Opinion formation in time-varying social networks

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Language Dynamics

- Language is complex adaptive system
- Evolves through the process of self-organization
- Question: How can one explain the interplay of structure and dynamics of such a system?
  => Statistical Physics tools

A Physical System Perspective

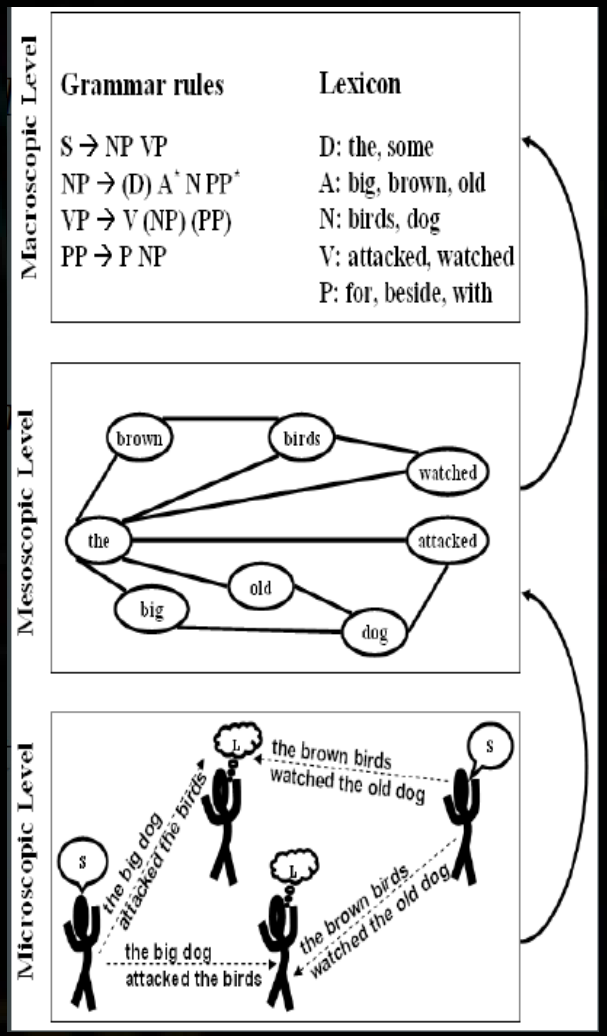
Language as a whole (grammatical constructs)

↓

Language as a collection of interactions among linguistic units

↓

Language as a collection of utterances



Macroscopic level

↓

Mesoscopic level

↓

Microscopic level

A Physical System Perspective

Language as a whole (grammatical constructs)

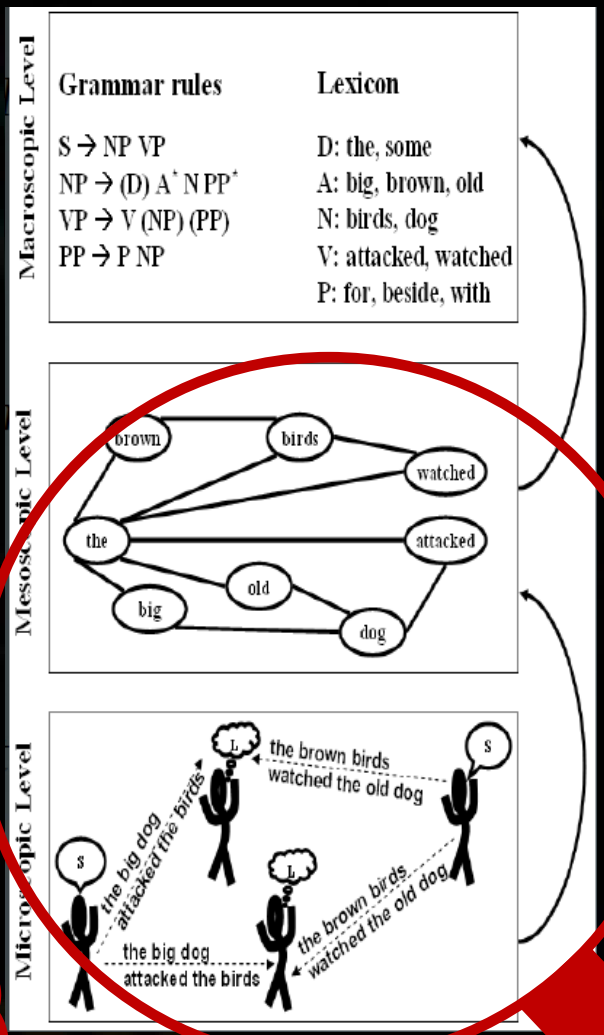
↓

Language as a collection of interactions among linguistic units

↓

Language as a collection of utterances

dynamic



Macroscopic level

↓

Mesoscopic level

↓

Microscopic level

Names for meanings

SPAM !

Names for meanings

SPAM !

Spiced HAM

Monty Python's spam comedy (1970 TV show)

Mr. and Mrs. Bun enter a cheap pub

Mr. Bun: What have you got, then?

Waitress: egg and SPAM; egg, bacon, and SPAM; egg, bacon, sausage and SPAM; SPAM, bacon, sausage, and SPAM; SPAM, egg, SPAM, SPAM, bacon, and SPAM; SPAM, SPAM, SPAM, egg, and SPAM; baked beans, SPAM and SPAM….

Mrs. Bun : Have you got anything without SPAM in it?

Waitress: Well, there's SPAM, egg, sausage, and SPAM. That's not got MUCH SPAM in it.

Mrs. Bun: I don't want any SPAM!

Mr. Bun: Why can't she have egg, bacon,

SPAM, and sausage?

Mrs. Bun: That's got SPAM in it!

Mr. Bun: Not as much as SPAM, egg,

sausage, and SPAM.

Mrs. Bun: Look, could I have egg, bacon,

SPAM, and sausage without the SPAM?

Waitress: Uuuuuuuuuggggggh!

Mrs. Bun: What d'you mean uuugggh!? I don't like SPAM.

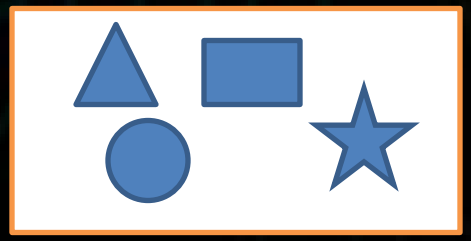
Vikings: (singing) SPAM, SPAM, SPAM, SPAM..SPAM, SPAM, SPAM, SPAM... Lovely SPAM,wonderful SPAM....

((e-)spam to spam)?

The Naming Game

The “Talking Heads” Experiment

Speaker



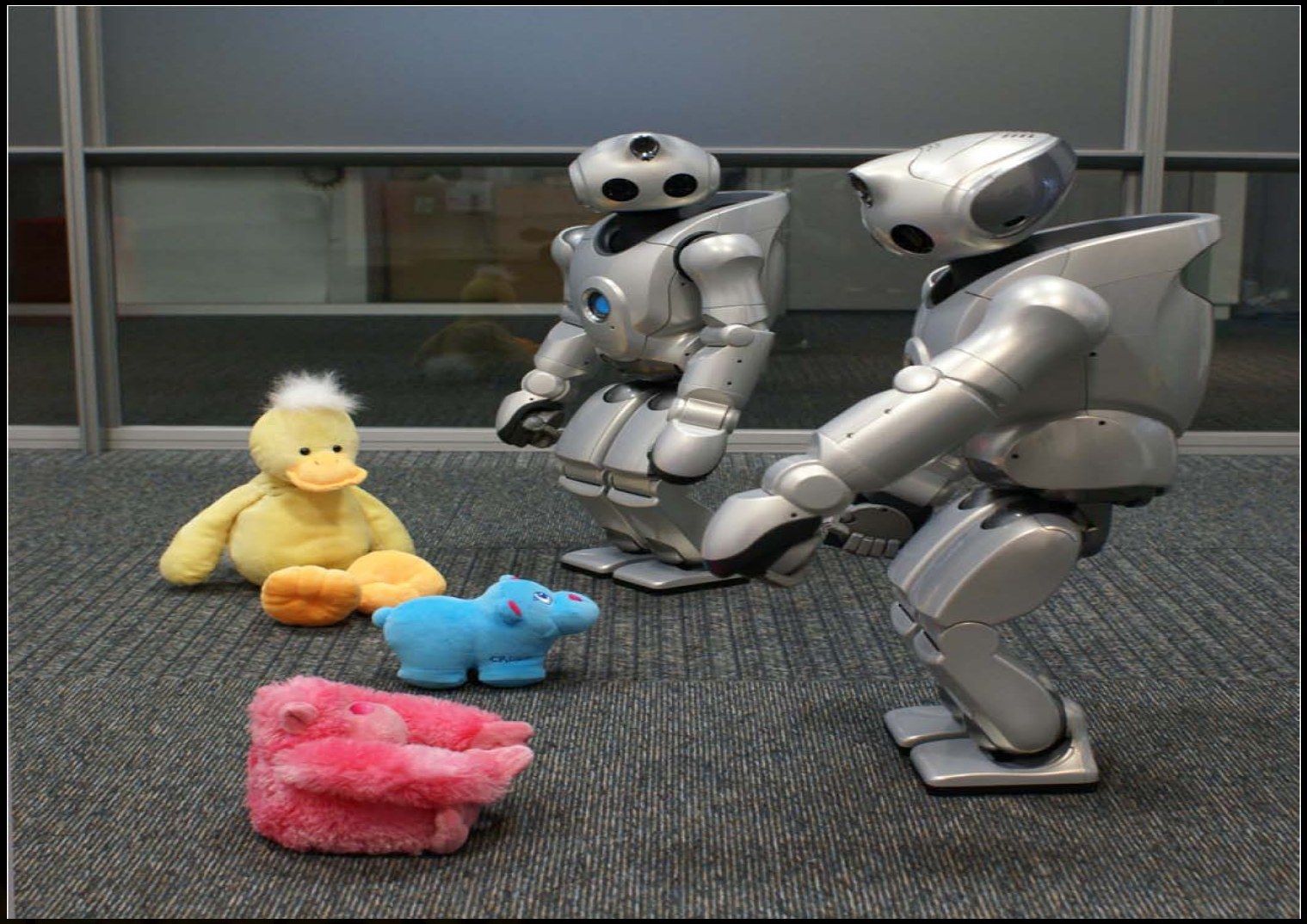
Hearer

- Perceive scene
- Choose topic
- Conceptualize
- Verbalize

interpret utterance
perceive scene
apply meaning
point to referent

Luc Steels, Autonomous Agents and Multi-agent Systems (1998)

The Grounded Naming Game



Bleys et al., Roman-09 (2009)

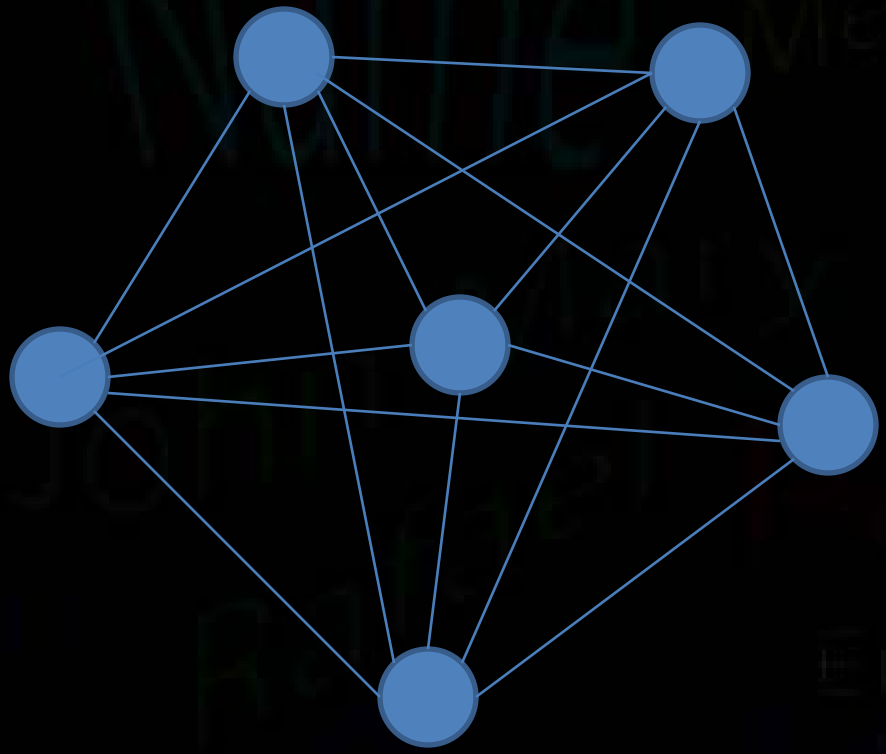
Minimal Naming Game

- In silico settings
- Interactions of *N* agents who communicate on how to associate a name to a given object

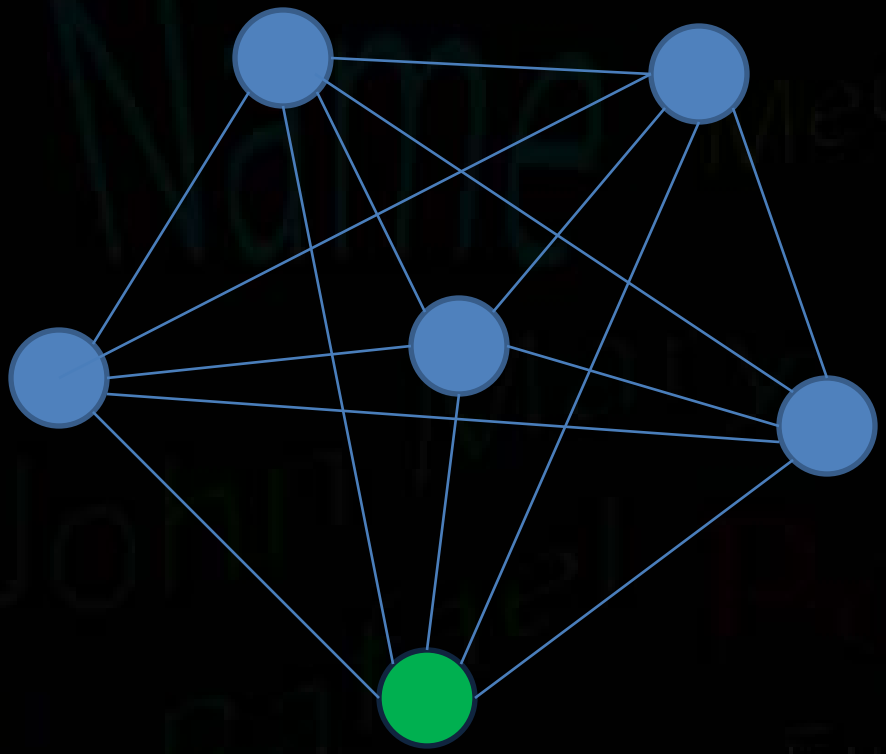
- Agents:
- can keep in memory different words
- can communicate with each other

Baronchelli et al., J. Stat. Mech. (2006)

Mean field: fully-connected network



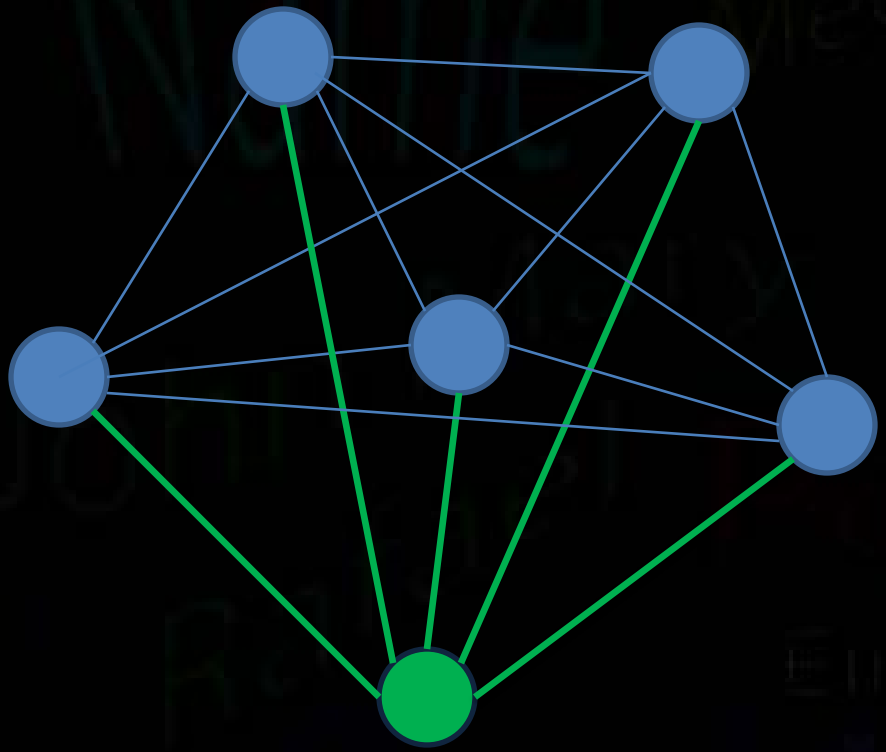
Mean field: fully-connected network



Speaker

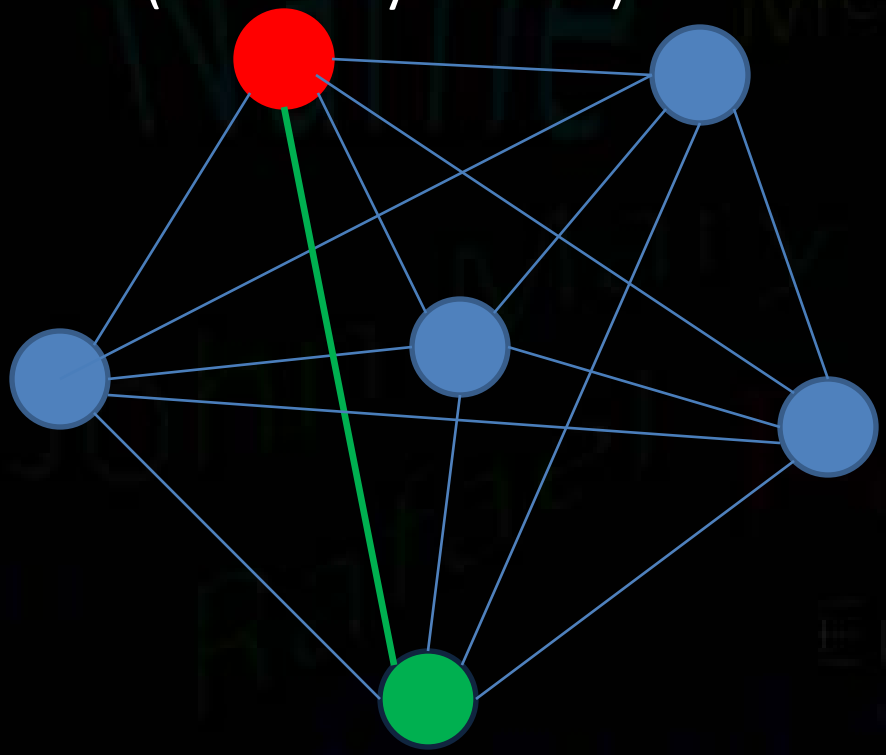
(randomly chosen from population)

Mean field: fully-connected network



Speaker

Mean field: fully-connected network



Game Rules

Speaker

Bottle
Apple
Tiger
Car

Hearer

Bag
Blackberry
Tree

Game Rules

Speaker

Bottle
Apple
Tiger
Car

Hearer

Bag
Blackberry
Tree

Randomly choose a word

Game Rules

Not Found → Failure!!

Game Rules

Speaker

Bottle
Apple
Tiger
Car

Hearer

Bag
Blackberry
Tree
Apple

Add the word

Game Rules

Speaker

Bottle
Apple
Tiger
Car

Hearer

Bag
Apple
Tree

Randomly choose a word

Game Rules

Speaker

Bottle
Apple
Tiger
Car

Hearer

Bag
Apple
Tree

Uttered word found → Success

Game Rules

Speaker

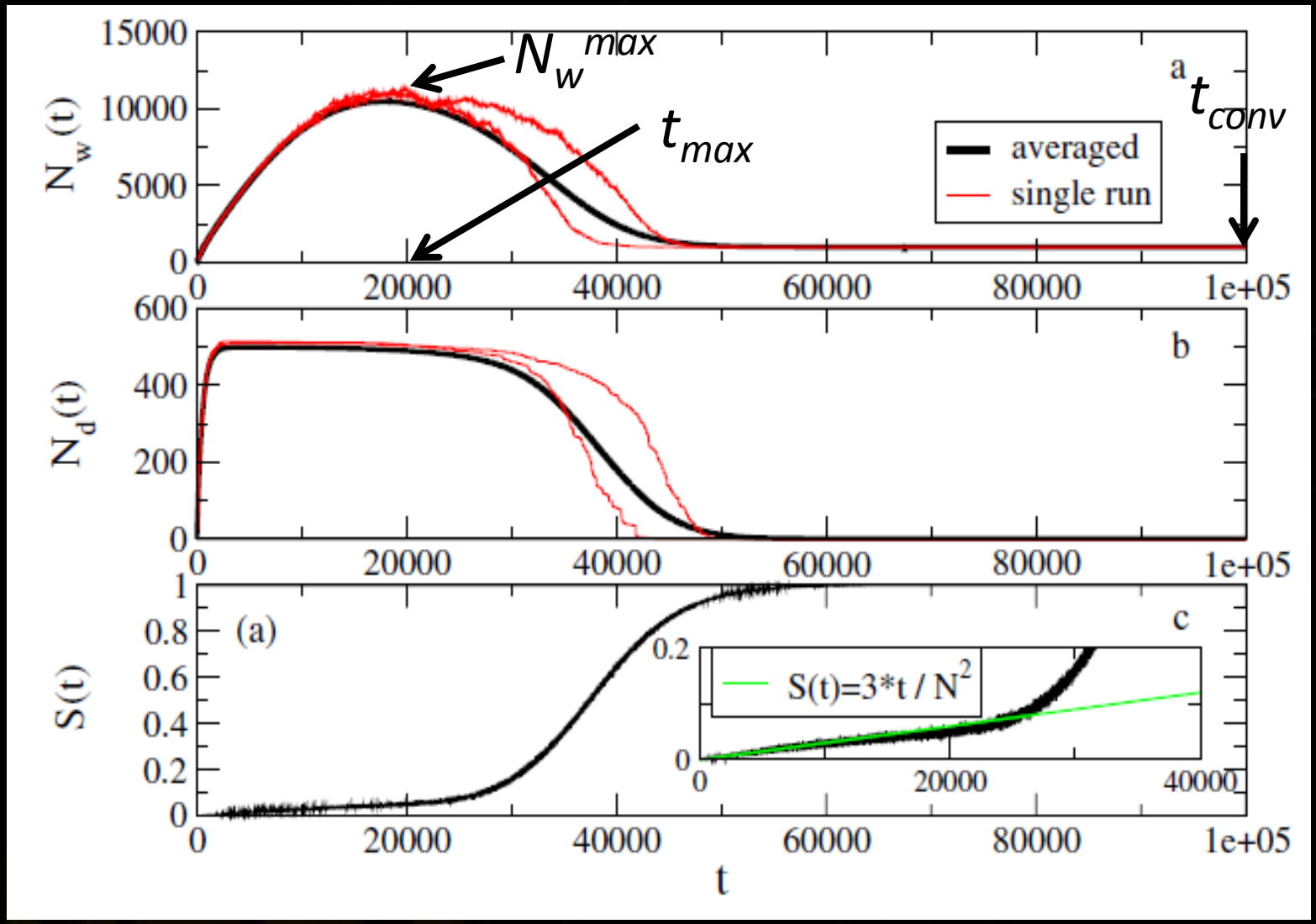
Hearer

Retain only the successful word

Phenomenology

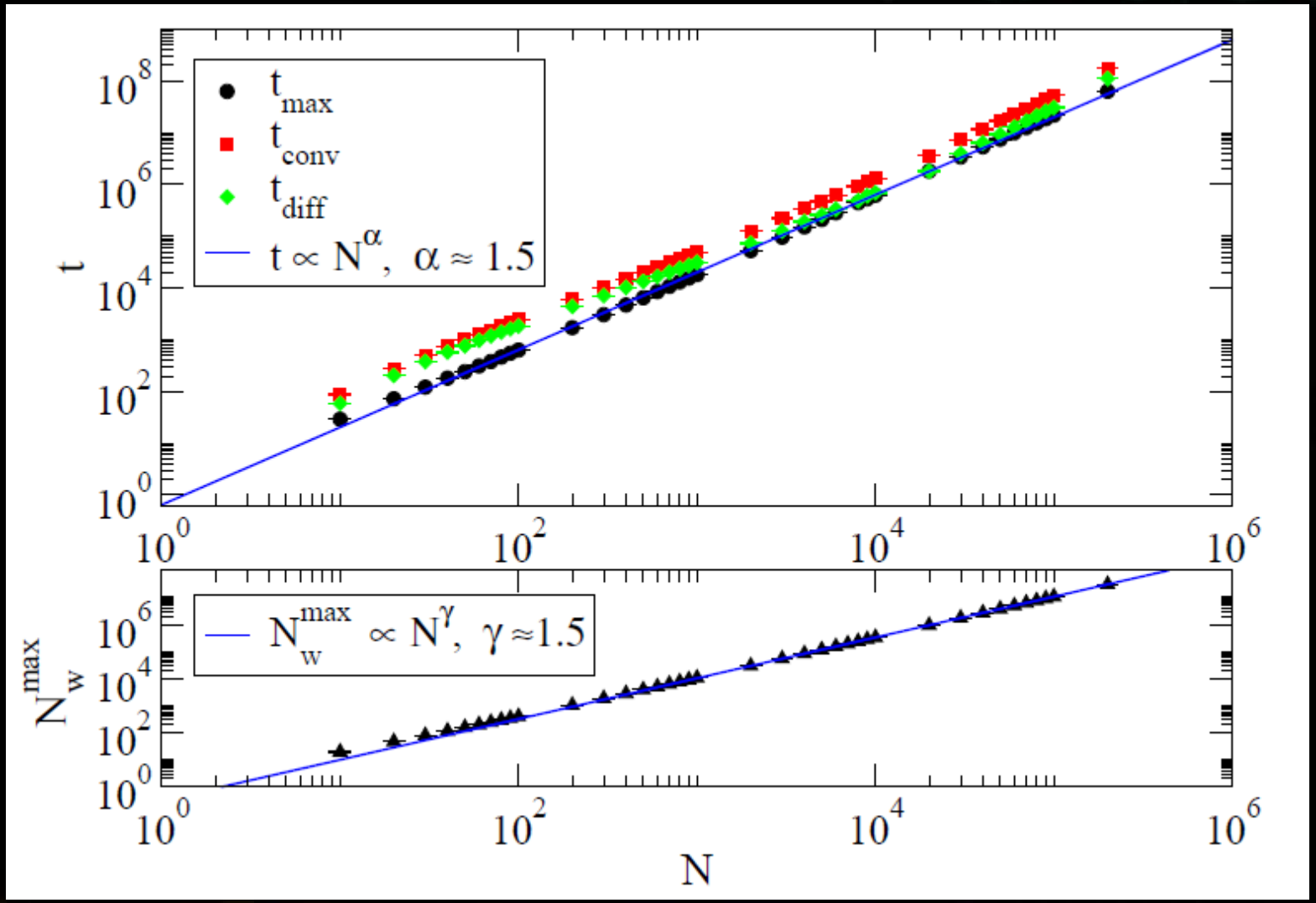
- t - Game time (no. of games)
- $N_w(t)$ - total number of words in the system at time t
- $N_d(t)$ - number of different words in the system at time t
- $S(t)$ - average success rate at time t
- N_w^{max} - maximum memory required by the system
- t_{max} - the time required to reach the memory peak
- t_{conv} - the time required to reach the global consensus

Temporal evolution of observables



Baronchelli et al., J. Stat. Mech. (2006)

Scaling Relations



Baronchelli et al., J. Stat. Mech. (2006)

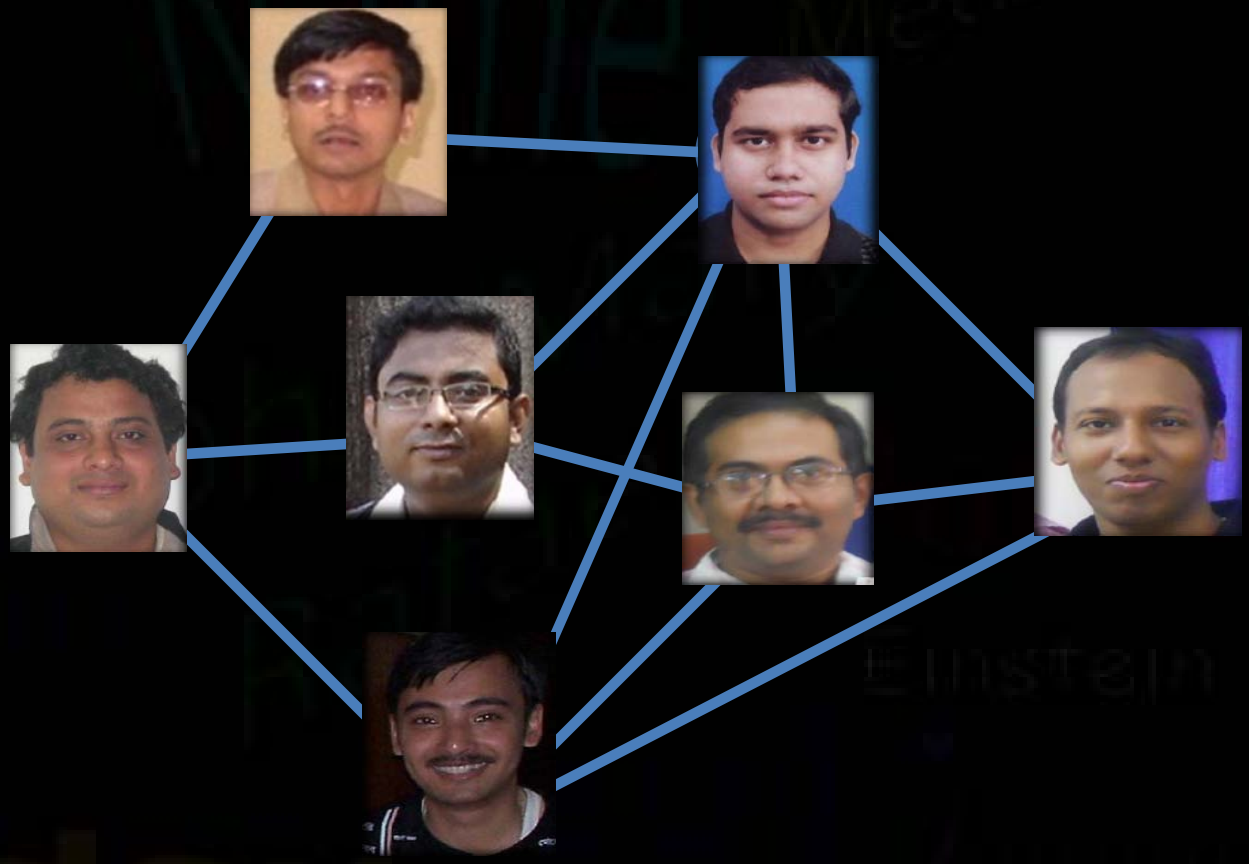
Scaling relations for various topologies

	N^w_{max}	t_{max}	t_{conv}
Mean-field	$N^{1.5}$	$N^{1.5}$	$N^{1.5}$
Scale-free	N	N	$N^{1.4}$
Erdos-Renyi	N	N	$N^{1.4}$
Small-world	N	N	$N^{1.4}$

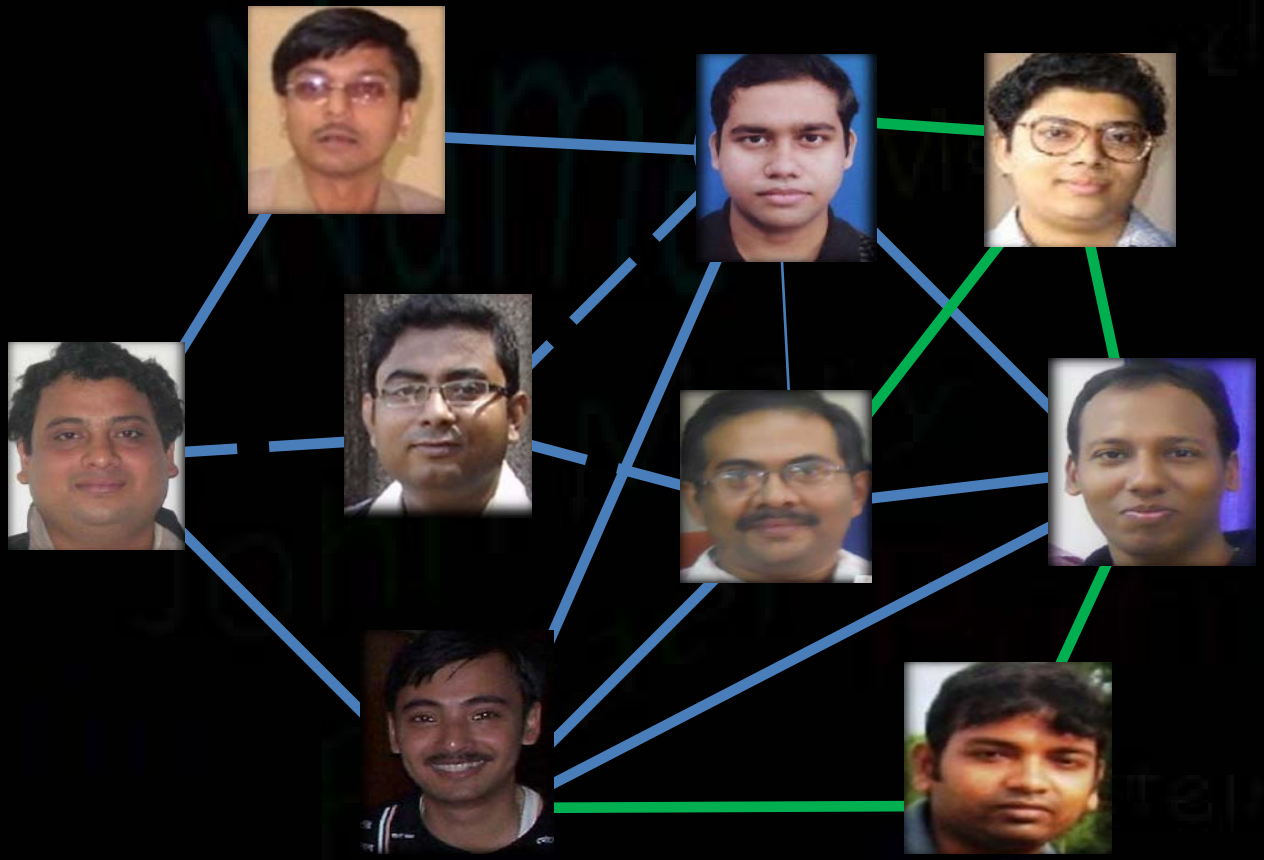
What about time-varying networks?

- Social interactions and human activities are intermittent
- Links appear and disappear from the system
- As time progresses, societal structure keeps changing with social conventions, shared cultural and linguistic patterns reshaping themselves

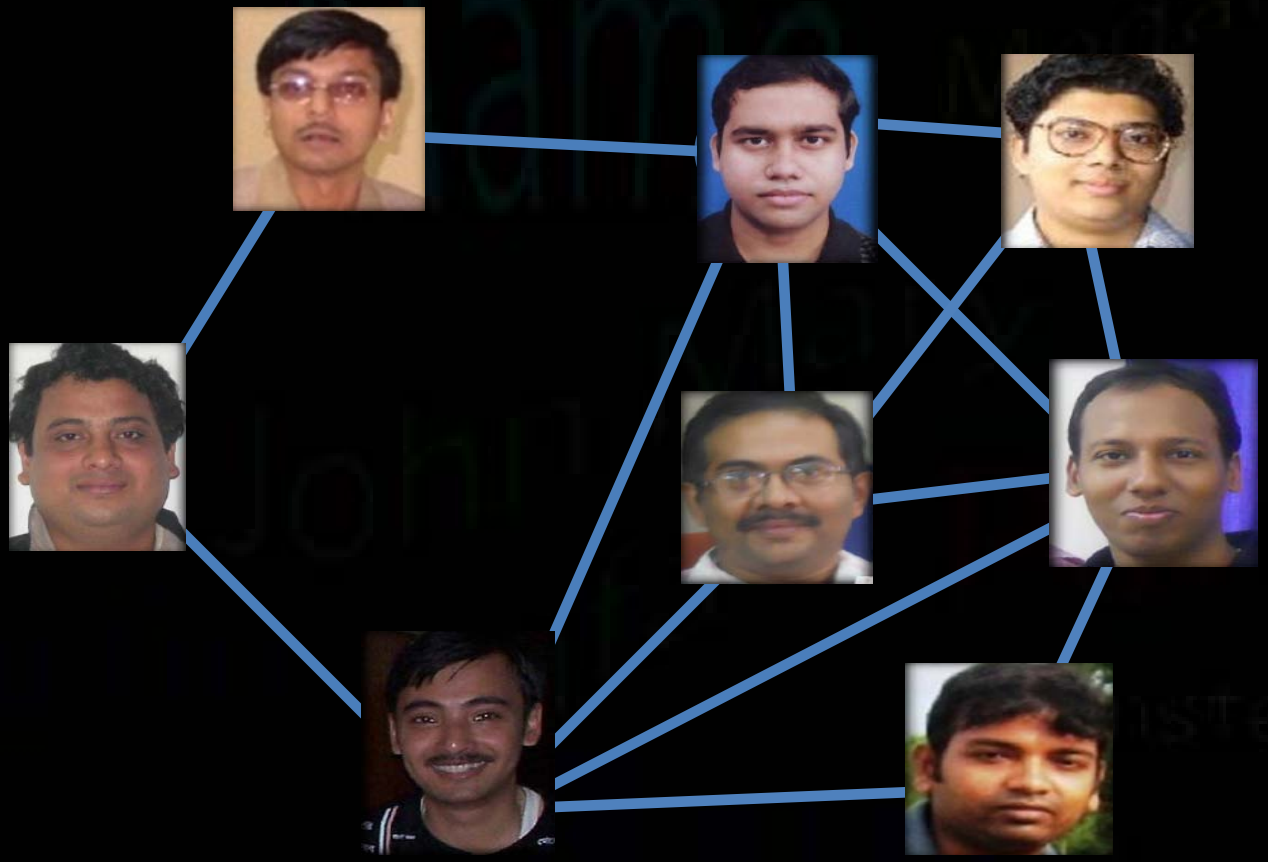
At time *t*



$t \rightarrow t+1$



At time *t*+1



Opinion formation

- Opinions evolve over time
  - some get trapped into groups
  - some die competing with others
  - usually a single opinion emerges as the winner but multi-opinion state may exist

Datasets

- Face-to-face interaction (SG)
  - Science Gallery in Dublin, Ireland (2009)
  - "INFECTIOUS:STAY AWAY" initiative for 69 days
- Face-to-face interaction (HT)
  - conference attendees of the ACM Hypertext 2009
- Nodes -> visitors/participants
- Edges -> close-range face-to-face proximity existent for 20 seconds

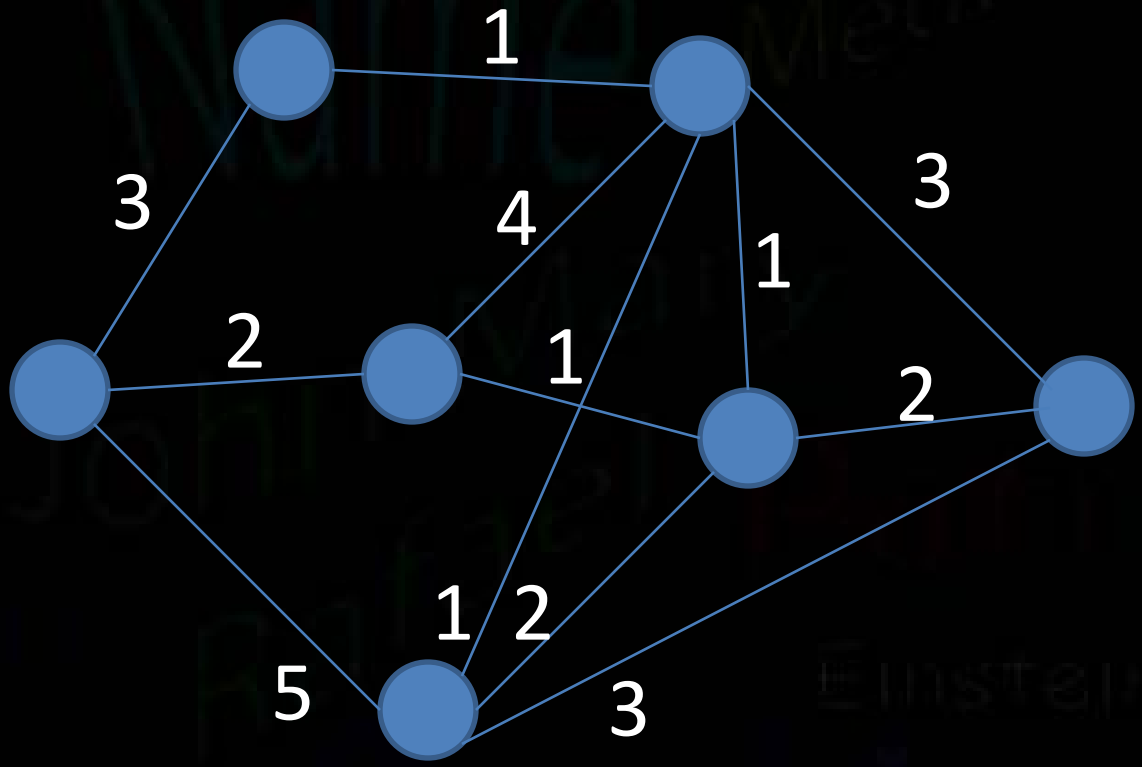
http://www.sociopatterns.org/datasets/

Experiments on SG Dataset (Daywise)

- The speaker *i* is chosen randomly from the population
- The hearer *j* is chosen preferentially among the neighbors (w_{ij} → number of 20 second intervals that *i* have face-to-face interaction with *j*)

$$p_{ij} = \frac{w_{ij}}{\sum_{j=1}^{k} w_{ij}}$$

Experiments on SG Dataset (Daywise)



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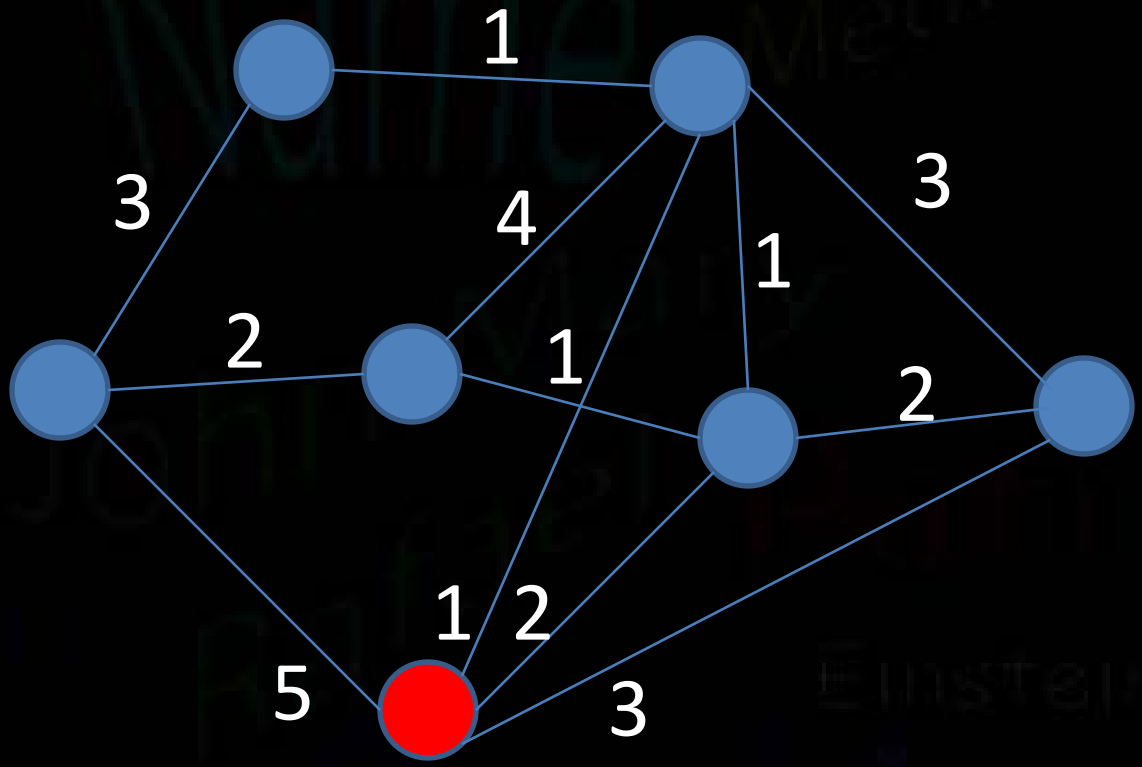

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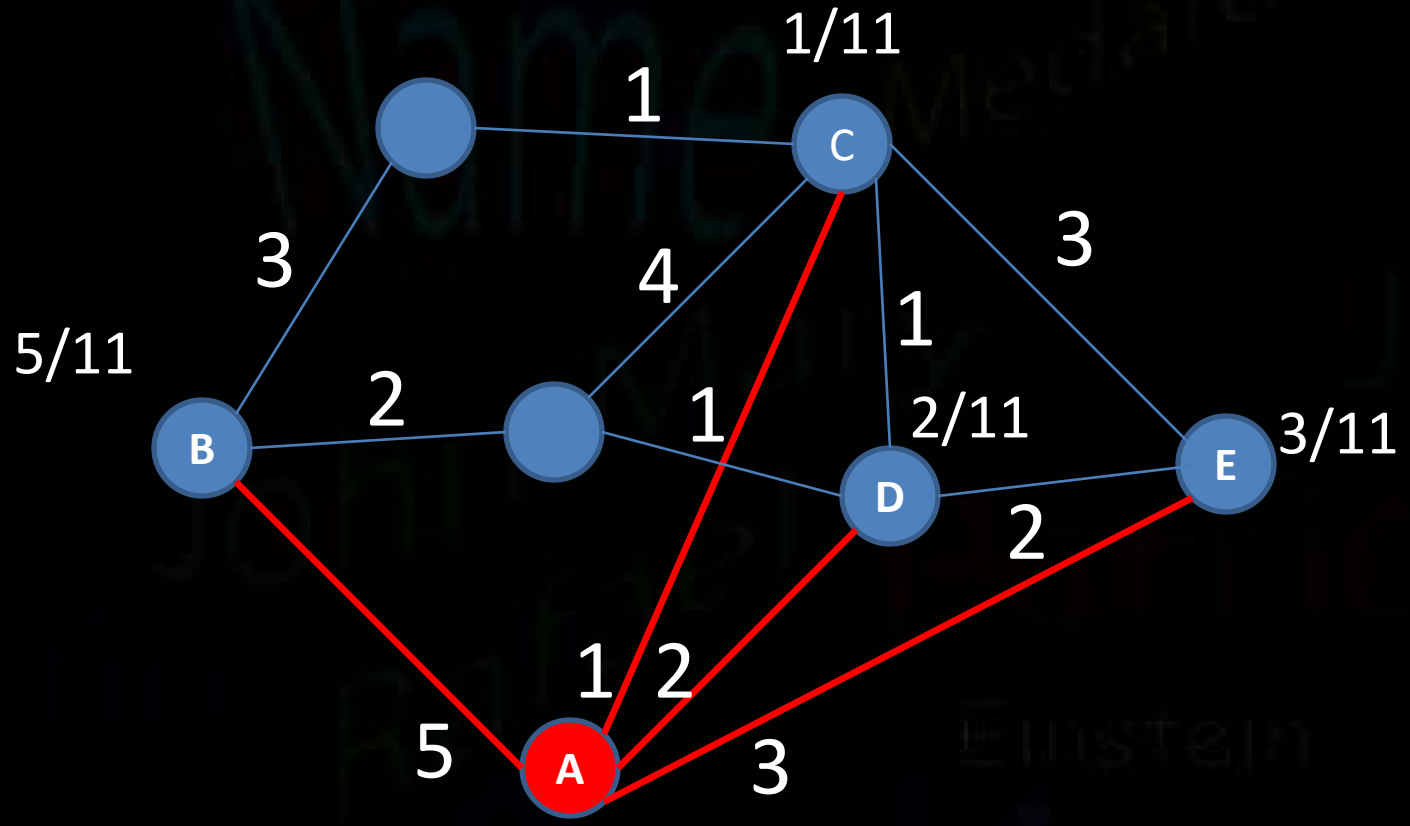

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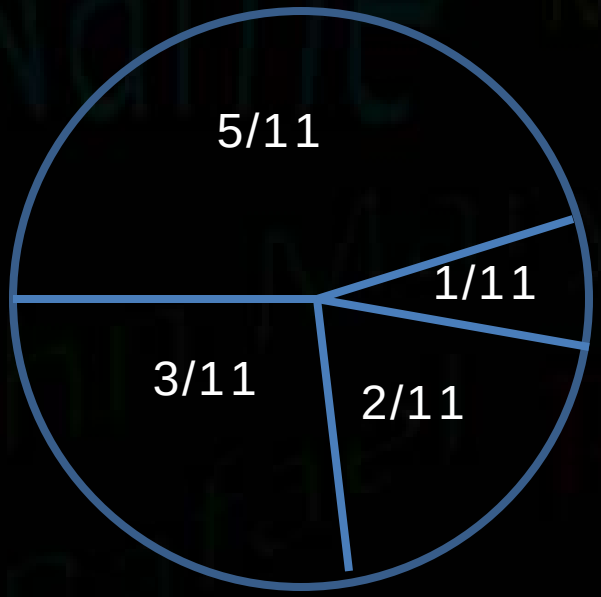

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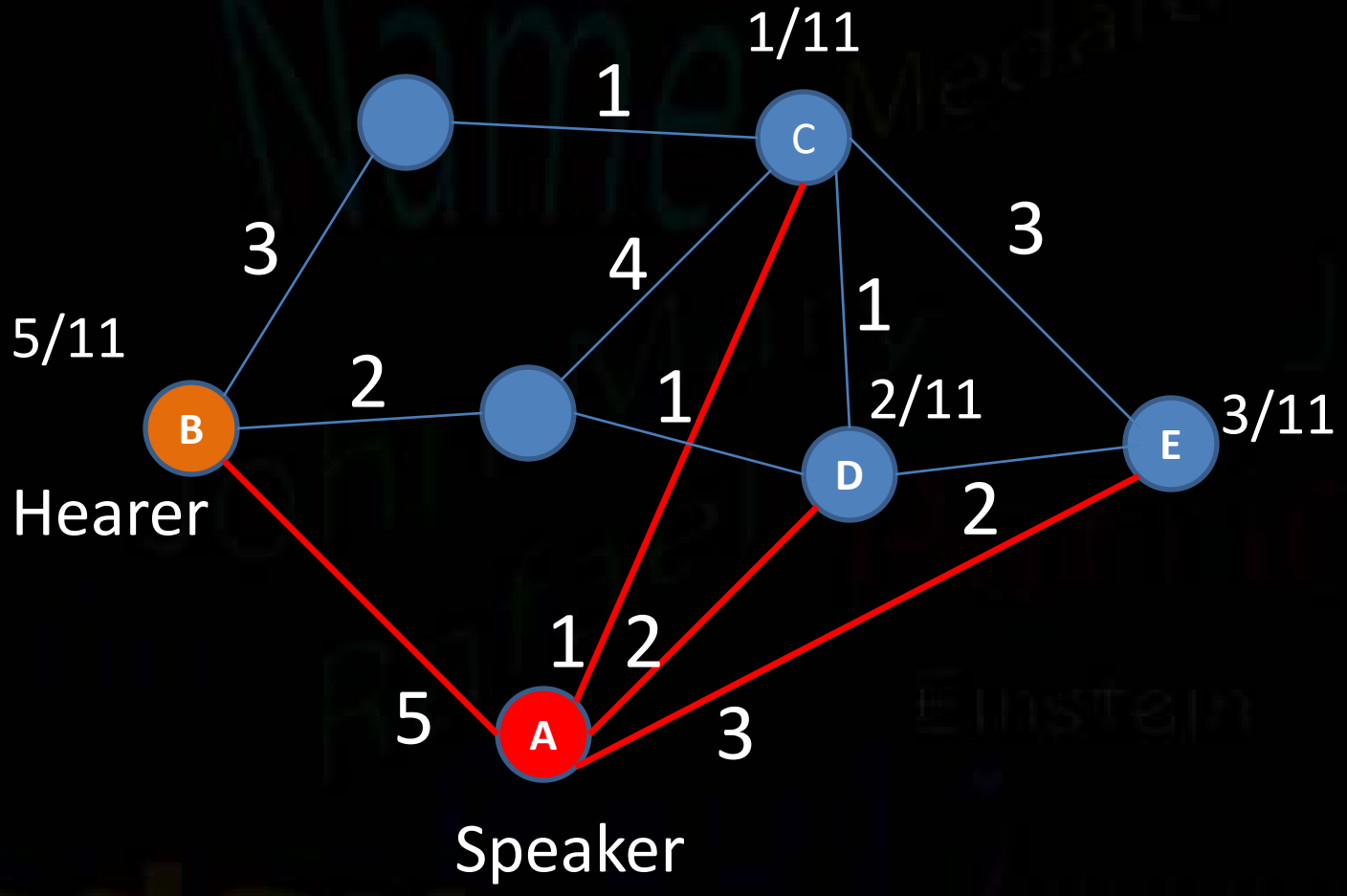
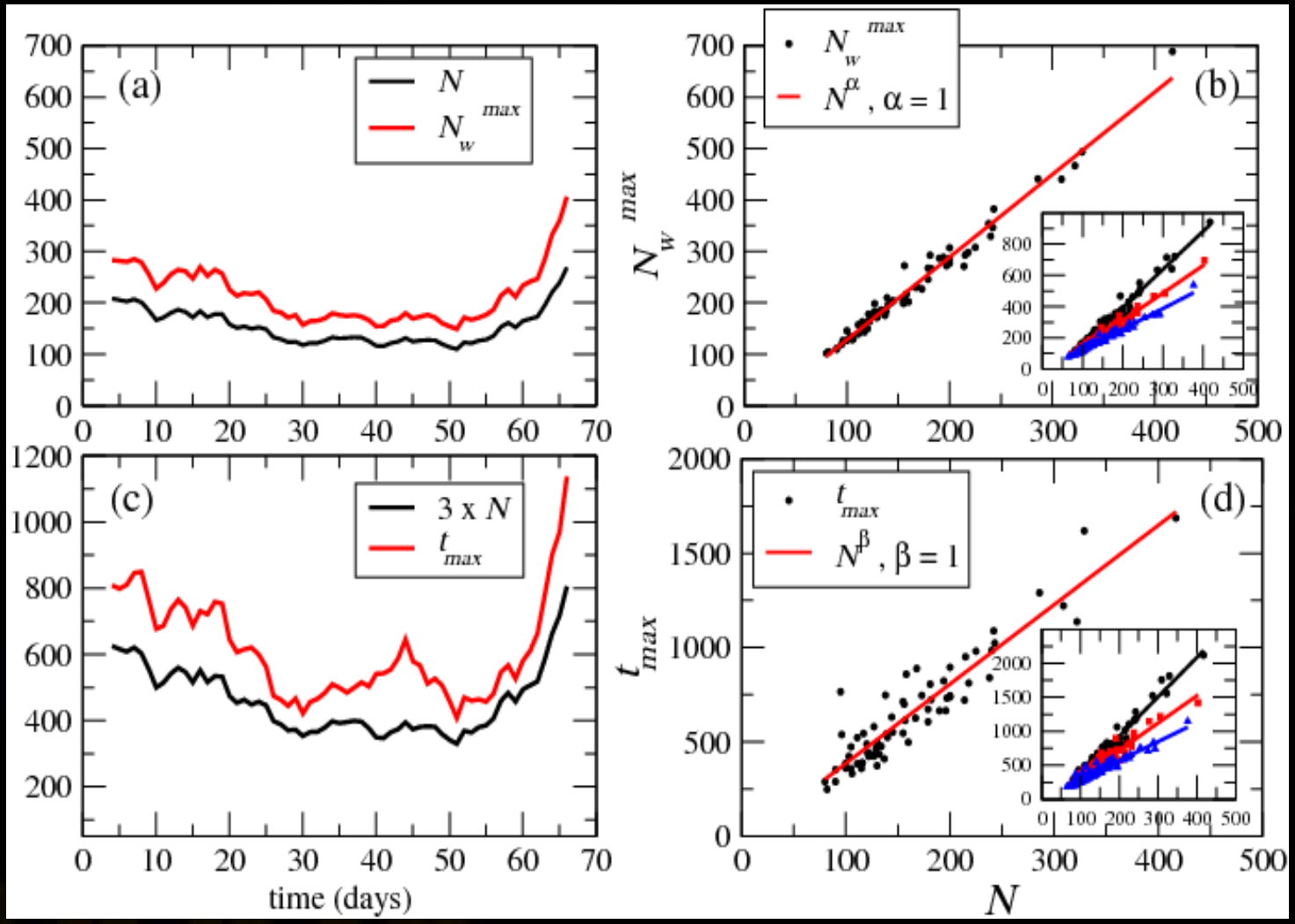
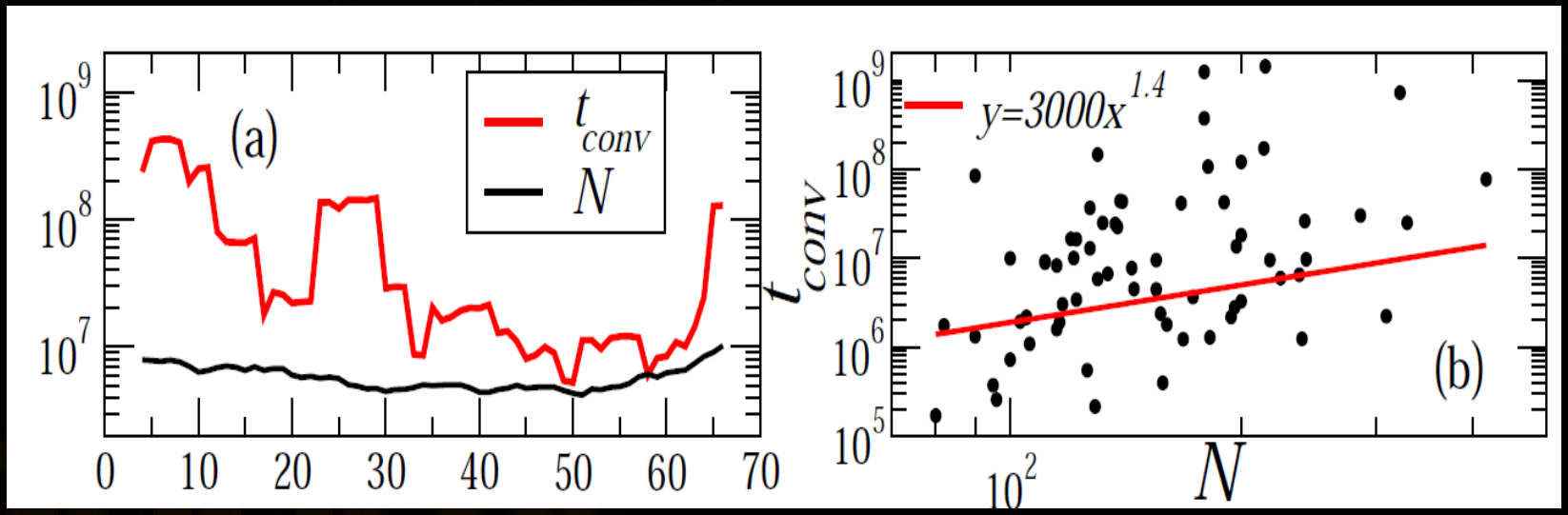


Scaling of N_w^{max} and t_{max}

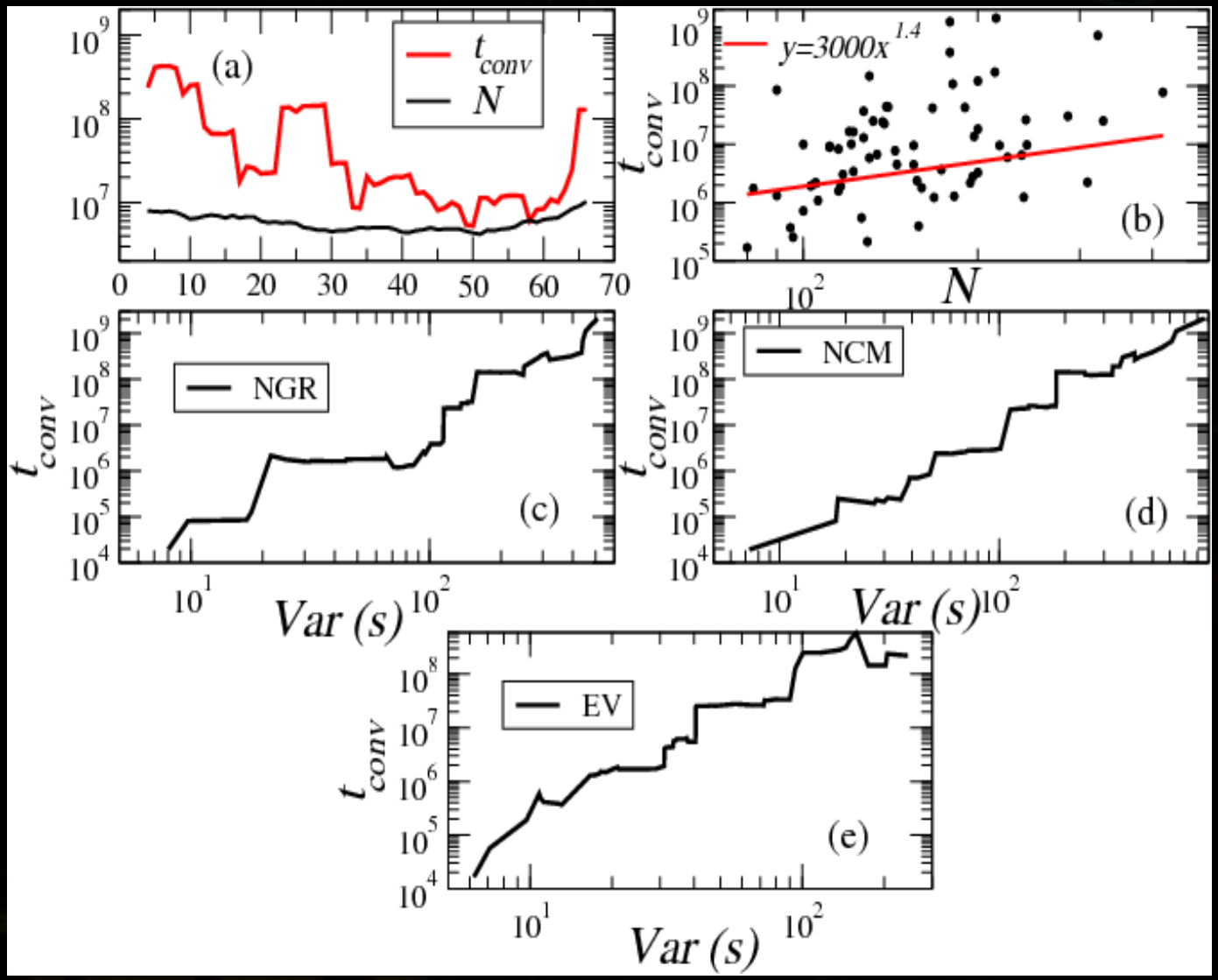


Scaling Relations

- N_w^{max} ~ O(N) [✓]
- t_{max} ~ O(N) [✓]
- But what about t_{conv} ? ~~$O(N^{1.4})$~~



Opinions trapped in communities



Examples of individual days

Daily Network	Connectedness	Convergence Type
Day 9	Connected	Slow
Day 20	Disconnected	Fast
Day 22	Connected	Fast
Day 26	Disconnected	Slow

Metrics

- Average unique words per community U(t)

$$U(t) = \frac{\sum_{i=1}^{C} |A_i|}{C}$$

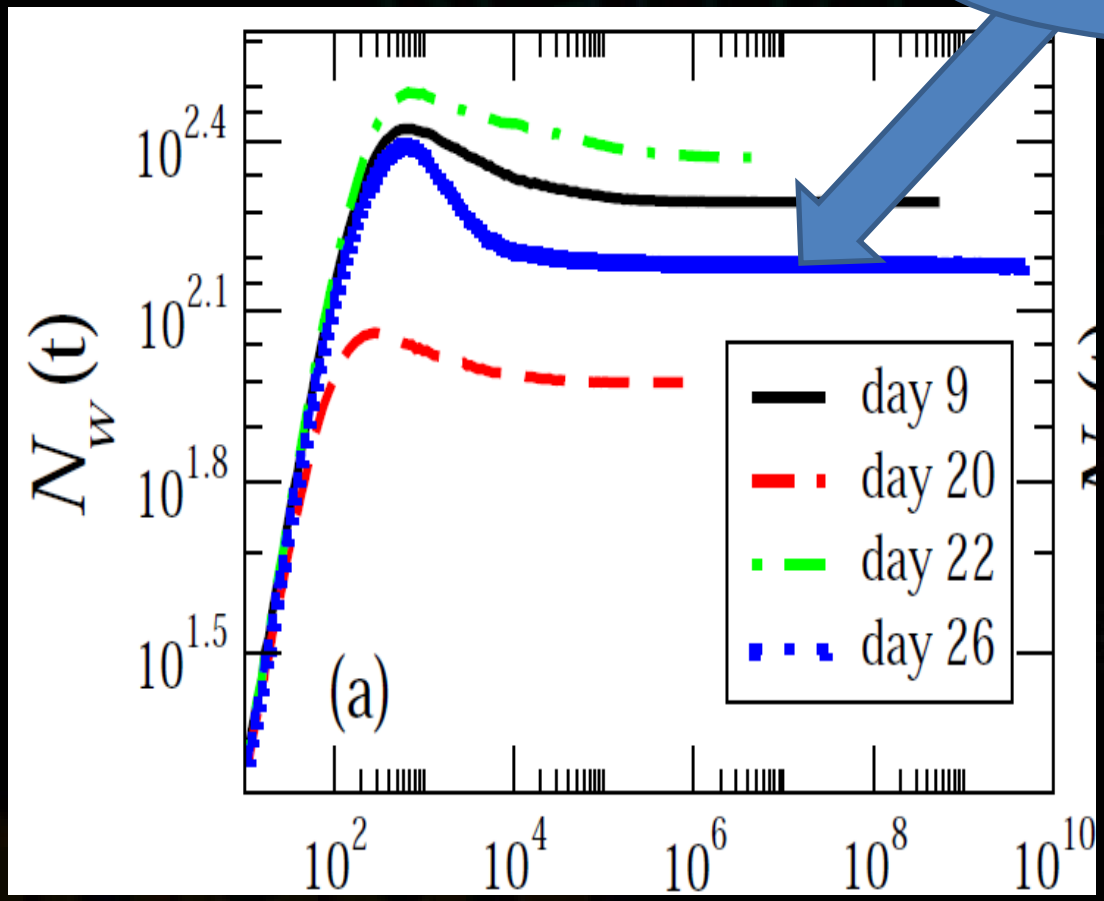
- Average overlap of unique words across communities $O_c(t)$

$$O_c(t) = \frac{2}{C(C-1)} \sum_{i>j} \frac{2(|A_i \bigcap A_j|)}{\sqrt{2(|A_i|^2 + |A_j|^2)}}$$

A_i → list of unique words within community *i;*
C → number of communities

Darmstadt

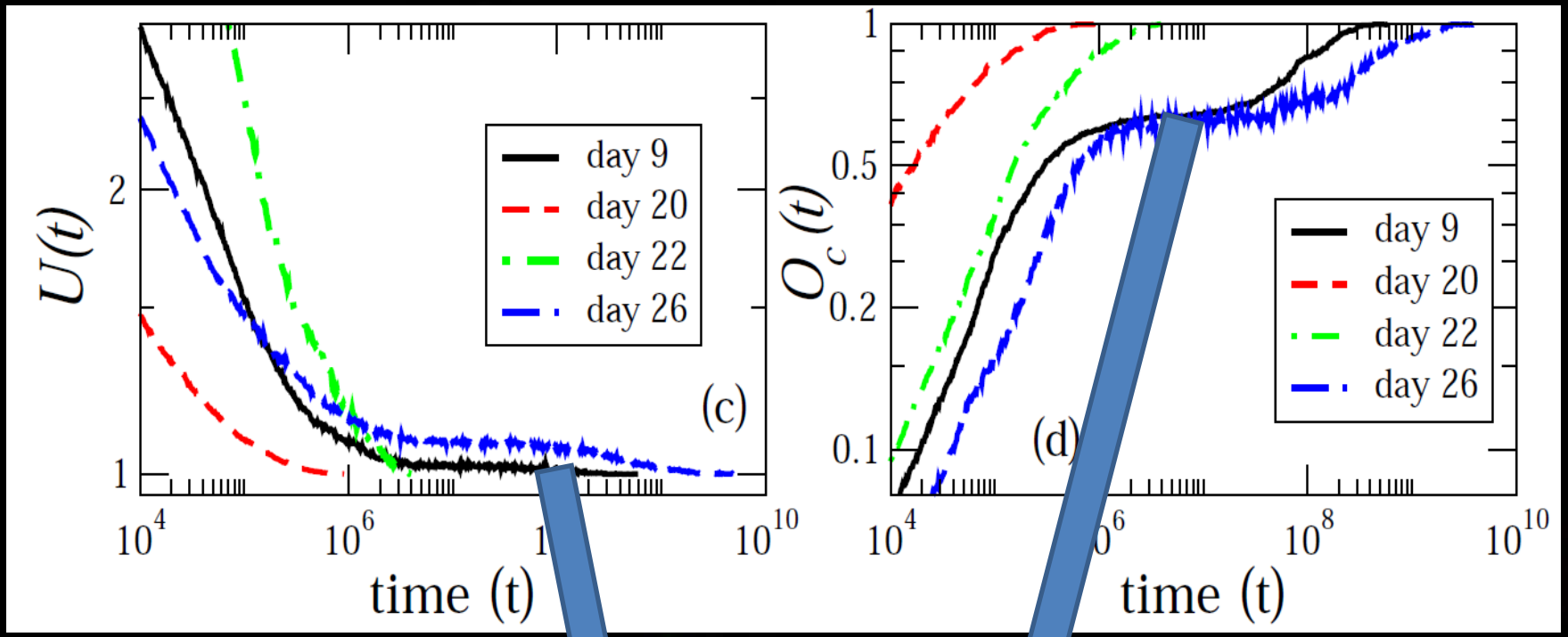
Emergence of metastability



3 phases

1. Steady growth
2. Reorganization
3. Long plateau

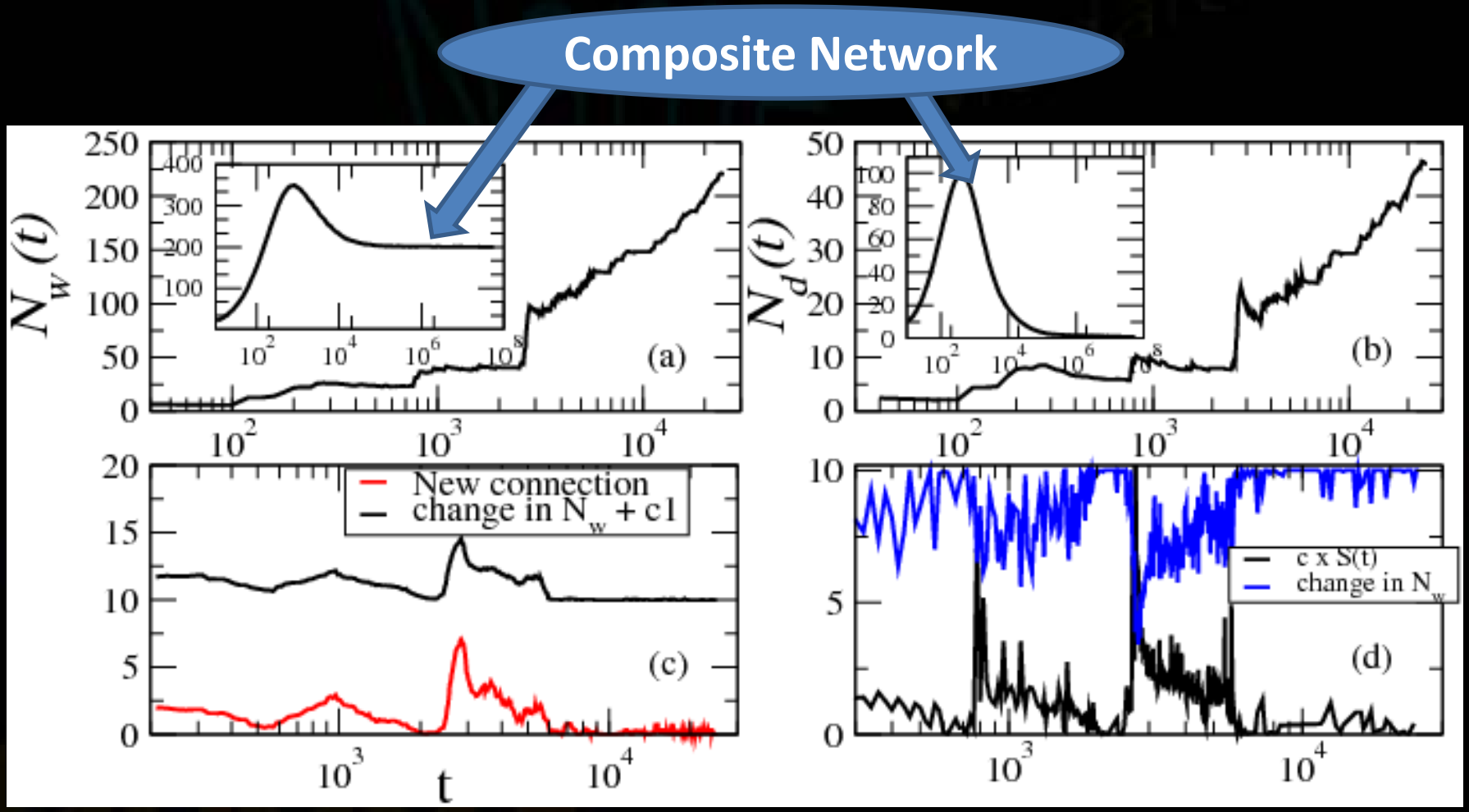
Multi-opinion states



Existence of multi-opinion states and metastability

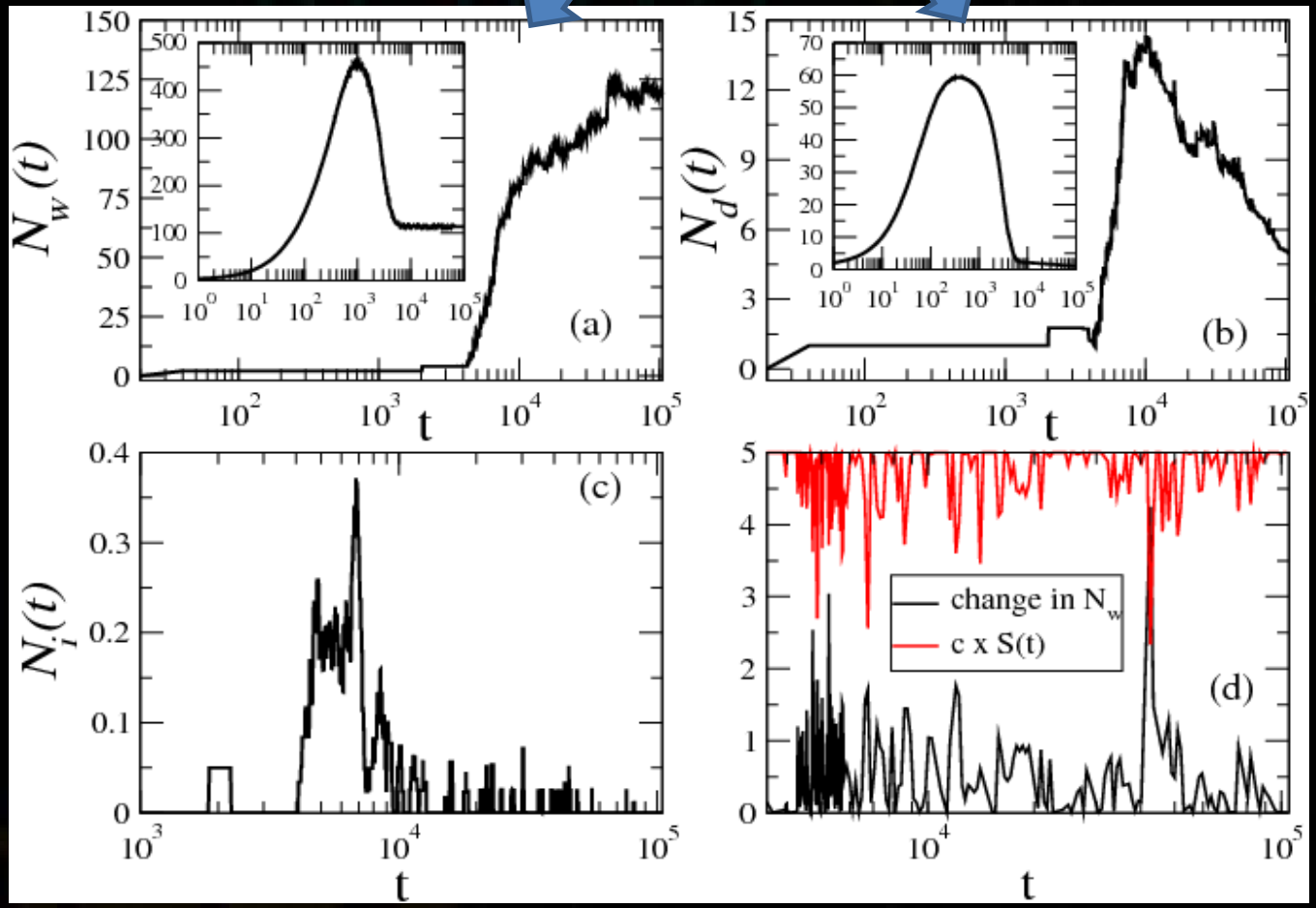
Time resolved SG data

Day 9 (Results for all the other days are representative)



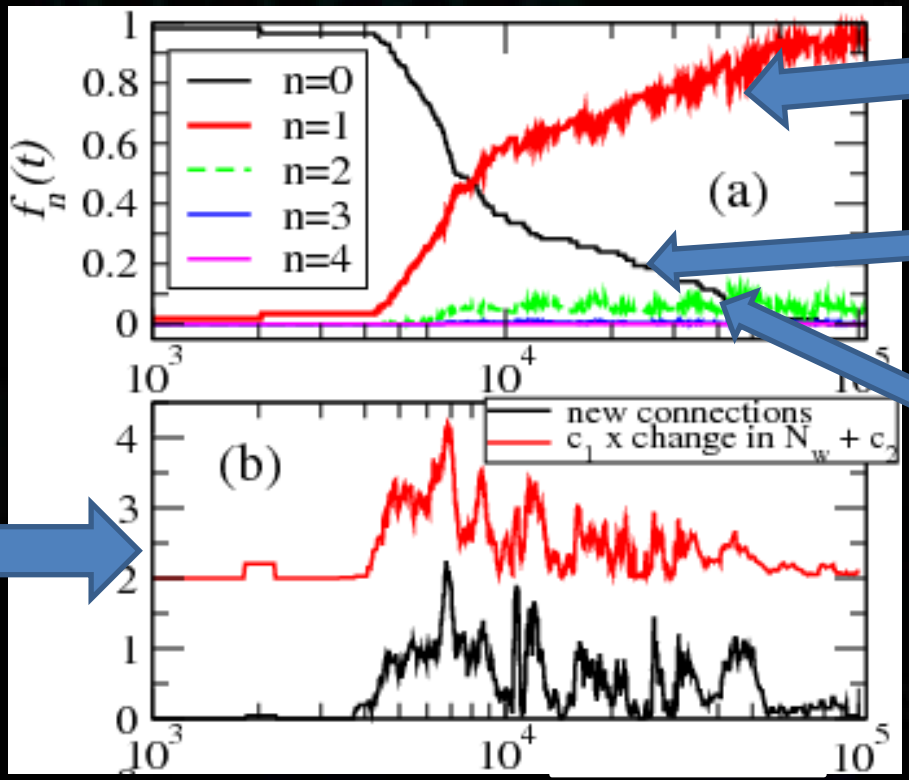
HT Dataset

Composite Network



Further Experiments

The new connections at each time step causes late-stage failures

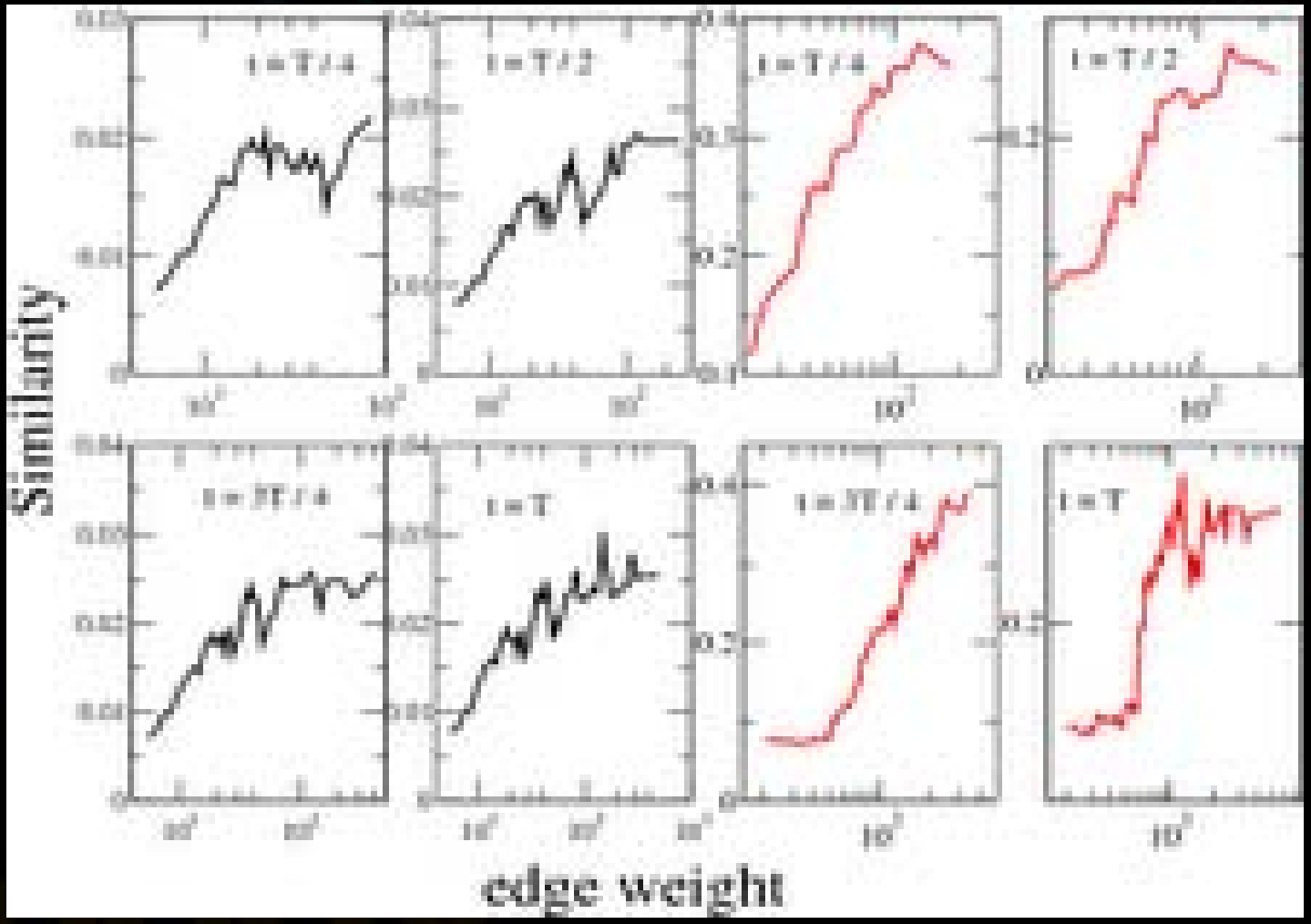


increases

diminishes

roughly stable

More interaction favors similarity



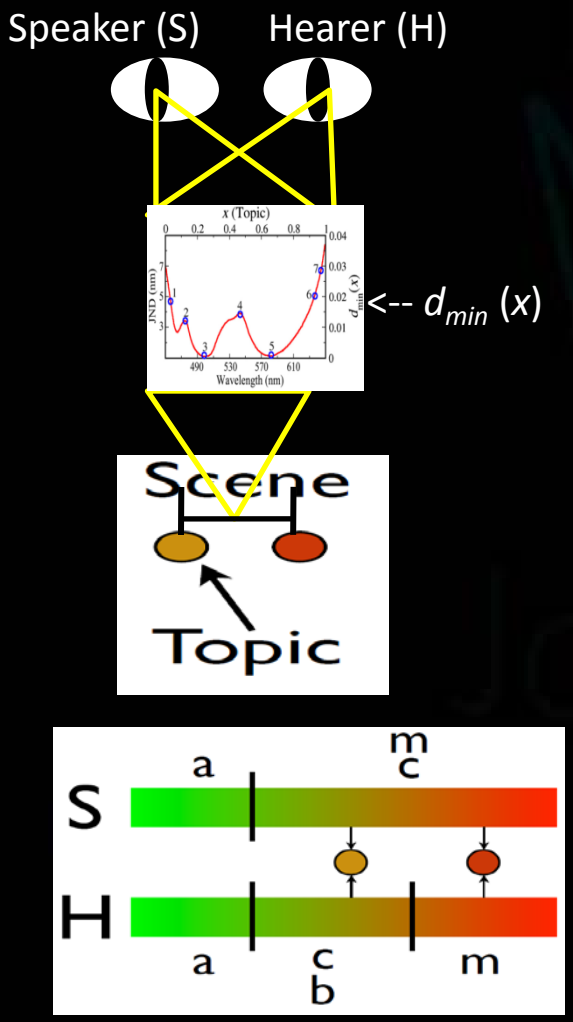
Summary

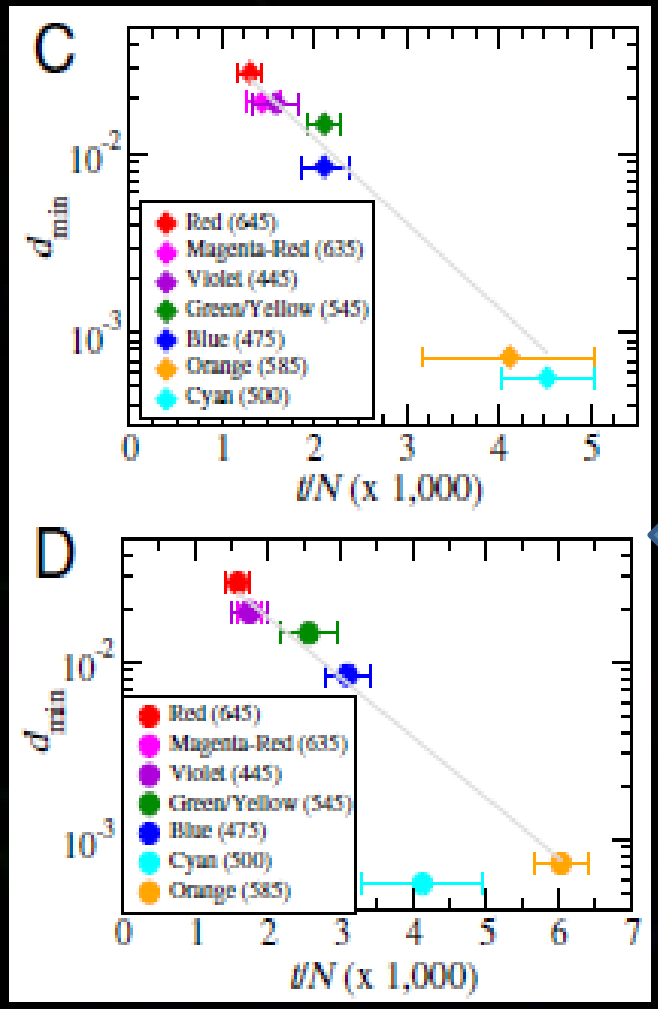
The presence of community structure

a continuous influx of new connections (leading to late-stage failures in the system)

steady growth of N_w in its final regime of evolution

Naming to Color Naming





[white black] < [red] < [green yellow] < [blue] < [brown] < [purple pink orange gray],

Loreto, Mukherjee and Tria, On the origin of the hierarchy of color names, *PNAS* May 1, 2012 vol. 109 no. 18 6819-6824

Danke ....