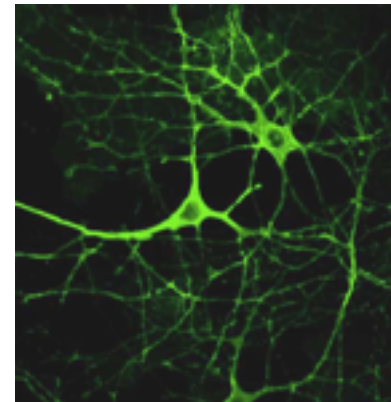
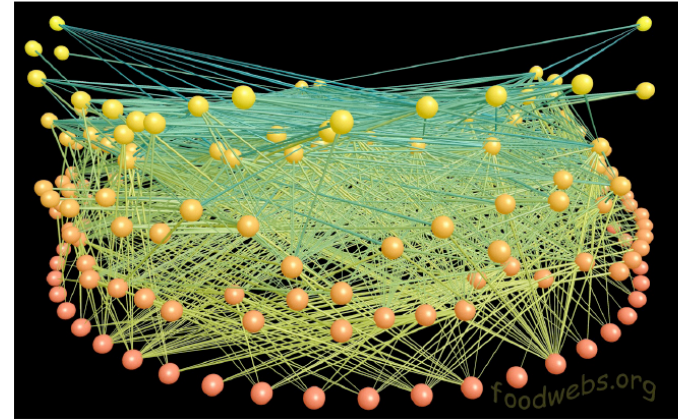
Dept. of Applied Physics, Grad. School of Engineering, The University of Tokyo



Can an ***Evolving Open System*** grow by adding new elements to it?

- ecosystems
- living organisms (evolutionary time scale)
- biological/artificial neural networks (development)
- social communities & market
- ...

El Verde Rainforest (located in the Caribbean National Forest in Puerto Rico)



(Nature **464**, 1025 (2010))

“Will a large complex system be stable?”



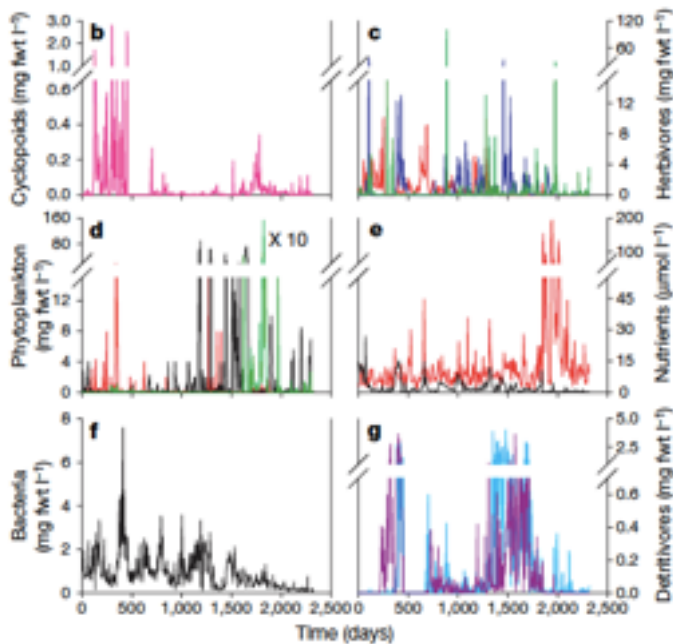
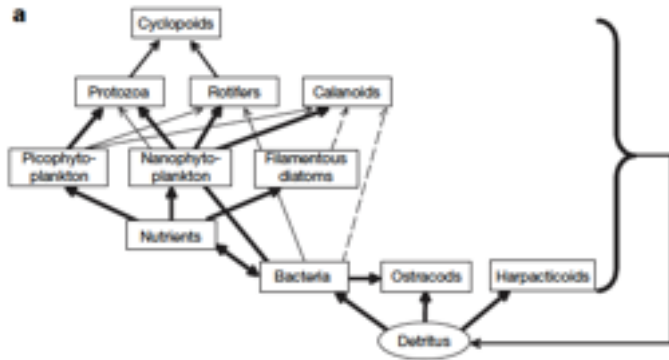
theory (1972)

$$S: \begin{pmatrix} 0 & r_1 & \cdots & 0 \\ -1 & 0 & \cdots & 0 \\ r_2 & -1 & \cdots & r_3 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & r_M & \cdots & -1. \end{pmatrix}$$

(from Walter Wick Studio)

Standard questions: any ecosystem-specific secret? structuring?

“Ecosystem” is hardly stationary



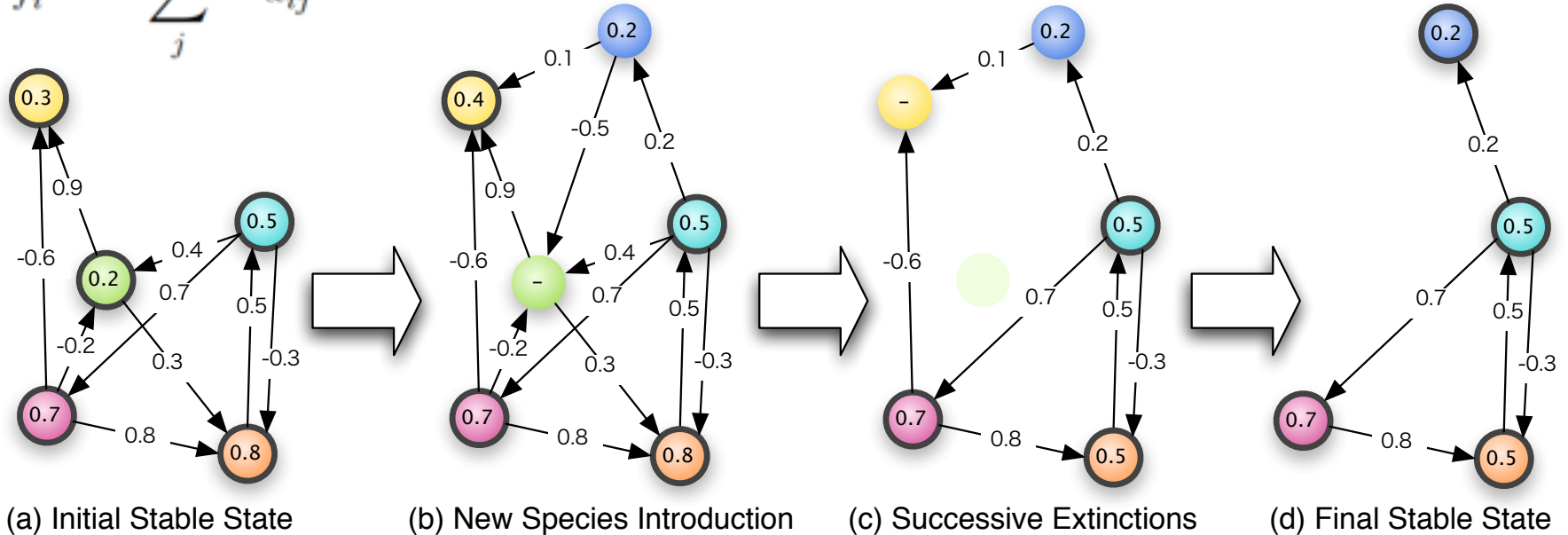
- nonlinear
(especially near extinctions)
- can be chaotic
- noise
- ...

*“Apparently, stability is not required
for the persistence of complex food webs.”*

“Chaos in a long-term experiment with a plankton community” E. Beninca et al., Nature vol. 451, 822 (2008)

The (eco-/bio-/econo-/**socio**-systems inspired) Model

$$f_i = \sum_j^{\text{incoming}} a_{ij}$$



1. Every species must have positive fitness: $f_i = \sum_j^{\text{in}} a_{ij} > 0$ otherwise that goes extinct
2. Once the system gets stable, a new species comes with m new interactions:
 - ▶ to/from random resident species
 - ▶ a_{ij} is drawn from the standard distribution (random, mean 0)



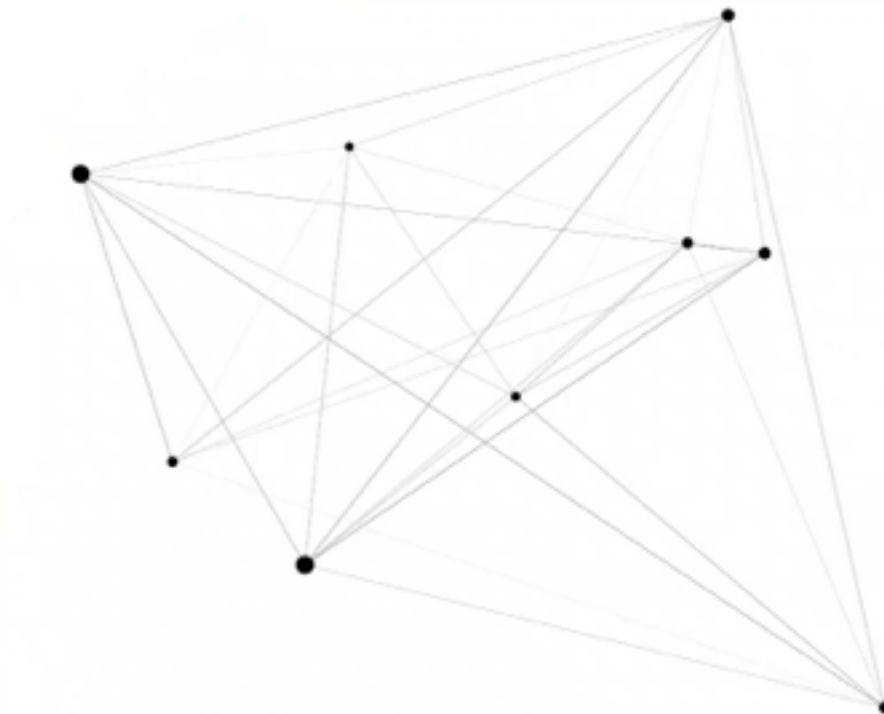
m (# of interactions per new species): the only one parameter

The question

addition process: neutral

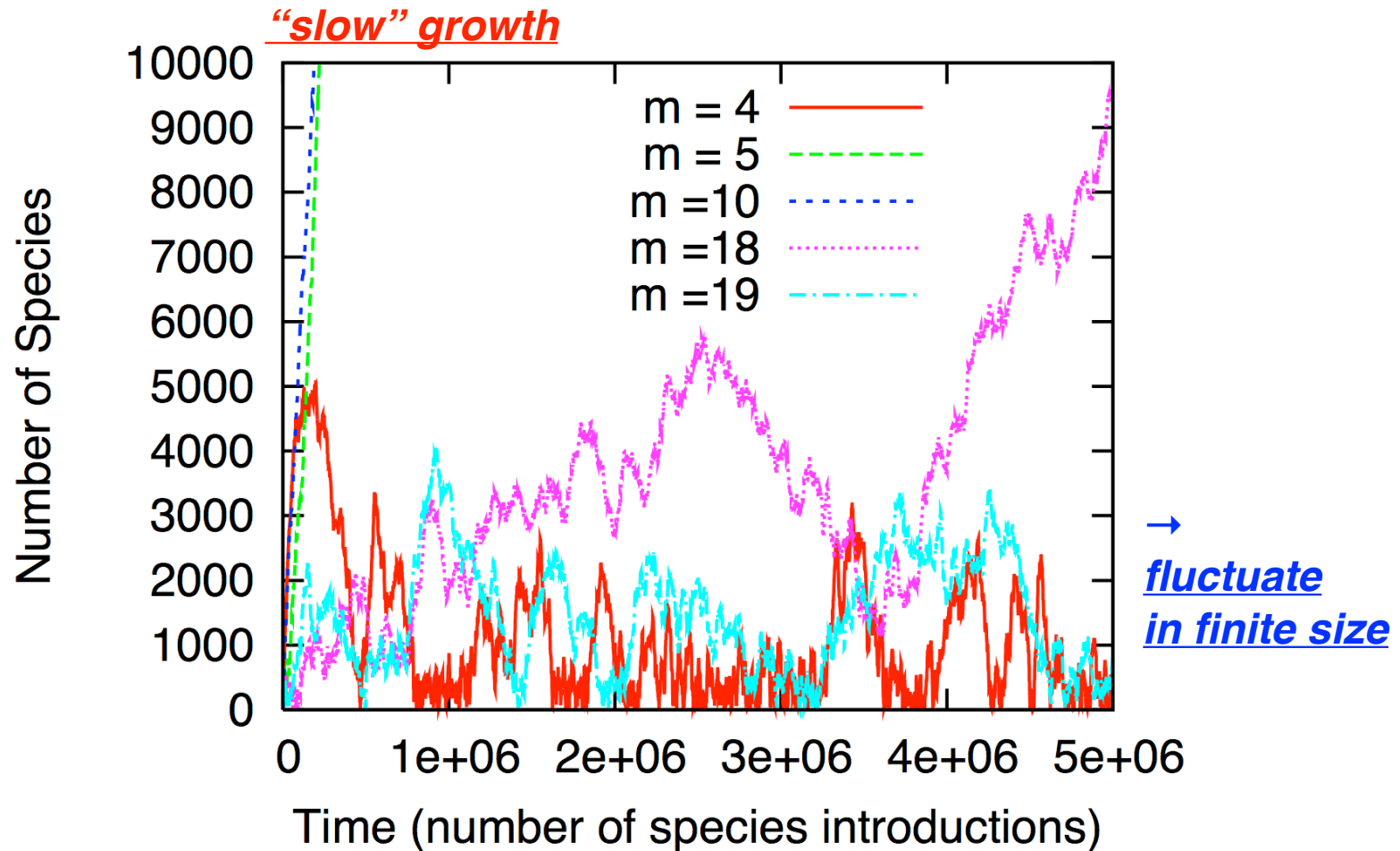
deletion process: neutral

Can this system grow?



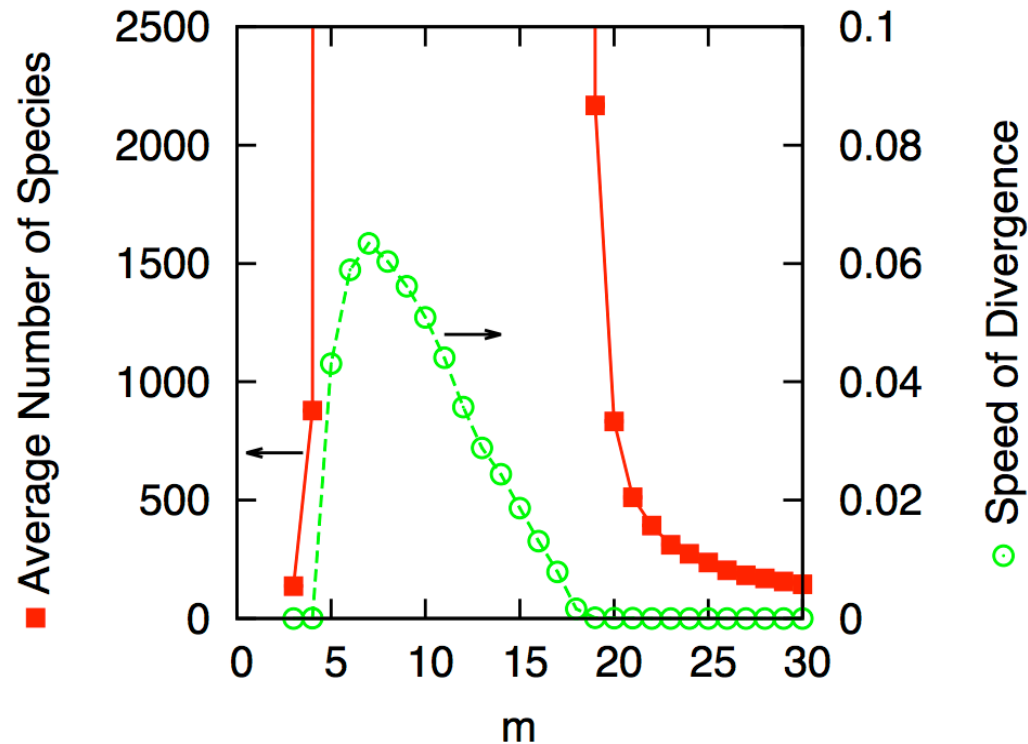
$M = 10$
 $\epsilon = 0$
 $n = 10$

Answer: both can happen



as m increases, # of species is: finite \rightarrow diverging \rightarrow finite

Transitions in the growing behavior



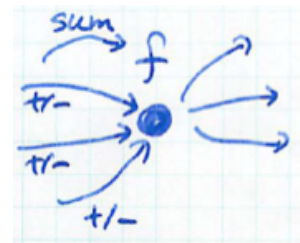
Why the nontrivial transition at $m_c = 18.5$?



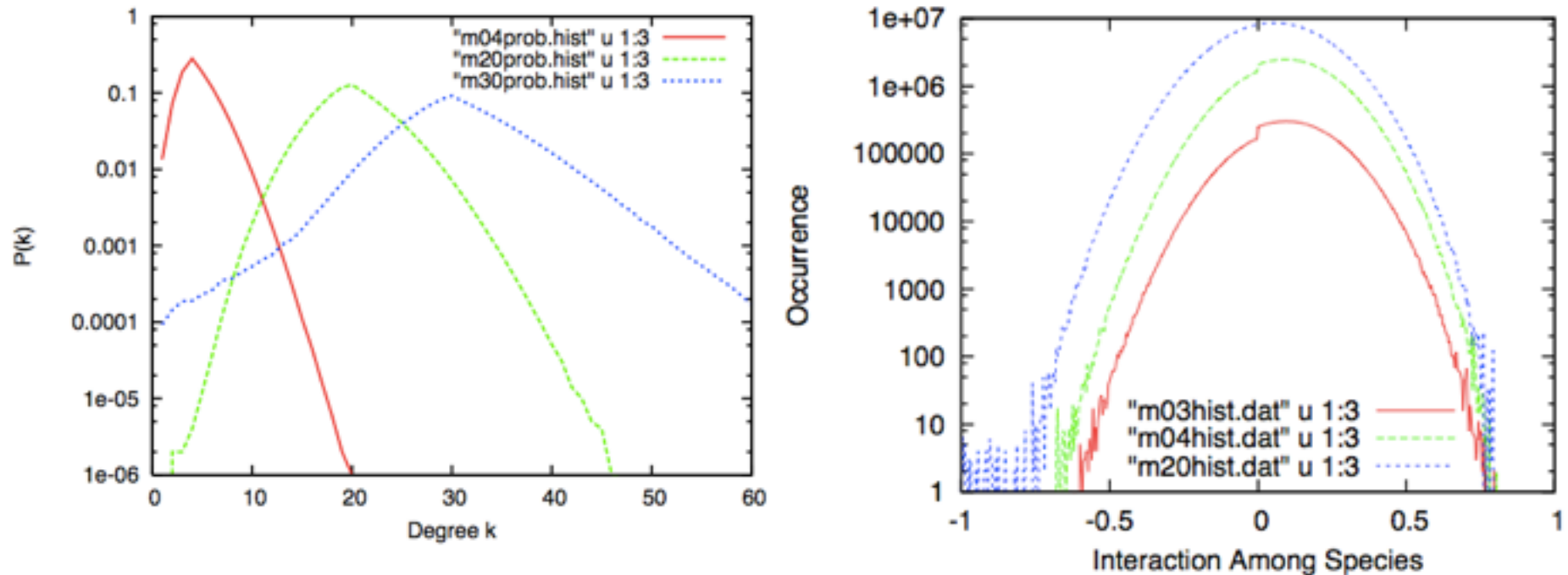
(the transition at $m_c = 4.5$ is easy)



average # of in-degree with positive value is 1 for $m=4$
 → The web is tree-like and very fragile



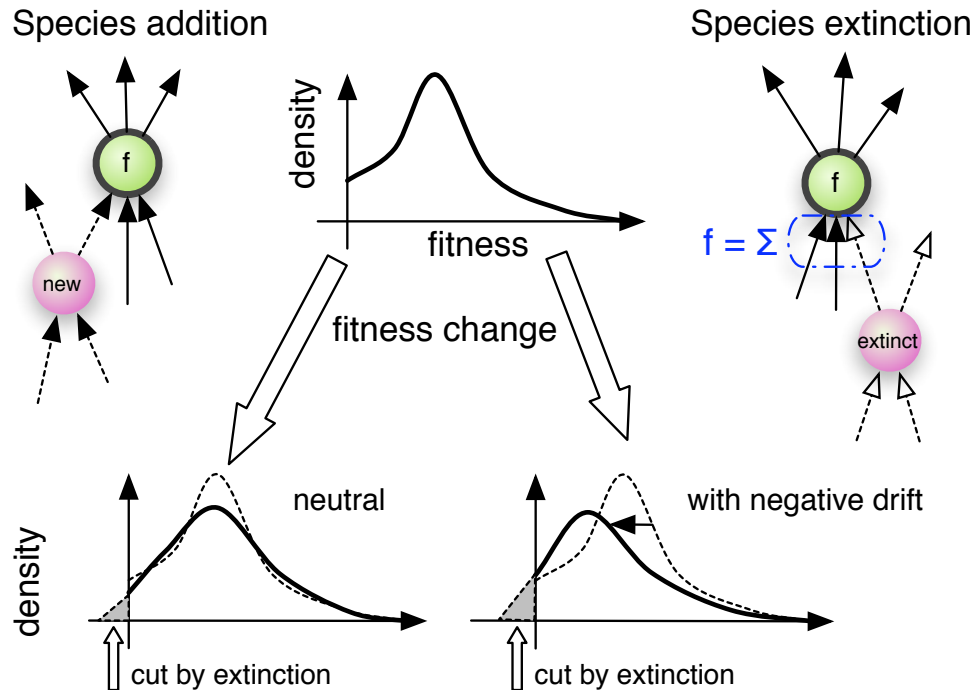
A clue to understanding the mechanism: no prominent structuring



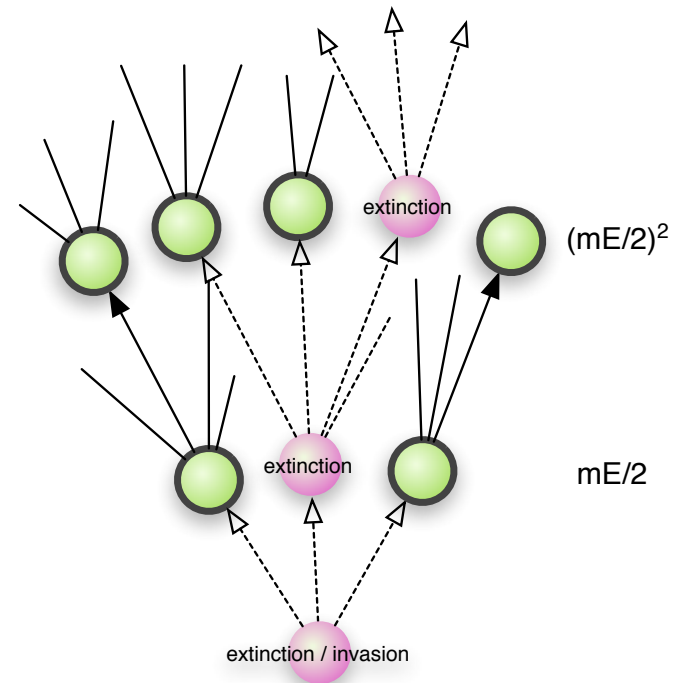
Both degree distribution and fitness distribution indicate that the emergent system is almost like a random net
(looks little to do with complex network properties)

A mean field picture:

successive convolution-and-cut process on fitness distribution function

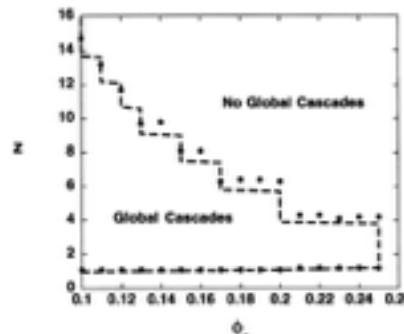


(a) Changes in the fitness distribution during species addition/extinction



(b) Extinction Cascade

$$N_E = \sum_{n=1}^{\infty} \left(\frac{mE}{2}\right)^n = \frac{mE}{2-mE}$$



(cf. "global cascade" Duncan J. Watts, PNAS Vol. 99, pp. 5766-5771 (2002))

Semi-analytical estimation of the transition point

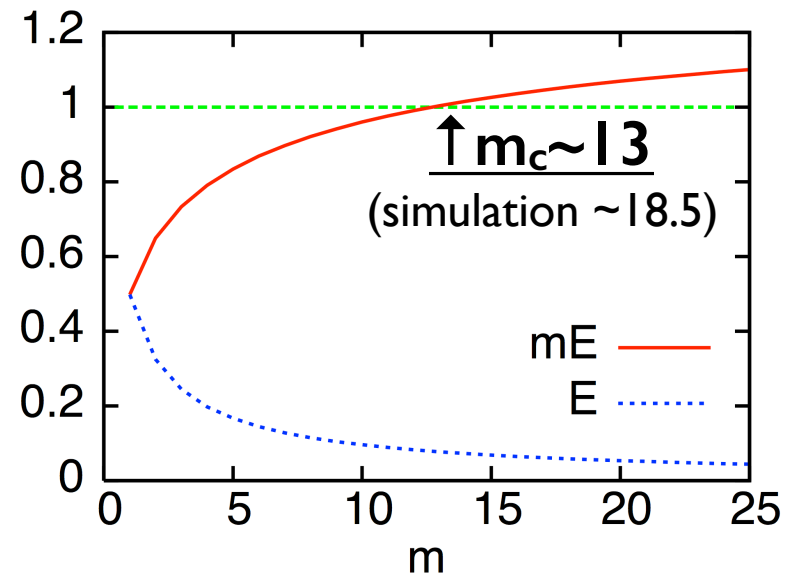
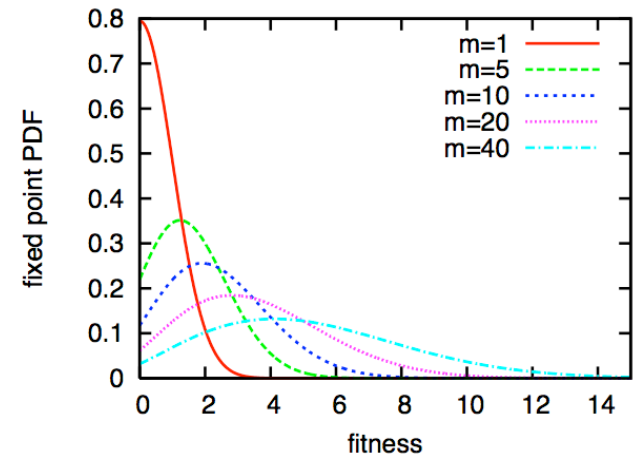
$$F_0(m, x) = \begin{cases} 0 & (x \leq 0) \\ 2G(\sqrt{\frac{m}{2}}, x) & (x > 0) \end{cases}$$

$$F_{g+1}(m, x) = \begin{cases} 0 & (x \leq 0) \\ \int_0^\infty \beta^{-1} F_g(m, \beta^{-1} \xi) G(1, x - \xi) d\xi & (x > 0) \end{cases}$$

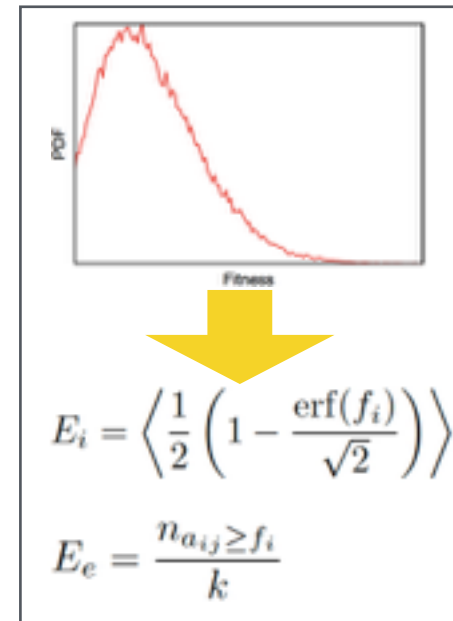
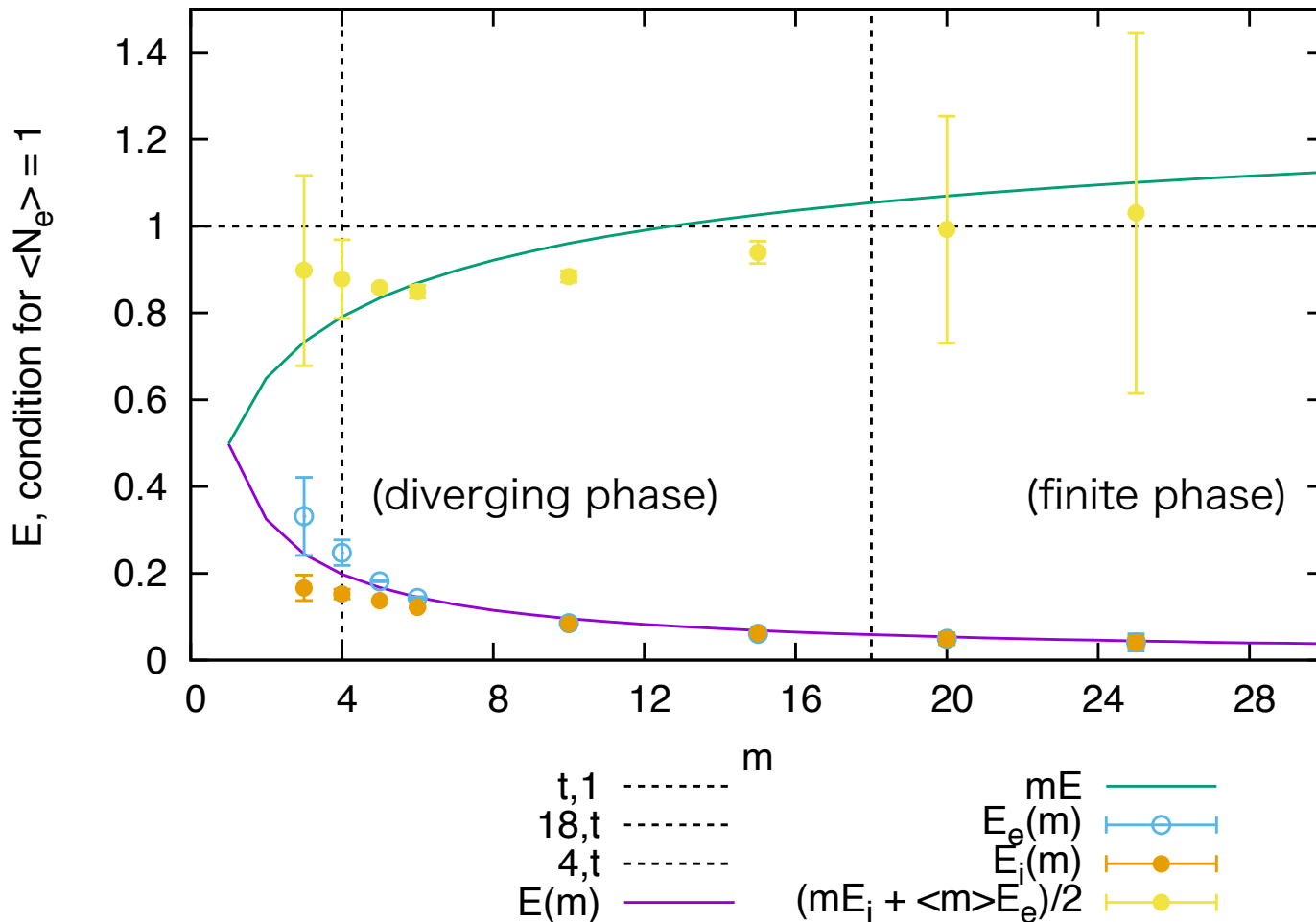
$$\beta = \frac{m-1}{m}$$

$$E(m) = \frac{\sum_{g=0}^{\infty} n_g(m) E_g(m)}{\sum_{g=0}^{\infty} n_g(m)} = \frac{1}{\sum_{g=0}^{\infty} n_g(m)}$$

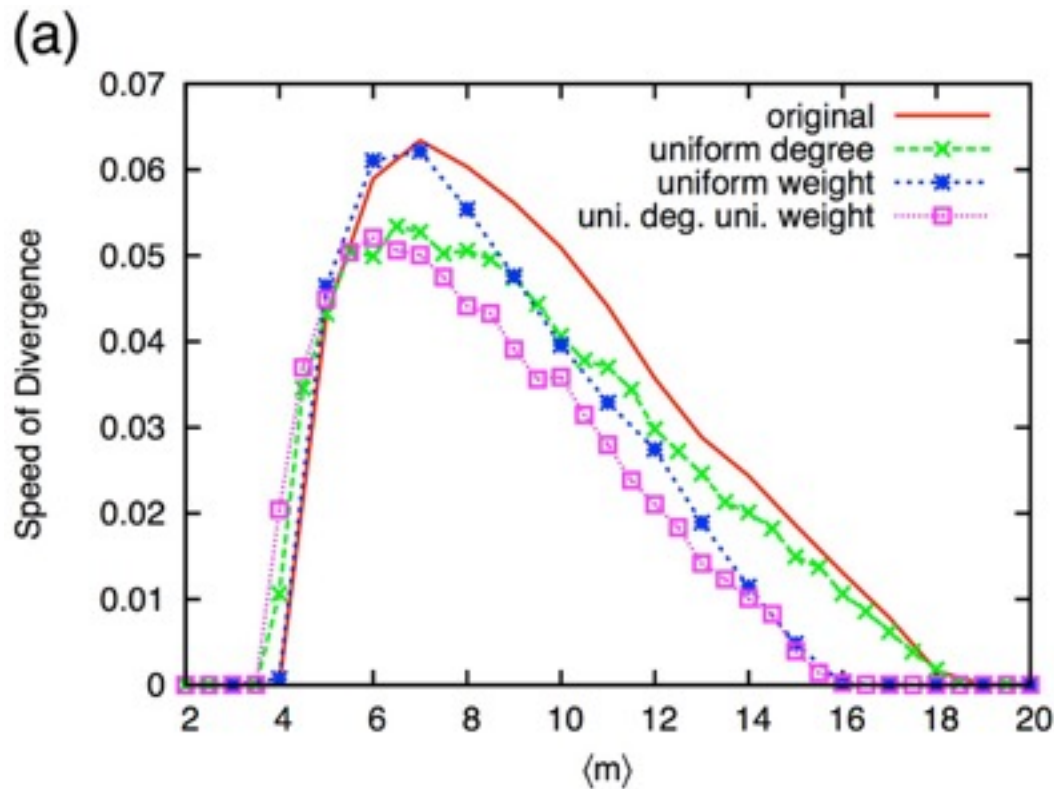
$$n_g(m) = \int_0^\infty F_g(m, x) dx$$



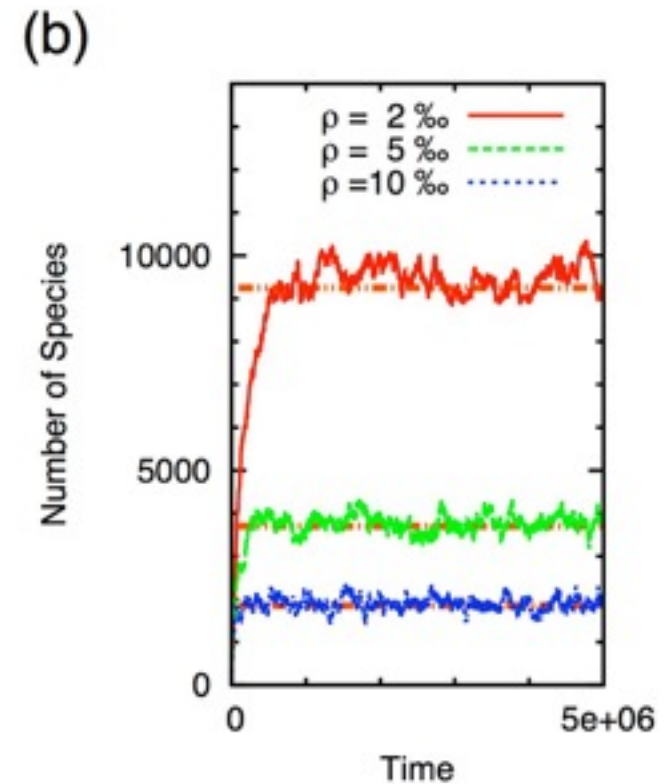
Mean-field estimation of m_c from real fitness distributions



The transition is universal among variant models



(a) Slightly modified models share the same phase portrait



(b) Giving an interaction **density**:
 $N(t) \sim N^* = 18.5/\rho$

A possible origin of the sparseness of real complex systems ($\langle k \rangle \ll N$)?

Network	Size	$\langle k \rangle$	κ	γ_{out}	γ_{in}	ℓ_{real}	ℓ_{rand}	ℓ_{pow}	Reference	Nr.
WWW	325,729	4.51	900	2.45	2.1	11.2	8.32	4.77	Albert, Jeong, Barabási 1999	1
WWW	4×10^7	7		2.38	2.1				Kumar <i>et al.</i> 1999	2
WWW	2×10^5	7.5	4,000	2.72	2.1	16	8.85	7.61	Broder <i>et al.</i> 2000	3
WWW, site	260,000				1.94				Huberman, Adamic 2000	4
Internet, domain*	3,015 - 4,389	3.42 - 3.76	30 - 40	2.1 - 2.2	2.1 - 2.2	4	6.3	5.2	Faloutsos 1999	5
Internet, router*	3,888	2.57	30	2.48	2.48	12.15	8.75	7.67	Faloutsos 1999	6
Internet, router*	150,000	2.66	60	2.4	2.4	11	12.8	7.47	Govindan 2000	7
Movie actors*	212,250	28.78	900	2.3	2.3	4.54	3.65	4.01	Barabási, Albert 1999	8
Coauthors, SPIRES*	56,627	173	1,100	1.2	1.2	4	2.12	1.95	Newman 2001b,c	9
Coauthors, neuro.*	209,293	11.54	400	2.1	2.1	6	5.01	3.86	Barabási <i>et al.</i> 2001	10
Coauthors, math*	70,975	3.9	120	2.5	2.5	9.5	8.2	6.53	Barabási <i>et al.</i> 2001	11
Sexual contacts*	2810			3.4	3.4				Liljeros <i>et al.</i> 2001	12
Metabolic, E. coli	778	7.4	110	2.2	2.2	3.2	3.32	2.89	Jeong <i>et al.</i> 2000	13
Protein, S. cerev.*	1870	2.39		2.4	2.4				Mason <i>et al.</i> 2000	14
Ythan estuary*	134	8.7	35	1.05	1.05	2.43	2.26	1.71	Montoya, Solé 2000	14
Silwood park*	154	4.75	27	1.13	1.13	3.4	3.23	2	Montoya, Solé 2000	16
Citation	783,339	8.57			3				Redner 1998	17
Phone-call	53×10^6	3.16		2.1	2.1				Aiello <i>et al.</i> 2000	18
Words, cooccurrence*	460,902	70.13		2.7	2.7				Cancho, Solé 2001	19
Words, synonyms*	22,311	13.48		2.8	2.8				Yook <i>et al.</i> 2001	20

“Statistical Mechanics of Complex Networks” R. Albert and A.-L. Barabasi (2001)

- Gene Regulatory Networks
E. Coli: 2.5~4.5, Yeast: 3~8, 27, Arabidopsis thaliana: 5~14
- Brain: log-normal synaptic weights
- (R. May’s linear stability condition: $\langle k \rangle \sim 1$)

Summary

- Another scenario for the complexity-robustness relation, especially for dynamic systems (Gardner & May's, and also SOC, network structure,...)
- Balance effect causes the transition: denser interaction is better for each species, but not for the system
- Adaptation, but no ever-winner: "good" species tend to get worse at change, merely because that is currently good



Thanks!

Let's keep this meeting open,
until you get $m_c=19$ friends!