

Complex Dynamical Networks:

Lecture 7b: Naming Game on Networks

EE 6605

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Naming Game with Finite Memories

An Example of Cascading Reactions

Outline

- ❖ Brief review of the naming game with infinite memories: theory and simulations on different networks
- ❖ Introducing the naming game with finite memories: theory and simulations on different networks

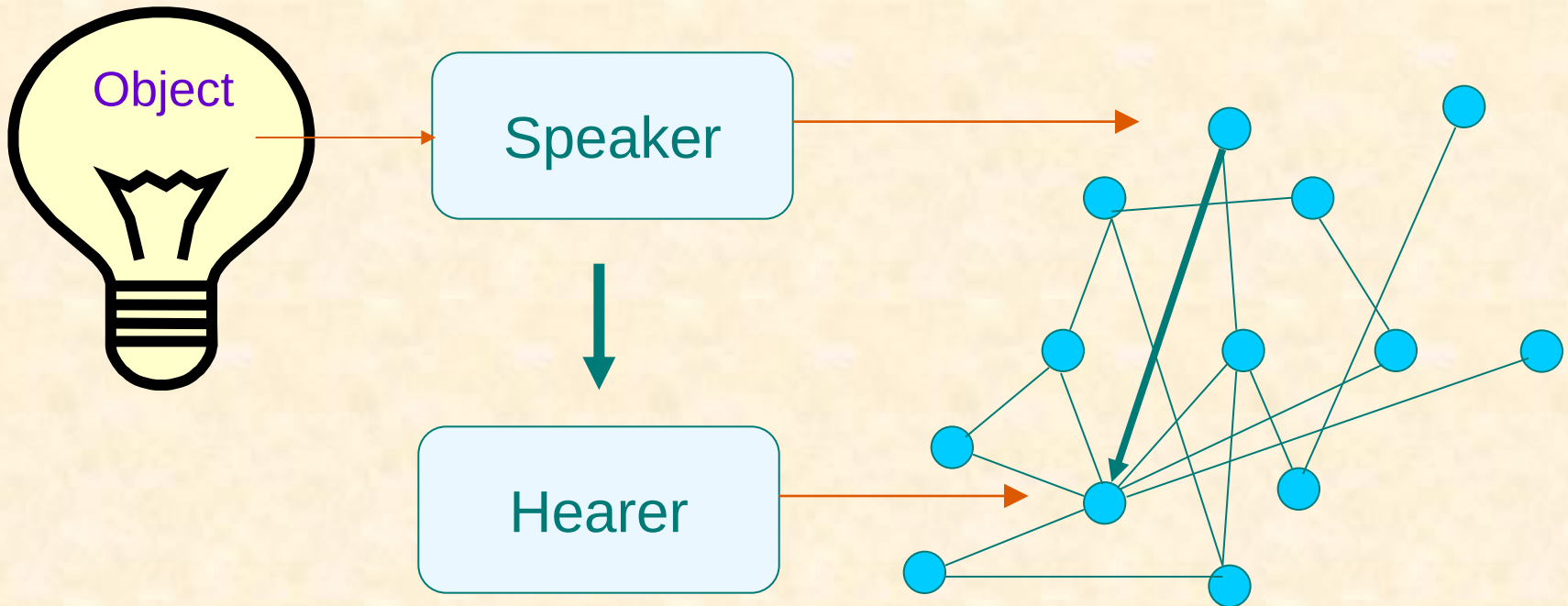
Naming Game: Introduction

Naming Game is an experiment using computer simulations to explore the emergence of shared lexicons in a population of agents about some objects they observed.

In the simplest (minimal) naming game, agents interact with each other, where repeated interactions lead to the development of a common word for naming a single object.

By varying experimental parameters, it is possible to explore the effects of environmental issues (such as memory limitations, uncertainties) and the contacts between different language groups.

Minimal Naming Game



Here, consider the **simplest** experiment:

A population of agents are trying to learn one common word

Minimal Naming Game

Consider:

a population of agents who are communicating on giving a name to a single observed object

Assume:

- only one object is being observed
- all agents have infinite memories
- all agents can keep different words in their memories

Minimal Naming Game

- Initially, each agent has an empty memory. The speaker invents a name for the object he observed, and tells the name to a hearer

At each time step:

- Two agents, a **speaker** and a **hearer**, are randomly selected from the population
- The **speaker** randomly picks a name from his memory and tells the name to the **hearer** (if the speaker has nothing in his memory, then he invents a name, or picks a name from a vocabulary, for the object)
- If the **hearer** already has the same name in his memory
 - success
 - else → failure

Minimal Naming Game

(with two agents)

If success → speaker and hearer retain the uttered word as the correct name and cancel all other words from their memories

If failure → hearer adds to his memory the word given by the speaker

Minimal Naming Game

(with two agents, one name)

Speaker

tiger
apple
car

Hearer

moon
tree
boy

failure



Speaker

tiger
apple
car

Hearer

moon
tree
boy
apple

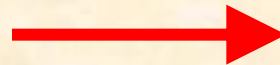
Speaker

tiger
apple
car

Hearer

apple
tree
boy

success



Speaker

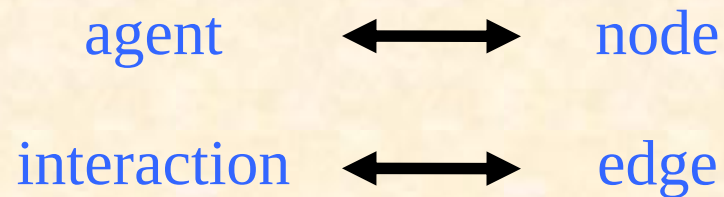
apple

Hearer

apple

Naming Game

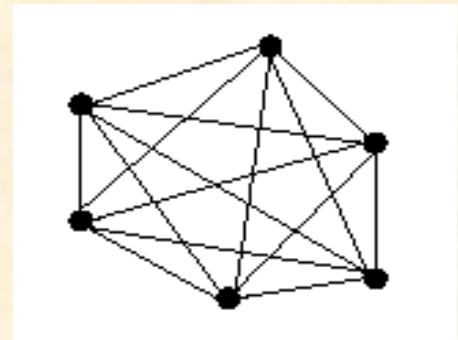
Mutual interactions among N agents in a network:



Simplest community case:
A fully connected network



Every node interacts equally with all the others



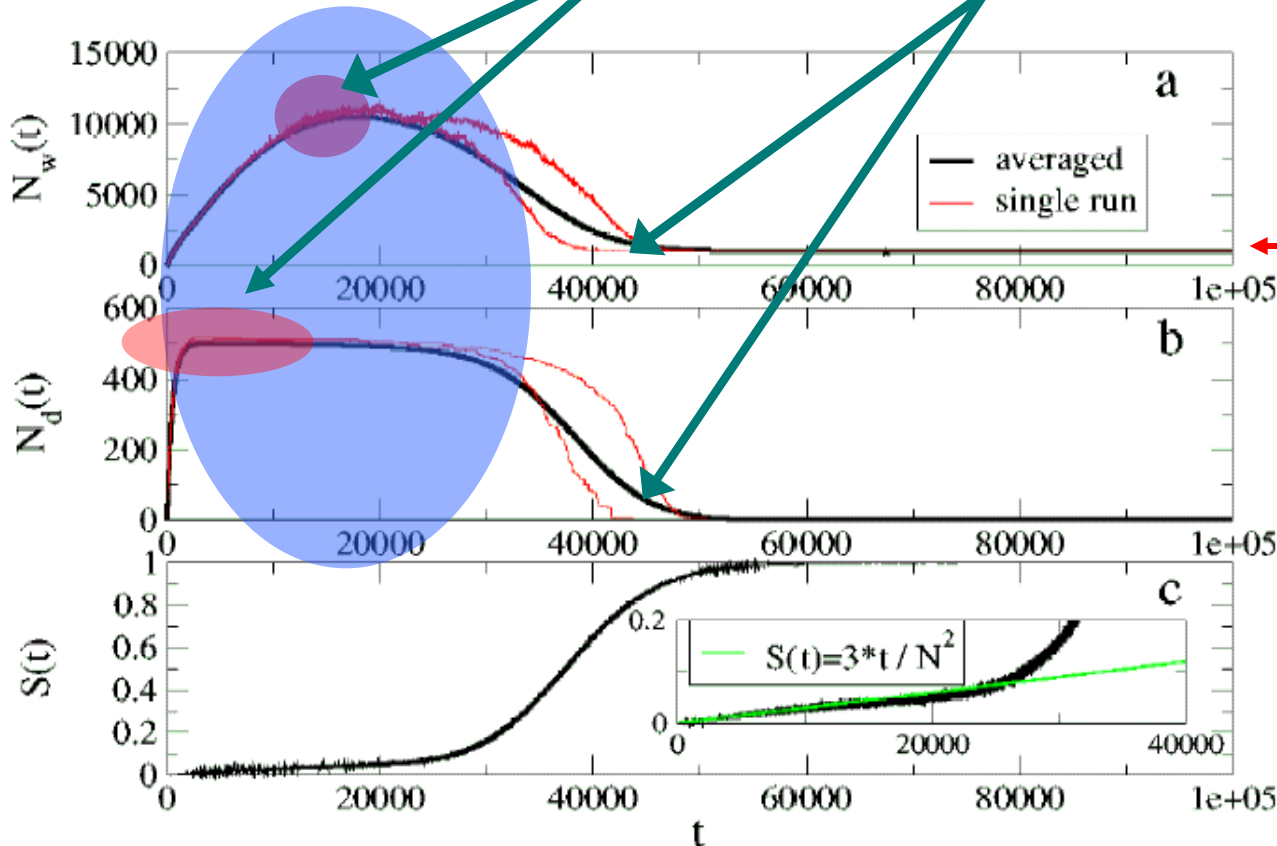
Simulation Results - I

Agents on a fully-connected network

$N = 1024$ agents

Memory peak

Convergence



total number of words
= total memory N_w

This is 1
(magnified)

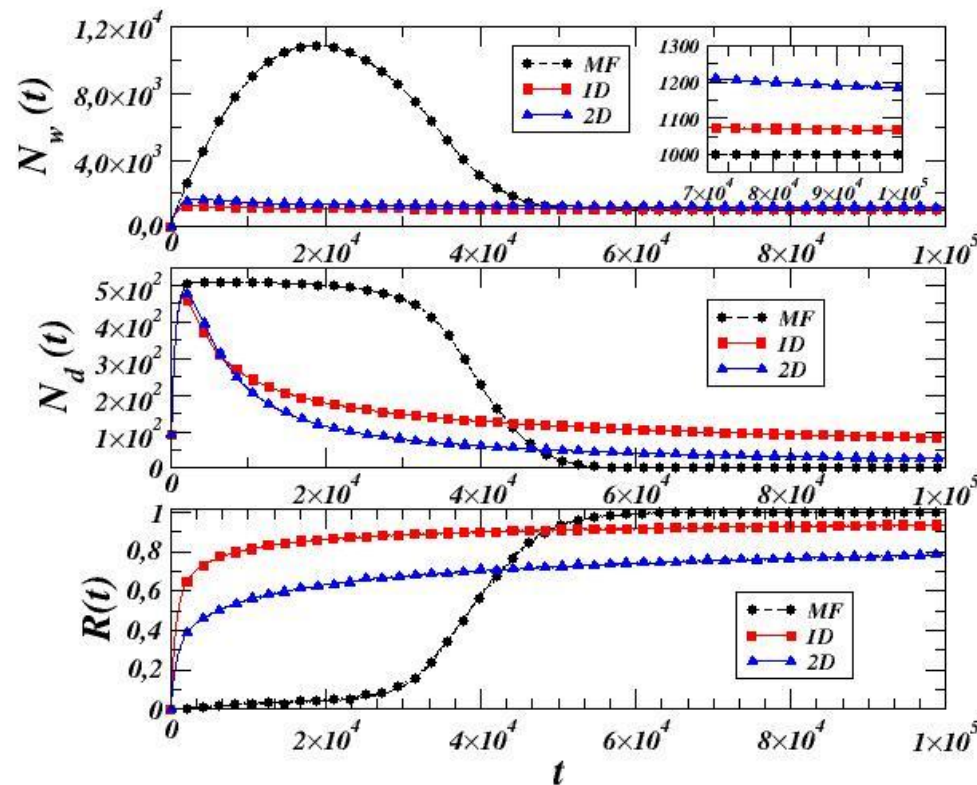
total number of
different words N_d

success rate $S(t)$

(Baronchelli *et al.*, 2005)

Simulation Results - II

Agents on a regular lattice



$N = 1000$ agents

MF = fully-connected network

1D, 2D: agents on regular lattices

N_w = total number of words

N_d = total number of distinct words

R = success rate

(Baronchelli *et al.*, 2005)

Naming Game

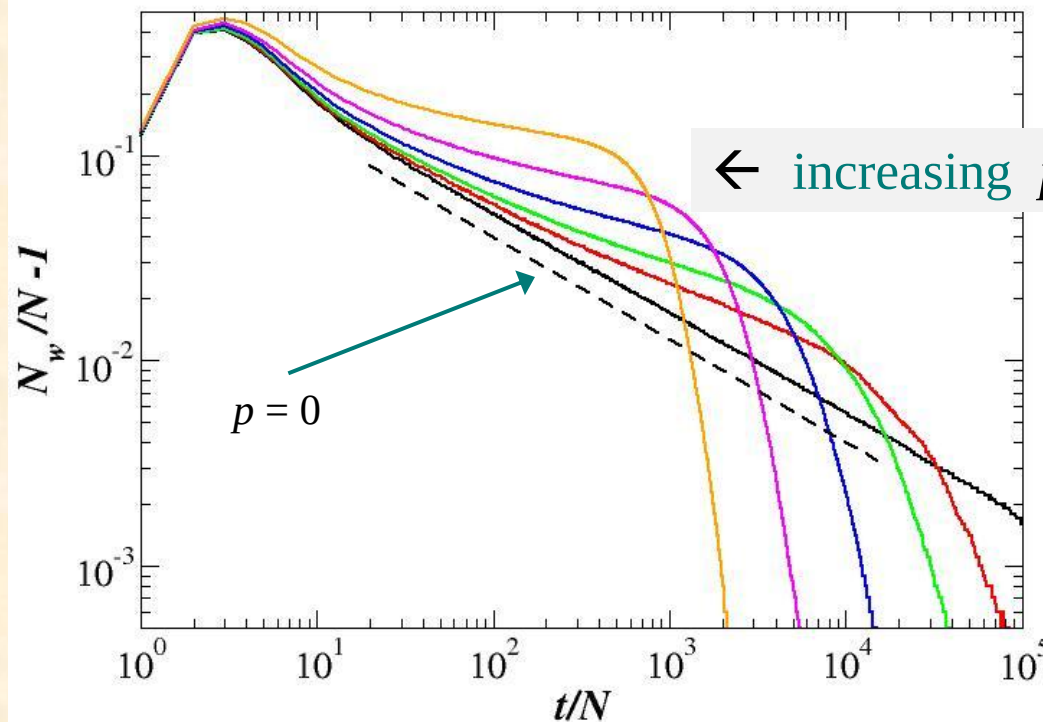
Comparison

	Fully Connected Networks	Regular Lattices	
Maximum Memory	$N^{1.5}$	N	
Convergence Time	$N^{1.5}$	N^3	

N – number of agents

Naming Game

Agents on a small-world network



N_w = total number of words

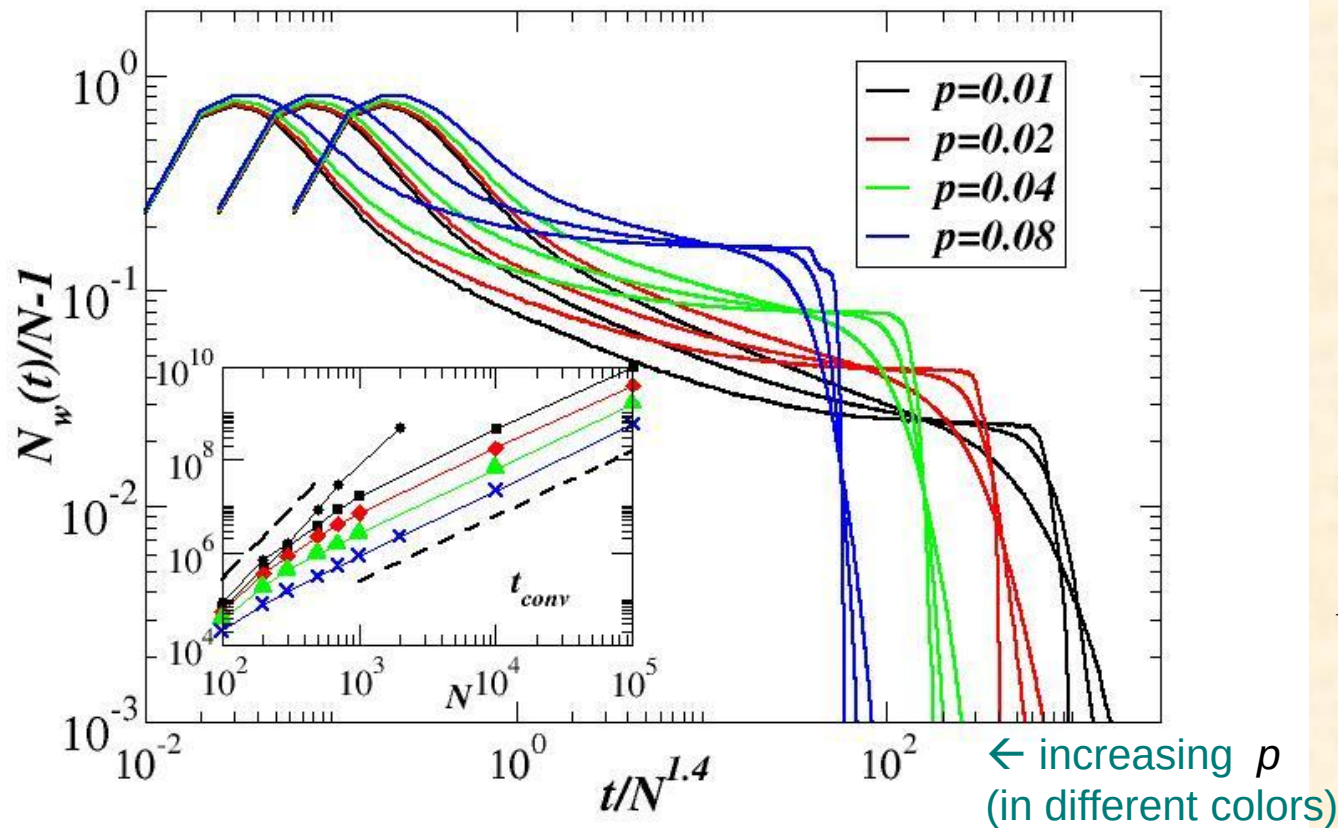
$p = 0$: linear chain

other p : small-world

(Dall'Asta *et al.*, 2006)

Naming Game

Agents on a small-world network



maximum
memory: $\sim N$

convergence
time: $\sim N^{1.4}$

N_w = total number of
words

$p = 0$: linear chain

other p : small-world

Naming Game

Comparison

	Fully Connected Networks	Regular Lattices	Small-World Networks
Maximum Memory	$N^{1.5}$	N	N
Convergence Time	$N^{1.5}$	N^3	$N^{1.4}$

→ Better not to have all-to-all communications
 not to have a too-regular communication network topology

Naming Game

Agents on a heterogeneous network

Recall the original model:

→ Select a **speaker** and a **hearer** randomly from among all nodes

Possible modifications:

- First select a **speaker** and then a **hearer** from speaker's neighbors
- First select a **hearer** and then a **speaker** from hearer's neighbors
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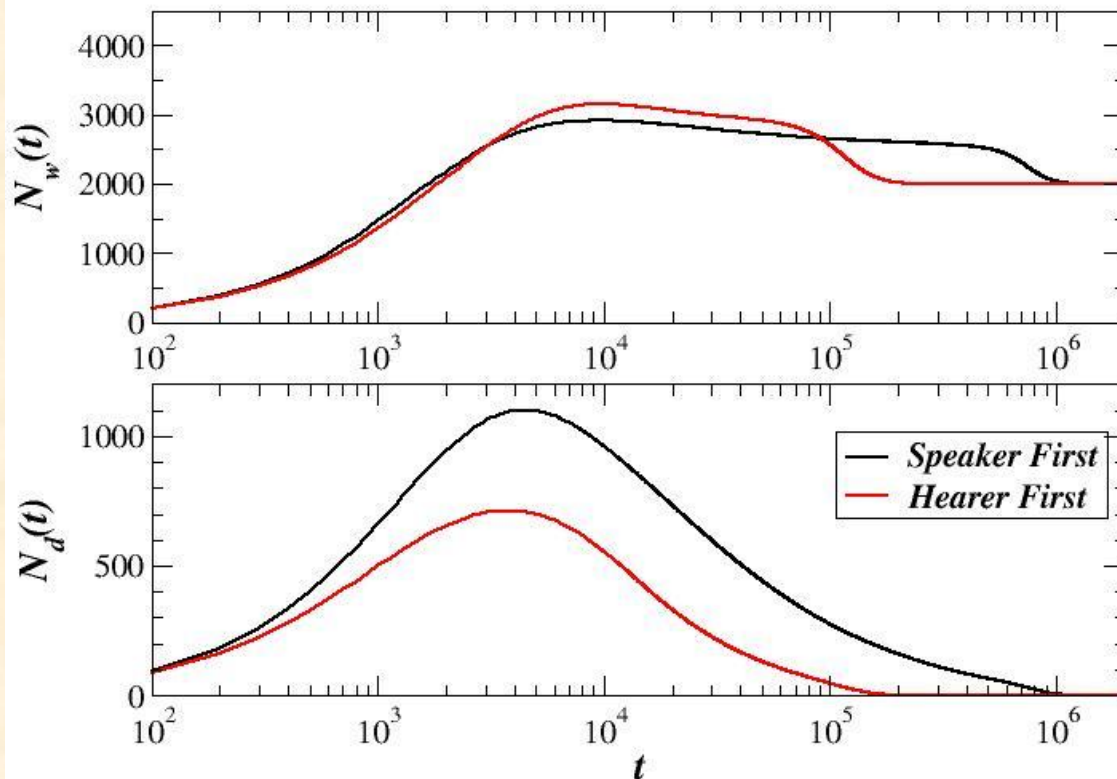
These modifications can be important in heterogeneous networks:

- a randomly selected node typically has a small degree
- in the neighborhood of a randomly selected node, there typically is a large node

Naming Game

Agents on a heterogeneous network

BA scale-free network:



Different behaviors
on the BA network



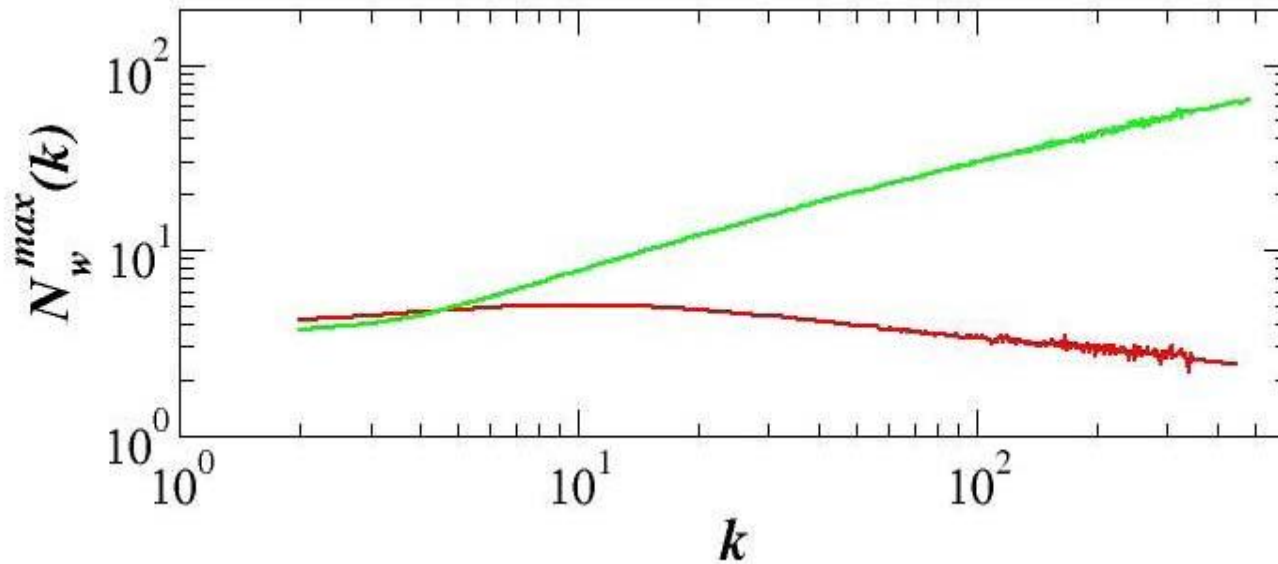
The importance
of understanding
the role of hubs
on heterogeneous
networks

N_w – total number of words

N_d – number of different words

Naming Game

Agents on a heterogeneous network



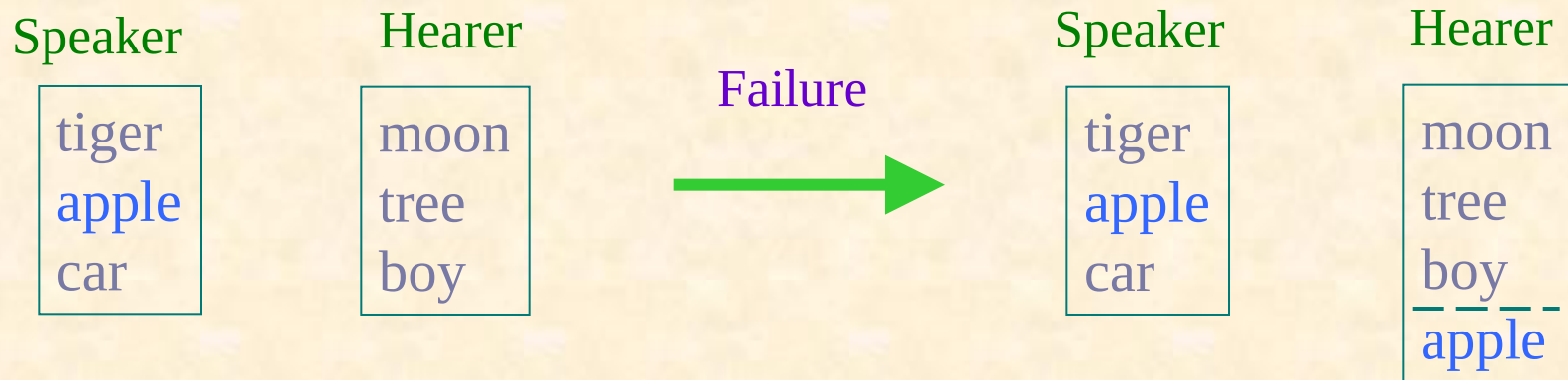
Speaker first — hubs accumulate more words

Hearer first — hubs have less words

→ faster spreading over the network

What happens if agents' memories are limited?

- It has been shown that the topology of a communication network can be quite important for the success of (fast) reaching a consent in naming an object by the whole population of agents
- One basic assumption therein is that all agents have infinite memories, which allows hearers to unlimitedly accumulate words in case of “failure”:

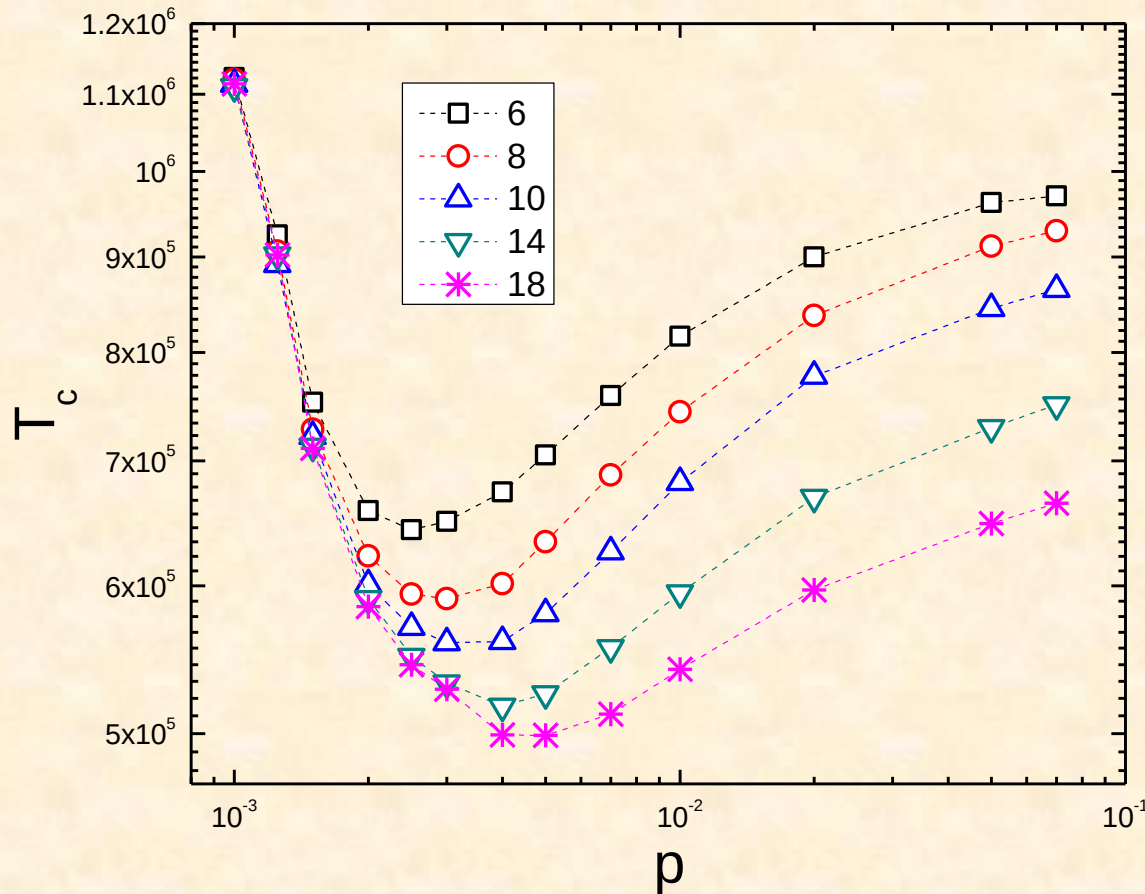


- So, the question is: What happens if agents' memories are limited?

Naming Game with Finite Memories

- ❖ Every agent has a limited memory of length L
(when $L \rightarrow \infty$ this new model reduces to the old one)
- ❖ At each time step:
 - First, a speaker is randomly selected; then, the speaker randomly selects a hearer from its neighbors
 - The speaker randomly picks a name from his memory and tells the name to the hearer:
 - if the hearer already has the name in his memory → success → both agents keep this name and discard all other names
 - else → failure →
 - if hearer's memory is not full then add the new name to his memory
 - else, with probability 0.5 a randomly selected old name is replaced by the new one (i.e., with probability 0.5 nothing is done)

Simulations on Random Networks - I

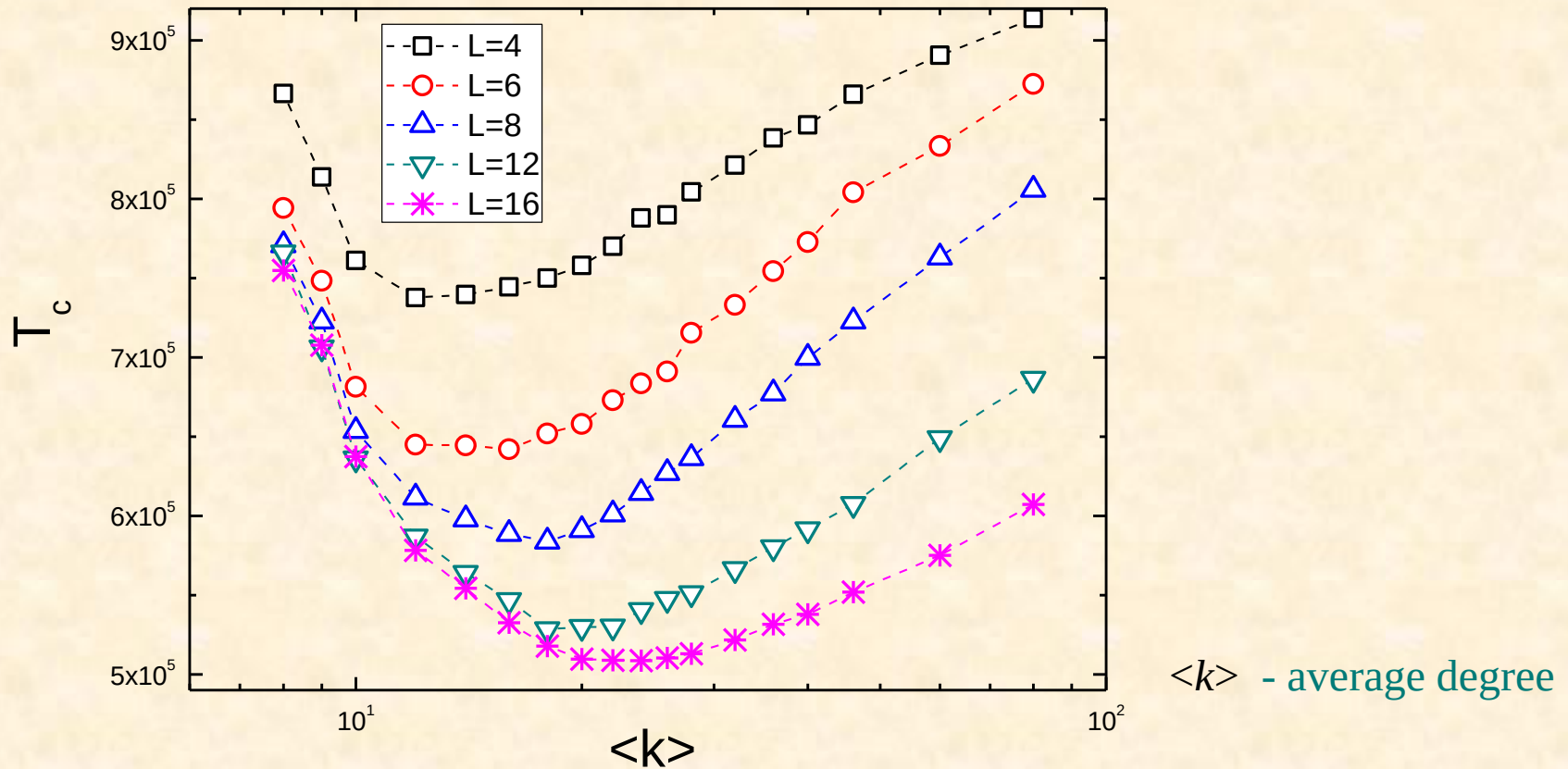


- $N = 5,000$
- p – random network generation probability
- Each curve is the average of 1000 runs
- For memory lengths $L = 6, 8, 10, 14, 18$

T_c – convergence time →
There are optimal convergence times

Wang et al. (2007)

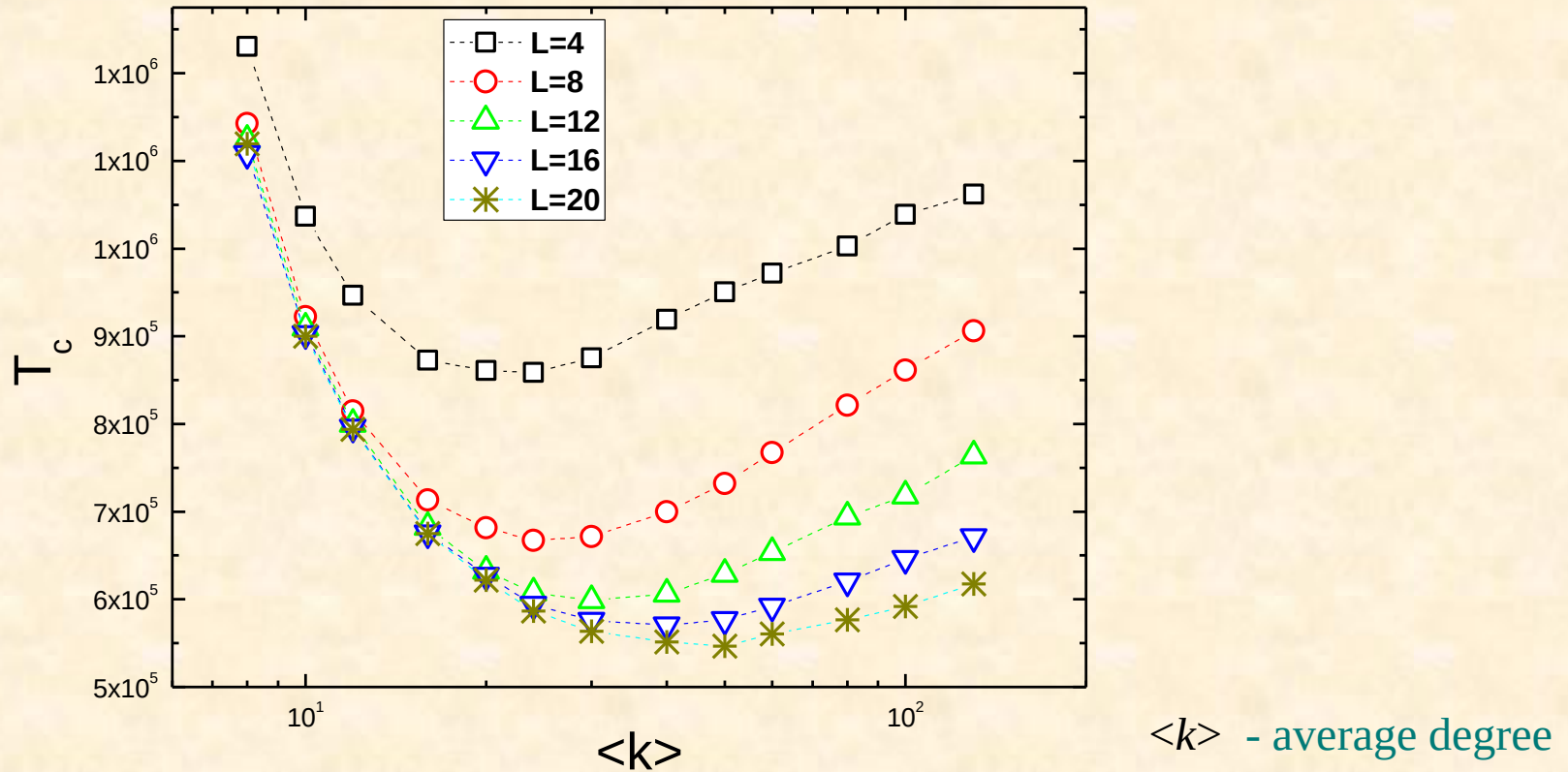
Simulations on Small-World Networks - I



T_c – convergence time →
There are optimal convergence times

Wang et al. (2007)

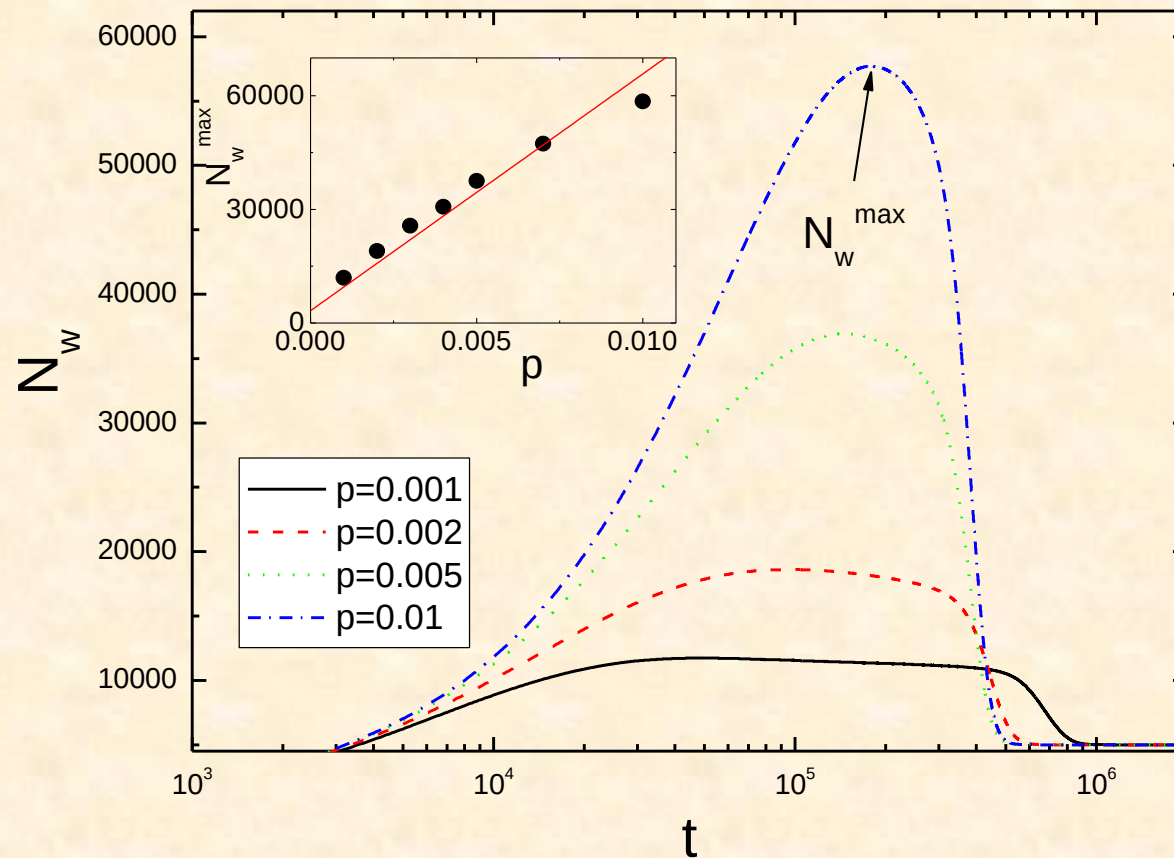
Simulations on Scale-Free Networks - I



T_c – convergence time →
There are optimal convergence times

Wang *et al.* (2007)

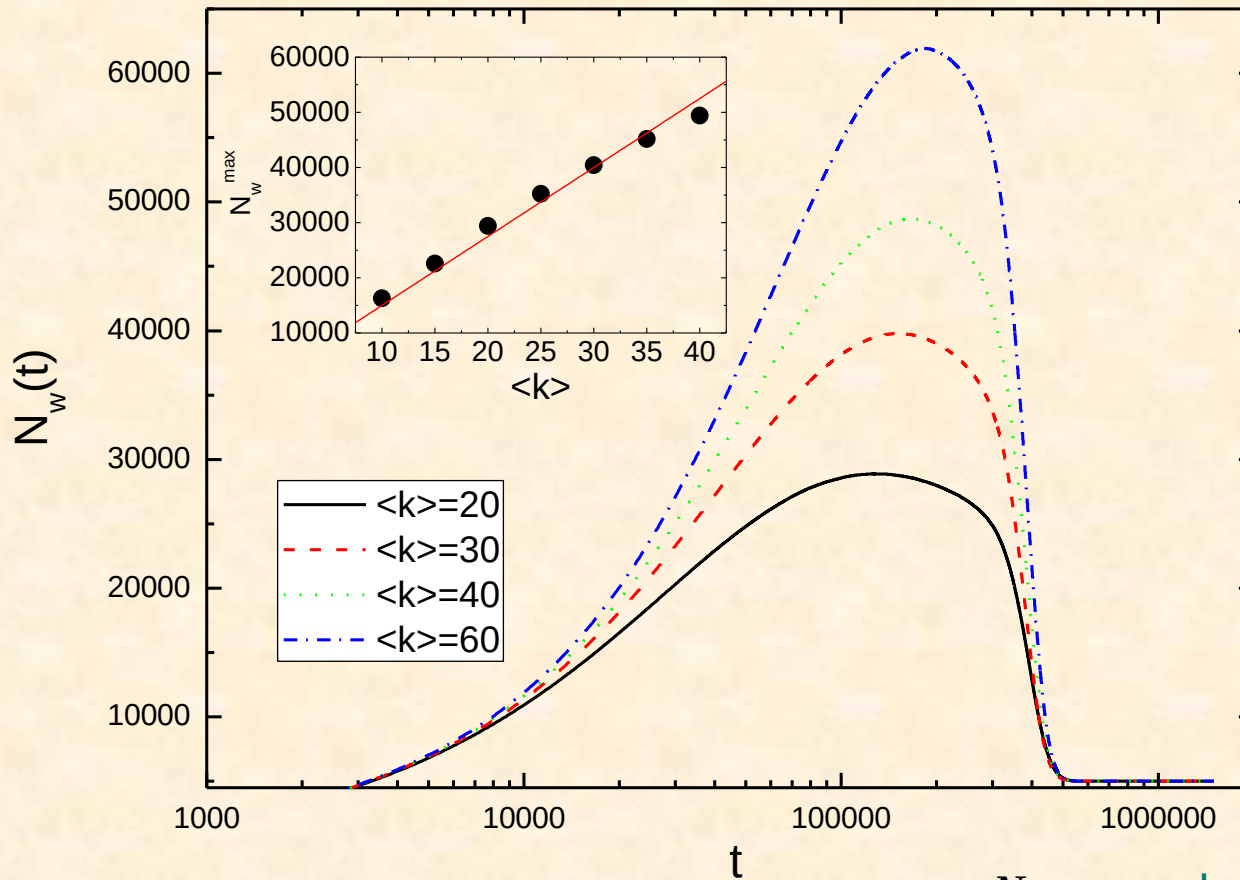
Simulations on Random Networks - II



N_w – number of new words →
There are maximum numbers

Wang *et al.* (2007)

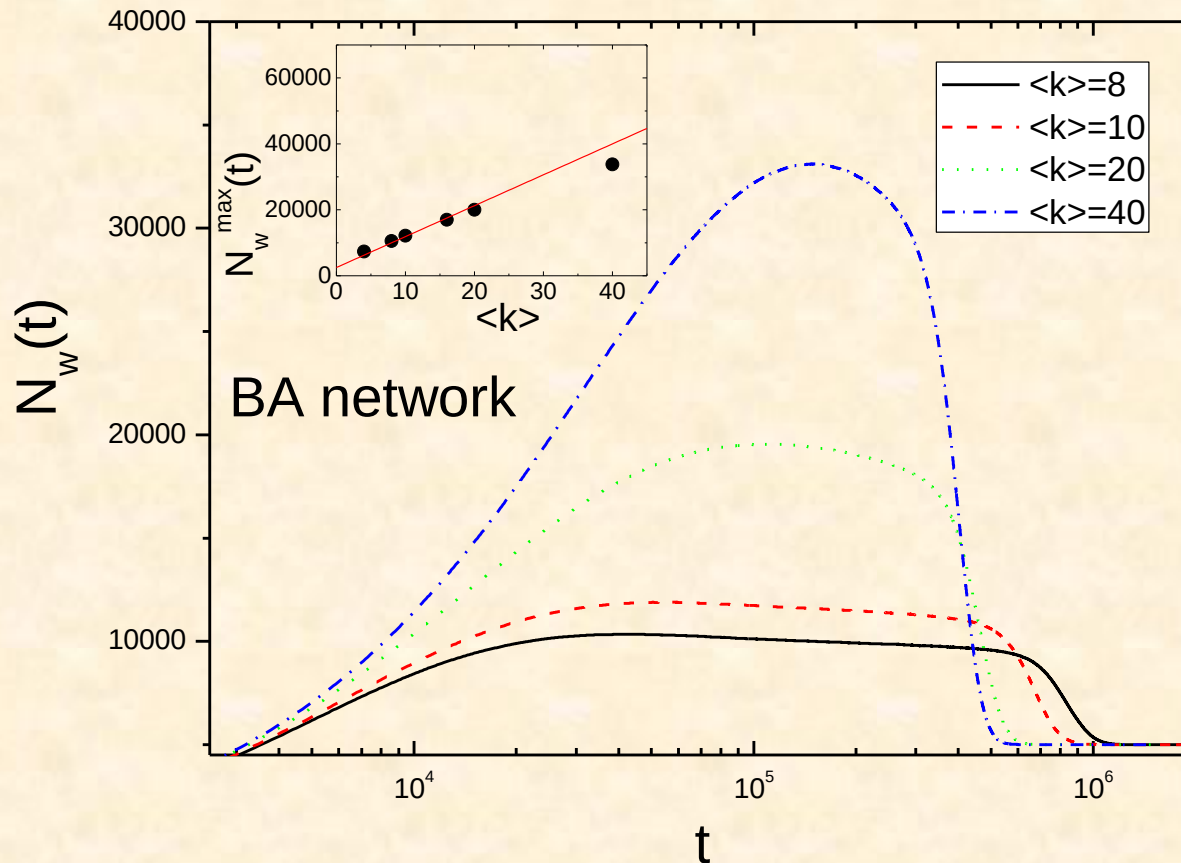
Simulations on Small-World Networks - II



N_w – number of new words →
There are maximum numbers

Wang et al. (2007)

Simulations on Scale-Free Networks - II



N_w – number of new words →
There are maximum numbers

Wang *et al.* (2007)

Concluding Remarks

- ❖ Naming Game with infinite memory
- ❖ Naming Game with finite memory
- ❖ **Related Topics:**
 - Language evolution
 - Opinion formation
 - Business cooperation and competition
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- ❖ **Future Topics:**
 - Naming games with multiple speakers-hearers
(one student project in 2013, developed to be a research paper, which is under review in 2014)
 - Naming games with multiple objects
 - Naming games on networks with community or hierarchical structures
 - Applications to language studies
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References

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Q. Lu, G. Korniss and B. K. Szymanski, J. Econ. Interact Coord., 4, 221 (2009)

❖ Finite Memory:

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❖ Multiple Hearers:

B. Li, G. Chen and T. Chow, Naming game with multiple hearers, Comm. Nonlinear Sci. Numer. Simul., 18, 1214 (2013)

❖ Multiple Speakers-Hearers:

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End

