Impact of individual nodes in Boolean network dynamics

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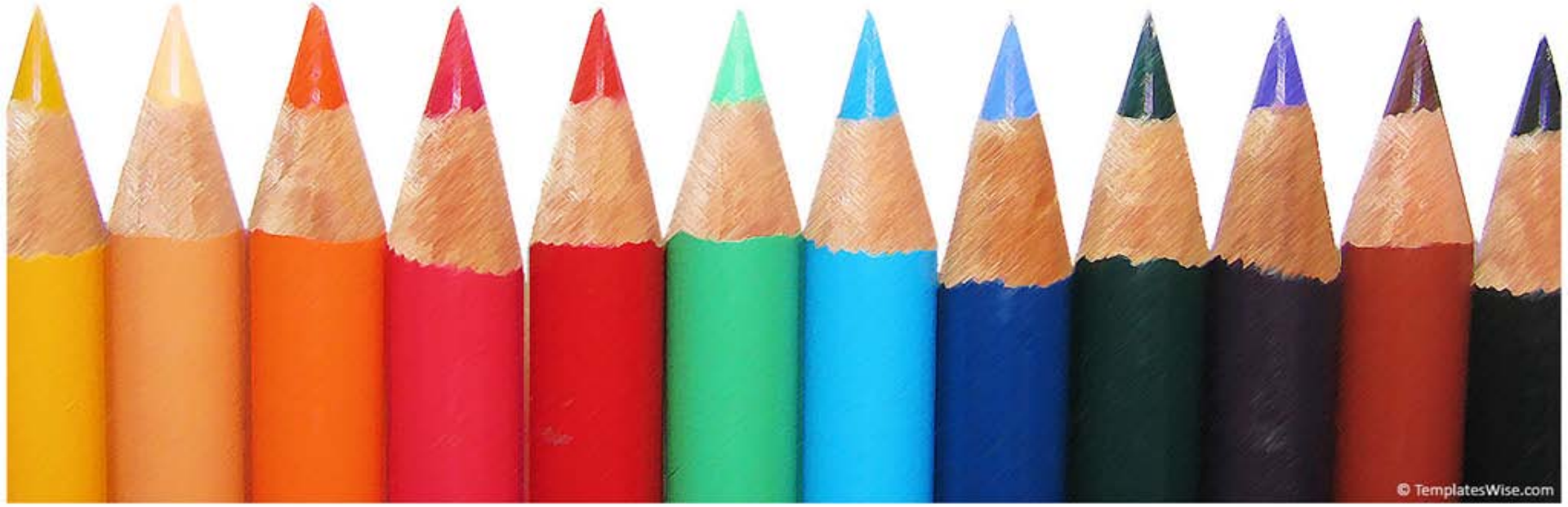
arXiv:1111.5334v1

Dresden, May 2012



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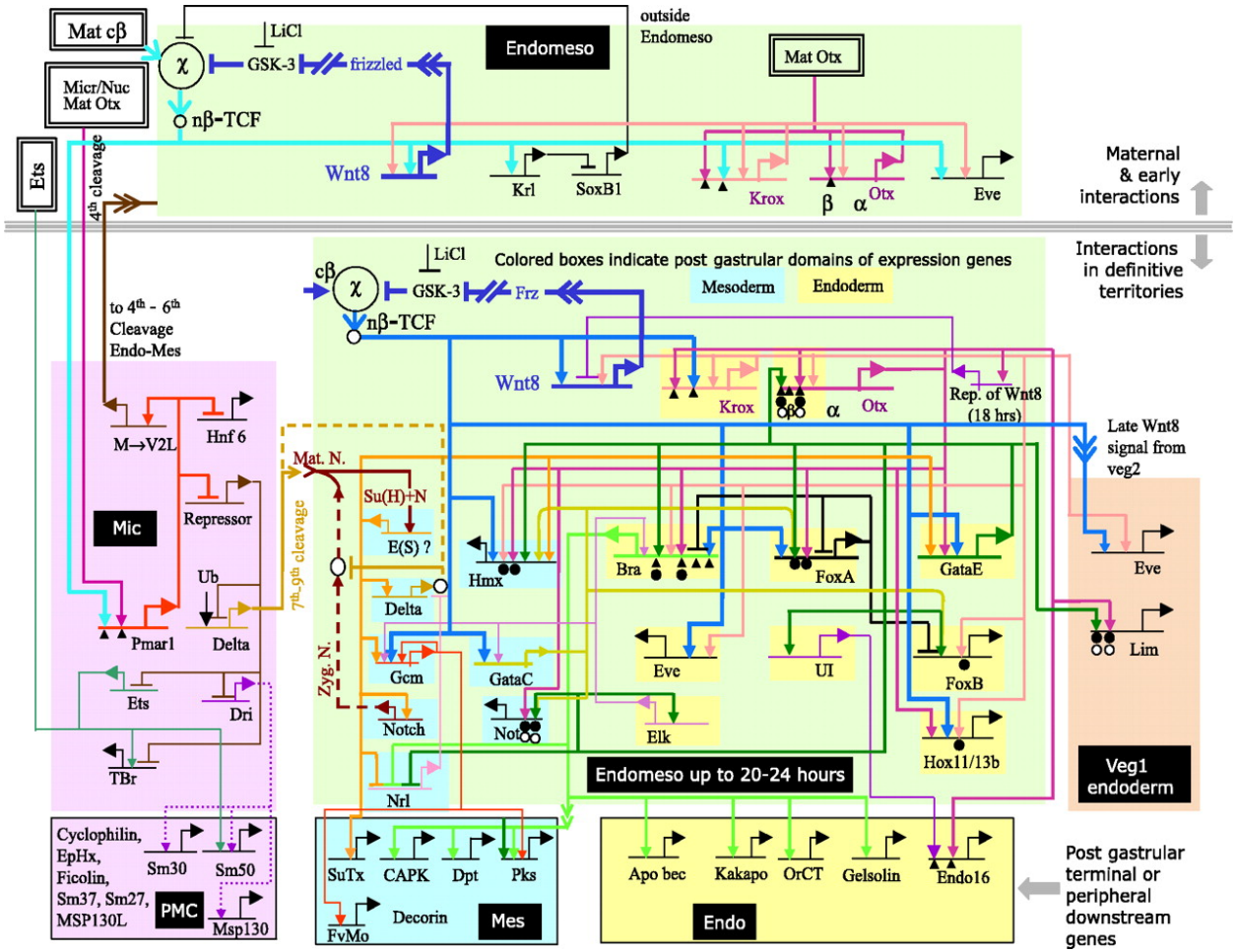
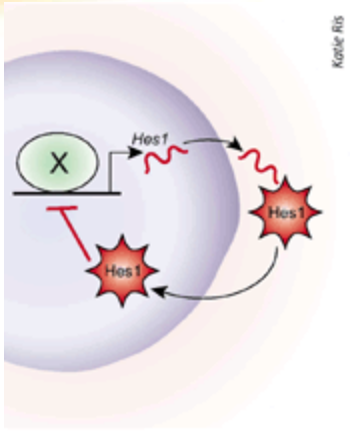
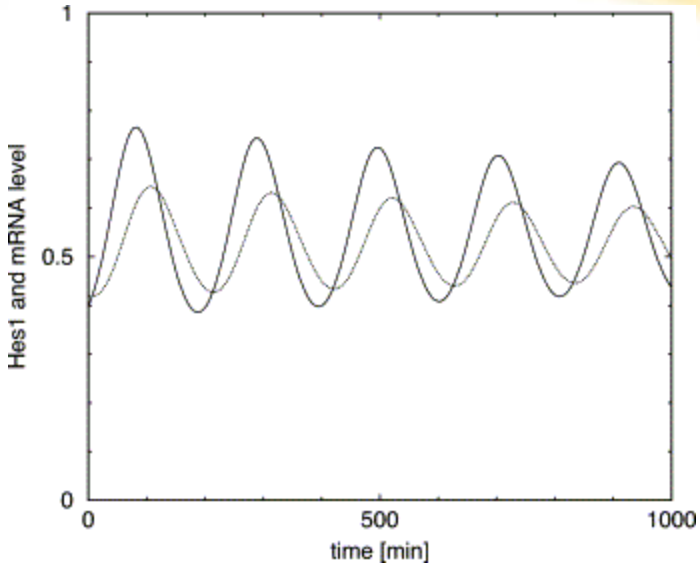


P. Oliveri, E. H. Davidson Current Opinion in Genetics & Development - 2004

Regulatory Dynamics





$$\frac{d[mRNA(t)]}{dt} = \frac{\alpha k^h}{k^h + [Hes1(t-\tau)]^h} - \frac{[mRNA(t)]}{\tau_{rna}}$$

$$\frac{d[Hes1(t)]}{dt} = \beta[mRNA(t)] - \frac{[Hes1(t)]}{\tau_{hes1}}$$

M.H. Jensen, K. Sneppen, G. Tiana, FEBS Letters 541, 176 (2003)

Regulatory Dynamics

$$\frac{d[mRNA(t)]}{dt} = \frac{\alpha k^h}{k^h + [Hes1(t-\tau)]^h} - \frac{[mRNA(t)]}{\tau_{rna}}$$

$$\frac{d[Hes1(t)]}{dt} = \beta[mRNA(t)] - \frac{[Hes1(t)]}{\tau_{hes1}}$$

- parameters: production delay, production rates, binding threshold, characteristic degradation times Hes1 & rna
- six parameters for a single gene
- larger systems?!!!

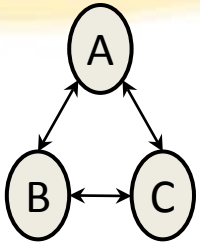
Discrete Abstract Model

- ON/Off States
- Interactions Network
- Dynamics (time evolution of states):

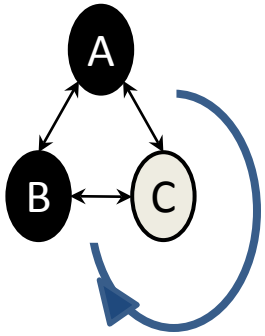
Logical Operators

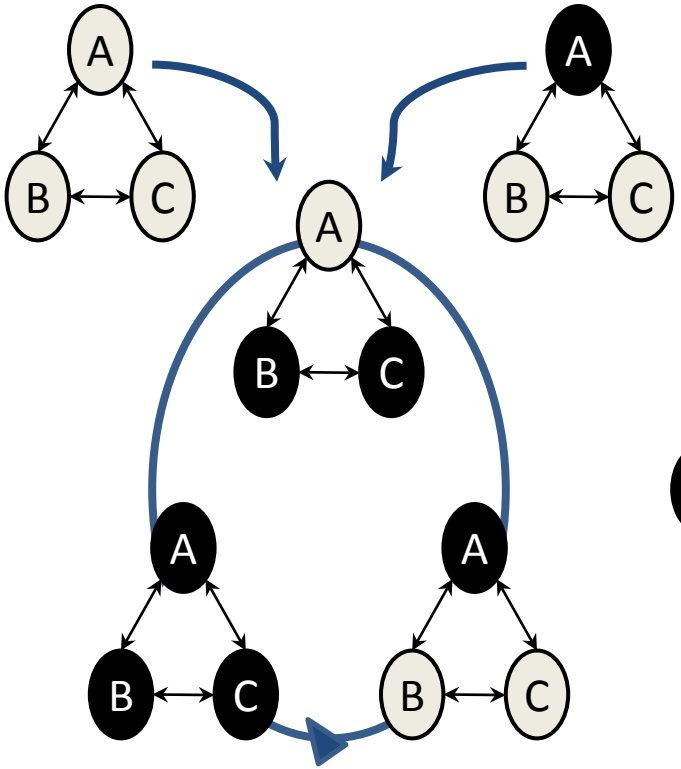
Boolean Networks

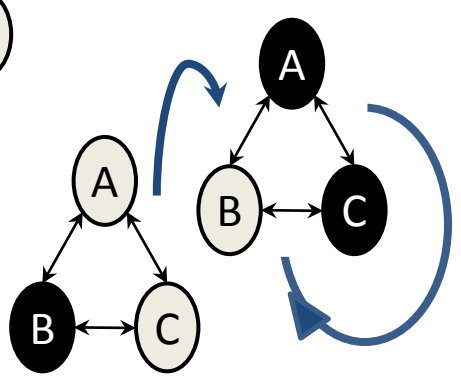
Attractors



	ABC
00	011
01	011
10	011
11	100







Activity & Sensitivity

	F
00	0 F_0
01	0 F_1
10	1 F_2
11	1 F_3

	F
10	F_2
11	F_3
00	F_0
01	F_1

	F
00	1 F_0
01	0 F_1
10	1 F_2
11	1 F_3

	F
10	F_0
11	F_3
00	F_2
01	F_1

$$a(f_i) = 2^{-n} \sum_{x \in \{0,1\}^n} |f(x) - f(x^{\updownarrow j})|$$

$$s(f_i) = \sum_{j=1}^{n} 2^{-n} \sum_{x \in \{0,1\}^n} |f(x) - f(x^{\updownarrow j})|$$

Impact of individual nodes in Boolean network dynamics

Short term

Long term

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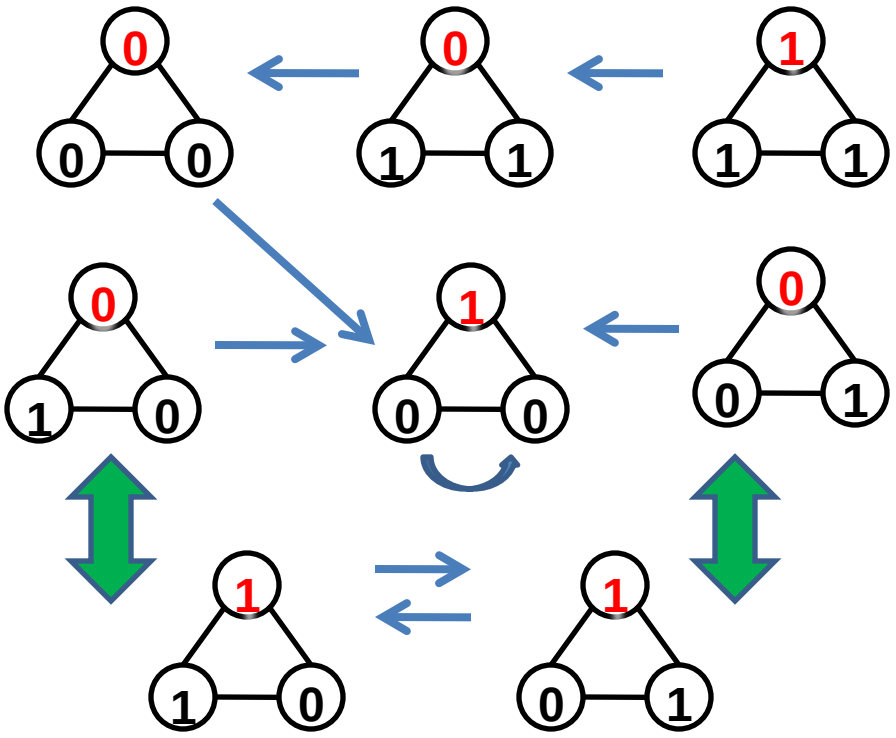
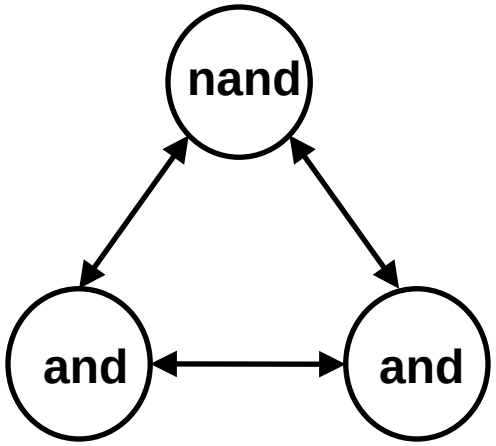
Computing the dynamical impact of nodes



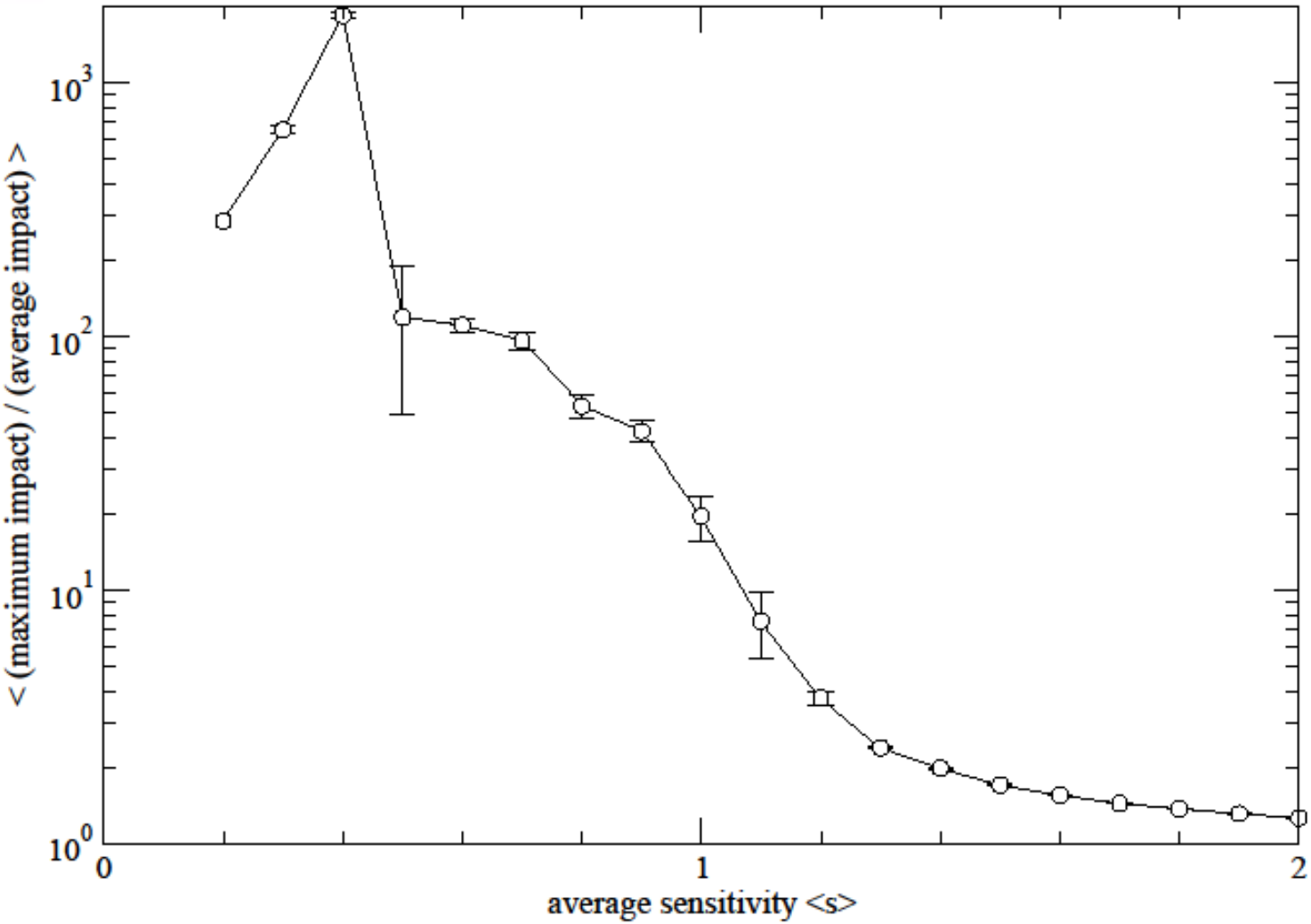


Flip:

0→1

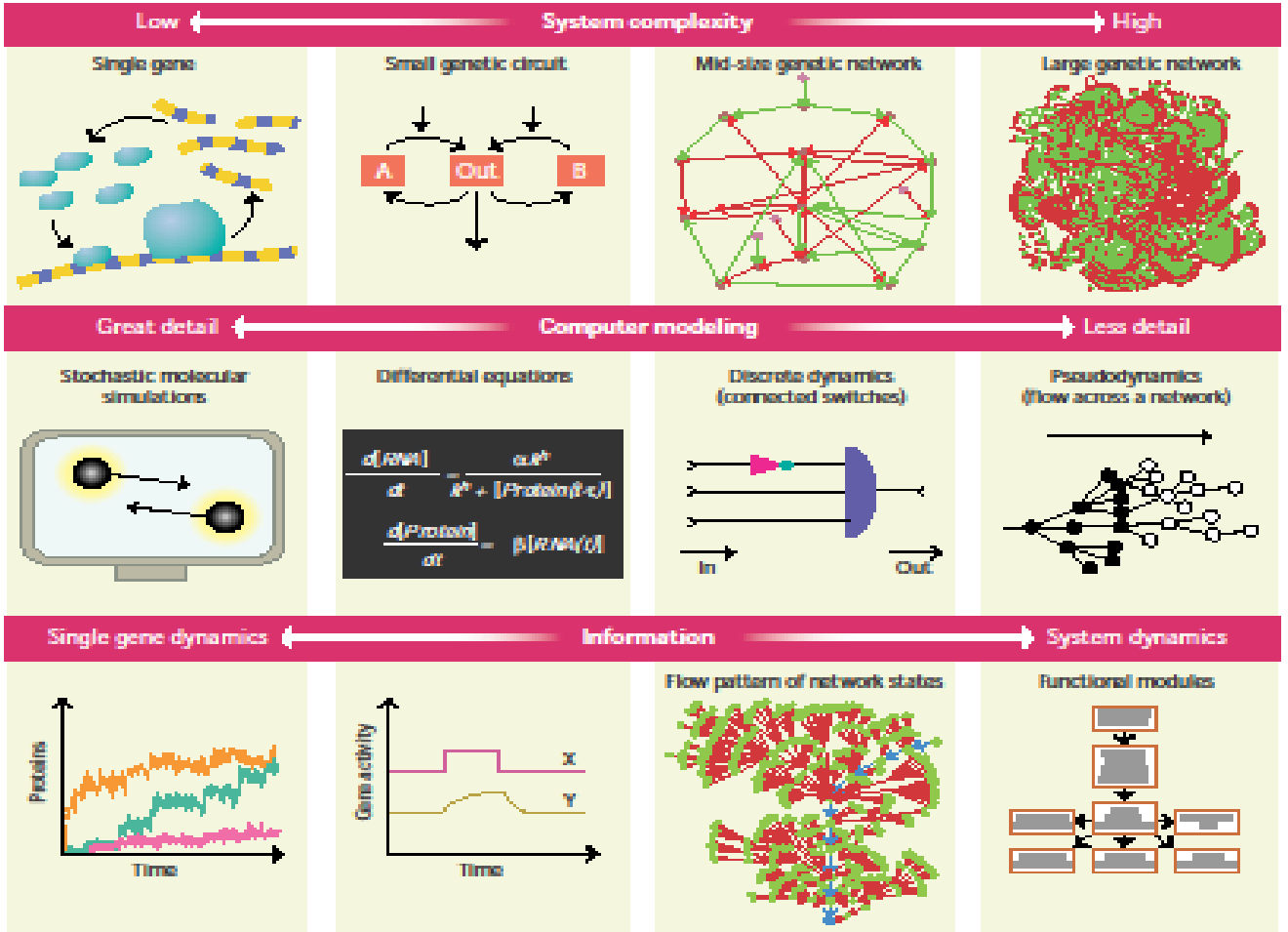
1→0

Variation of dynamical impact across nodes in random Boolean networks



Predicting of dynamical impact

- Why ?



S. Bornholdt. Science Vol. 310 no. 5747 pp. 449-451

Predicting of dynamical impact

- How ?

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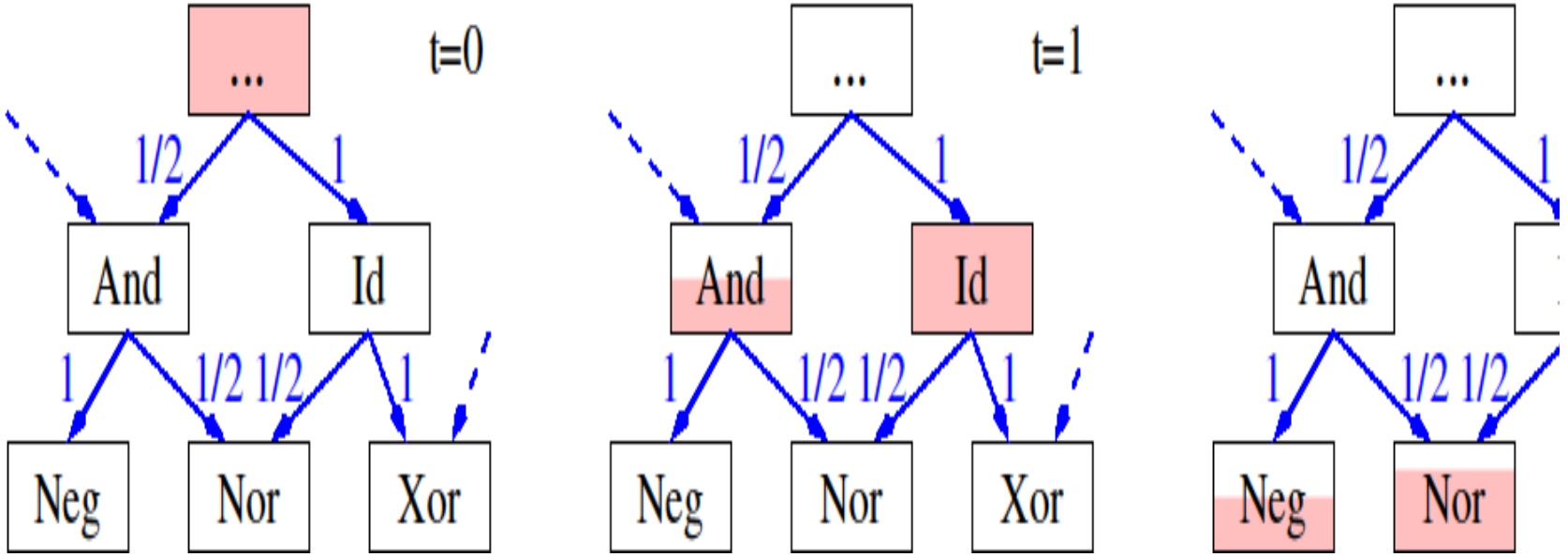
Probabilistic description of damage spreading in a Boolean dynamics



$$p_j(t) \propto \sum_{i=1}^{N} \alpha_{ji} p_i(t-1)$$

$$p(t) = \aleph^{\mathrm{T}} p(t-1)$$

$$p(t) = (\aleph^{\mathrm{T}})^t p(0)$$

Impact of individual nodes in Boolean network dynamics

Centrality measures considered as predictors for the dynamical impact

Range	Adjacency matrix	Activity matrix
local	**out-degree**	**strength**
global	**eigenvector**	**eigenvector**

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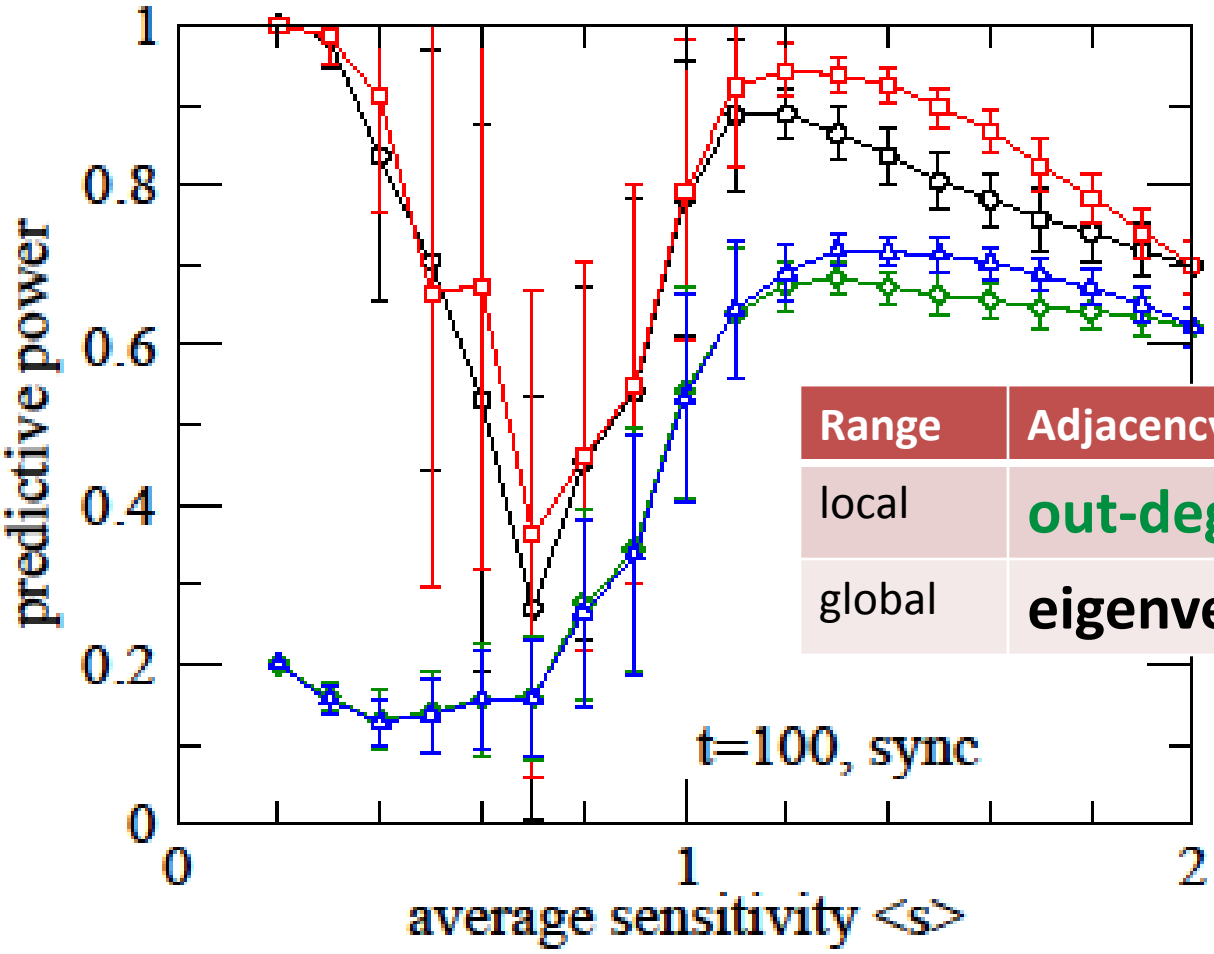
Results for random Boolean networks



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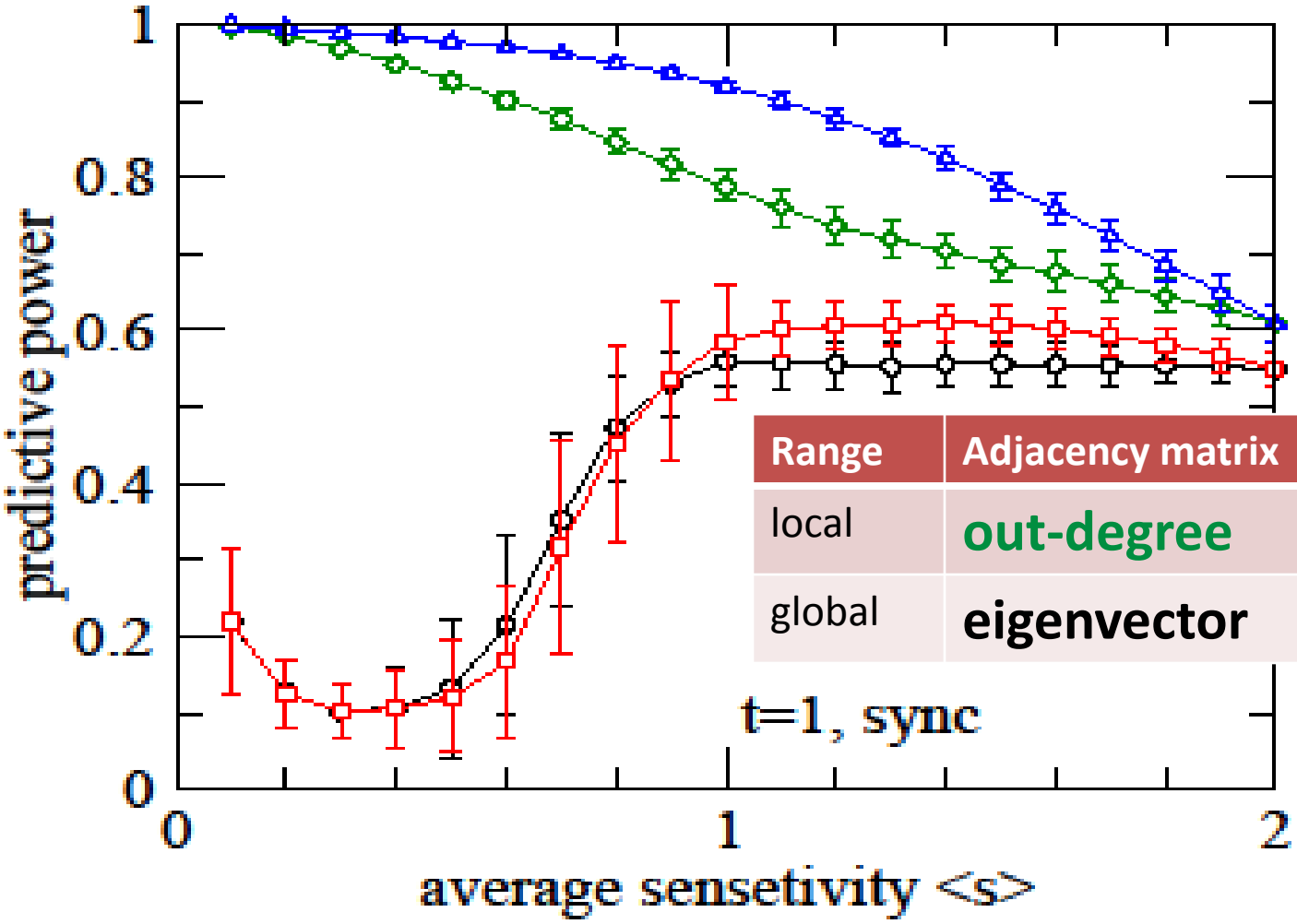
Results for random Boolean networks



Range	Adjacency matrix	Activity matrix
local	out-degree	strength
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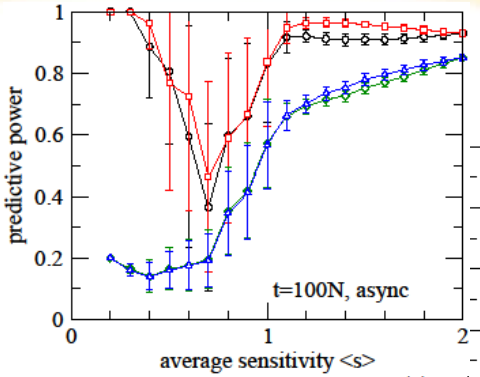
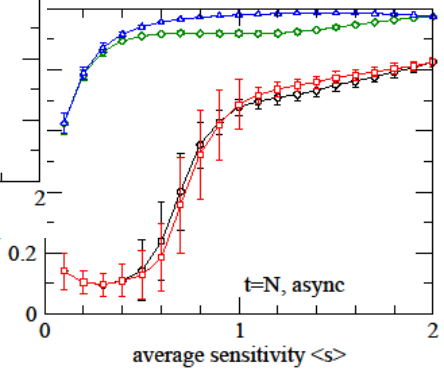
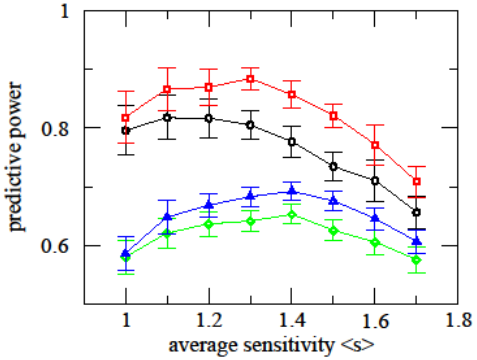
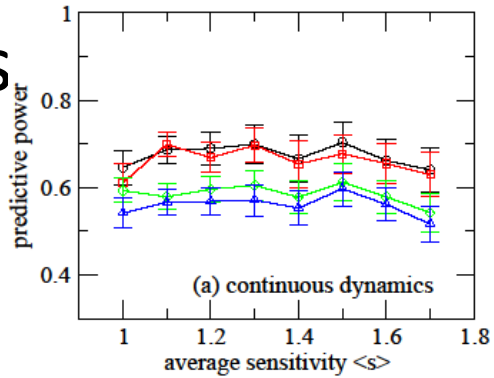
More cases

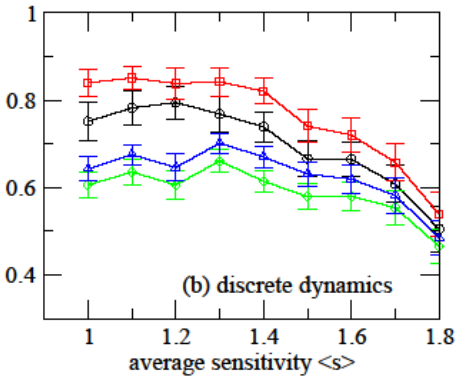
- Asynchronous updating
- Attractor switching
- With small perturbations











Dynamical impact in a real network

fibroblast signal transduction

		all nodes			
		$\mathcal{P}_\epsilon$	$\mathcal{P}_e$	$\mathcal{P}_\sigma$	$\mathcal{P}_d$
synchronous	$t = 1$	0.671	0.454	**0.930**	0.455
	$t = 100$	**0.920**	0.734	0.746	0.523
asynchronous	$t = N$	0.706	0.528	**0.904**	0.564
	$t = 100N$	**0.854**	0.694	0.748	0.542

		only core nodes			
		$\mathcal{P}_\epsilon$	$\mathcal{P}_e$	$\mathcal{P}_\sigma$	$\mathcal{P}_d$
synchronous	$t = 1$	0.633	0.467	**0.946**	0.528
	$t = 100$	**0.911**	0.777	0.738	0.611
asynchronous	$t = N$	0.658	0.543	**0.919**	0.656
	$t = 100N$	**0.834**	0.731	0.741	0.631

T. Helikaret al; PNAS 105, 1913 (2008)

Impact of individual nodes in Boolean network dynamics

- Linear algebra
- Random Boolean networks
- Empirical Boolean networks

Range	Adjacency matrix	Activity matrix
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global	**eigenvector**	**eigenvector**

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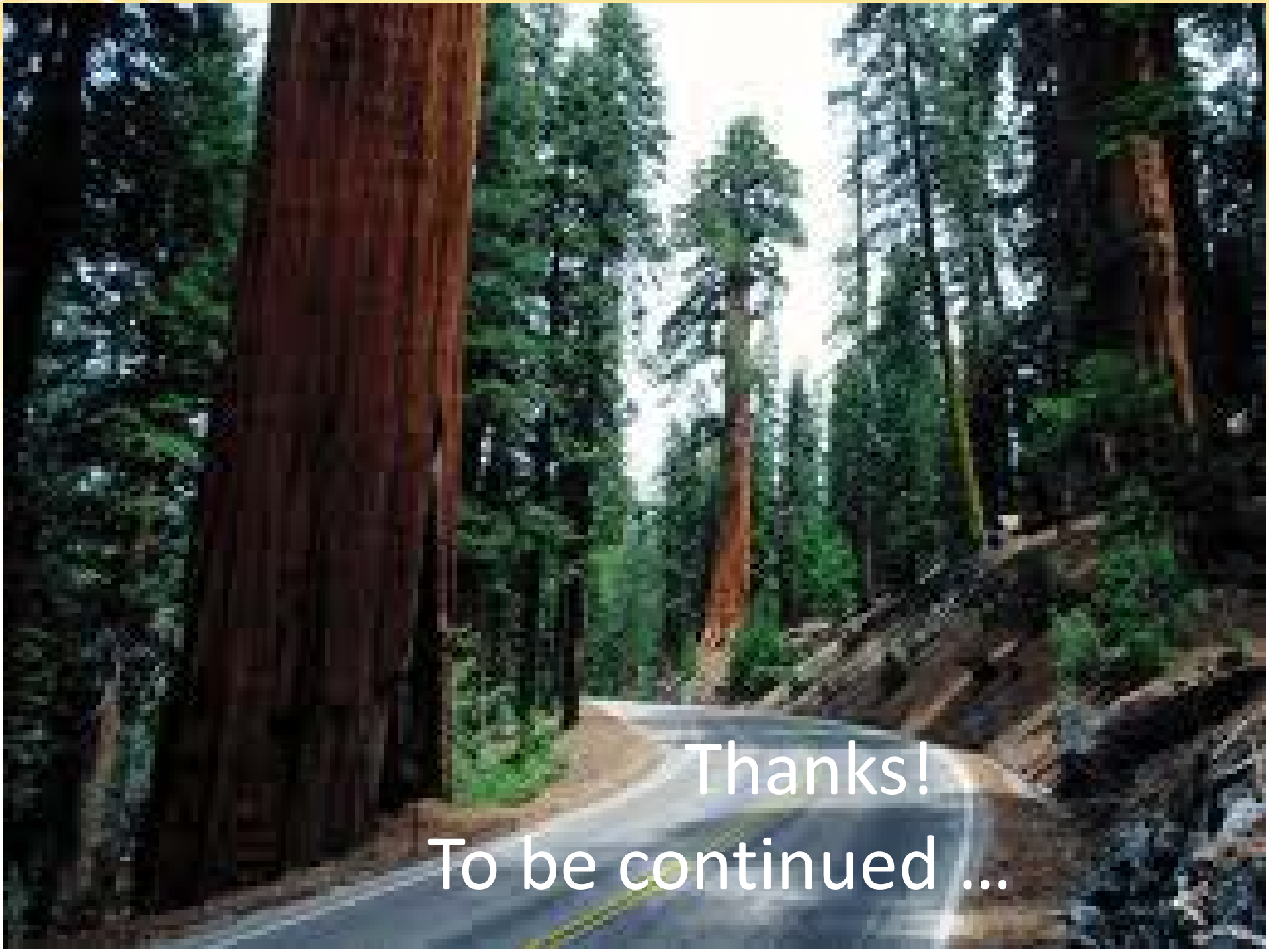
Thanks!
To be continued …

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Konstantin Klemm

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Stability of Boolean and continuous dynamics

Phys. Rev. Lett. 107.188701