LANGUAGE EVOLUTION AND POPULATION DYNAMICS IN A SYSTEM OF TWO INTERACTING SPECIES

(competition of 2 languages)

The Problem

We study the evolution of words and the population of dynamics of a system comprising two interacting species which initially speak two different languages using Monte Carlo simulations and assumptions from evolutionary game theory.

Description of the system

- *A* and *B*, are randomly distributed on a 2D lattice.
- Initially speak two different languages.
- *A* has a common vocabulary of 10 words.
- B, initially a common vocabulary of 10 words, but these words are different from the words of *A*.
- The species move on the lattice performing random walks.

- Learn words that are unknown to them or forget words that are in their vocabulary.
- Individuals have fitness=> measure of their genetic activity.
- Children have an identity and vocabulary identical to their parent.
- Correct communication between individuals increases their fitness.
- Individuals die at a constant rate.

Some of the Questions we want to answer

- Will a difference in the initial fitness lead to a permanent advantage?
- Will this advantage affect the vocabulary of the species or the population dynamics?
- How will the spatial distributions of the species be affected?
- Does the system exhibit pattern formation or segregation?

Monte Carlo Method

- Individuals have an Identity (A or B species) and a vocabulary of 10 words. Activities allowed: Movement, communication, reproduction and mortality.
- We draw Random Numbers in order to decide about:
- Movement: Random motion (Diffusion) on a rectangular lattice.
- Communication: Individuals meet and may learn words known to their neighbor or forget words unknown to their neighbor. Correct communication conveys a payoff which increases the fitness of the individual.

- Reproduction: The probability of reproduction for an individual is proportional to the individual fitness. Normalization of the probability is either local (in the 8 closest neighbors of the individual) of global (over the complete lattice). Offspring inherit the parental identity and vocabulary.
- Results presented below follow the local normalization choice.
- Mortality: Individuals die at a constant rate. For our present results the average lifetime of an individual is 19 Monte Carlo Steps (MCS)

Initial Vocabulary

1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0

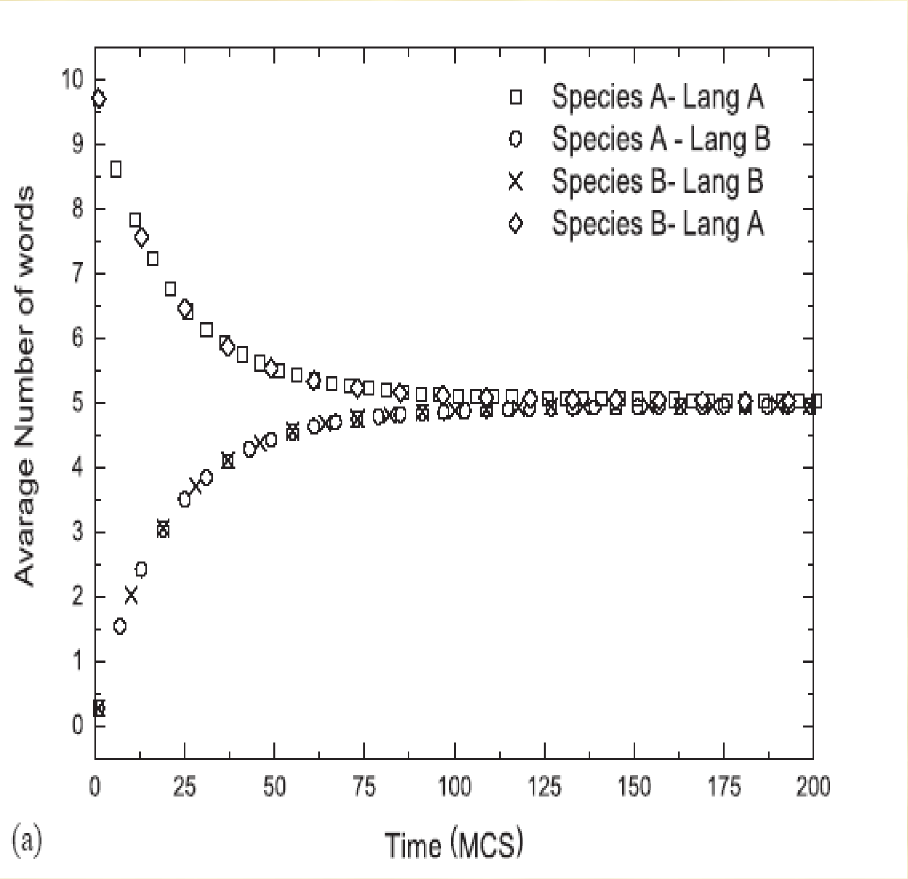
Species A at time t=0

0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1

Species B at time t=0

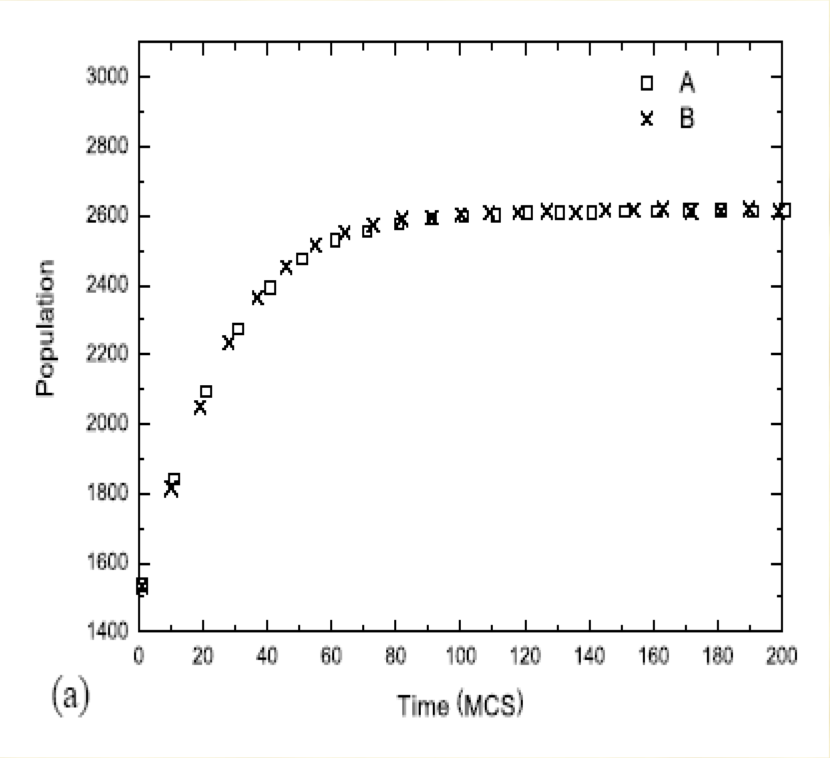
Homogeneous system with constant number of individuals

- Number A = Number B
- Fitness A= Fitness B
- No Reproduction or Death



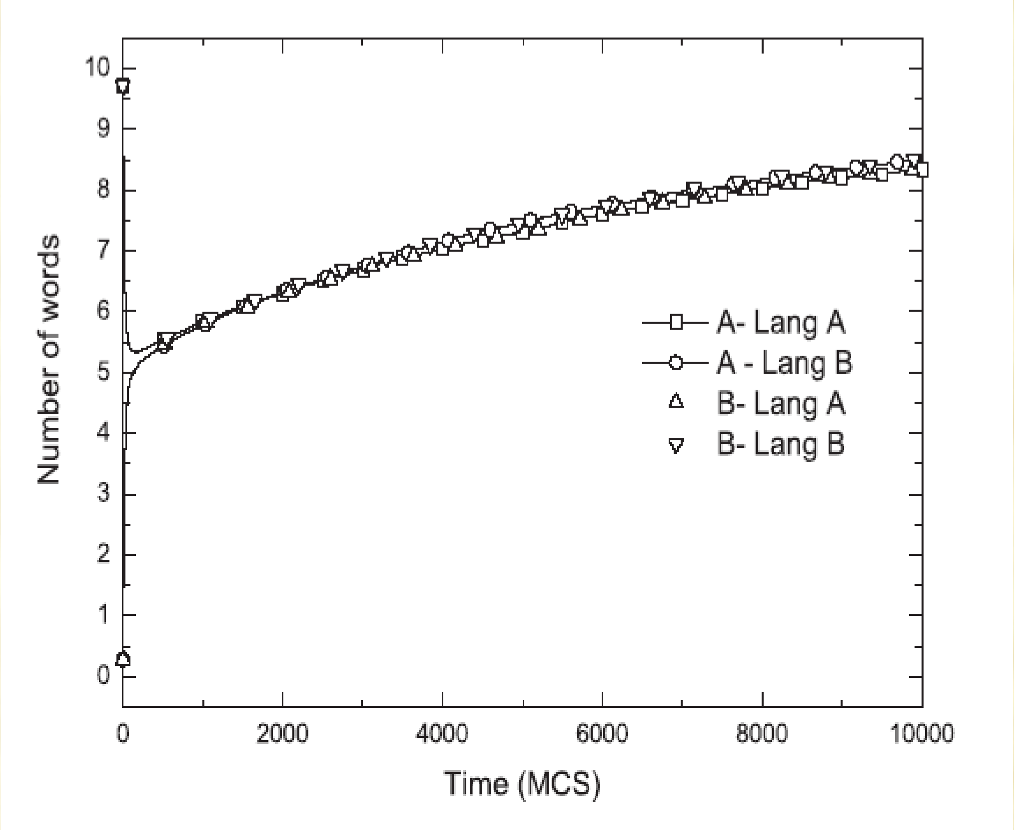
Homogenous System with variable number of individuals

- A system where the number of A's is the same as the initial number of B's and reproduction and mortality is allowed. Then:
- The averages population of the A species equals that of B, and is determined by the size of the system.



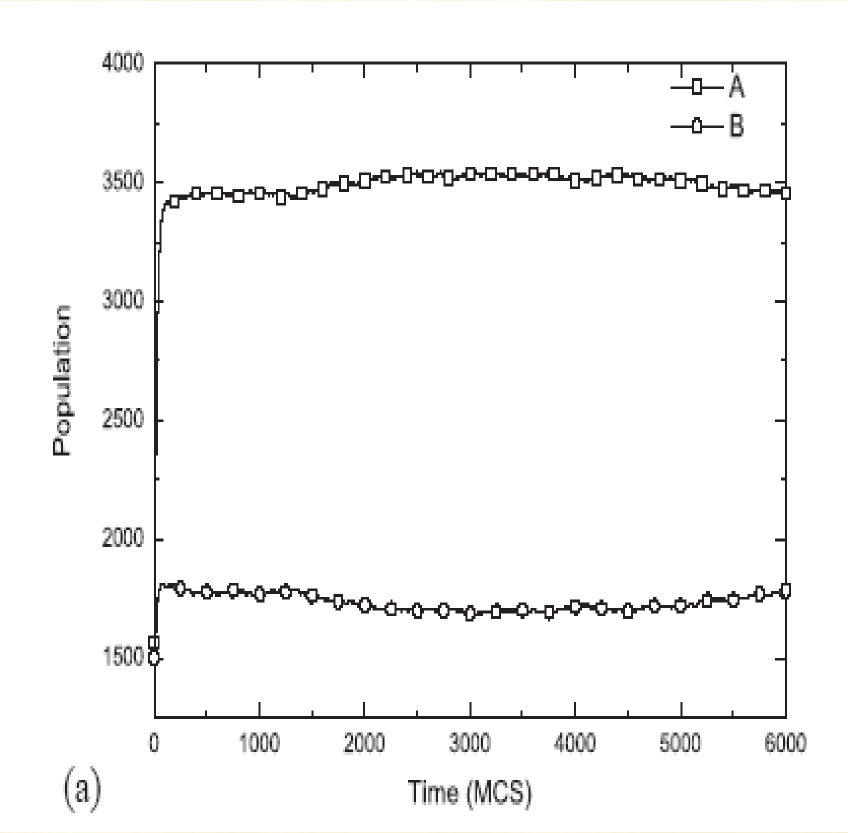
Homogenous System with variable number of individuals

The species start with a vocabulary of 10 words and end up with a vocabulary of (on average) 19.7 words, i.e. the system becomes bilingual.



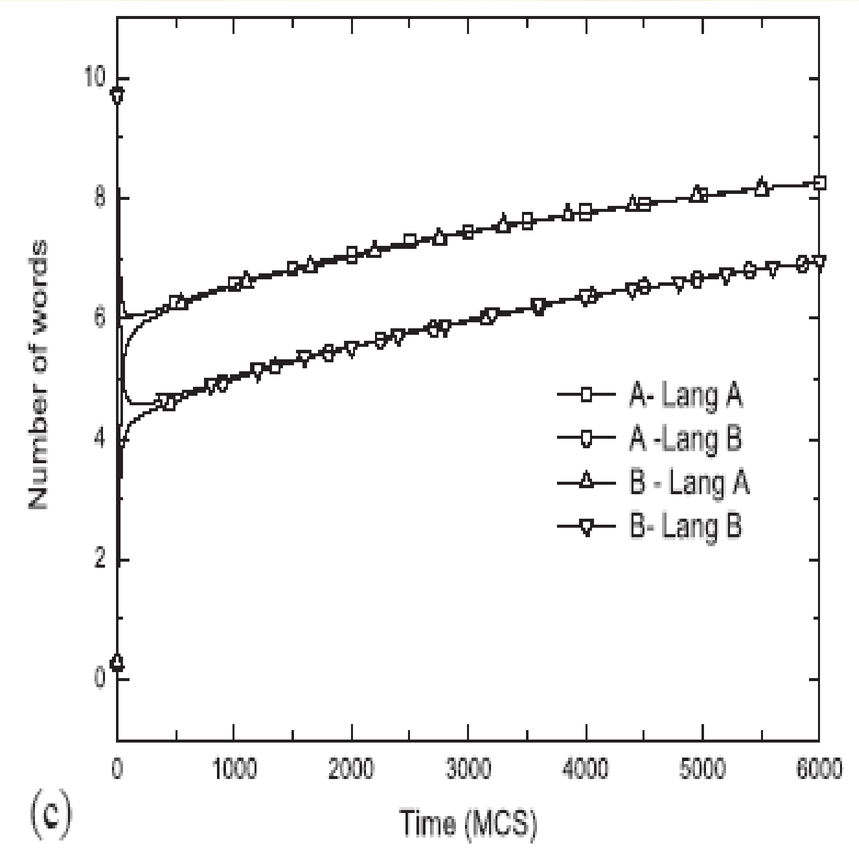
Inhomogeneous System (Different initial Fitness)

- A system where initially the A's and the B's are equal in number but the A's have higher initial fitness.
- The initial fitness advantage leads to numerical superiority for the *A's.*



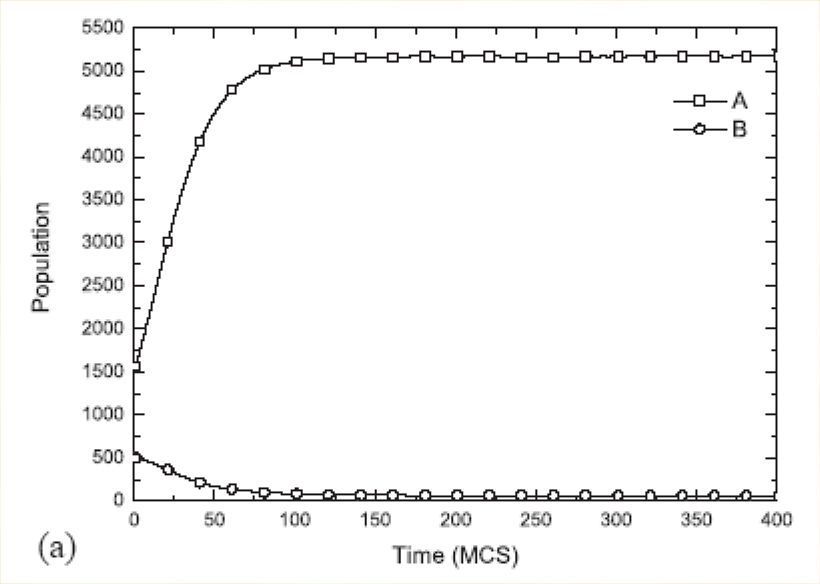
Inhomogeneous System (Different initial Fitness)

- For a long time interval, an average individual knows slightly more words of the A Language than of the B Language.
- The B language survives and finally the system is bilingual.



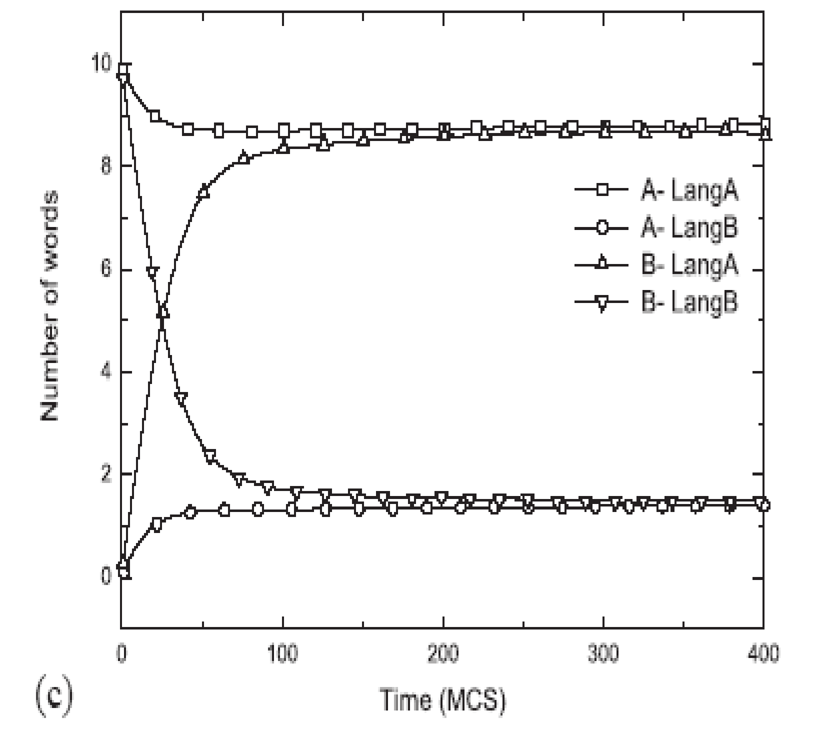
Highly Inhomogeneous System

- For a system where initially the A's greatly outnumbers the B's in number *and* fitness
- The population of the B's rapidly vanishes.



Highly Inhomogeneous System

- Some words of Language B survive in the vocabulary of species A
- A richer language containing synonyms is created.



SEGREGATION

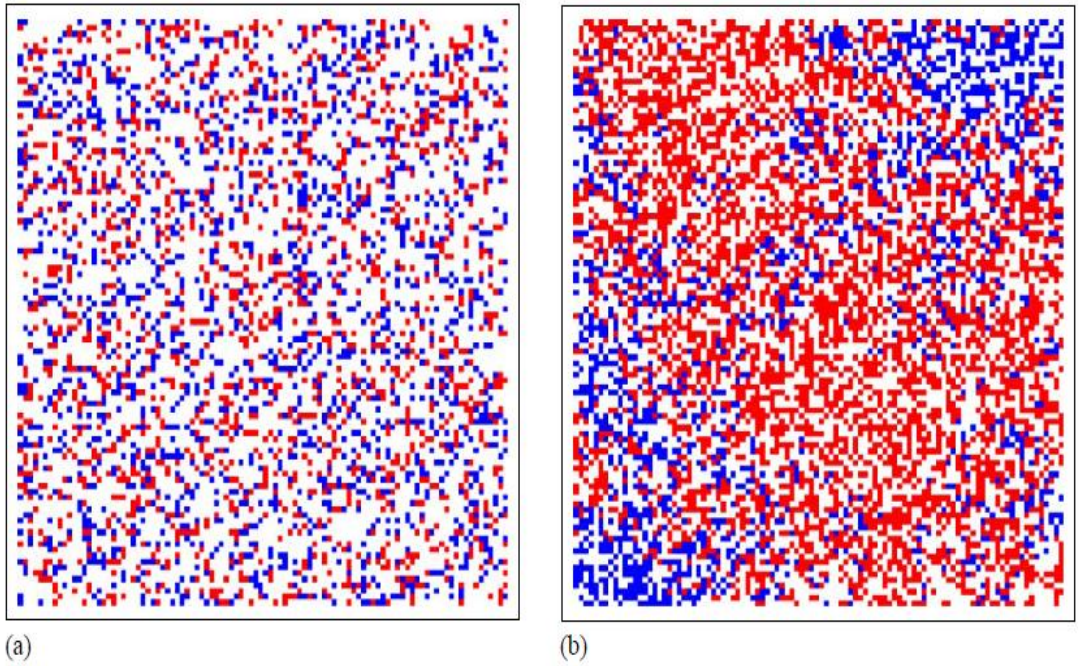


Fig. 7. A snapshot of the system at time $t = 1$ MCS (a) and at time $t = 10000$ MCS (b). Red sites are occupied by A individuals while blue sites by B individuals. The initial concentration of the species is $c_A = 0.15$ and $c_B = 0.15$. The initial fitness of the A species is $f_A = 30$ units and the initial fitness of the B species $f_B = 30$ units (particle size not to scale)

CONCLUSIONS

- When none of the species has no initial genetic advantage (or a small genetic advantage) both species end bilingual.
- Total number of words is the maximum possible.

- When one of the species comprises from rather few individuals with small initial fitness then it is quickly lead to extinction. A part of their vocabulary however survives and the final state of the system practically consists that of one species speaking a “richer” language containing *synonyms.*

Vocabulary on a scale –free network

- Why Scale-free ?
- Traditionally a 2D lattice is adequate.
- Modern technologies facilitate long range interactions: An acquaintance in China may be equally important to a next door neighbor.

SCALE FREE NETWORKS

- Individuals are nodes on a graph, linked only if they know each other.
- Several social networks have a degree distribution $p(k) \sim k^{-\gamma}$
- Scale-free networks, => existence

  of nodes with very high degree (“hubs”)

MONTE CARLO SIMULATIONS

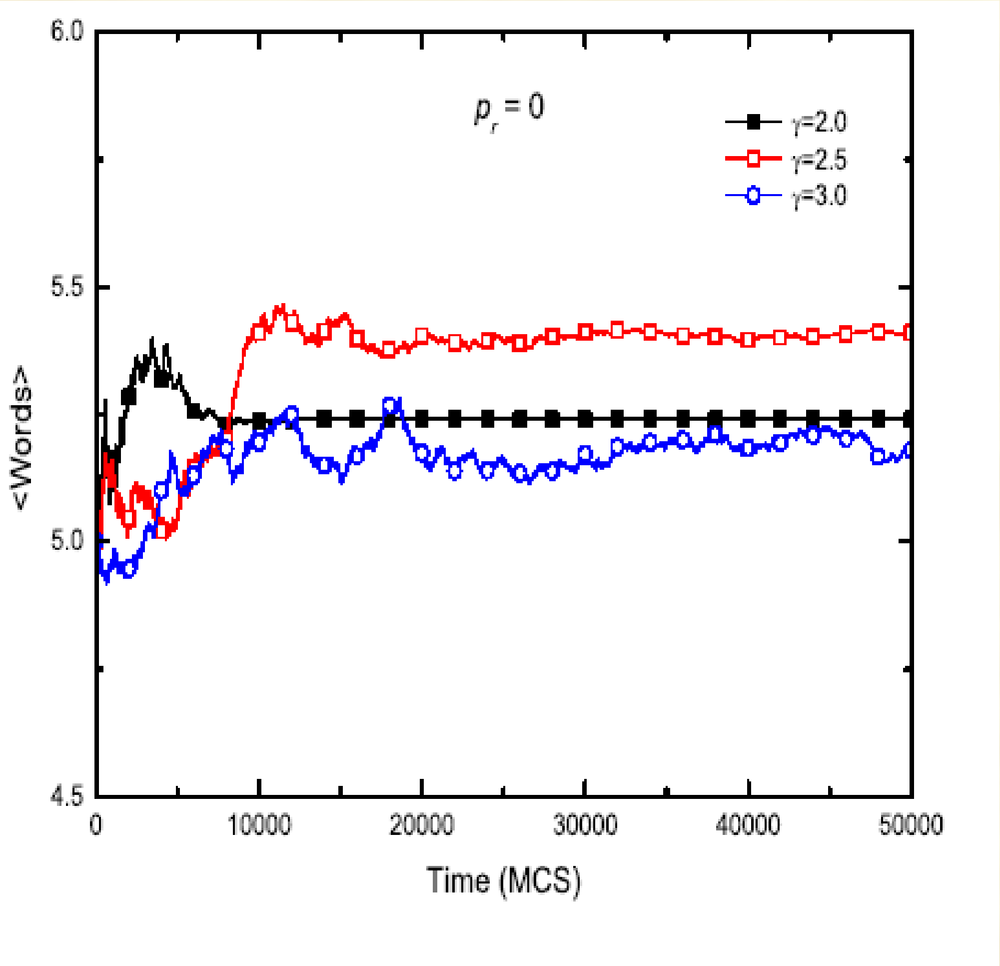
- Individuals are nodes on a scale free network
- Each has a maximum vocabulary of 10 words.
- Initially individuals know on average 5 words, randomly chosen out of the 10 possible.

MONTE CARLO SIMULATIONS

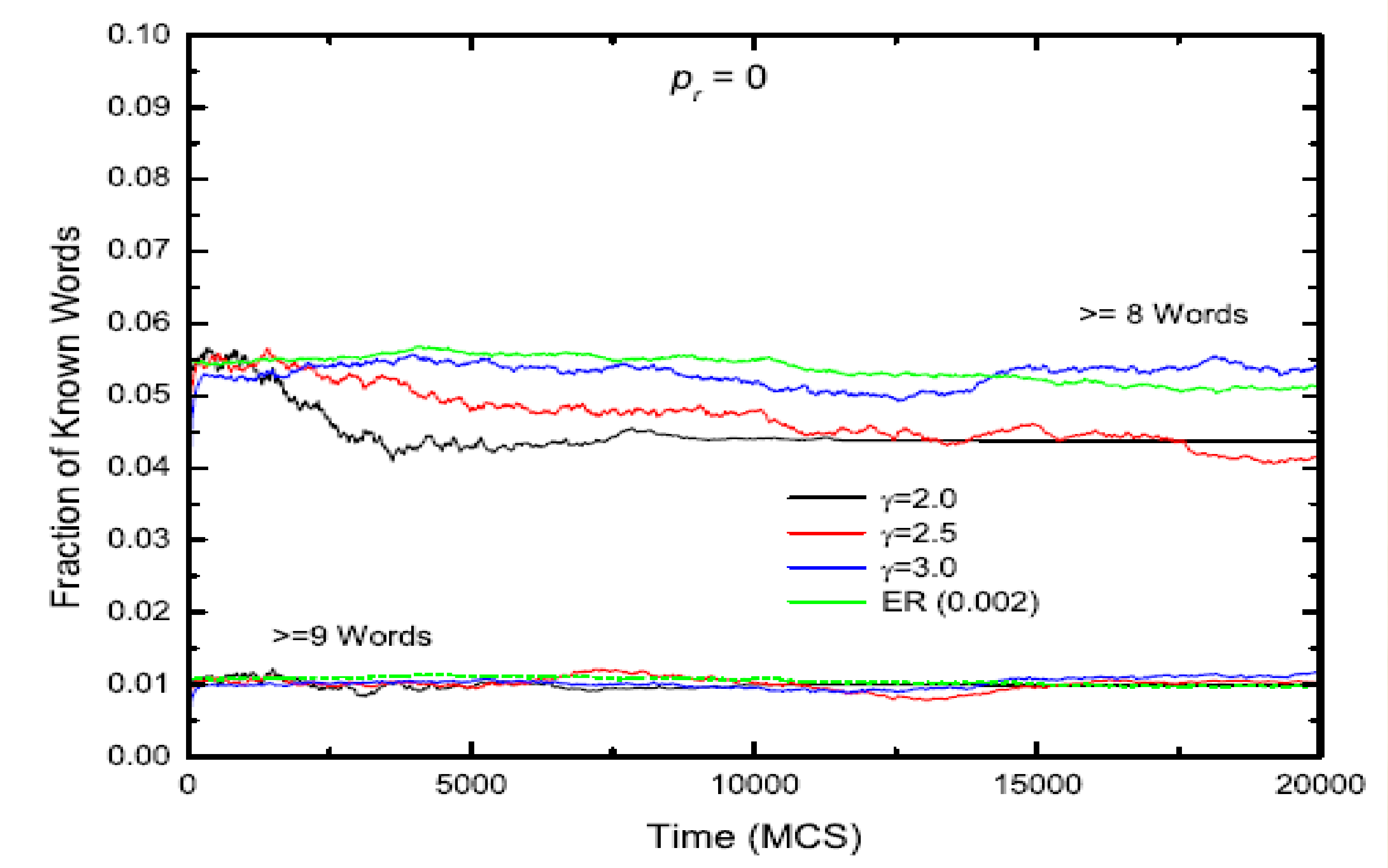
- They communicate with their neighbors, gaining fitness.
- They may learn new words from their neighbors, with probability P_L
- They may forget words not known to their neighbors, with probability $P_{f.}$
- Reproduction probability proportional to fitness.
- Child replaces a randomly selected node.
- Child has the fitness of the parent.

No Reproduction

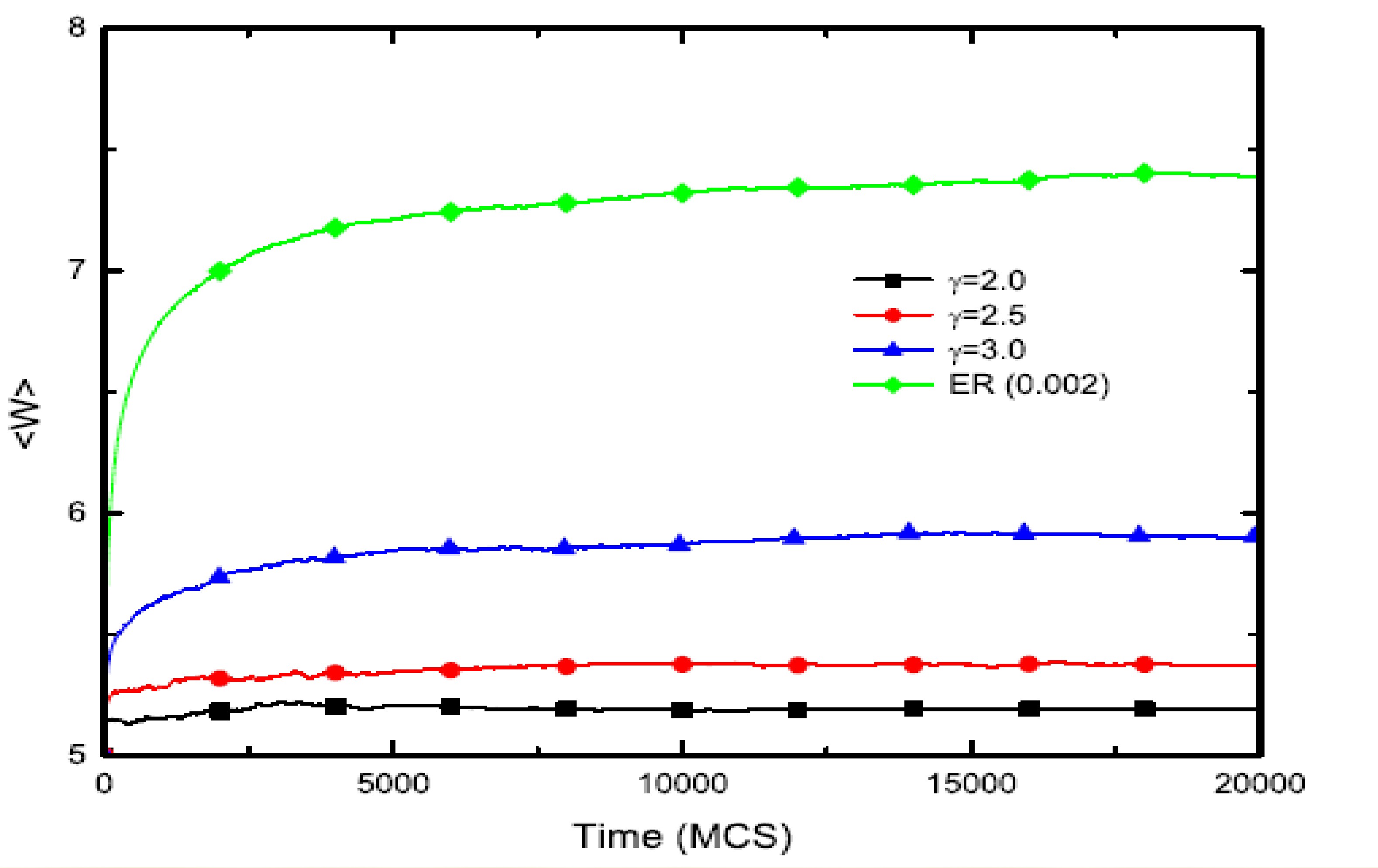
Average number of words = Initial number of words.



No Reproduction



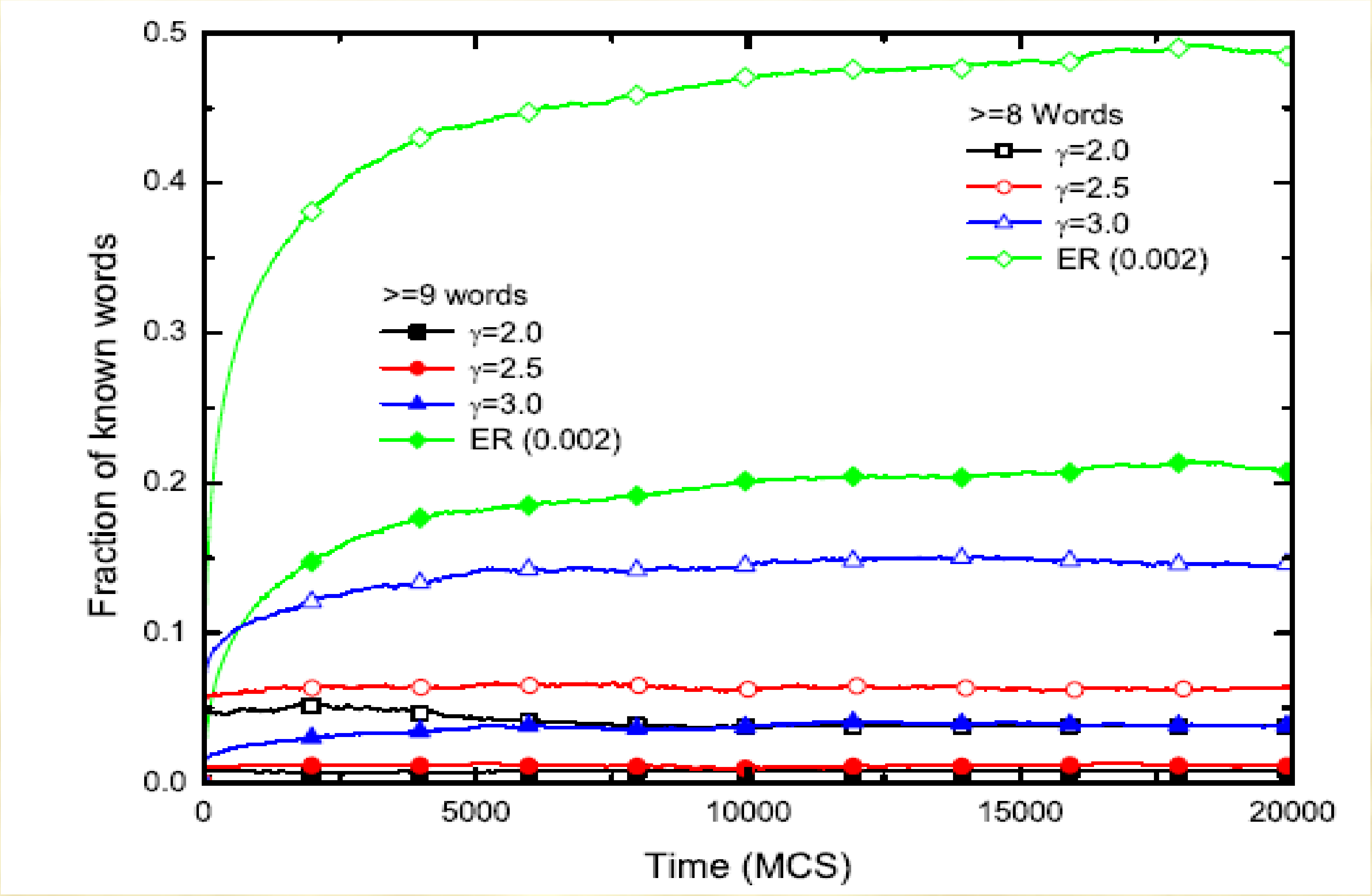
Reproduction



Reproduction

- Especially for $\gamma=2.0$, the number of words is quite below the maximum vocabulary size.
- The reason for this is that in such a network there are several hubs.
- A new fitness generating mechanism=>Knowing the words of hubs.

Reproduction



CONCLUSION

- On scale-free networks it is not necessary to know everything.
- Survival chances are increased by using the vocabulary of the “hubs” .
- The existence of the “hubs” in a scale-free network is the source of an additional important fitness generating mechanism.