MAX-PLANCK-GESELLSCHAFT

Identifying Selective Pressures on Language Change

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Language change

- Language is the most complex socio-cultural system in human beings (Hruschka et al., 2009), and human languages undergo constant changes:

- Language change can be viewed as the temporal shift in the proportions of different linguistic variants used by individuals within a population (Hruschka et al., 2009).
  - The *Great Vowel Shift* in English from the 16th to 18th century (Wolfe, 1972);
  - The creoles emerging in the 18th and 19th centuries in African slave populations (Mufwene, 2001);

- N.B. language origin (from no languages to languages, MacWhinney, 1999) and language death (disappearance of language speakers, Minett and Wang, 2008) are also changes;

- Hruschka, D. J., et al. 2009. Building social cognitive models of language change. TRENDS in Cog. Sci., 13: 464-469.
- Wolfe, P. M. 1972. Linguistic Change and the Great Vowel Shift in English. Berkeley: University of California Press.
- Mufwene, S. S. 2001. The Ecology of Language Evolution. Cambridge, MA: Cambridge University Press.
- MacWhinney, B. (Ed.) 1999. *The emergence of language*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Minett, J. W., and Wang, W. S-Y. 2008. Modeling endangered languages: The effects of bilingualism and social structure. Lingua, 118, 19-45.

Language change

- Studies in language change concern the manners in which various kinds of features of a language arise, vary, and fall out of use over time.

- Understanding language change can help to explore;
  - What are the cognitive capacities for language;
  - How these capacities have evolved in humans;
  - What are the effects of socio-cultural constraints on linguistic interactions.

- Some general questions in language change:
- Question 1: What is changing?
  - Linguistic variants in lexicon, semantics, syntax, phonology, morphology, etc.
- Question 2: Who are the creators of these variants?
  - It is children who introduce linguistic variants (Bickerton, 1990; Senghas et al., 2004):
  - Both adults and children contribute linguistic variants (Mufwene, 2008):

- Bickerton, D., 1990. Language and Species. University of Chicago Press, Chicago, IL.
- Senghas, A., Kita, S., Özyürek, A. 2004. Children creating core properties of language: Evidence from an emerging sign language in Nicaragua, Science 305: 1179-1782.
- Mufwene, S. S. 2008. What do creoles and pidgins tell us about the evolution of language? In: Mufwene, S. S. (Ed.), Language evolution: Contact, competition and change. London: Continuum, pp. 74-92.

General questions in language change studies

- Question 3: What factors affect the diffusion of linguistic variants in populations?
  - Language-internal factors (Labov, 1994):
  - Linguistic feature:
    - E.g., [ŋo] (“I”) > [o]; [nei] (“you”) > [lei]; [k^hoi] (“he/she/it”) > [hoi] in Cantonese
    - Ease in production.
  - Language-external factors (Labov, 2001):
  - Social prestige:
    - Speakers’ social identities are correlated with the way they speak (Croft, 2000);
    - E.g., couch <> sofa; toilet <> lavatory; driver <> chauffeur (Johnstone, 2010);
    - Ordinary people tend to copy the way or forms used by people with higher status.
  - Social constraints:
    - E.g., geographical constraints (Nettle, 1999);
    - Cultural dissemination (Axelrod, 1997);

- Labov, W., 1994. Principles of Linguistic Change: Internal Factors. Basil Blackwell, Oxford.
- Labov, W., 2001. Principles of Linguistic Change: Social Factors. Basil Blackwell, Oxford.
- Croft, W. 2000. Explaining Language Change: An Evolutionary Approach. Harlow, UK: Longman.
- Johnstone, J. 2010. Locating language in identity. in *Language and Identity*, Llamas, C. and Watt, D. (eds.), Edinburgh, UK: Edinburgh University Press. Available at: http://works.bepress.com/barbara_johnstone/4.
- Axelrod, 1997. The dissemination of culture: A model with local convergence and global polarization. The Journal of Conflict Resolution, 41(2): 203-226.
- Nettle, D. 1999. Using Social Impact Theory to simulate language change. Lingua, 108: 95-117.

Our approach

- Focus: What factors affect the diffusion of linguistic variants?
  - Assumptions:
    - Linguistic variants are already existent;
    - These variants can be learned during communications;
  - Two targeting factors on diffusion:
    - Social prestige → the type frequencies of variants;
    - Social constraint → the communication patterns among individuals;
- Approach:
  - Computational simulation of communications;
  - Statistical analysis on the effects of the two targeting factors;

Computational simulation

- Computational simulations are "operational" hypotheses or theories expressed in computer programs (Parisi and Mirolli, 2007);
- Simulation results are "empirical predictions" derived from the incorporated hypotheses or theories (Cangelosi and Parisi, 2002);
- In linguistic research, there are mainly two types of simulations:
    - Behavioral models: simulate individual linguistic behaviors during communications;
    - Mathematical models: abstract those behaviors or communication processes as mathematical equations;
    - Computational models can reasonably reconstruct linguistic behaviors in communications and recapitulate language history, both of which can help to reconsider the effects of various factors on language evolution and evaluate related linguistic hypotheses or theories.

Cangelosi, A., Parisi, D. (Eds.), 2002. Simulating the Evolution of Language. Springer-Verlag, London.
Parisi, D., Mirolli, M., 2007. The emergence of language: How to simulate it. In: Lyon, C., Nehaniv, C. L., Cangelosi, A. (Eds.), Emergence of Communication and Language. Springer-Verlag, London, pp. 269-285.

Pólya Urn model from statistical physics

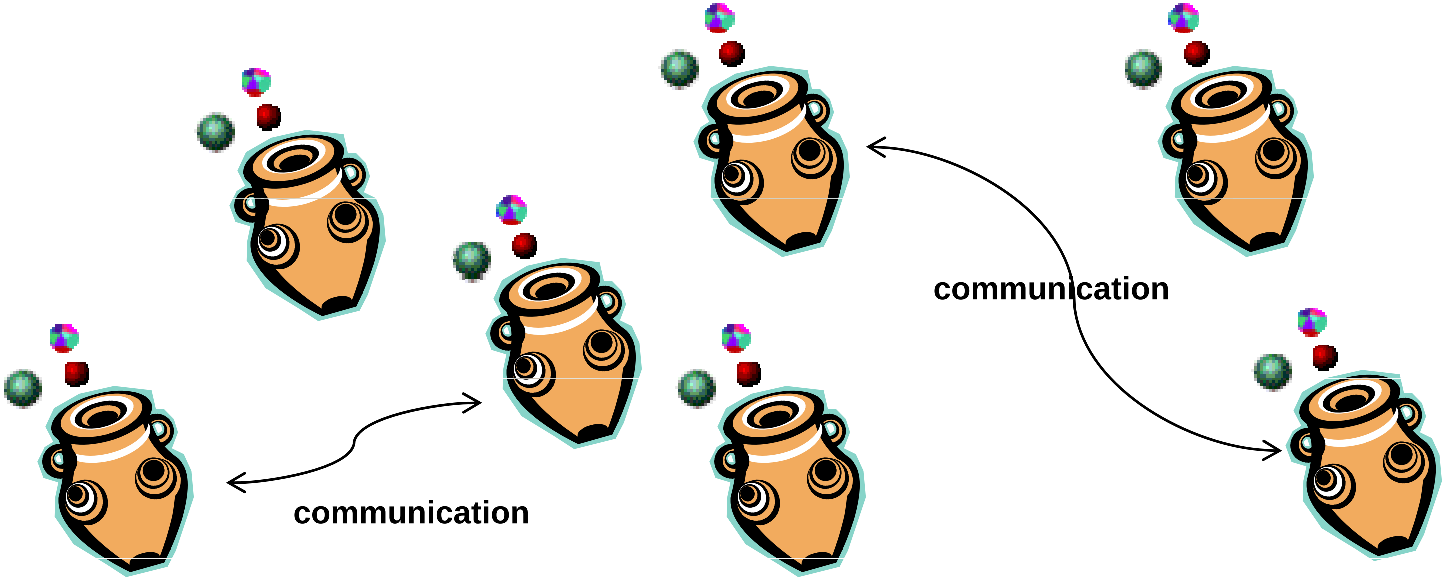
- Pólya urn model (Johnson and Kotz, 1977; Marshall and Olkin, 1993)
  - Study the spread of disease within populations;
  - Components:
    - One urn with V tokens (v_1, v_2, … v_V);
    - Each token: a feature z_i (Z) and a prestige p_i (P);
  - Dynamics:
    - Random selection of v_i ;
    - Return with some tokens of the same type;
    - Mutation: some different types of tokens may be added (M);
  - Statistical analysis: the Markov chain;

- Johnson, N. L. and Kotz, S. 1977. Urn Models and Their Applications. New York: Wiley.
- Marshall, A. W. and Olkin, I. 1993. Bivariate life distributions from Pólya urn model for contagion. Journal of Applied Probability, 30: 497-508.

Pólya Urn model from statistical physics

- *Z* ➔ features of linguistic variants;
- *P* ➔ prestige assigned on linguistic variants;
- *M* ➔ transmission error or learning bias during communications;

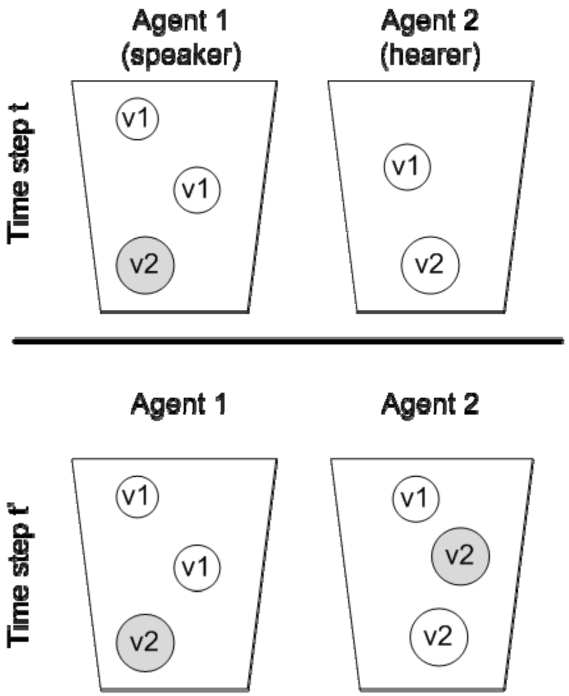
- Modified Pólya urn based language change model:
  - Multi-agent: each agent is a urn;
  - Communication: two agents (a speaker and a hearer), only hearer updates its urn;



Pólya Urn model from statistical physics

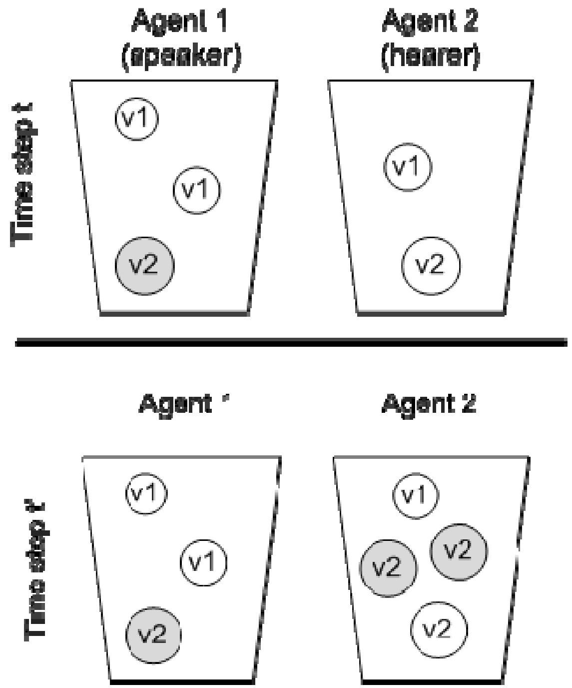
No prestige; no mutation:

$Z = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$ $P = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$ $M = \begin{bmatrix} 1.0 & 0.0 \\ 0.0 & 1.0 \end{bmatrix}$



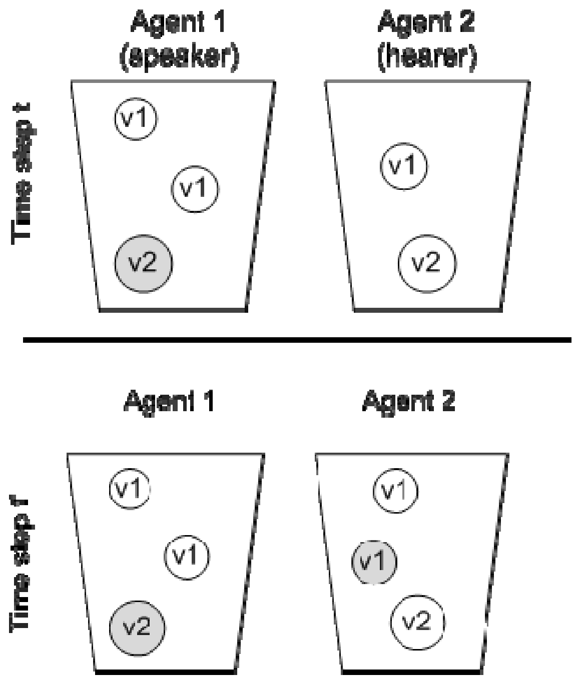
Prestige; no mutation:

$Z = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$ $P = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$ $M = \begin{bmatrix} 1.0 & 0.0 \\ 0.0 & 1.0 \end{bmatrix}$



No prestige; mutation:

$Z = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$ $P = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$ $M = \begin{bmatrix} 0.8 & 0.2 \\ 0.2 & 0.8 \end{bmatrix}$



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Price equation from theoretical biology

- Price equation (Price, 1970; Gardner, 2008)

$$\Delta z = Cov((w_i / w, z) + E((w_i / w)\Delta z_i)$$

  - Describes how the average value of any quantifiable feature changes in a biological population from one generation to the next.

  - z_i: a particular feature value in individuals;
  - w_i: the number of tokens of a particular feature;
  - Δz_i: the discrepancy between the feature values of itself and its offspring.

  - *Covariance* (selection):
    - consistently positive (or negative);
  - *Expectation* (mutation or bias):
    - non-zero: offspring differ from their parents;

- Price, G. R. 1970. Selection and covariance. Nature, 227: 520-521.
- Gardner, A. 2008. The Price equation. Current Biology, 18: R198-R202.

Price equation from theoretical biology

- Apply Price equation in our Pólya urn model

$$\Delta z = Cov((w_i / w, z) + E((w_i / w)\Delta z_i)$$

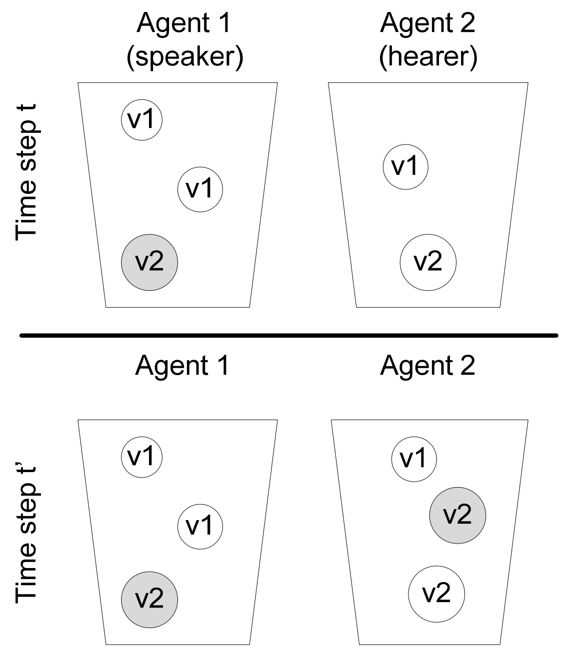
- q_i: the proportion of the population made up of v_i in t
- q_i': the proportion of the population made up of v_i in t'
- $w_i = q_i'/q_i$: the average number of v_i in t'; $w = avg(w_i)$;
- z_i: the average feature value of v_i in t;
- z_i': the average feature value of v_i in t'.

	q_i	q_i'	w_i	w_i/w	z_i	z_i'	Δz
v_1	0.6	0.5	0.83	0.4	1.0	1.0	0.0
v_2	0.4	0.5	1.25	0.6	2.0	2.0	0.0

$$Cov((w_i / w, z) = 1/2 \times [(0.4 - 0.5) \times (1.0 - 1.5) + (0.6 - 0.5) \times (2.0 - 1.5)] = 0.05$$

No prestige; no mutation:

$$Z = \begin{bmatrix} 1 \\ 2 \end{bmatrix} \quad P = \begin{bmatrix} 1 \\ 1 \end{bmatrix} \quad M = \begin{bmatrix} 1.0 & 0.0 \\ 0.0 & 1.0 \end{bmatrix}$$



Simulation Setup

- Population size: N = 100;
- Iterated communications: C = 2000 (20 communications per agent);
- No social constraints: all communications are between randomly chosen agents;

- The urn model:
  - Only two types of variants: *V*=2;
  - Three conditions:
    - Congruent condition: $Z = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$ $P = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$
    - Incongruent condition: $Z = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$ $P = \begin{bmatrix} 2 \\ 1 \end{bmatrix}$
    - Neutral condition: $Z = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$ $P = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$

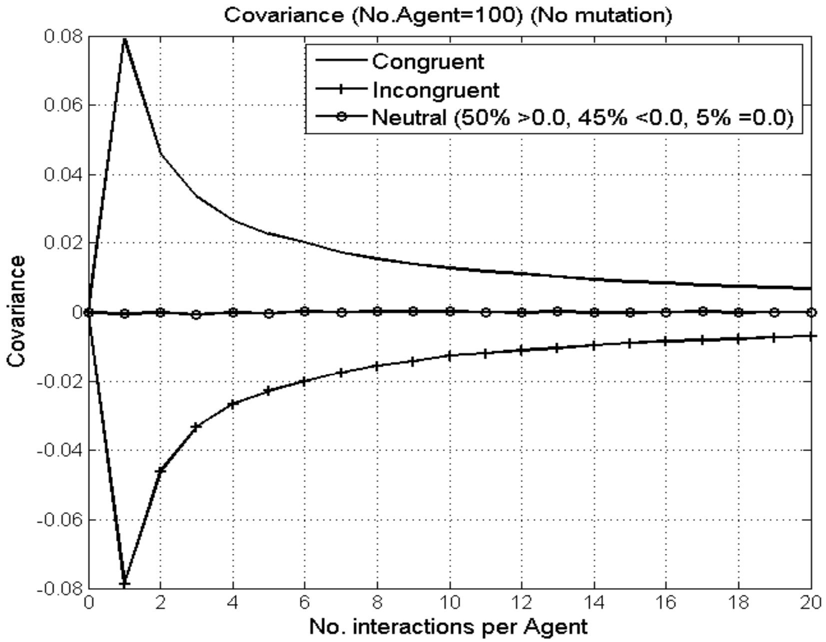
    - Without mutation and with mutation (mutation rate = 0.01);

      $M = \begin{bmatrix} 1.0 & 0.0 \\ 0.0 & 1.0 \end{bmatrix}$ $M = \begin{bmatrix} 0.99 & 0.01 \\ 0.01 & 0.99 \end{bmatrix}$

- 1000 simulations in each condition for analysis;

Simulation results

$$\Delta z = \boxed{Cov((w_i / w, z)} + E((w_i / w)\Delta z_i)$$

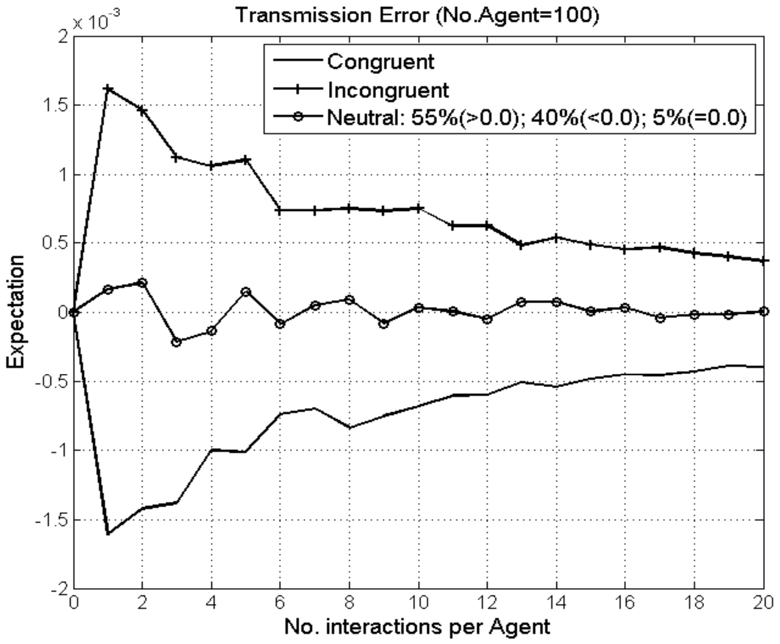


Covariance without mutation

- Covariance:
  - Selective pressures in the congruent and incongruent conditions, but not in the neutral condition;
  - The selective pressure of the variant prestige;

Simulation results

$$\Delta z = Cov((w_i / w, z) + \boxed{E((w_i / w)\Delta z_i)}$$

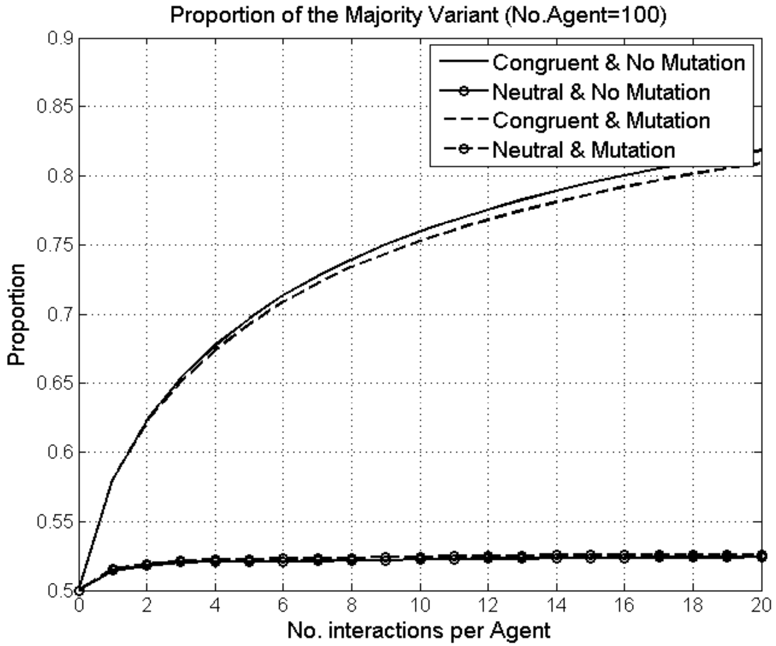


Expectation with mutation

- Expectation:
  - Transmission error reduces the selective pressure of the prestige;
  - Due to low mutation rate, this effect is much smaller than that of the prestige;

Simulation results

$$prop = \max_i(sum(v_i) / \sum_i sum(v_i))$$

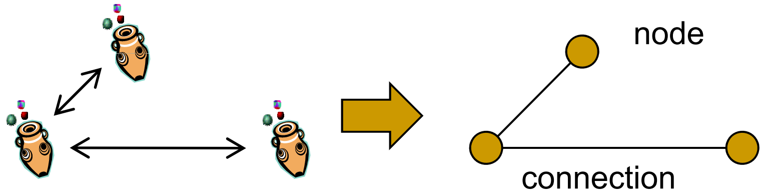


Proportion of the majority variant type

- Different majority variant types in the congruent and incongruent conditions;
- Proportion of the majority variant type confirms:
  - The selective pressure of the variant prestige;
  - Transmission error reduces the selective pressure of the prestige;

Social constraints on language change

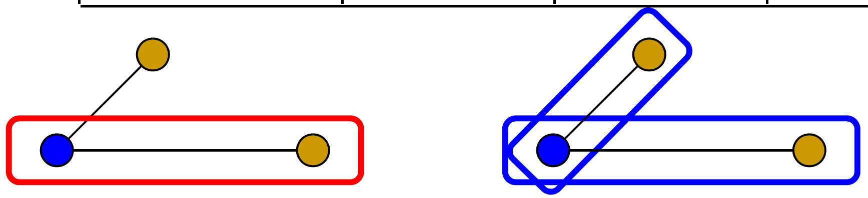
- Approach: Agents as nodes and communications as connections among nodes;



- Simulation setup
  - N = 100;
  - C = 2000;
  - Six types of simple networks:

Network type	Avg. degree (connection)	Clustering coefficient	Avg. shortest path length
fully-connected	99	1.0	1
neighbor	2	0.0	25.25
2D lattice	4	0.5	12.88
small-world	4	0.17	3.79
scale-free	7.80	0.18	2.36
star	1.98	0.0	1.98

  - Two types of simulations
    - 1-to-1 set;
    - 1-to-many set;



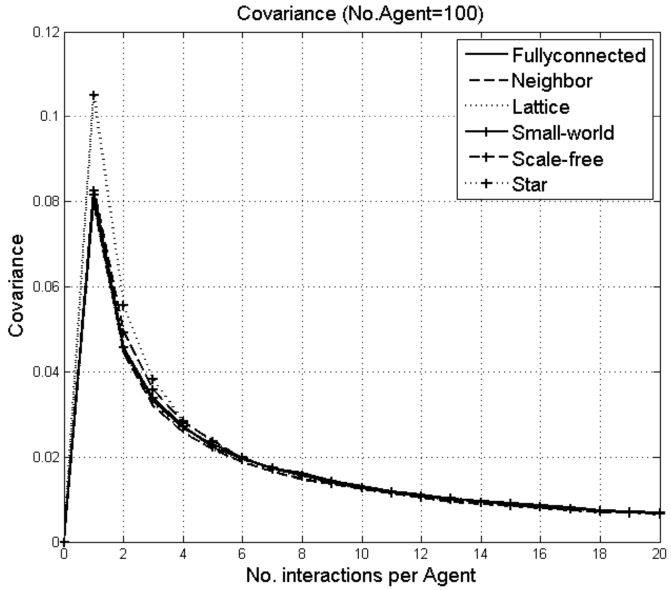
  - The congruent and neutral conditions without mutation;

$$Z = \begin{bmatrix}1\\2\end{bmatrix} F = \begin{bmatrix}1\\2\end{bmatrix} \qquad Z = \begin{bmatrix}1\\2\end{bmatrix} F = \begin{bmatrix}1\\1\end{bmatrix} \qquad M = \begin{bmatrix}1.0 & 0.0\\0.0 & 1.0\end{bmatrix}$$

  - 1000 simulations in each condition;

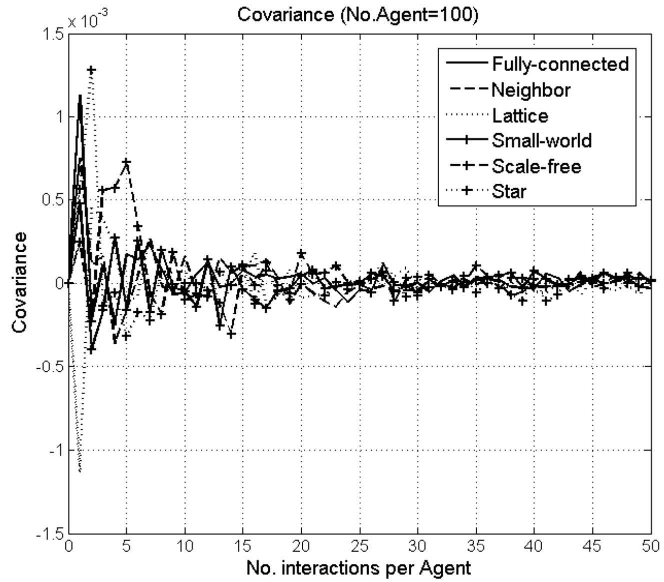
Simulation Results

Covariance in the congruent condition



1-to-1 set

Covariance in the neutral condition



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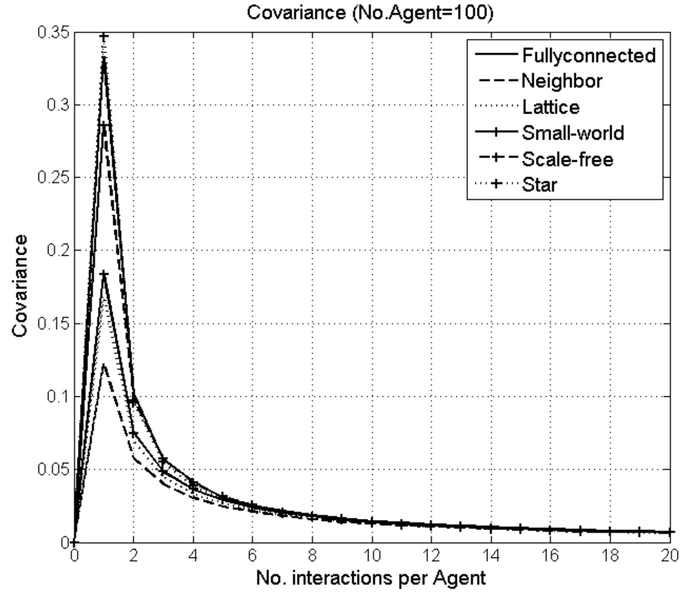
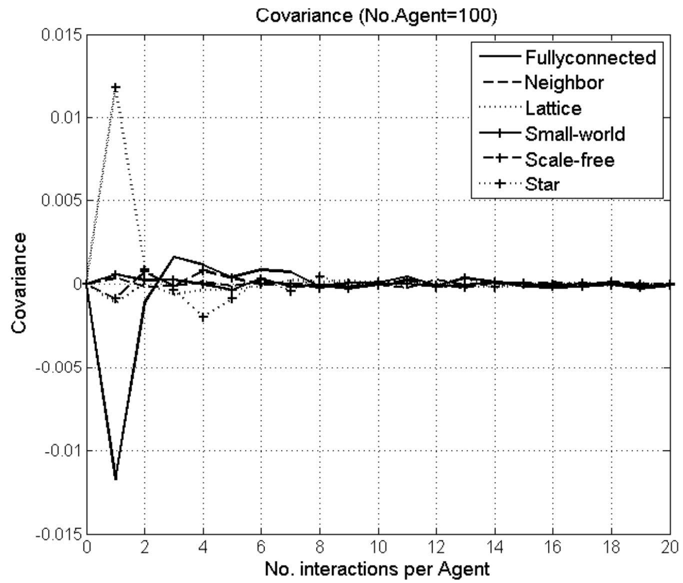
Simulation Results

Covariance in the congruent condition



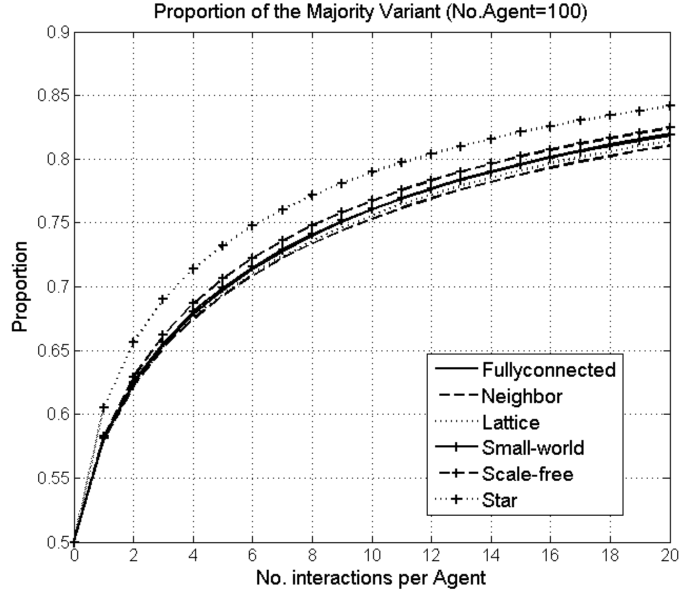
1-to-many set

Covariance in the neutral condition



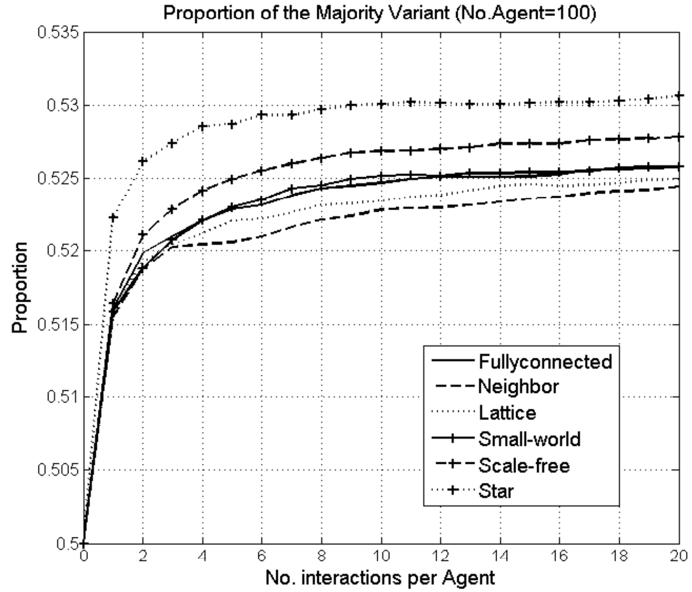
Simulation Results

Proportion in the congruent condition



1-to-1 set

Proportion in the neutral condition



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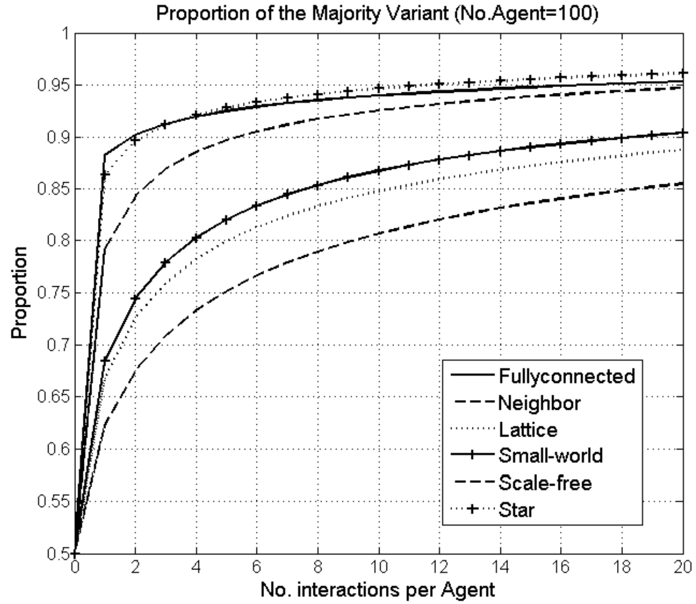
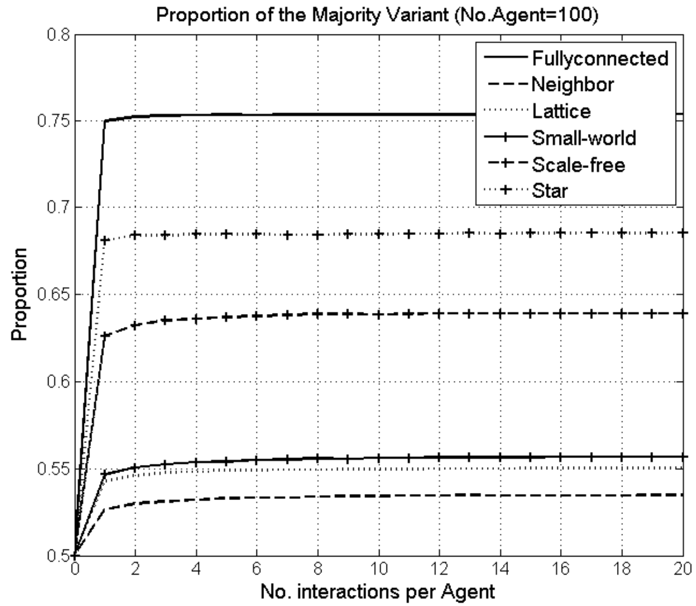
Simulation Results

Proportion in the congruent condition



1-to-many set

Proportion in the neutral condition



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Effects of social constraints

Fully-connected > Star > Scale-free >> Small-world > Lattice >> Neighbor

Network type	Avg. degree (connection)	Clustering coefficient	Avg. shortest path length
fully-connected	99	1.0	1
neighbor	2	0.0	25.25
2D lattice	4	0.5	12.88
small-world	4	0.17	3.79
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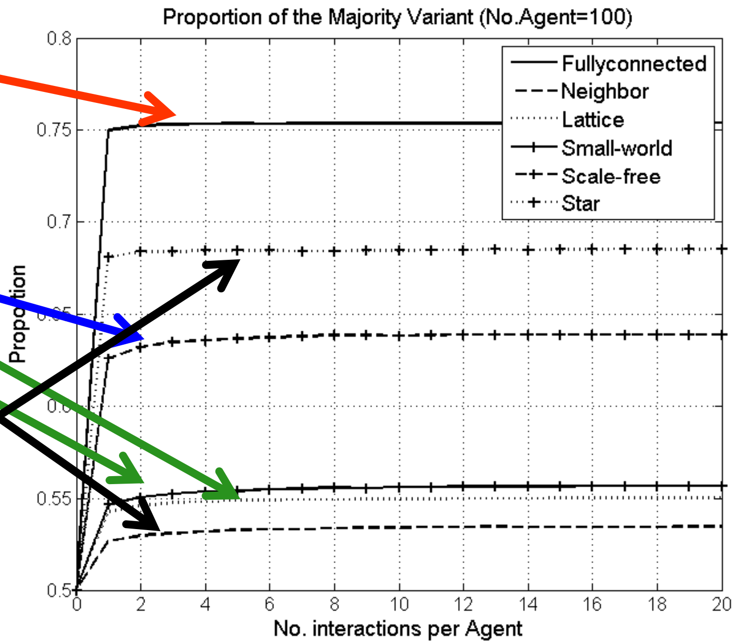
star	1.98	0.0	1.98

1-to-many set

Proportion in the neutral condition



- This social constraint is neutral to variant types;
- Two structural factors:
  - Average degree:
    - Fully-connected > Scale-free >> Small-world > Lattice>> Neighbor;
  - Level of centrality:
    - Star > Scale-free >> …

Effects of structural features

Fully-connected > Star > Scale-free >> Small-world > Lattice >> Neighbor

Network type	Avg. degree (connection)	Clustering coefficient	Avg. shortest path length
fully-connected	99	1.0	1
neighbor	2	0.0	25.25
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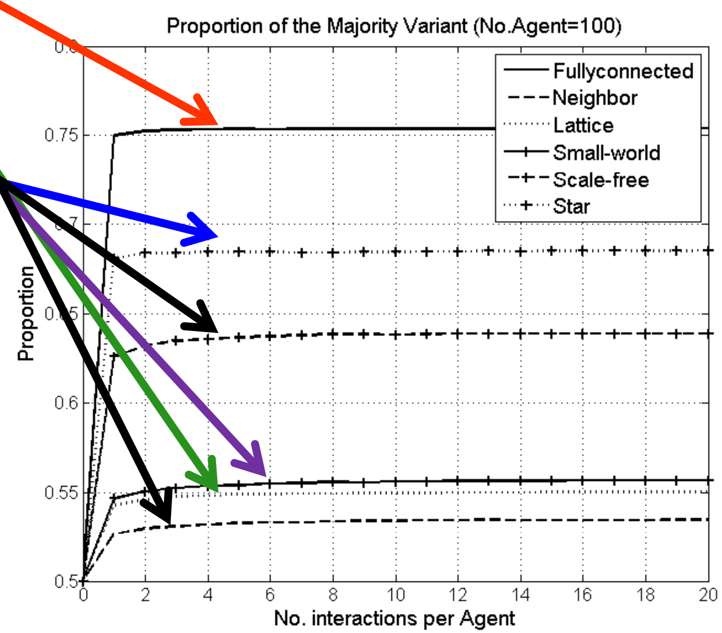
1-to-many set

Proportion in the neutral condition



- Avg. shortest path length unifies the effects of average degree and level of centrality:
  - With the increase in the avg. shortest path length, the proportion values will drop.

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Discussions & Conclusions

- We adopt a simple method to study language change;
  - Pólya urn: general information transmission framework;
  - Price equation: not specific for biological evolution;
  - There is no particular linguistic functions involved;

- The selective pressures:
  - Price equation: $\Delta z = Cov((w_i / w, z) + E((w_i / w)\Delta z_i)$
  - Factors affecting the type frequency of variants can exert a selective pressure on diffusion.
    - Social prestige directly adjust the type frequency;
    - Social constraints indirectly adjust the type frequency;
  - Social prestige can be independent of variant feature;
    - The example of Cantonese pronouns change;

- Neutral amplification role of social constraints:
  - Instead of linguistic reasons, some linguistic diffusion may be due to the structural factors;
  - Language-external factors are influential to language change, especially at the population level;

- Future work:
  - Individual prestige; Coevolution of prestige and feature; Learning bias (mutation);

- Gong, T. and Tamariz, M. Identifying the selective pressures on language change. Communications in Computational Physics. submitted.

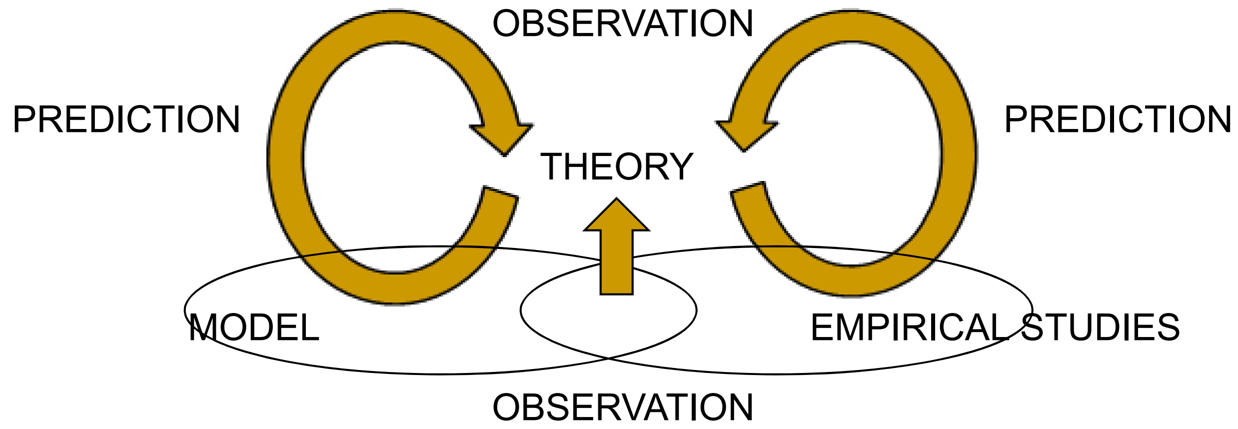
Computational Simulation revisited

- A general procedure of computational simulation;
  - Abstract the linguistic problems into computational model;
  - Analyze the simulation results;
  - Reconsider the incorporated theories;
- Other linguistic questions that can be studied by computational simulations:
  - In general linguistics / theoretical linguistics:
    - Lexicon-syntax Coevolution (Gong, 2009);
    - Word order bias (Gong et al., 2009);
  - In cognitive sciences / psycholinguistics:
    - Color categorization (Baronchelli et al., 2010);
    - Coevolution of shared intentionality and language (Gong, submitted);
  - In social sciences / sociolinguistics:
    - Cultural transmission (Gong, in press);
    - Social networks (Ke et al., 2009);

- Gong, T. 2009. *Computational simulation in evolutionary linguistics*. Taipei: Institute of Linguistics, Academia Sinica.
- Gong, T., Minett, J. W., & Wang, W. S-Y. 2009. A simulation study on word order bias. Inter. Stu., 10(1): 51–76.
- Baronchelli, A., Gong, T., Puglisi, A., & Loreto, V. 2010. Modeling the emergence of universality in color naming patterns. PNAS, Published online: Jan. 25, 2010.
- Gong, T. submitted. Displacement and shared intentionality during language evolution. Cog. Sci.
- Gong, T. under revision. Exploring the roles of horizontal, vertical, and oblique transmissions in language evolution. Adap. Beha.
- Ke, J-Y., Gong, T., & Wang, W. S-Y. 2008. Language change and social networks. Com. in Comp. Phys., 3(4): 935–949.

Final words:

simulation, empirical study and theory



multi-disciplinary nature of linguistic research