## <u>Welcome to our opening day of</u> 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 <u>2014:</u> SMSEC & AICS symp.

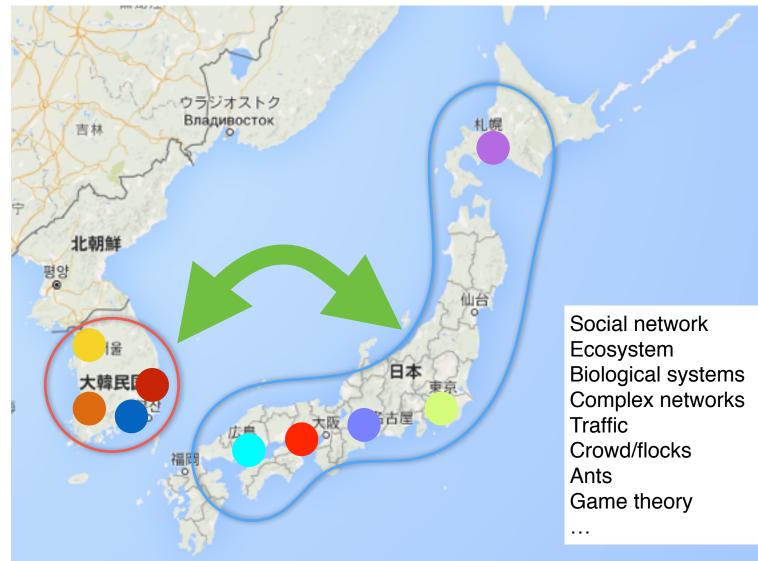


# The road to this bilateral project <u>2015:</u> PoSCo



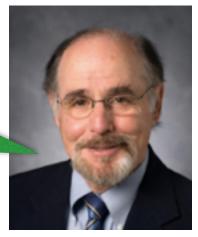
### The road to this bilateral project

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



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

## lt'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



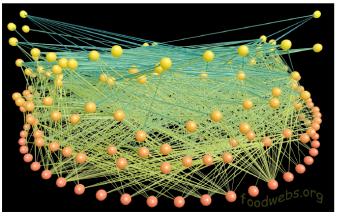


# Can an **Evolving Open System** grow by adding new elements to it?

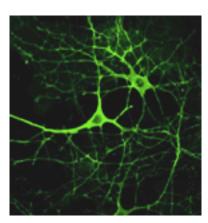
- ecosystems
- living organisms (evolutionary time scale)
- biological/artificial neural networks (development)
- social communities & market











(Nature 464, 1025 (2010))

#### "Will a large complex system be stable?"



Standard questions: any ecosystem-specific secret? structuring?

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<sup>14</sup> Theorem 2 and the second states of the seco

<sup>1</sup> Der R. R. and Prine, R. D., Physiol And M. Str. and Social Strength V, W. Witters, R. L. and Farsh, A. A. Strengt, Carolina, R. W. 1998, J. R. and Report, L. R. J. Physical Rev. Dec., 10, 111

tring, P. Sn. Association (1996).

#### Connectance of Large Dynamic (Cybernetic) Systems: Critical Values for Stability

Note process twing multiple study and decreases, longe and mapping) tables on an engage to the High plane, always with the process of the homes brack of the DP measures, it is not quiven, studying to a still generating transmission, the backward of the process of a start of processing decreasing of multiple second process is a still generating framework, the processing process is many different of the start (Decreased), process is many different for work decould be a still start of the start of the start decould be start start of the start of the start of the start decould be start start of the start of the start of the start decould be start start of the start of the start of the start decould be start and start of the start of the start of the start decould be start and start of the start of the start of the start decould be start and start of the s

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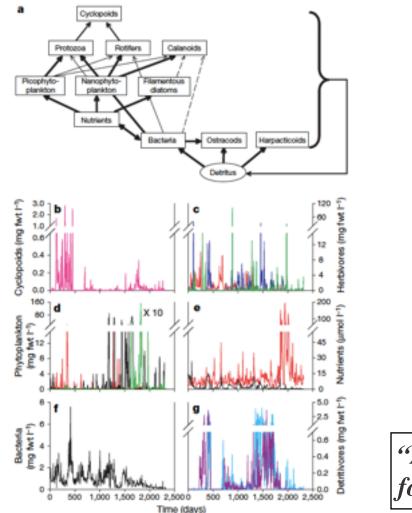
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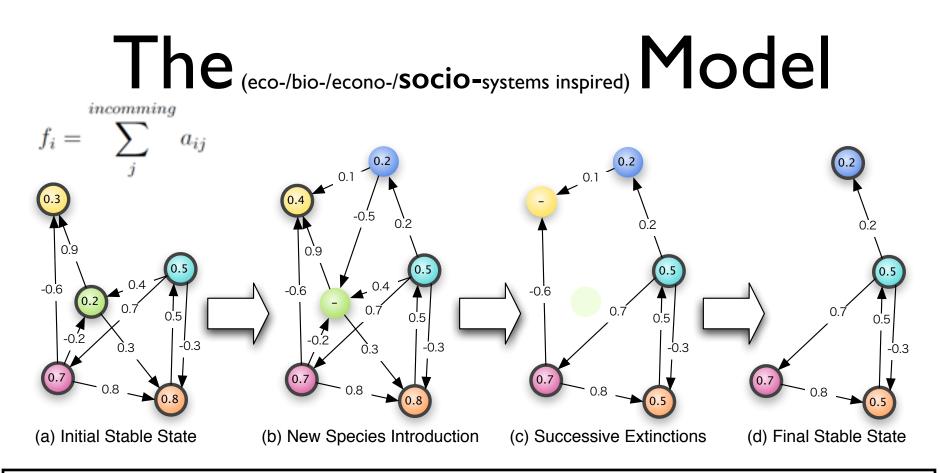
### "Ecosystem" is hardly stationary



- 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)



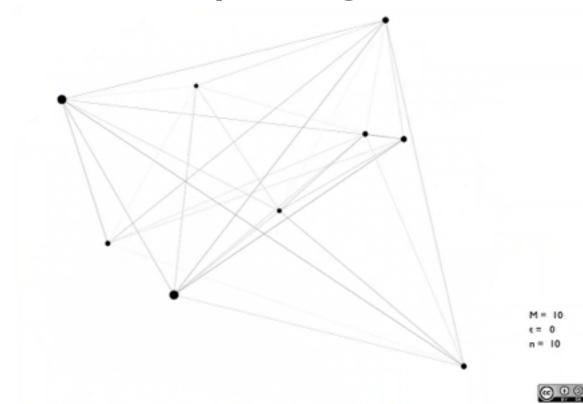
- I. Every species must have positive fitness:  $f_i = \sum_{j=1}^{in} a_{ij} > 0$  otherwise that goes extinct
- 2. Once the system gets stable, a new species comes with <u>m</u> new interactions:
  - to/from random resident species
  - a<sub>ij</sub> is drawn from the standard distribution (random,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

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

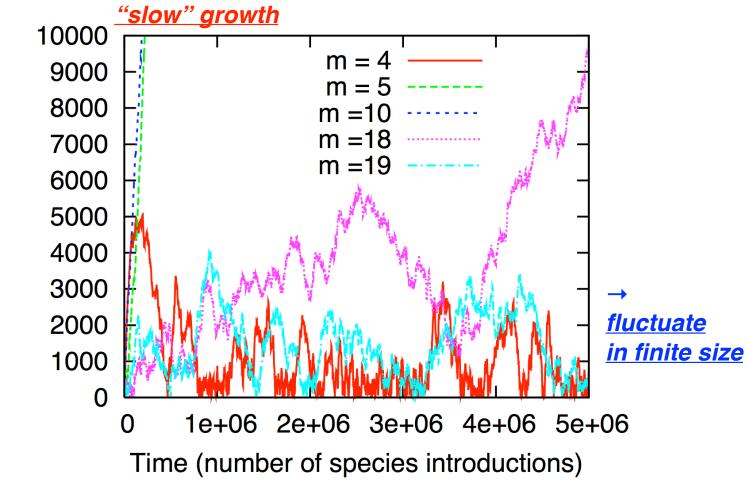
# The question

addition process: neutral deletion process: neutral

#### Can this system grow?

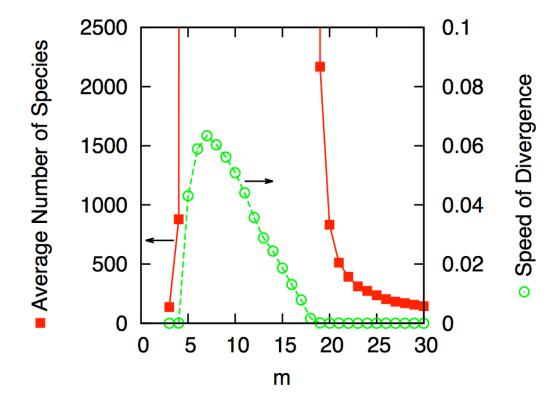


#### Answer: both can happen



as <u>m</u> increases, # of species is: finite  $\rightarrow$  diverging  $\rightarrow$  finite

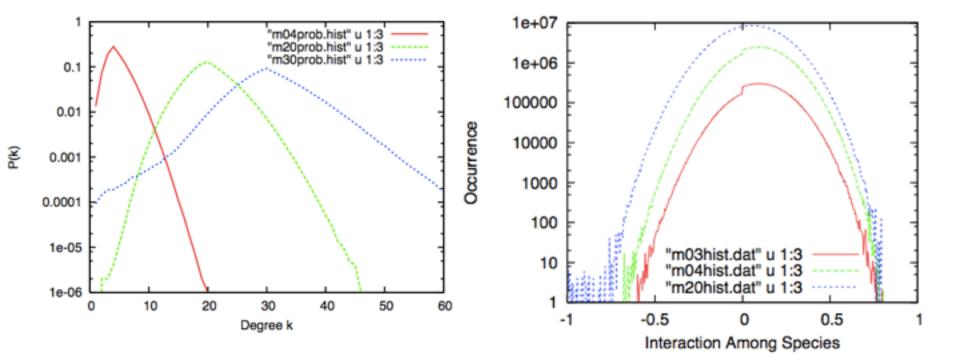
#### Transitions in the growing behavior



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  $\rightarrow$  The web is tree-like and very fragile

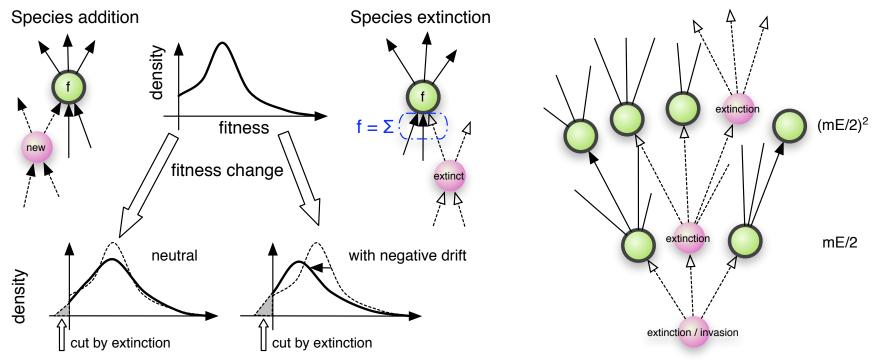
#### A clue to understanding the mechanism: no prominent structuring



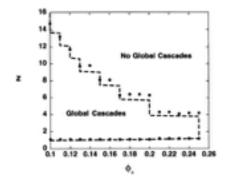
Both degree distribution and fitness distribution indicate that the emergent system is almost like a random net (looks little to do with complex network properties)

### A mean field picture:

successive convolution-and-cut process on fitness distribution function



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

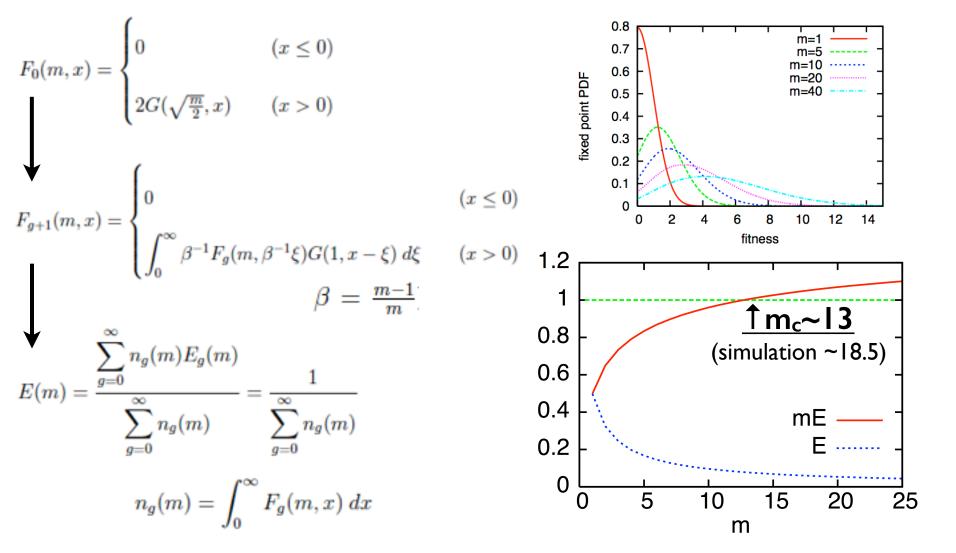


(cf. "global cascade" Duncan J. Watts, PNAS Vol. 99, pp. 5766-5771 (2002))

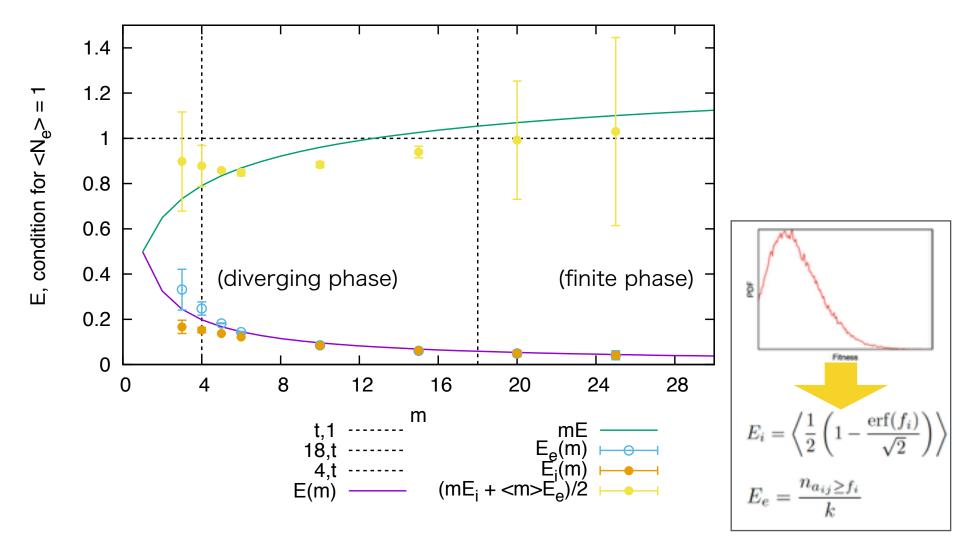
 $N_E = \sum_{n=1}^{\infty} \left(\frac{mE}{2}\right)^n = \frac{mE}{2-mE}$ 

(b) Extinction Cascade

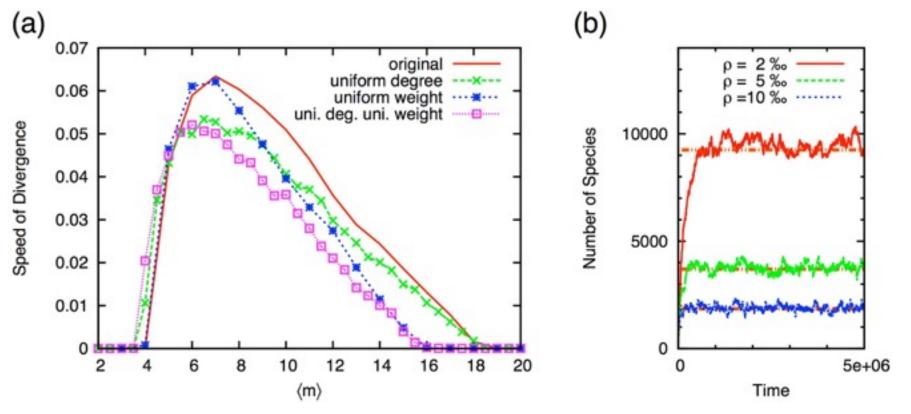
# Semi-analytical estimation of the transition point



# Mean-field estimation of m<sub>c</sub> from real fitness distributions



#### The transition is universal among variant models



(a) Slightly modified models share the same phase portrait

(b) Giving an interaction  $\underline{density}$ : N(t) ~ N<sup>\*</sup> = 18.5/ $\rho$ 

# A possible origin of the sparseness of real complex systems (<k> << N)?

Network	Size	$\langle k \rangle$	к	Yout	$\gamma_{in}$	lreal	$\ell_{rand}$	lpow	Reference	Nr.
WWW	325, 729	4.51	900	2.45	2.1	11.2	8.32	4.77	Albert, Jeong, Barabási 1999	1
WWW	$4 \times 10^{7}$	7		2.38	2.1				Kumar et al. 1999	2
WWW	$2 \times 10^{8}$	7.5	4,000	2.72	2.1	16	8.85	7.61	Broder et al. 2000	3
WWW, site	260,000		1		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 et al. 2001	10
Coauthors, math*	70,975	3.9	120	2.5	2.5	9.5	8.2	6.53	Barabási et al. 2001	11
Sexual contacts*	2810			3.4	3.4				Liljeros et al. 2001	12
Metabolic, E. coli	778	7.4	110	2.2	2.2	3.2	3.32	2.89	Jeong et al. 2000	13
Protein, S. cerev.*	1870	2.39		2.4	2.4				Mason et al. 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	$53 \times 10^{6}$	3.16		2.1	2.1				Aiello et al. 2000	18
Words, cooccurence*	460,902	70.13		2.7	2.7				Cancho, Solé 2001	19
Words, synonyms*	22,311	13.48		2.8	2.8				Yook et al. 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: <k> ~ 1)



- 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

T. Shimada, Scientific Reports 4, 4082 (2014)



# Thanks!

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