OPINION FORMATION IN TIME-VARYING SOCIAL NETWORK: THE CASE OF NAMING GAME

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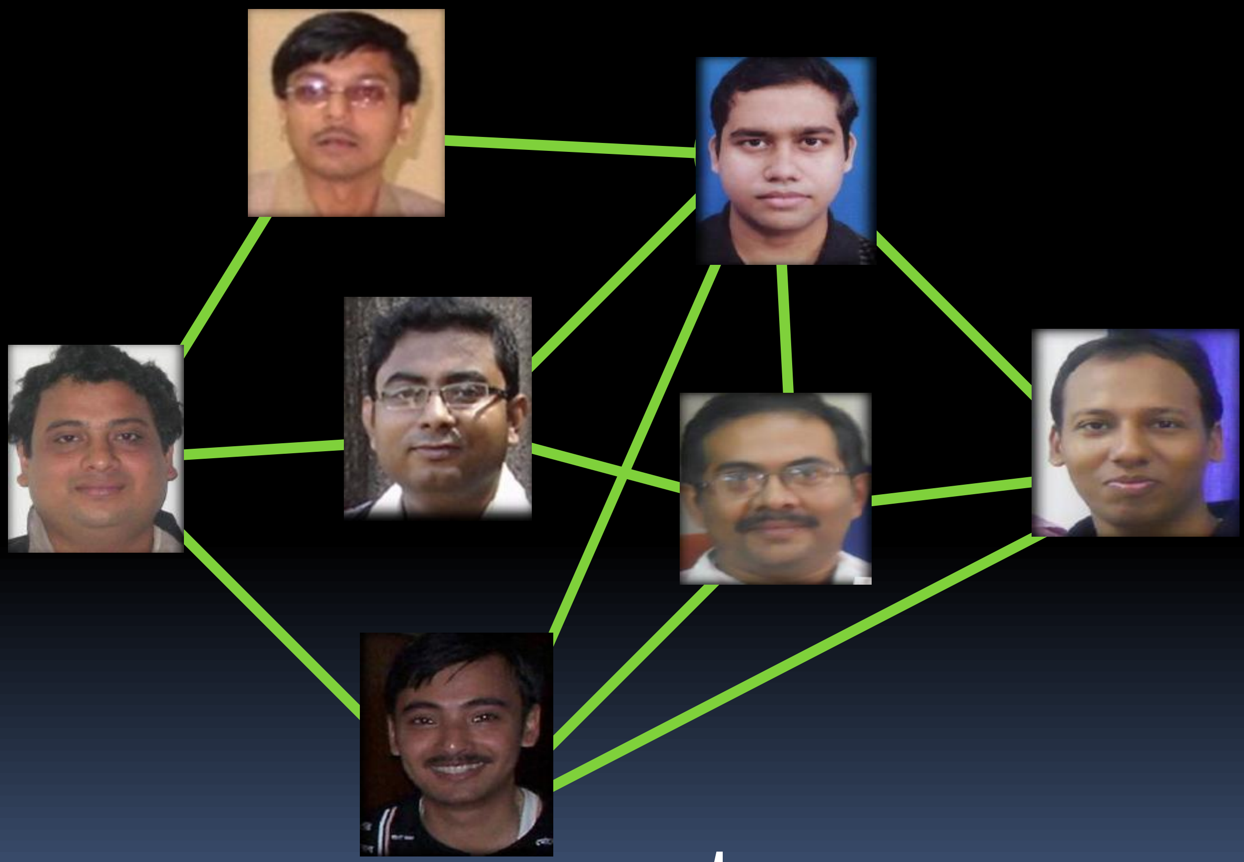
Naming Game in complex networks

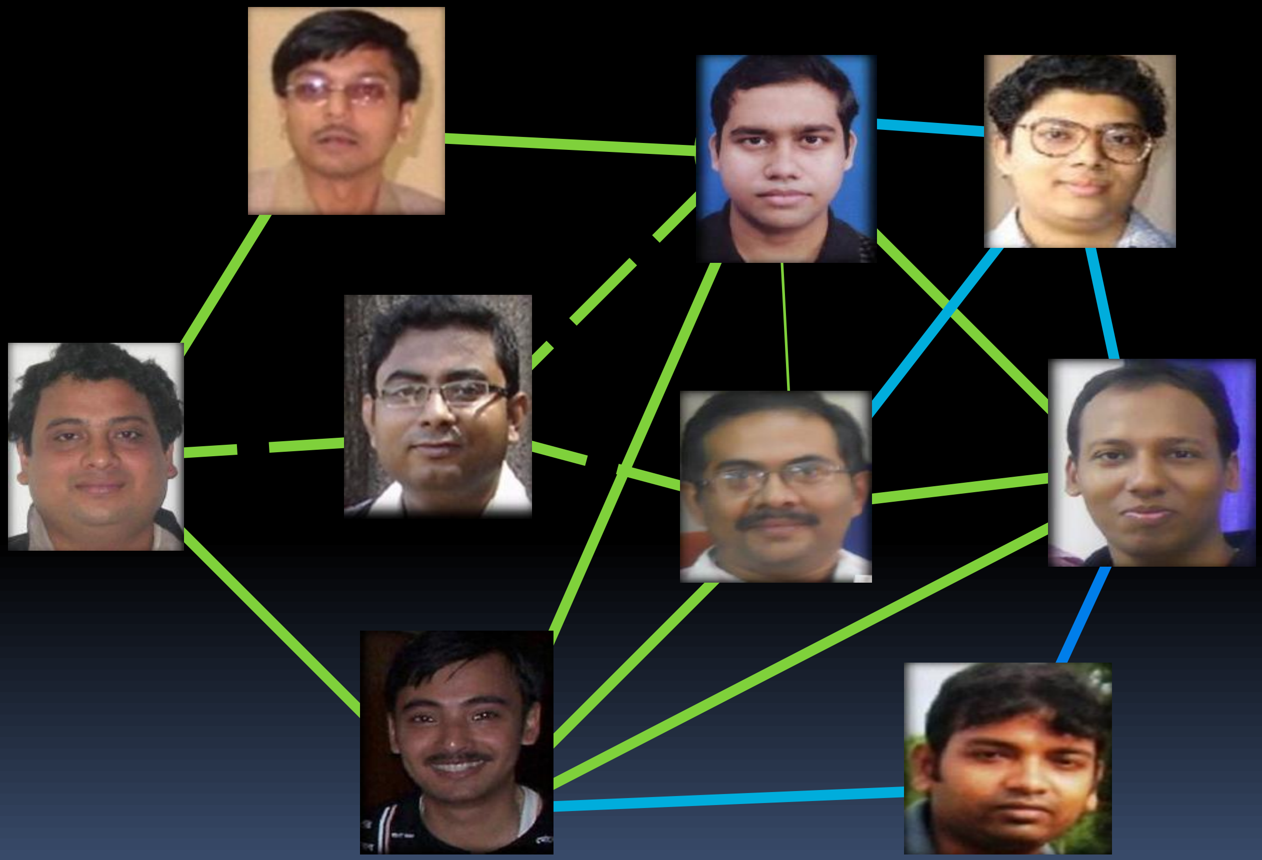
	N_{max}^{w}	t_{max}	t_{conv}
Fully connected Graph	$N^{1.5}$	$N^{1.5}$	$N^{1.5}$
Scale - free	N	N	$N^{1.4}$
Erdos – Renyi Network	N	N	$N^{1.4}$
Small World	N	N	$N^{1.4}$

Time-varying Network

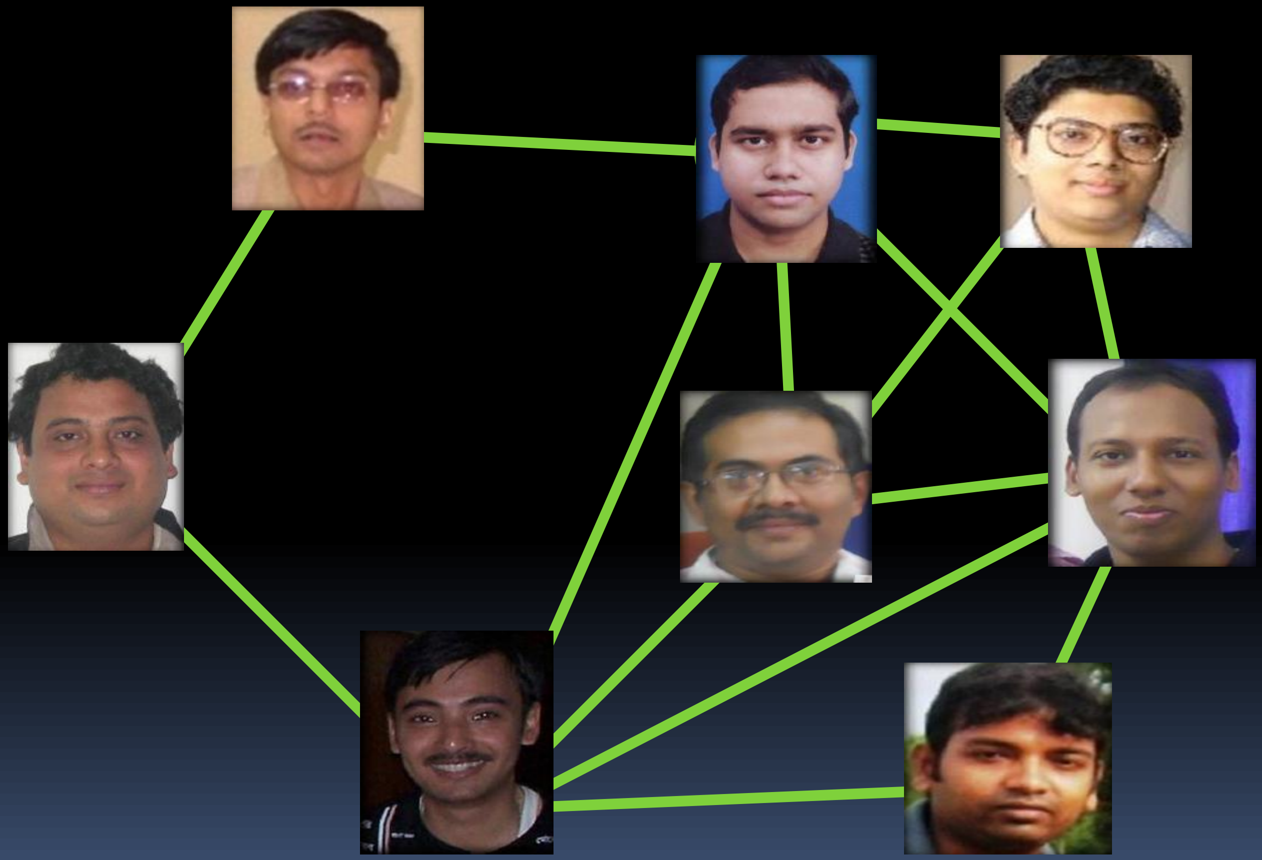
- But social network are inherently dynamic
- Social interactions and human activities are intermittent
- Links appear and disappear from the system
- As time progresses, societal structure keeps changing with social conventions, shared cultural and linguistic patterns reshaping themselves



t



t -> t+1



t+1

Workshop on Social Networks

Opinions in time-varying social network

- Opinions spread with the time-varying societal structure
- Opinions evolves over time
  - some get trapped into groups
  - some die competing with others
  - usually one opinion emerges as the winner but multi-opinion state may exist

Time-varying real world dataset (SG Dataset)

- face-to-face interaction
  - Science Gallery in Dublin, Ireland
  - spring of 2009
  - “INFECTIOUS:STAY AWAY”

- Nodes -> visitors of science gallery
- Edges -> close-range face-to-face proximity
- Weights ->the number of 20 seconds intervals during which close-range face-to-face proximity could be detected

Time-varying real world dataset (HT Dataset)

- face-to-face interaction data of the conference attendees of the ACM Hypertext 2009 conference held in ISI Foundation in Turin, Italy, from June 29th to July 1st, 2009
- Dynamical network consists of 115 conference attendees

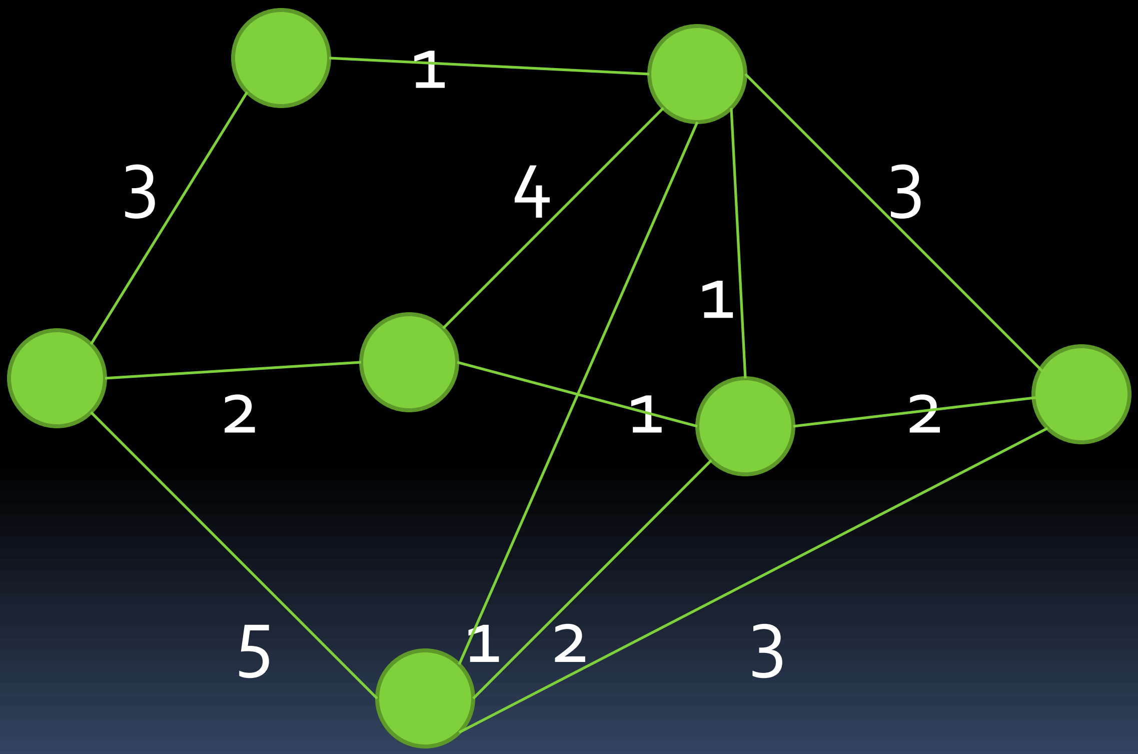
http://www.sociopatterns.org/datasets/

Results on SG Dataset

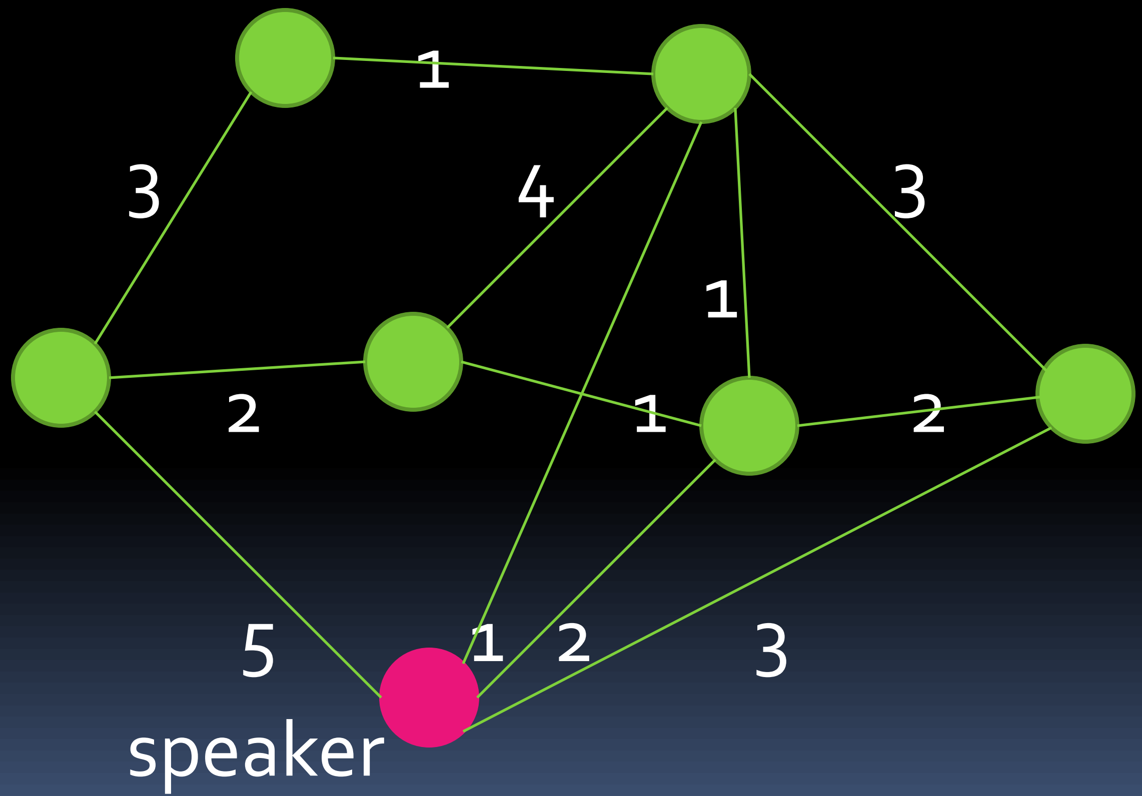
- The speaker i is chosen randomly from the population
- The hearer j is chosen preferentially among the neighbors

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

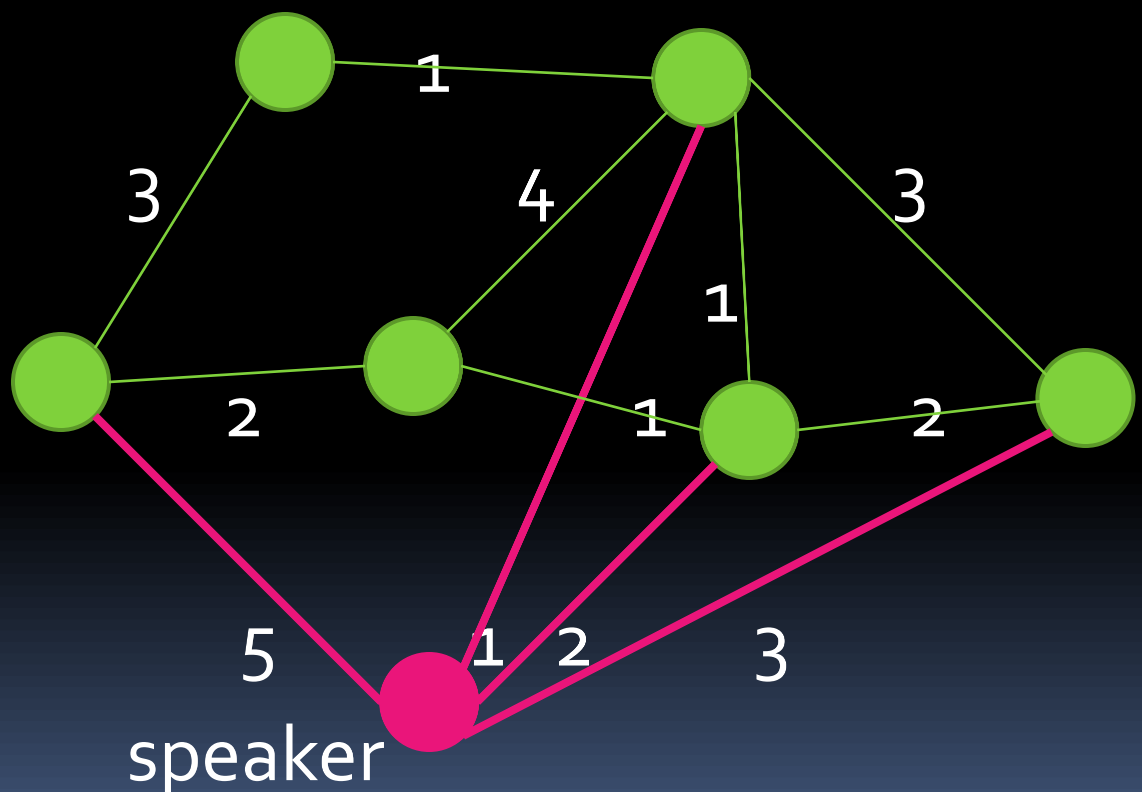
Results on SG Dataset



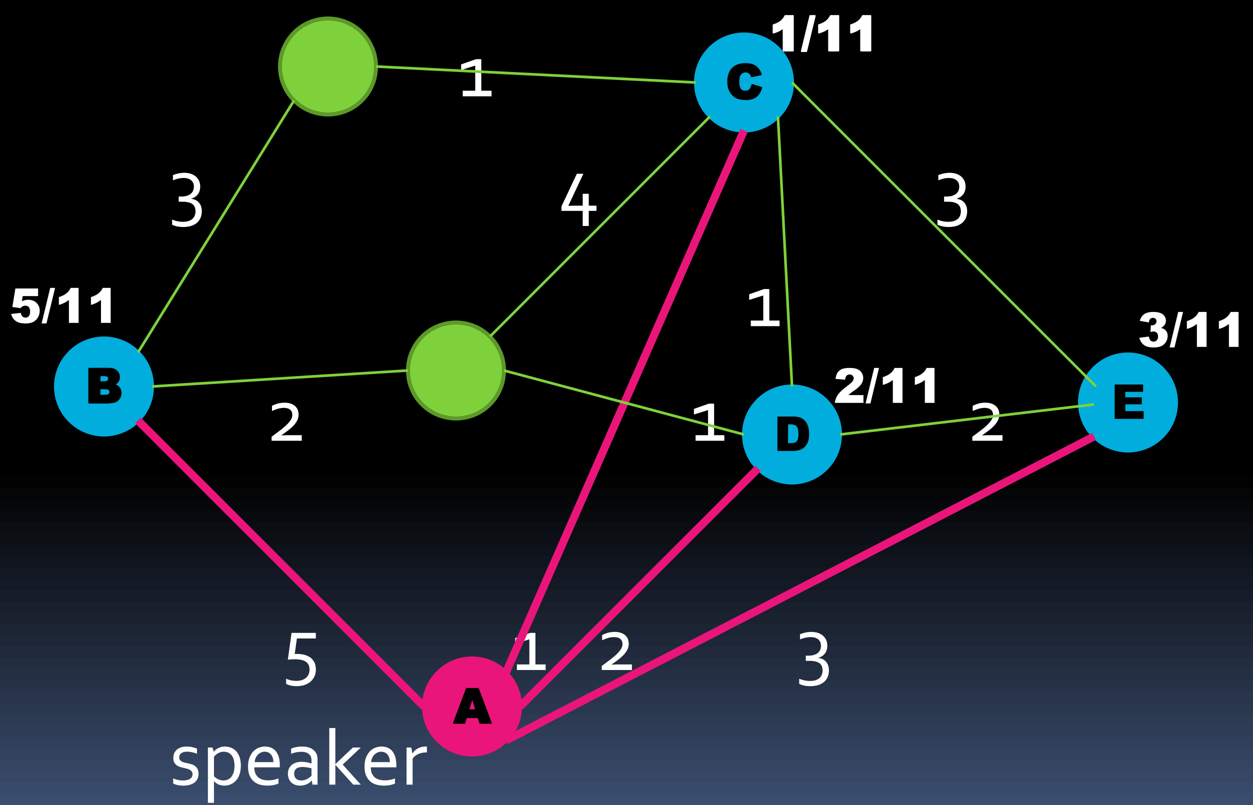
Results on SG Dataset



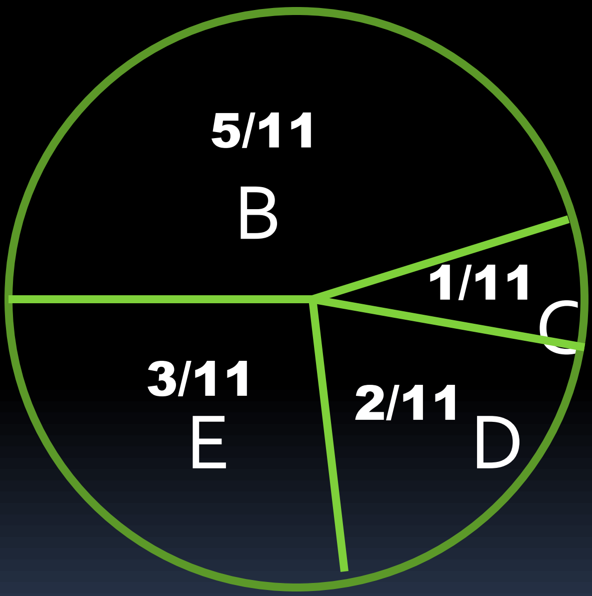
Results on SG Dataset



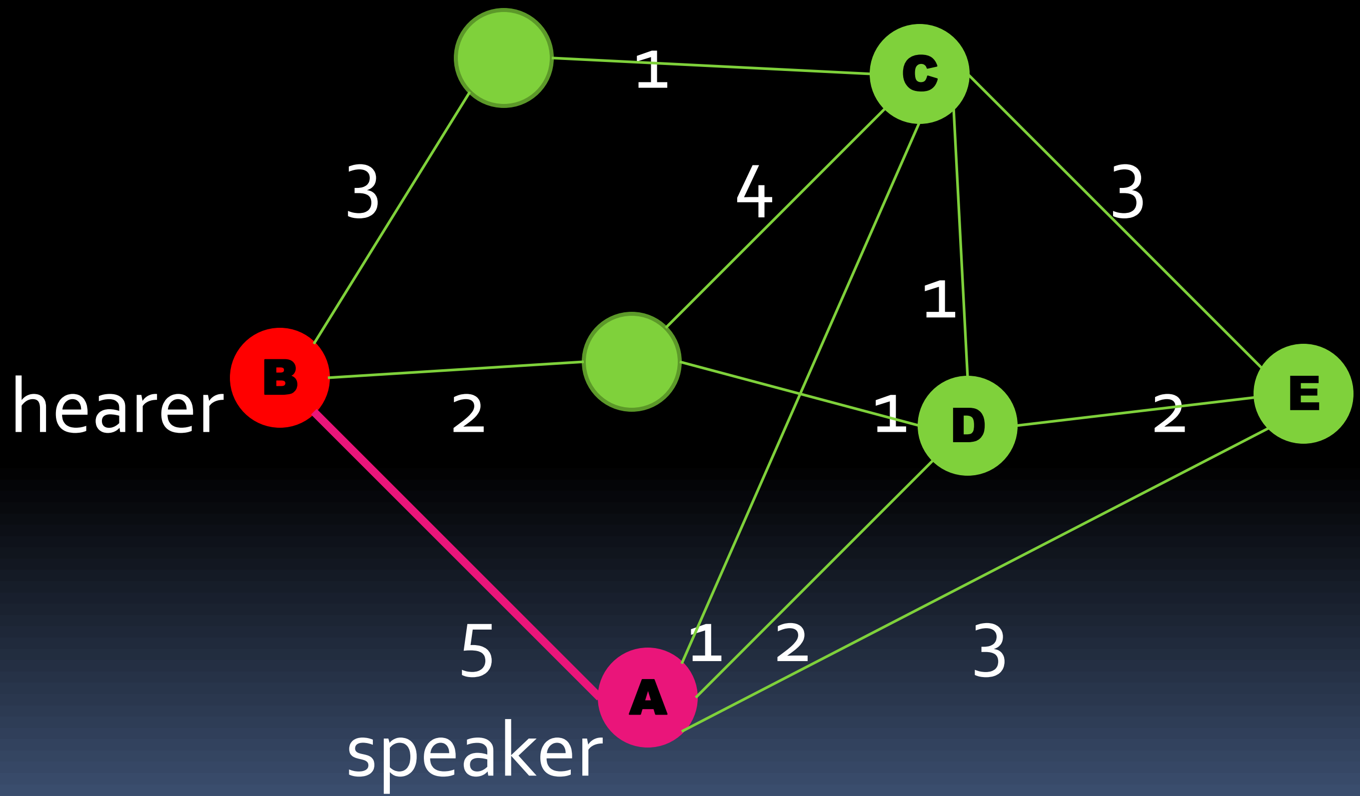
Results on SG Dataset



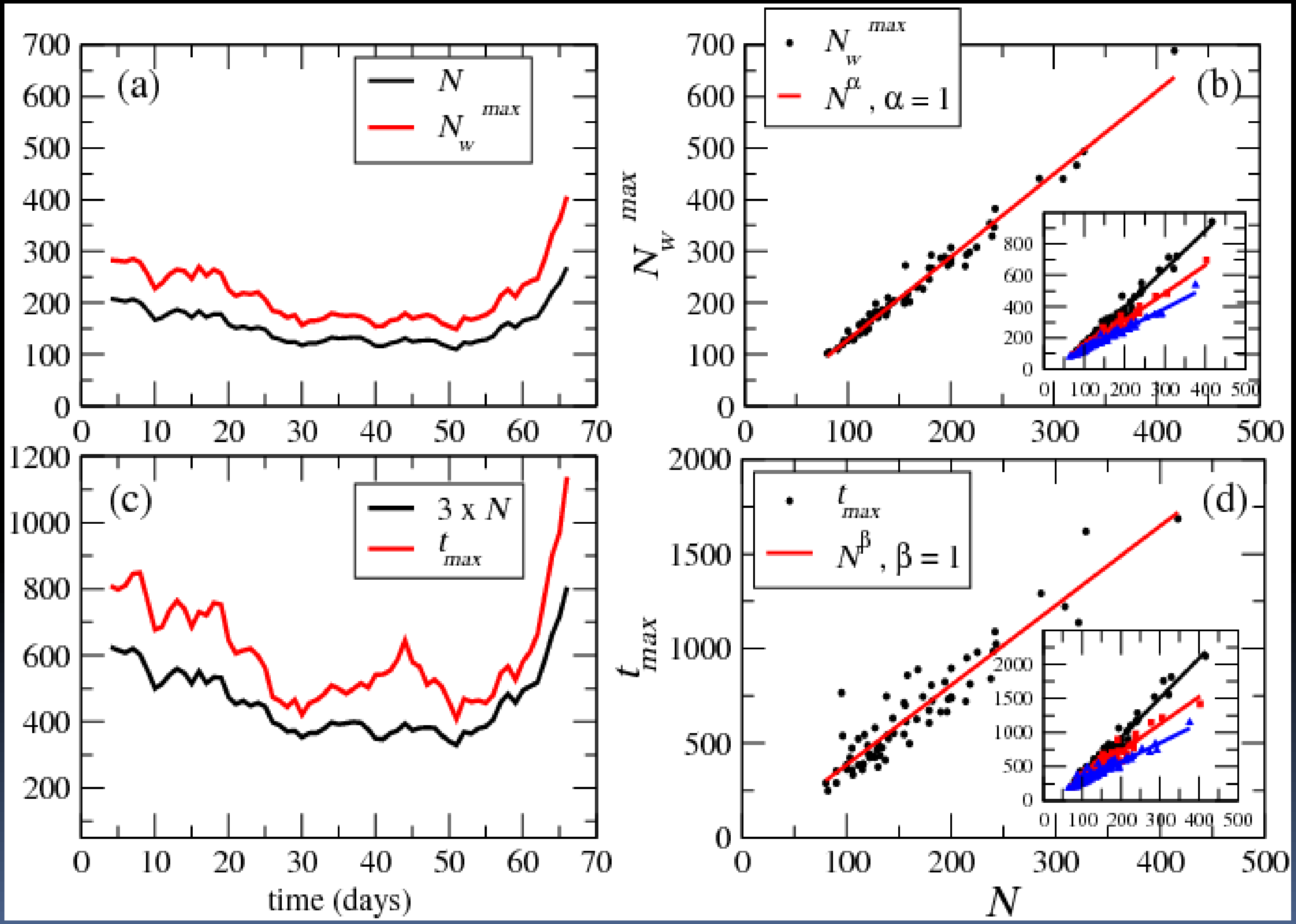
Results on SG Dataset



Results on SG Dataset

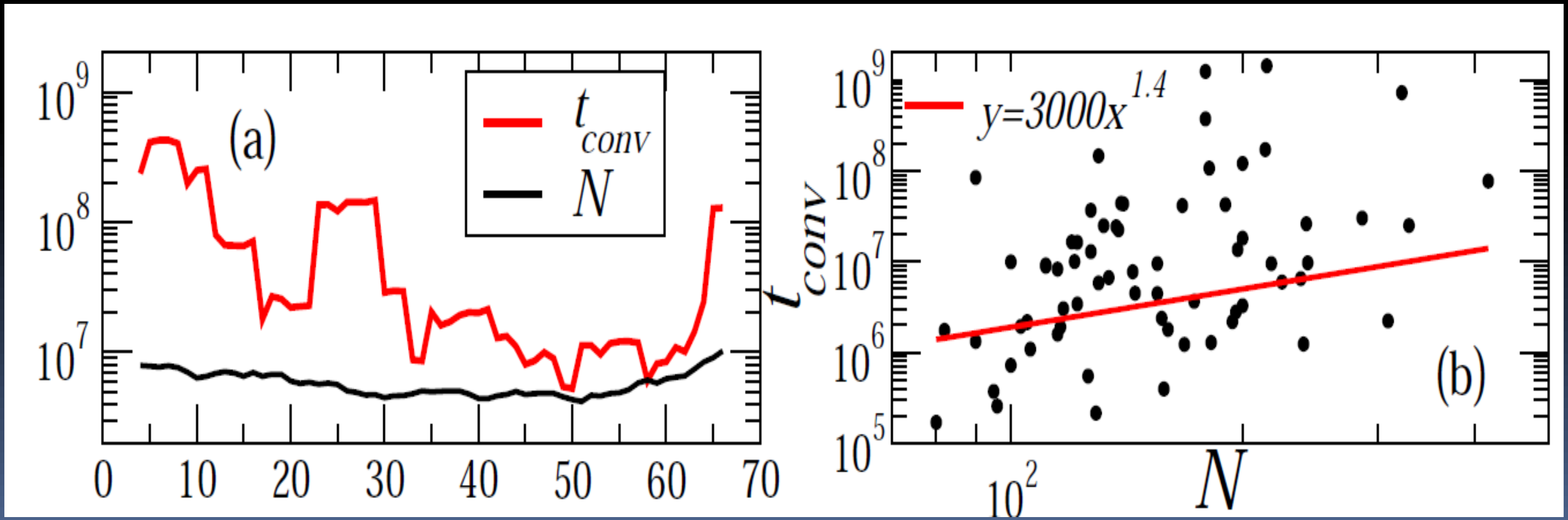


Scaling of N_w^{max} and t_{max}



- $N_w^{max} \sim O(N)$
- $t_{max} \sim O(N)$
- in perfect agreement with existing literature
- But what about t_{conv} ?

~~$O(N^{1.4})$~~



Community structure and t_{conv}

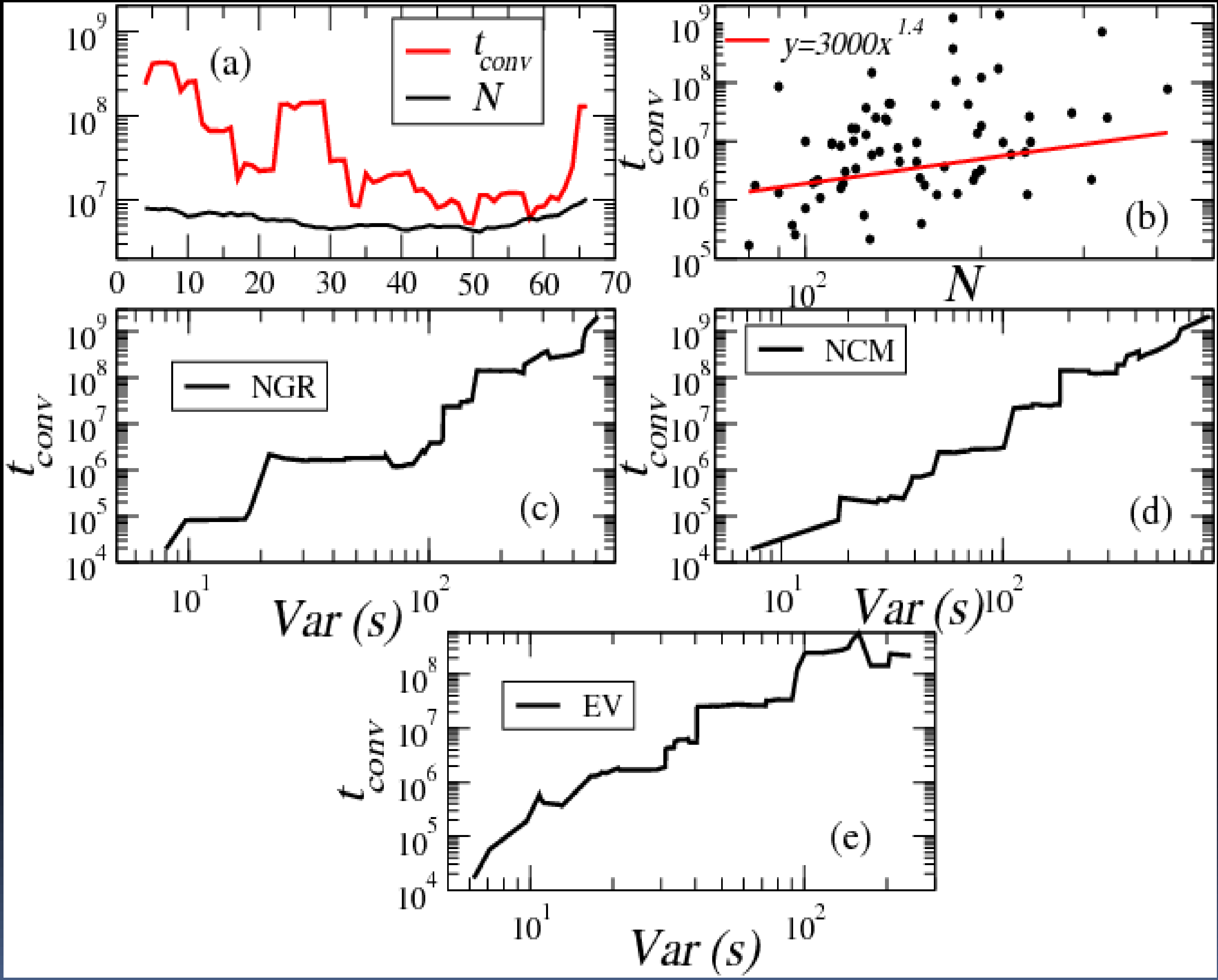
- Real world social networks consist of a number of communities
  - nodes within communities are densely connected
  - links bridging communities are sparse

- Leads to the emergence of long-lasting multi-opinion state at the late stage of the dynamics
  - fast internal consensus within community
  - very slow opinion spreading across communities

Community structure and t_{conv}

- slows down the dynamics
- makes the system even slower is the presence of different sized communities
  - agents in a larger size community have a higher probability of being chosen for a game than those belonging to a smaller size community

- t_{conv} is positively correlated with variance of community sizes well supported by simulation results



(a)
t_{conv}
N
(b)
y=3000x^1.4
t_{conv}
N
(c)
NGR
t_{conv}
Var (s)
(d)
NCM
t_{conv}
Var (s)
(e)
EV
t_{conv}
Var (s)

Examples of Individual Instances

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

- We propose two metrics to capture the two distinctive behavior of convergence time

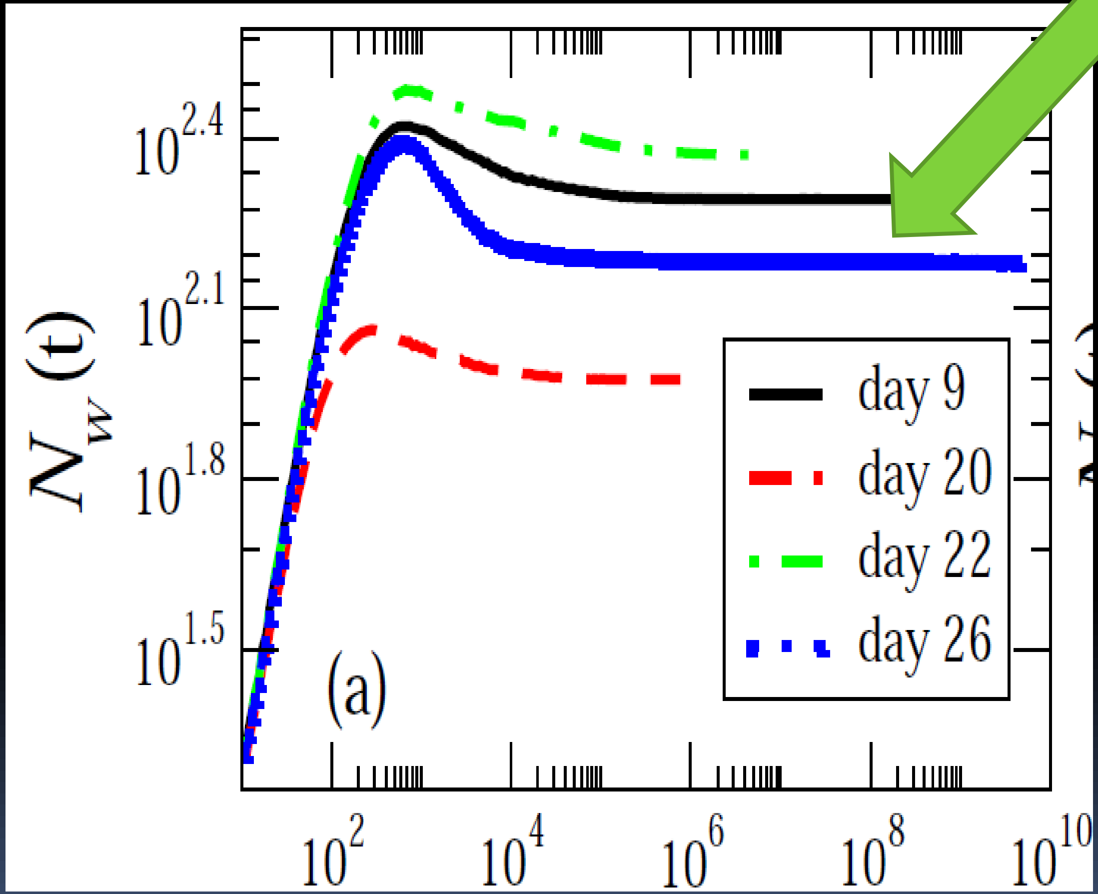
❖ average unique words per community $U(t)$

❖ average overlap of unique words across communities $O_c(t)$

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

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

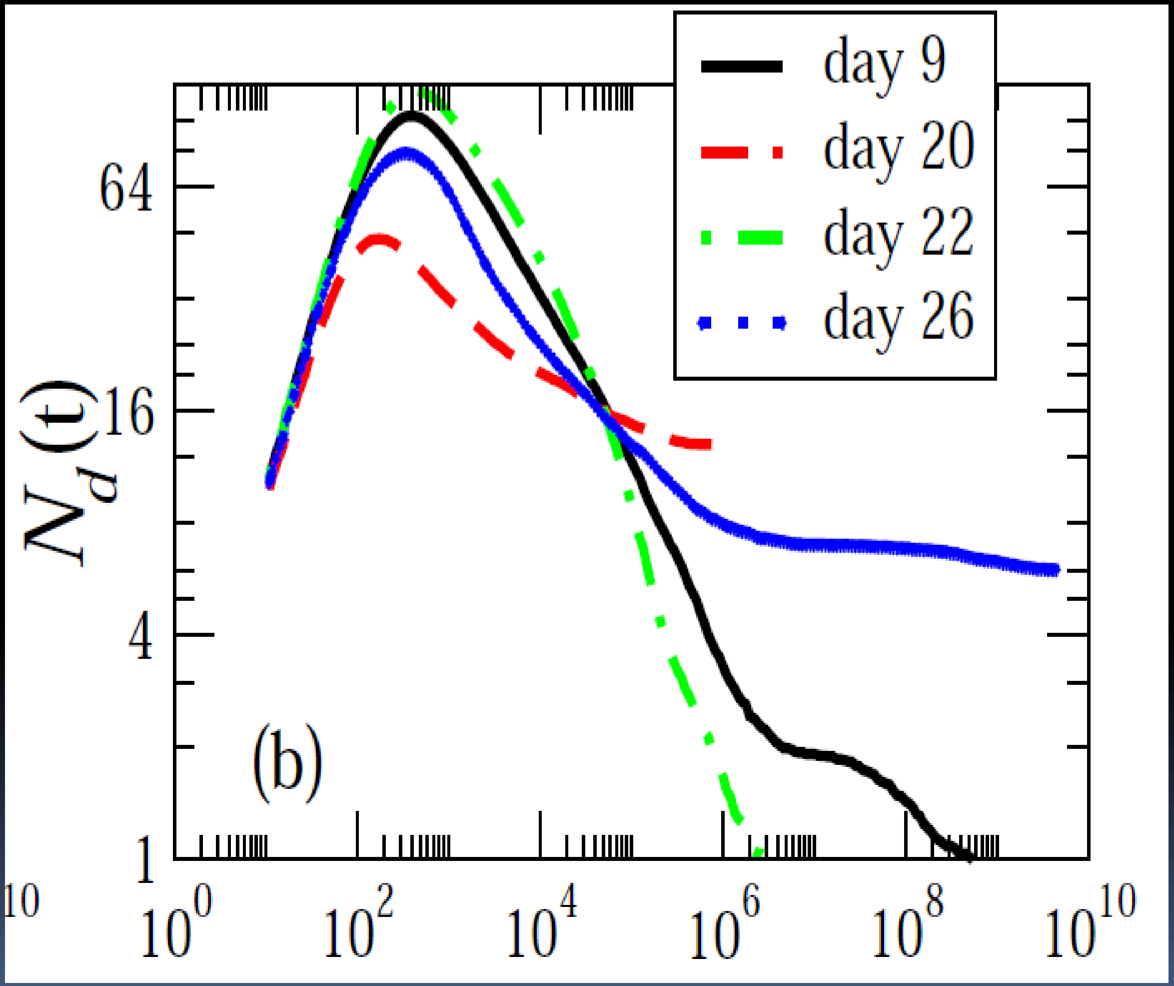
A_i is the list of unique words within community i and C is the number of communities



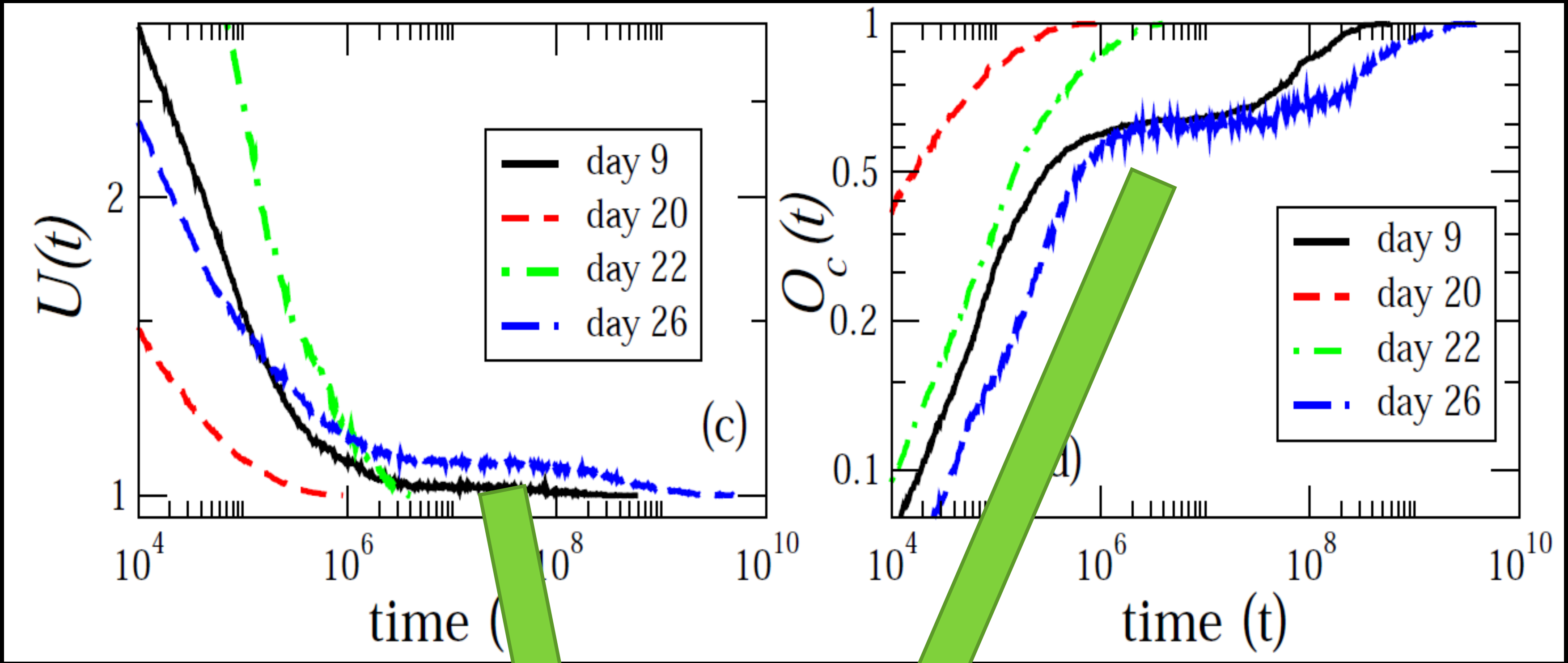
Metastability

3 phases

1. Steady growth
2. Reorganization phase
3. Long plateau



1. Steady rise
2. Steady fall
3. Plateau

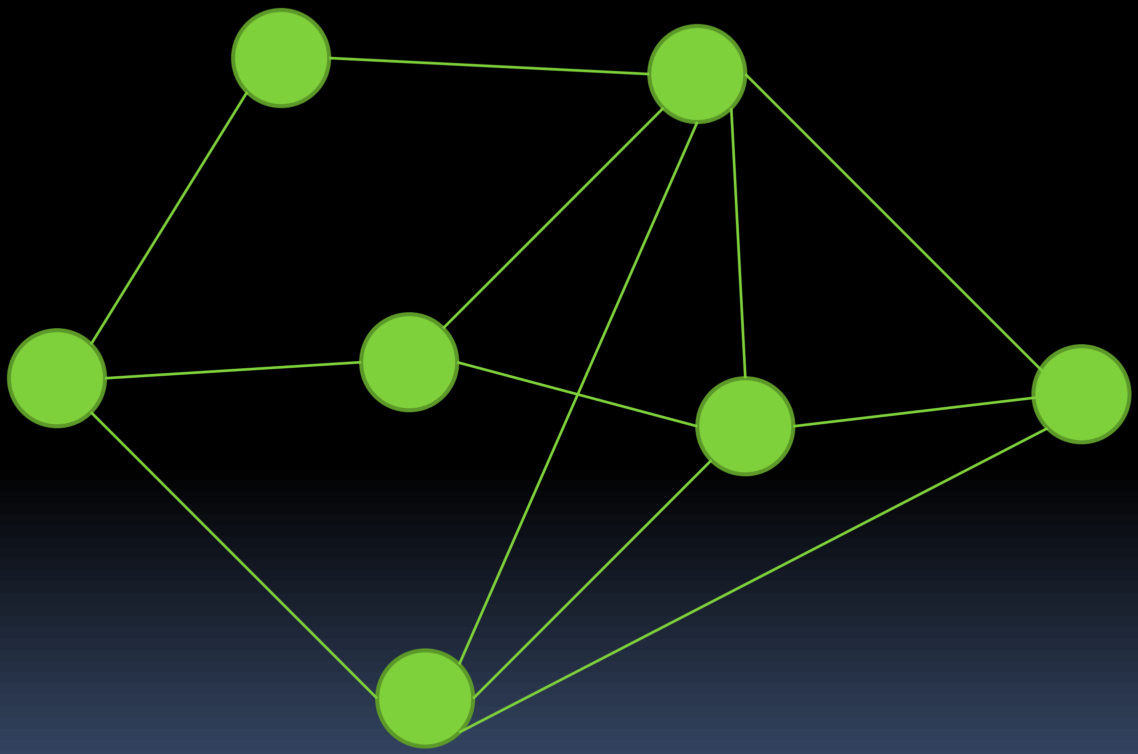


Existence of multi-opinion states and metastability

Results on HT Dataset

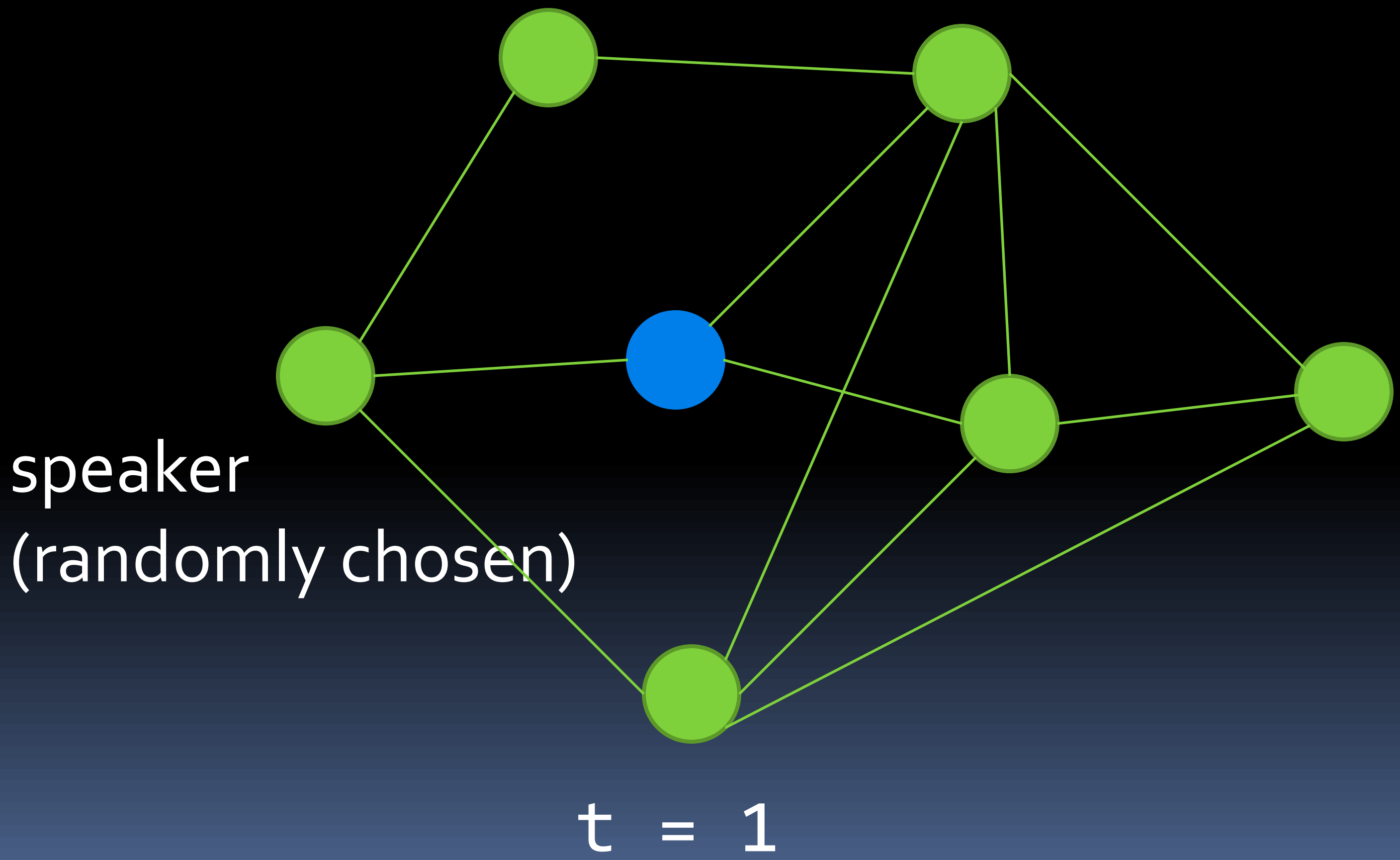
- In perfect synchronization with real time
  - a single game is played on a single time-evolving snapshot of the same network
  - at each time step t = 1, 2 . . . , the game is played among those agents that are alive at that particular instant of time in the network

Results on HT Dataset

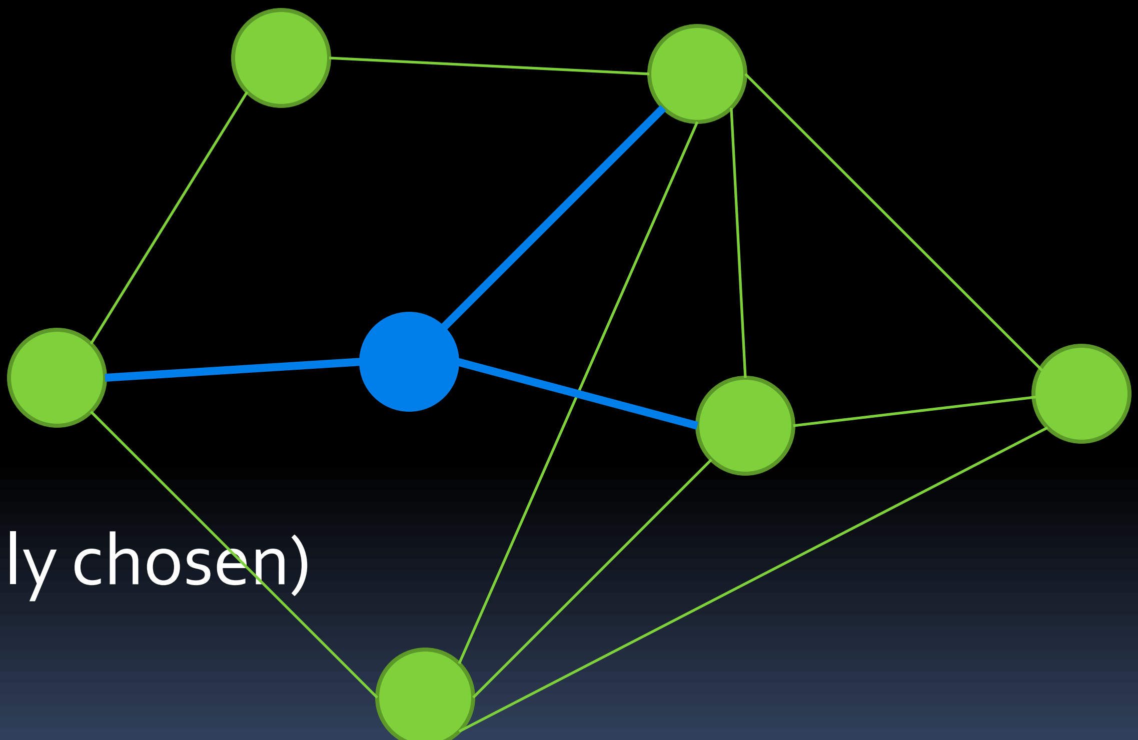


t = 1

Results on HT Dataset



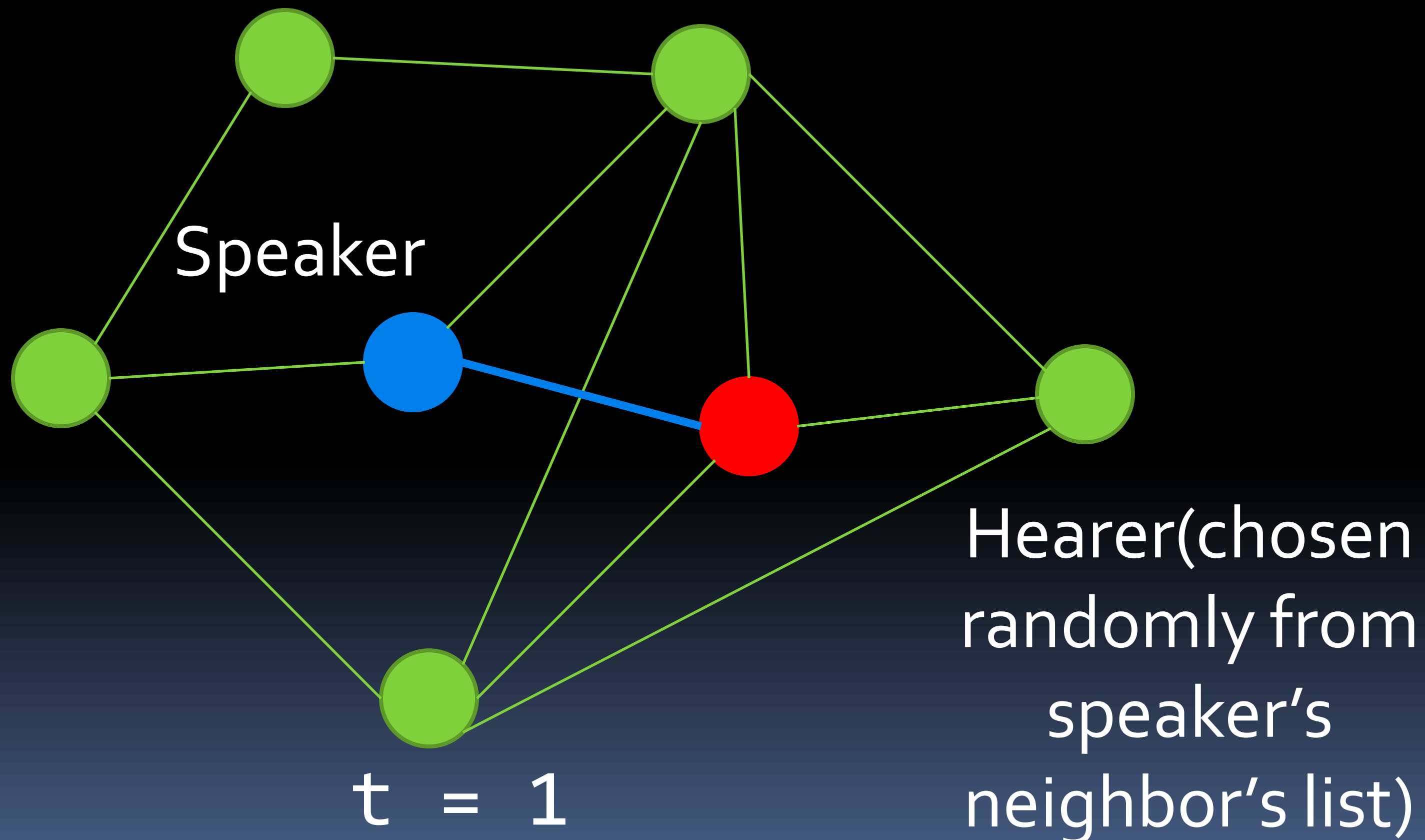
Results on HT Dataset



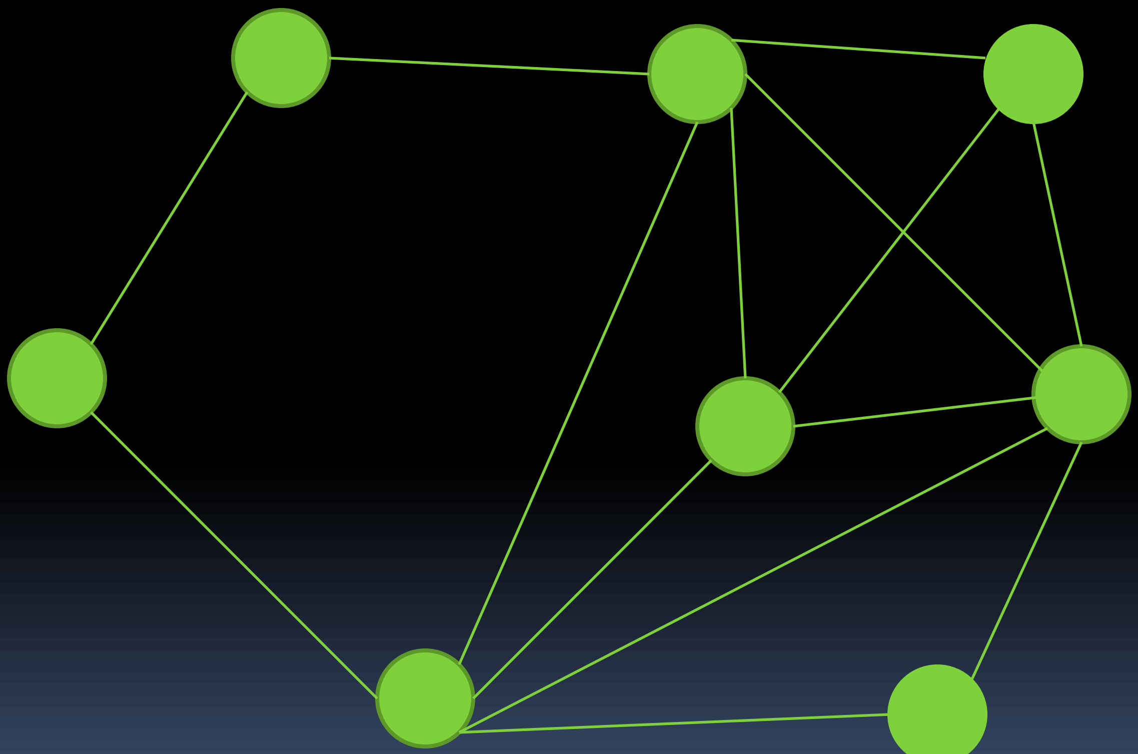
speaker
(randomly chosen)

t = 1

Results on HT Dataset

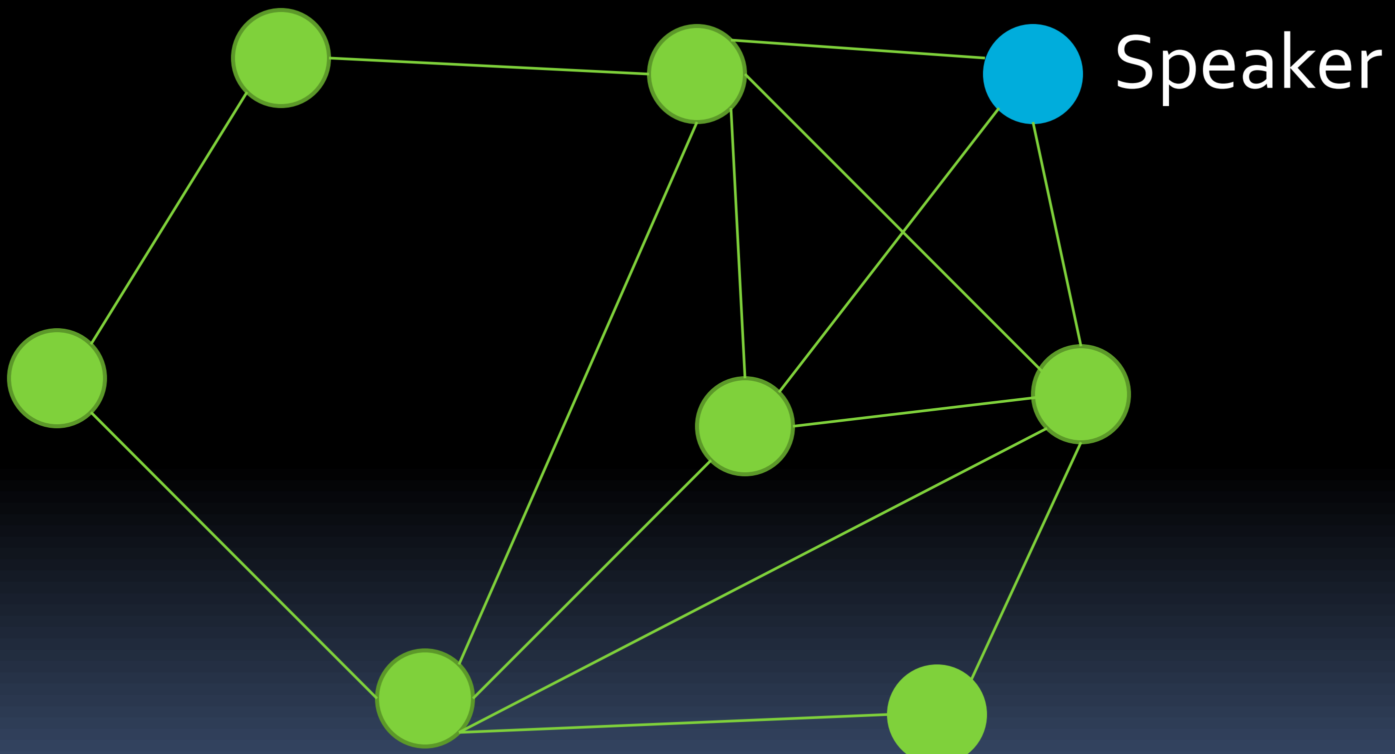


Results on HT Dataset



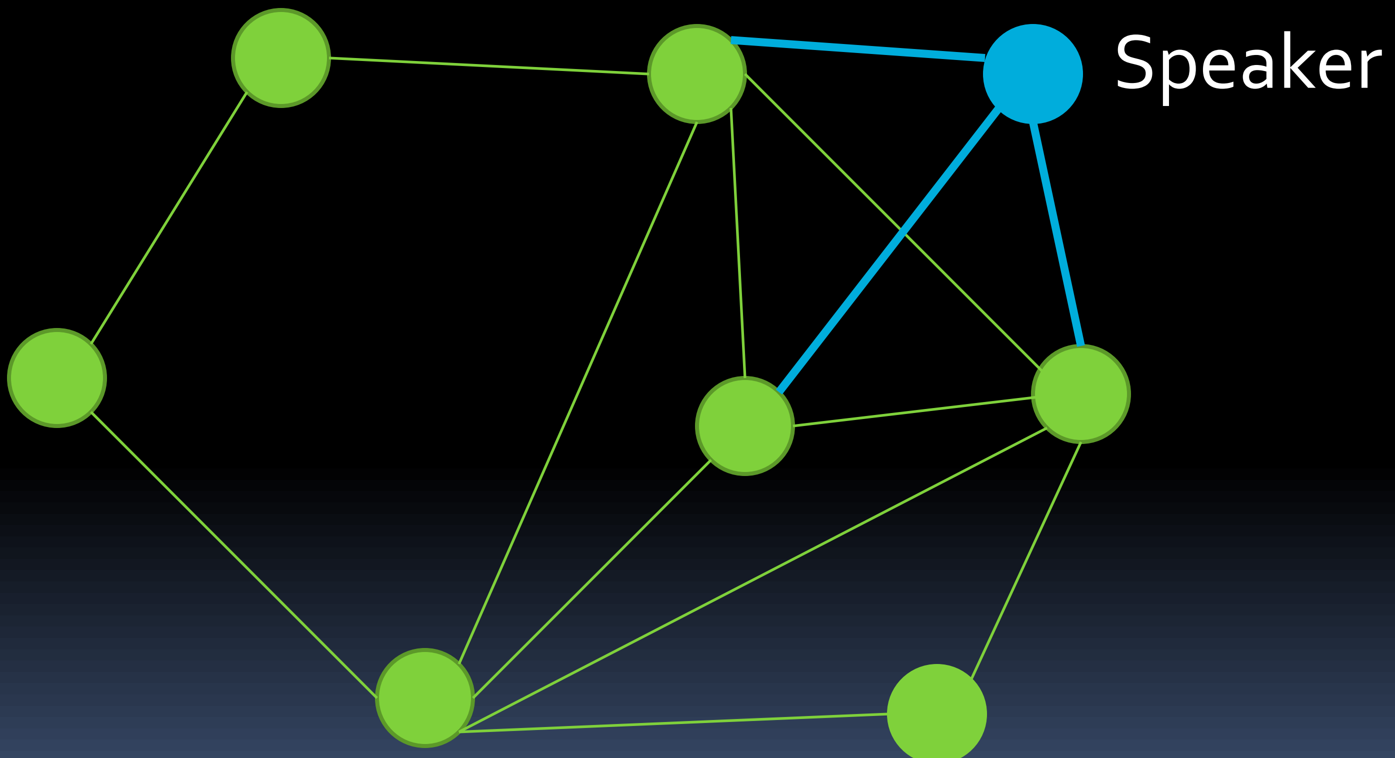
t = 2

Results on HT Dataset

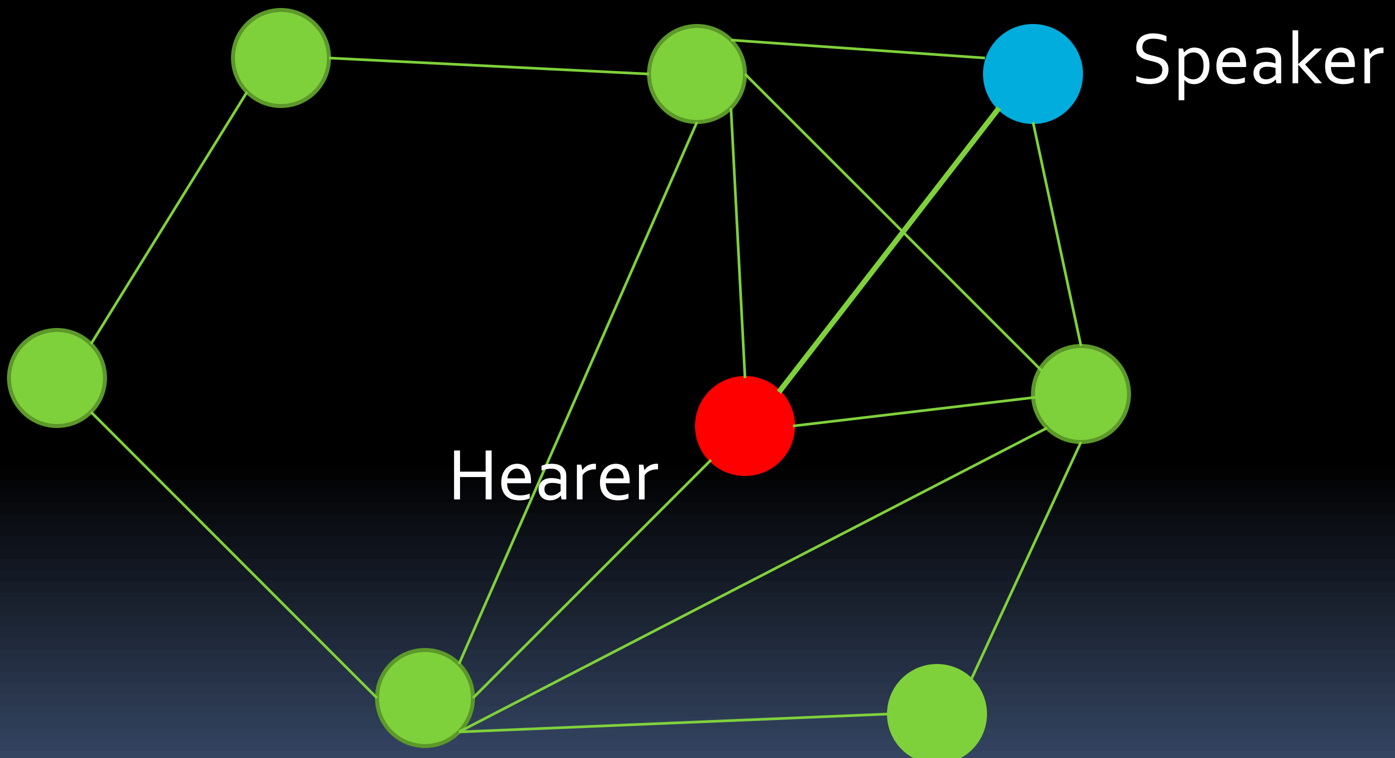


t = 2

Results on HT Dataset



t = 2



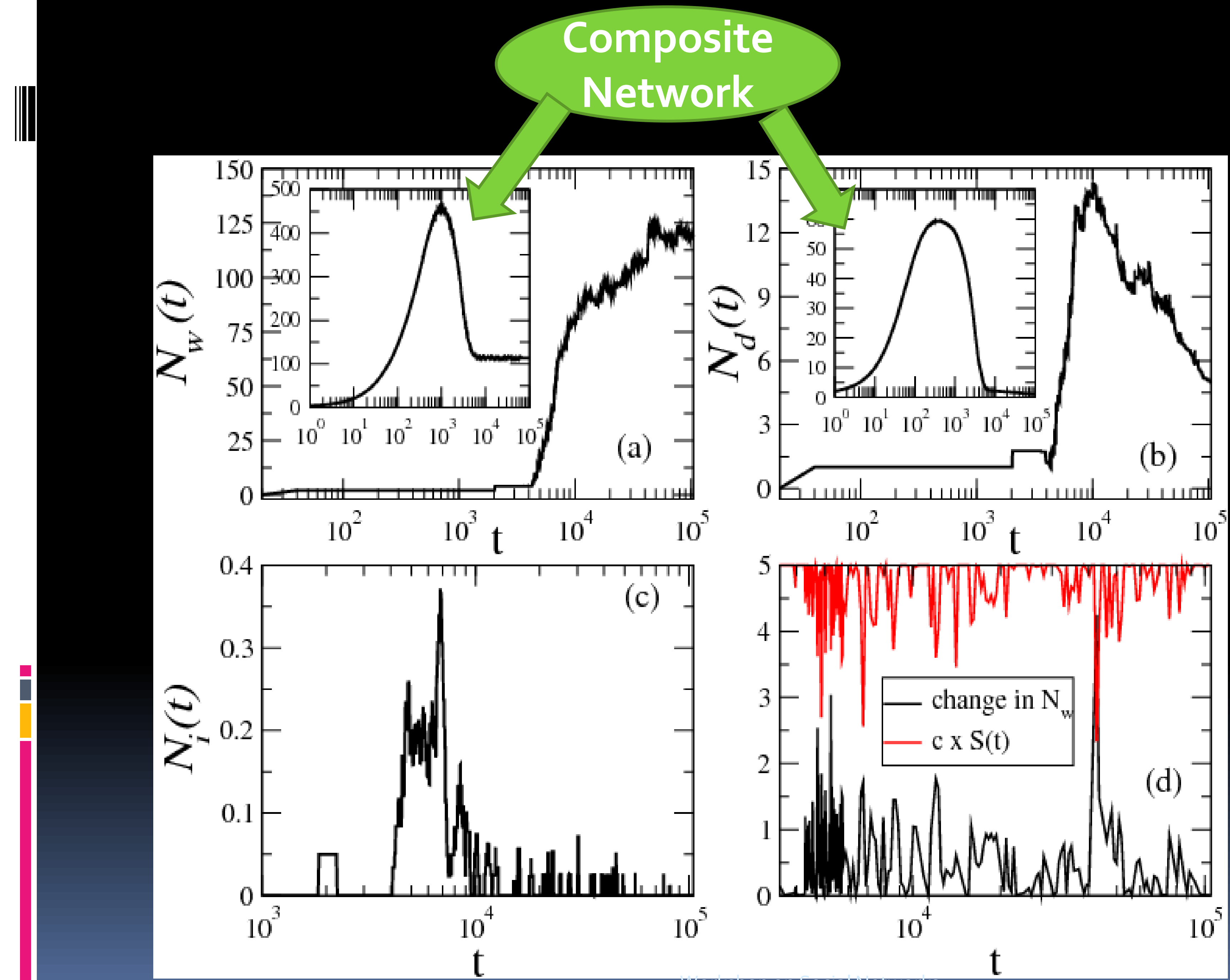
t = 2

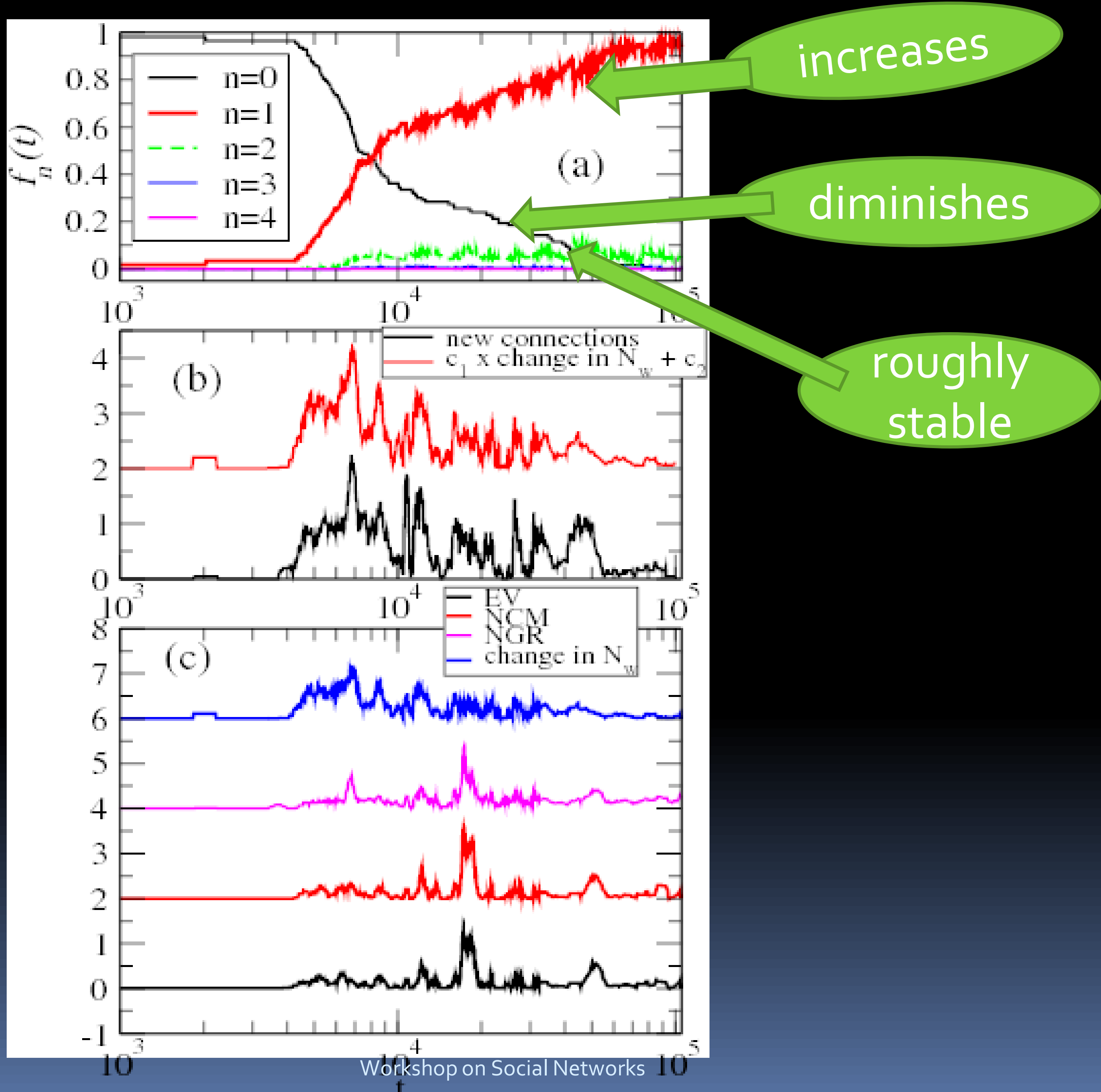
Results on HT Dataset

- The evolution of $N_w(t)$ shows
  - Initial slow growth (only a few agents present in the network)
  - Sharp transition (growth of population in the network)
  - Finally a steady growth regime (though inventions stop but old opinions trapped in different groups don't get disposed off the system and failure events still persist)
- markedly in contrast with the results if games were played on the composite network

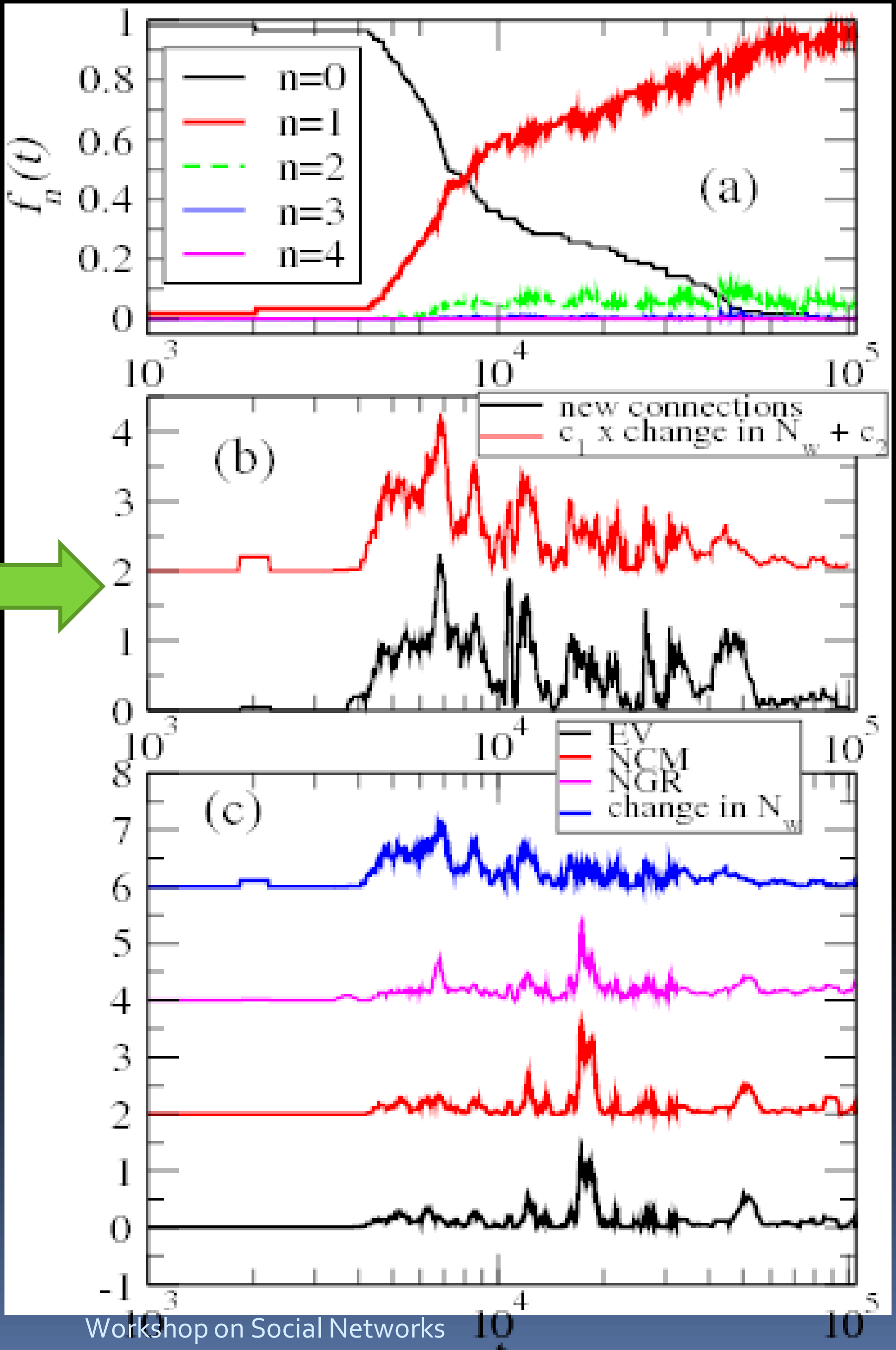
Results on HT Dataset

- The $N_d(t)$ curve shows
  - Initial slow growth (network size is very small)
  - Sharp transition towards peak (new individuals join the network)
  - Finally a drop, but no way close to 1 (new inventions stop)
- The absolute change in N_w is driven by S(t)
  - Increase in change in N_w , decrease in S(t) and vice versa

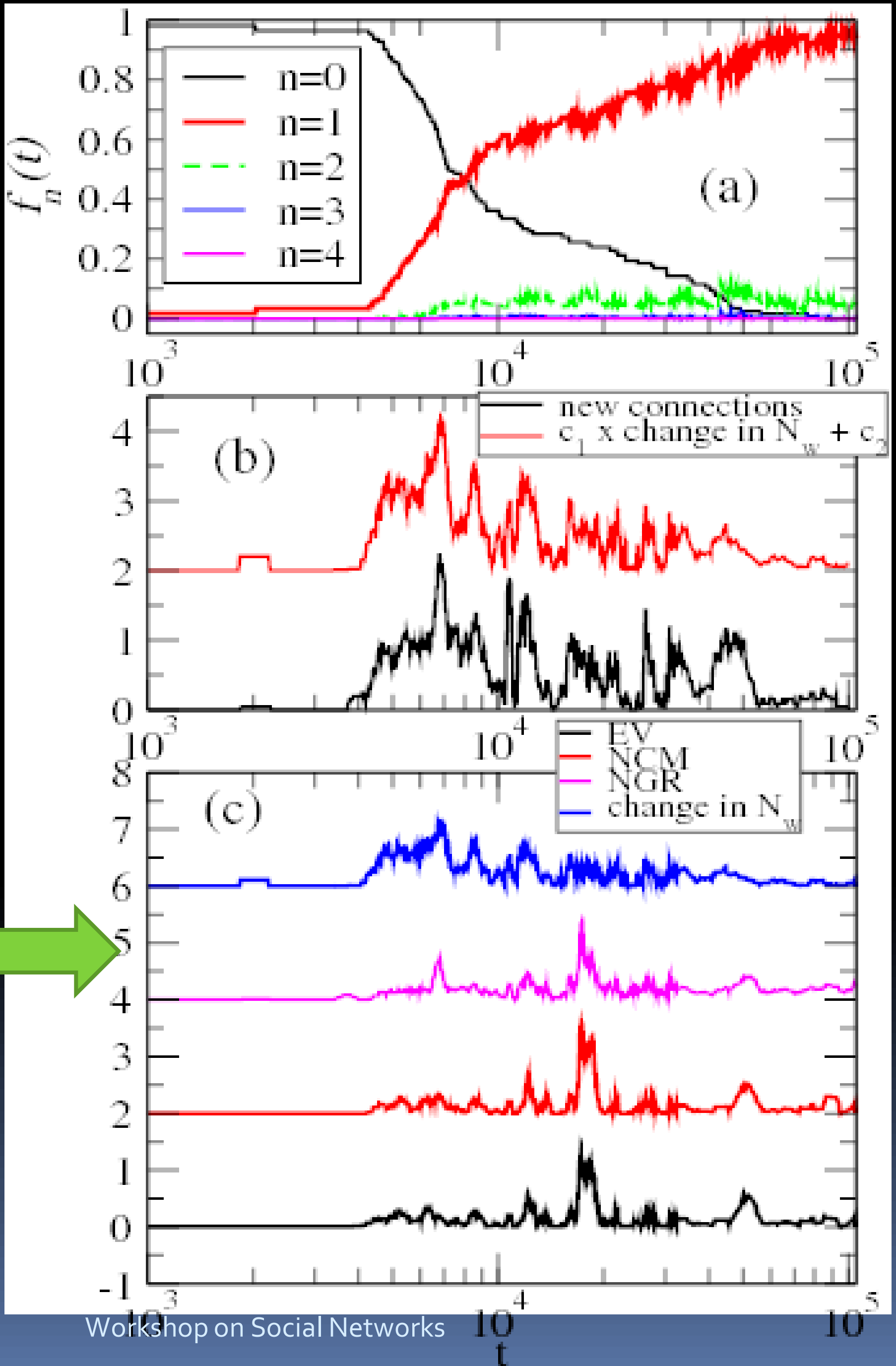

Composite Network
$N_w(t)$
(a)
$N_d(t)$
(b)
$N_i(t)$
(c)
change in N_w
c x S(t)
(d)
t


increases
diminishes
roughly stable
n=0
n=1
n=2
n=3
n=4
(a)
(b)
(c)
new connections
c1 x change in Nw + c2
EV
NCM
NGR
change in Nw
t

The new connections at each time step drives the change in N_w



The variance of community sizes also correlates with the change in N_w



- In a nutshell,

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

Conclusions

- In real world social networks, global consensus depends on community structures
- While the agreement process in perfect synchronization with time evolution exhibits different behavior of the emergent properties of the system

Future work

- Incorporating "dominance index" of the agents

- flexibility of the agents in adapting to new opinions modeled by a system parameter β

  (the probability with which the agents update their inventories in case of successful interactions)

THANK YOU

Any Questions?