EMERGENCE OF COMMUNICATION CONVENTIONS IN OPEN-ENDED SYSTEMS

E. Brigatti and I. Roditi[a]

Centro Brasileiro de Pesquisas Físicas

[a]E-mail address: roditi@cbpf.br

“ 2. ...The language is meant to serve for communication between a builder A and an assistant B. A is building with building-stones: there are blocks, pillars, slabs and beams. B has to pass the stones, and that in the order in which A needs them. For this purpose they use a language consisting of the words “block”, “pillar”, “slab”, “ beam”. A calls them out; B brings the stone which he has learnt to bring at such-and-such a call. ... ... I will call these games “language games” and will sometime speak of a primitive language as a language-game. ”

PHILOSOPHICAL INVESTIGATIONS, L. Wittgenstein

Language

$\updownarrow$

Cultural conventions shared by a group

$\updownarrow$

without a central control or a global coordinator

$\downarrow$

How these conventions occur and spread?

$\downarrow$

Need of mathematical models

Sociobiological Models
A better language acquisition strategy may bring a selective advantage that provides higher reproductive success. Emphasis in genetic factors

Sociocultural Models
A good strategy provides higher communication success implying a better ability in reaching cooperative goals Emphasis in peer interaction

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The Evolutionary Language Game

MARTIN A. NOWAK*, JOSHUA B. PLOTKIN AND DAVID C. KRAKAUER

Institute for Advanced Study, Olden Lane, Princeton, NJ 08540, *U.S.A.*

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We explore how evolutionary game dynamics have to be modified to accomodate a mathematical framework for the evolution of language. In particular, we are interested in the evolution of vocabulary, that is associations between signals and objects. We assume that successful communication contributes to biological fitness: individuals who communicate well leave more offspring. Children inherit from their parents a strategy for language learning (*a language acquisition device*). We consider three mechanisms whereby language is passed from one generation to the next: (i) parental learning: children learn the language of their parents; (ii) role model learning: children learn the language of individuals with a high payoff; and (iii) random learning: children learn the language of randomly chosen individuals. We show that parental and role model learning outperform random learning. Then we introduce mistakes in language learning and study how this process changes language over time. Mistakes increase the overall efficacy of parental and role model learning: in a world with errors evolutionary adaptation is more efficient. Our model also provides a simple explanation why homonomy is common while synonymy is rare.

A self-organizing spatial vocabulary.

Luc Steels
Artificial Intelligence Laboratory
Vrije Universiteit Brussel
Pleinlaan 2, B-1050 Brussels, Belgium
E-mail: `steels@arti.vub.ac.be`
(draft - to appear in Artificial Life Journal, 1996)

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Abstract

Language is a shared set of conventions for mapping meanings to expressions. This paper explores self-organization as the primary mechanism for the formation of a vocabulary. It reports on a computational experiment in which a group of distributed agents develop ways to identify each other using names or spatial descriptions. It is also shown that the proposed mechanism copes with the acquisition of an existing vocabulary by new agents entering the community and with the expansion of the set of meanings.

Definition of a negotiation dynamics.

Spreading of conventions: homogeneous quantity emerge out of an initial disordered state (Ising-like models, herding behavior)

Emergence of a shared vocabulary:

- agents characterized by a memory with a number of possible states, each one characterized by a number of possible choices (when infinite: open endness)

- interaction between agents should be asymmetric and characterized by the presence of memory and learning/feedback effects. Some possible mechanisms are: uploading, overlapping and agreement mechanism

A. Baronchelli, M. Felici, E. Caglioti, V. Loreto and L. Steels, J. Stat. Mech. P06014 (2006).

A. Baronchelli, V. Loreto and L. Steels, Int. J. Mod. Phys. C19 785 (2008).

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- At each time step ($t = 1, 2, ..$) two agents are randomly selected and interact: one of them plays the role of *speaker*, the other one that of *hearer*.

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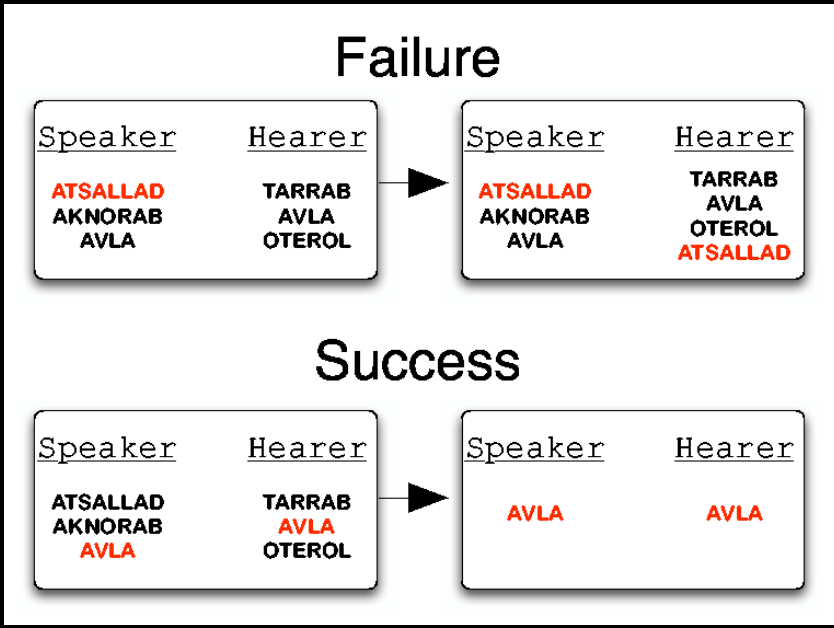
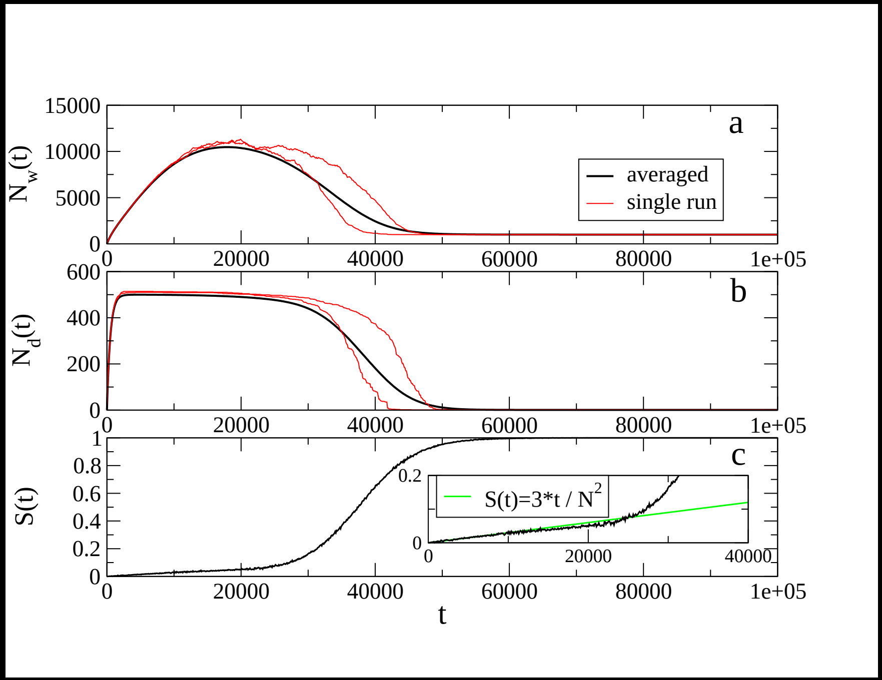
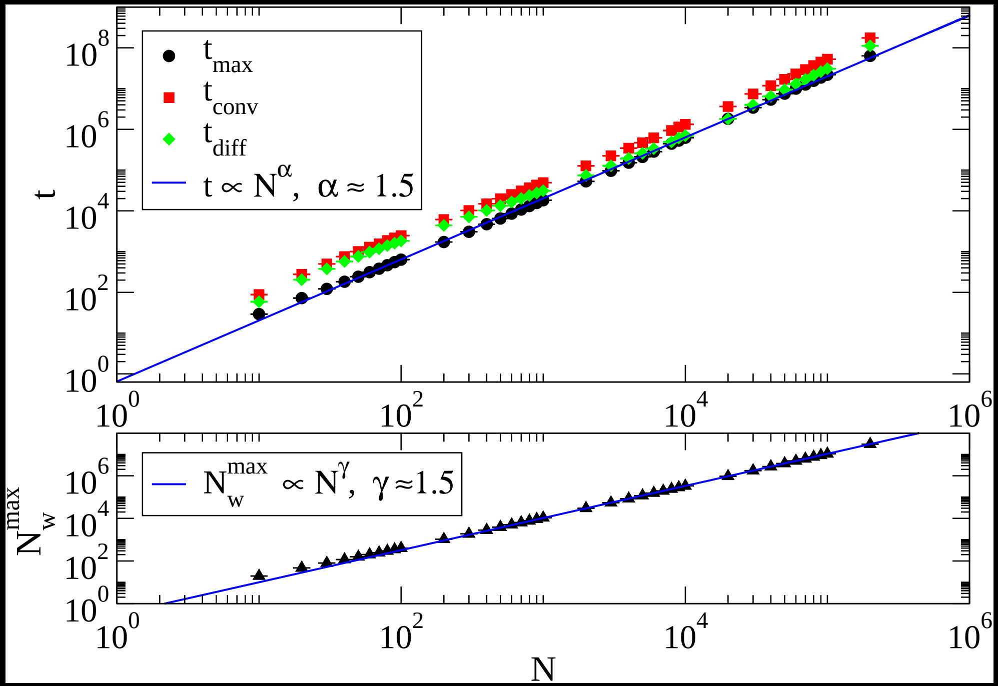
3. **Hearer:** If the name is not known, the game is a failure, and the hearer inserts the name in its inventory.



Naming game interaction rules.



Basic phenomenology. a) Total Number of names present in the system, $N_w(t)$; b) Number of different names, $N_d(t)$; c) Success rate $S(t)$, i.e., probability of observing a successful interaction at a time t. The inset shows the linear behavior of $S(t)$ at small times. Population of $N = 10^3$ agents. Final absorbing state, described by $N_w(t) = N$, $N_d(t) = 1$ and $S(t) = 1$, global agreement on the form (name) to assign to the meaning (individual object) has been reached.



Scaling with the population size N. In the upper graph the scaling of the peak and convergence time, t_{max} and t_{conv}, is reported, along with their difference, t_{diff}. All curves scale with the power law $N^{1.5}$. The lower curve shows that the maximum number of words (peak height, $N_w^{max} = N_w(t_{max})$) obeys the same power law scaling.

Modified Naming Game

A minimal model played by P agents

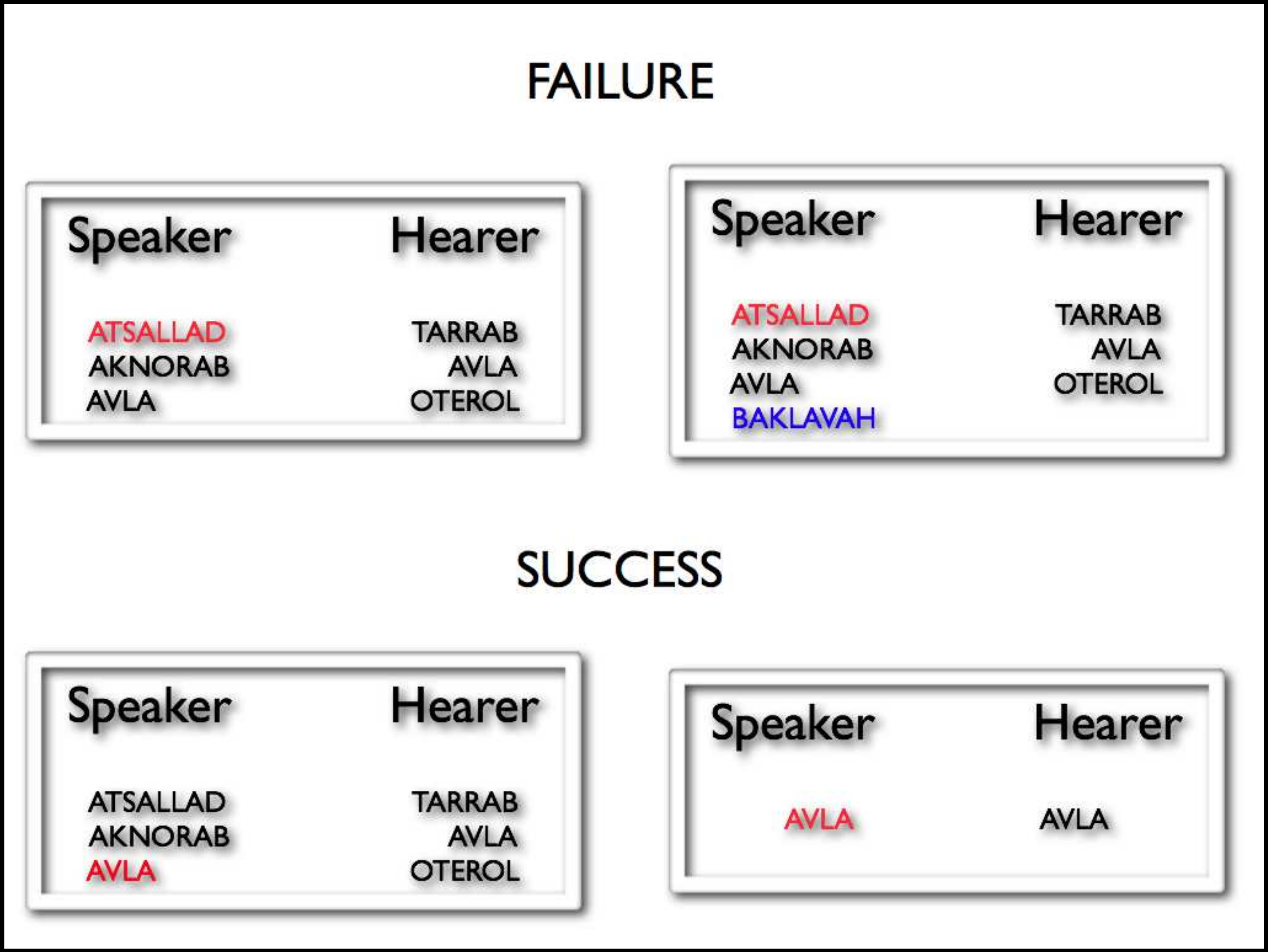
- No internal overlapping mechanism. The reservoir of words is subjected to some constraints

  The new words are distributed according to a Gaussian law $exp(-x^2/\sigma)$.

- The agreement mechanism is the only responsible for the order/disorder transition

  We look for a lower bound for the cognitive mechanisms

  - the speaker retrieves a word from its inventory associated with the chosen object, or, if its inventory is empty, invents a new word (chosen from a Gaussian with standard deviation σ).
  - the speaker transmits the selected word to the hearer.
  - if the hearer's inventory contains such a word (success), the two agents update their inventories so as to keep only the word involved in the interaction.
  - otherwise (failure): the speaker invents a new word.


FAILURE
Speaker
Hearer
ATSALLAD
AKNORAB
AVLA
TARRAB
AVLA
OTEROL
Speaker
Hearer
ATSALLAD
AKNORAB
AVLA
BAKLAVAH
TARRAB
AVLA
OTEROL
SUCCESS
Speaker
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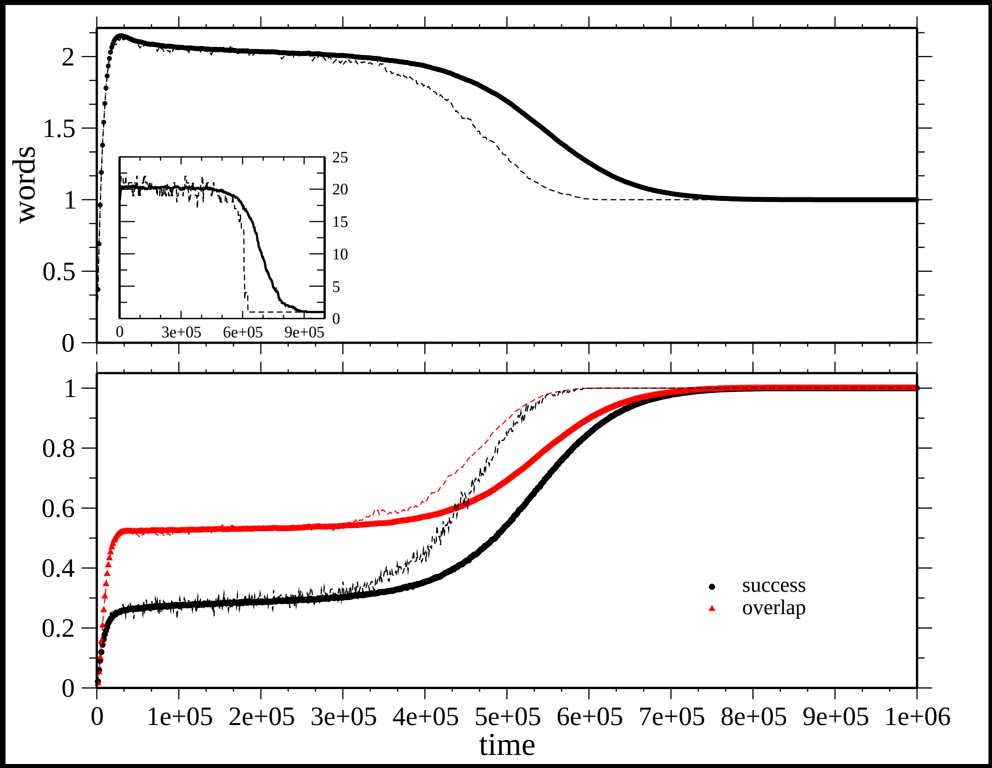
Phenomenology:

- **Global quantities**: the total number of words (N_{tot}) present in the population, the number of different words (N_{Diff}) and the success rate (S), which measures an average rate of success in communications.

- With the aim of characterizing with more details our system, describing directly its state and not just the outcome of the game, we looked at an $overlap\, function$ (Baronchelli et al.). It corresponds to the total number of words common to all the possible agents' pairs:

$$\mathcal{O} = \frac{2}{P(P-1)} \cdot \sum_{i \geq j} a_i \bigcap a_j .$$

The behavior of this quantity is similar to $S(t)$



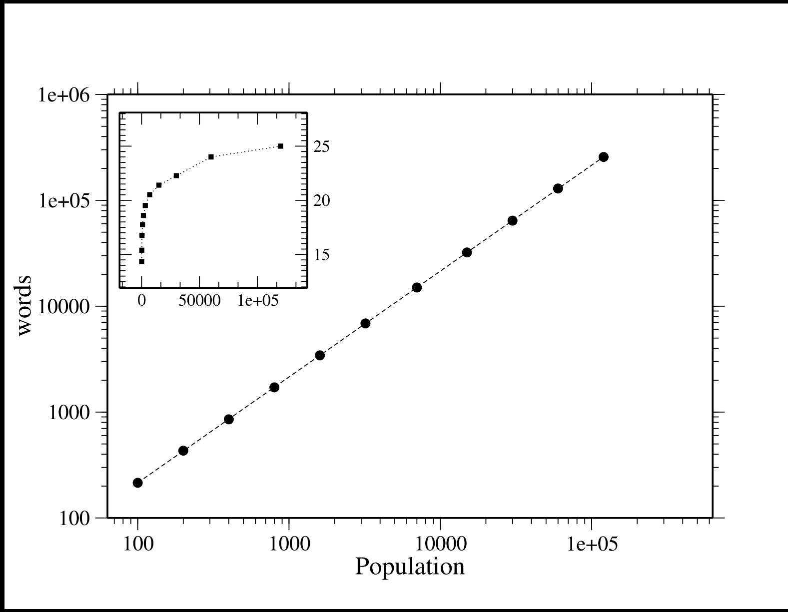
Top: temporal evolution for the total number of words divided by the total population. In the inset, total number of different words ($N_{Diff}(t)$). Bottom: the success rate ($S(t)$) and the overlap function $\mathcal{O}$. The dashed curves represent a single realization. All other data are averaged over 100 simulations. ($P = 7000$, $\sigma = 5$).

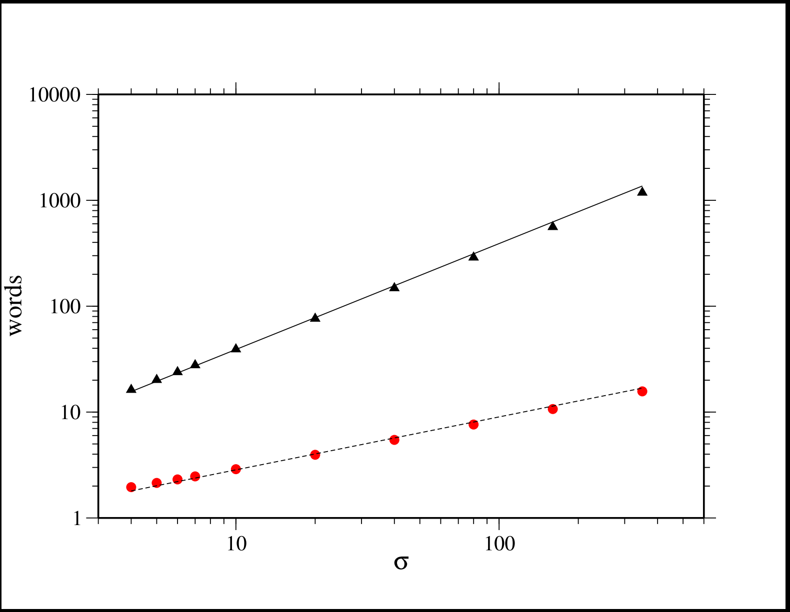
Scaling with the population size P:

- $N_{Diff.}$ is independent on P, for large P; $N_{tot.} \propto P$ (also analytically)

Scaling with σ:

- $N_{Diff.} \propto \sigma$; $N_{tot.} \propto \sigma^{1/2}$ (also analytically)





squares max. number of different words diff. popul.sizes; circles max. number of total words;

triangles max. number of different words diff. sigma.

The maximum number of total words linearly scales with the population number. In other words, the number of total words of each player is not dependent on the dimension of the community. This can be seen (Baronchelli et al.) if we represent the mean total number of words for agent, at time step t, by $n(t)$, and the mean total number of different words by $D(t)$. If we assume that $n(t)$ scales as β, unknown, we can write:

$$n(t+1) - n(t) \propto \frac{1}{n(t)^\beta}\Big(1 - \frac{n(t)^\beta}{D(t)}\Big) - \frac{1}{n(t)^\beta}\frac{n(t)^\beta n(t)^\beta}{D(t)} \qquad (1)$$

We are considering that the probability for the speaker to communicate a specific word is $\frac{1}{n(t)^\beta}$ and the probability for the hearer to own that words is $\frac{n(t)^\beta}{D(t)}$. It follows that the first term represents the gain term for a failed communication, and the second one the loss term We can use this equation for describing the P dependence. D, for large P, can be considered a constant. For this reason, at the stationary state, where we should impose $n(t+1) - n(t) = 0$, our equation reduces to $\frac{1}{n^\beta} \propto n^\beta$, which forces $\beta = 0$. This fact implies that the number of total words for each player is not dependent on P.

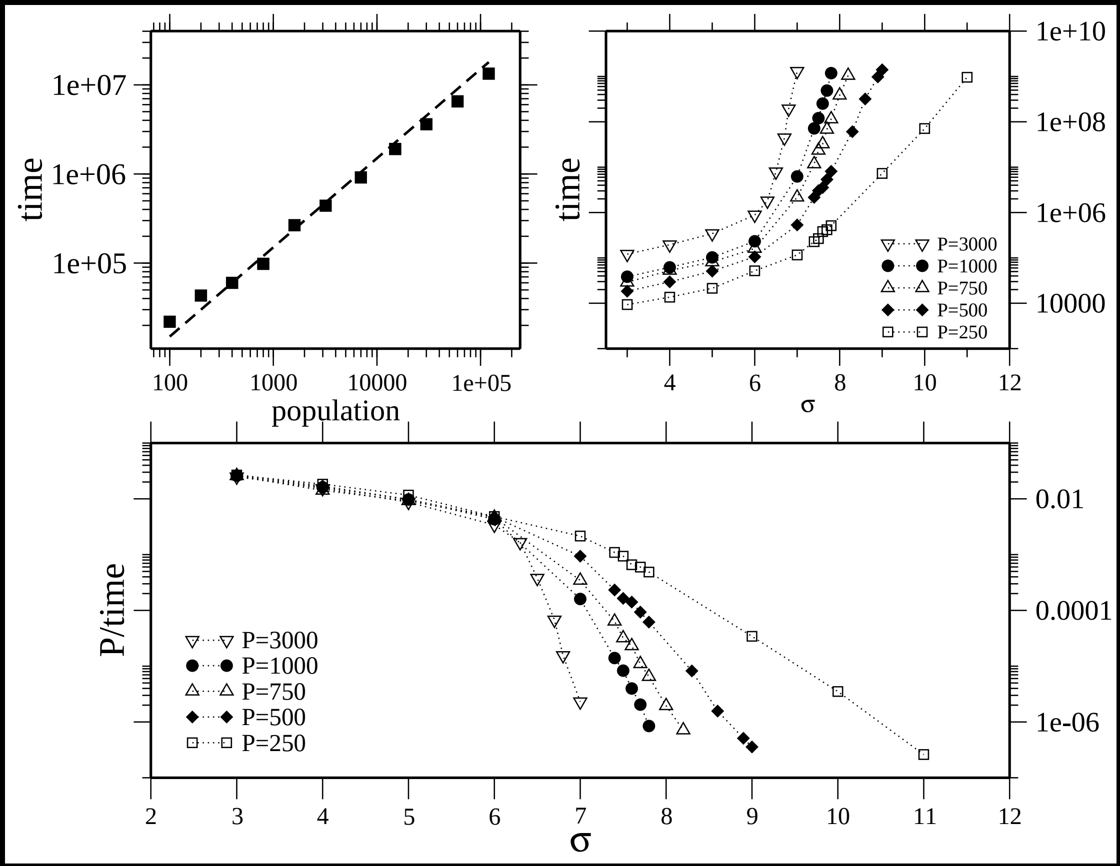
$N_{Diff.}$ linearly scales with σ. This result is quite intuitive if we approximate our distribution of new words with a box of dimension σ.

We can use again equation 1 for examining the dependence of N_{tot} on σ. We will look for a power-law dependence on σ; for this reason we consider that $n \propto \sigma^\gamma$ with γ unknown. Using the fact that, at equilibrium, $D \propto \sigma$, we obtain:

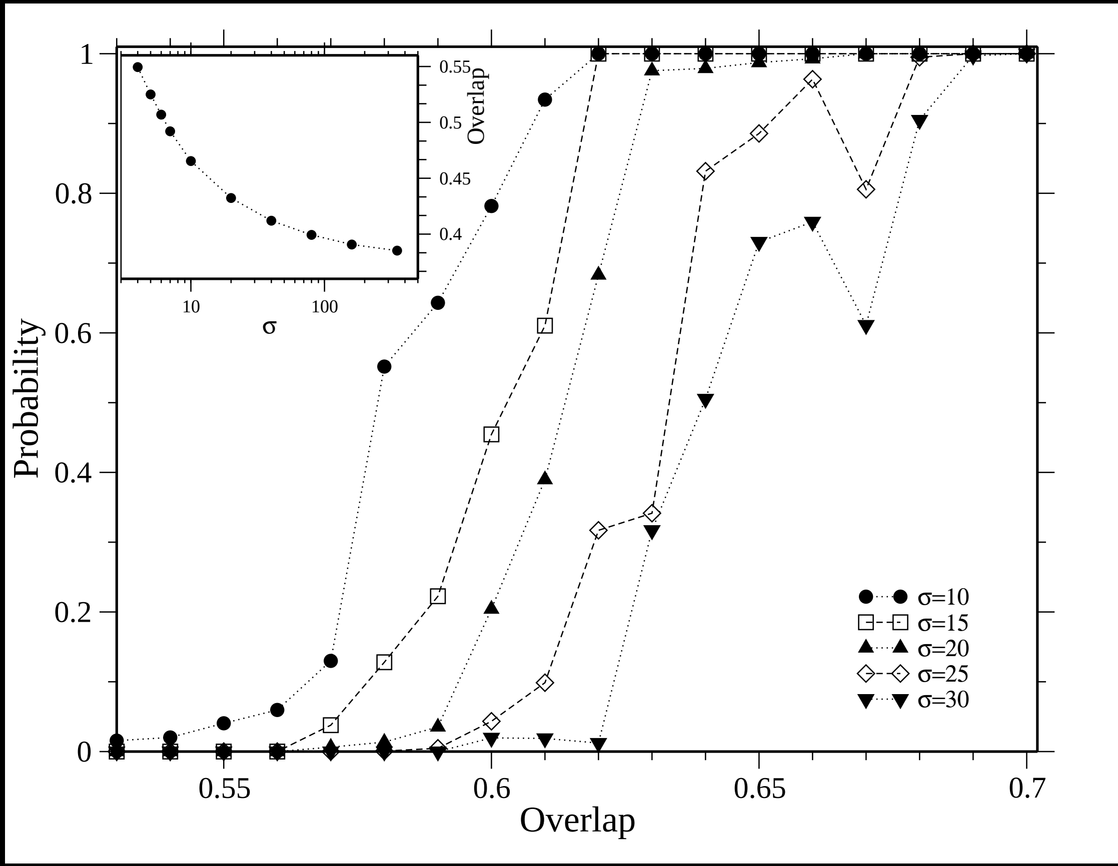
$$\frac{1}{\sigma^\gamma}\Big(1 - \frac{\sigma^\gamma}{\sigma}\Big) \propto \frac{1}{\sigma^\gamma}\frac{\sigma^\gamma\sigma^\gamma}{\sigma}$$

This equation implies that, at the stationary state, $\gamma = 1/2$. It follows that $N_{tot} \propto \sigma^{1/2}$, a result confirmed by the numerical data shown .

Convergence time



$T_C \propto P$; $T_C \to \infty$ for $6 < \sigma_{crit} < 7$



Probability of reaching consensus (frequency of runs which reach consensus) as a function of the $\mathcal{O} = \frac{2}{P(P-1)} \cdot \sum_{i \geq j} a_i \bigcap a_j$ value of the initial conditions, for different σ values ($P = 1000$). In the inset, mean value of $\mathcal{O}$ in the plateau region, as a function of σ, for standard initial condition.

Summary

- We showed a *minimal model for the spreading of conventions.*

- *RESULT: The agreement mechanism is sufficient for generating an ordering transition* [a]*.*

  an order/disorder transition in the σ *space exists*

  the system belongs to a different universality class

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[a] E.B. and I.Roditi *"Conventions spreading in open-ended systems"* New Journal of Physics 11 (2009) 023018