On Protolanguage Language
An Evolutionary Approach

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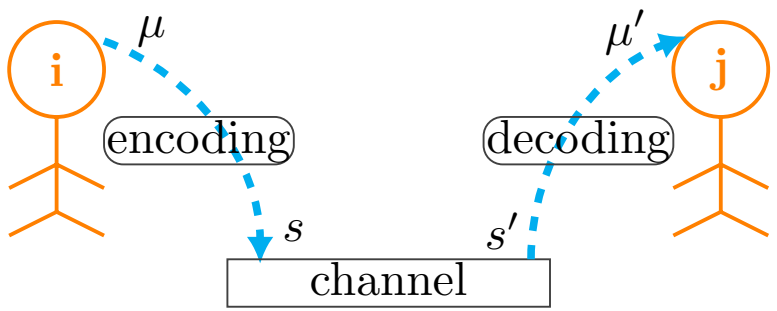
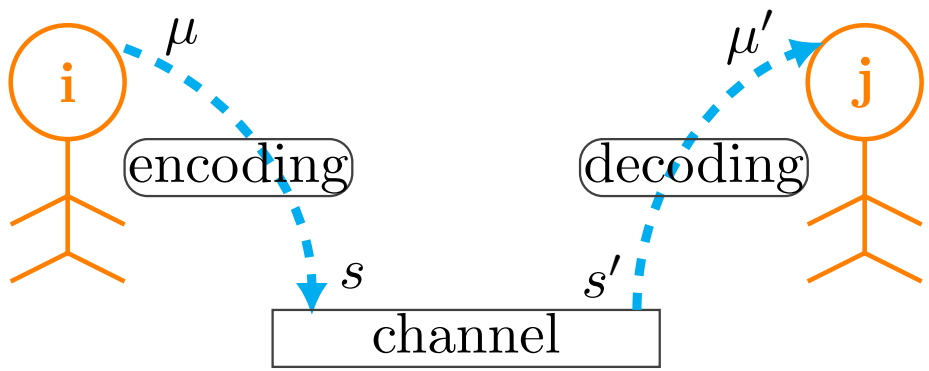
II. Karmaşık Sistemler ve Veri Bilimi Çalıştayı
Bogazici University, 2019-05-04

Content



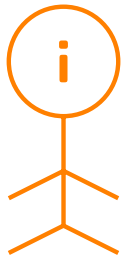
Protolanguage

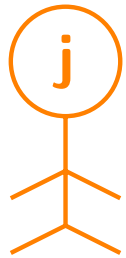


[Hurford, 1989, Nowak and Krakauer, 1999, Nowak et al., 1999]

Protolanguage

Goal: Agent *i* wants to transfer a meaning to agent *j*





Protolanguage

Goal: Agent i wants to transfer a meaning to agent j

- i thinks of a meaning μ

Protolanguage

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- i thinks of a meaning μ
- i encodes μ to symbol s

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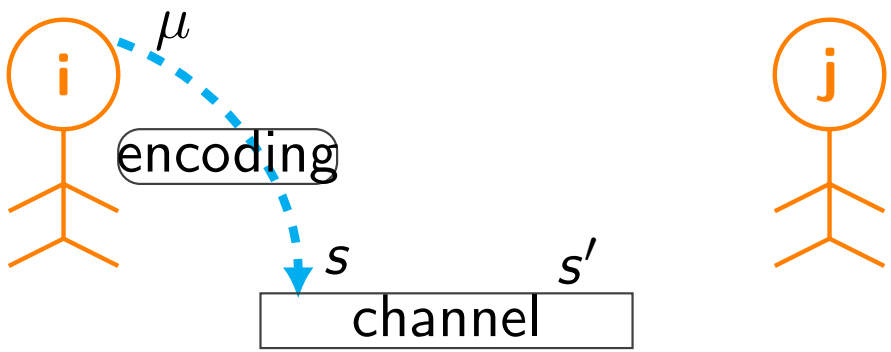
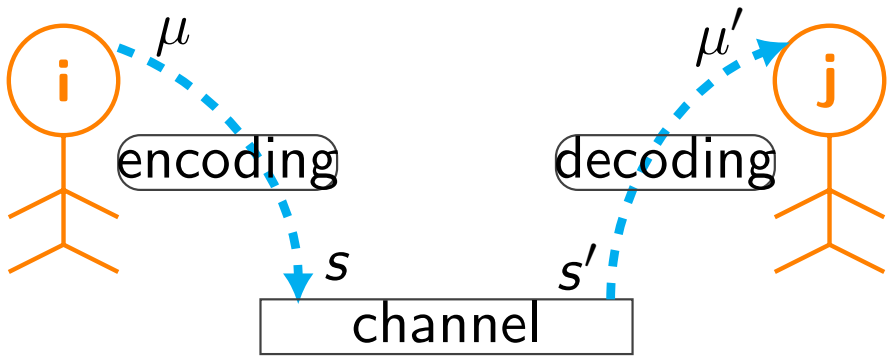
- channel carries over;
  due to noise s becomes s'



Protolanguage

Goal: Agent i wants to transfer a meaning to agent j

- i thinks of a meaning μ
- i encodes μ to symbol s
- channel carries over;
  due to noise s becomes s'
- j decodes s' as meaning μ'



Just communication. No grammer!

[Hurford, 1989, Nowak and Krakauer, 1999, Nowak et al., 1999]

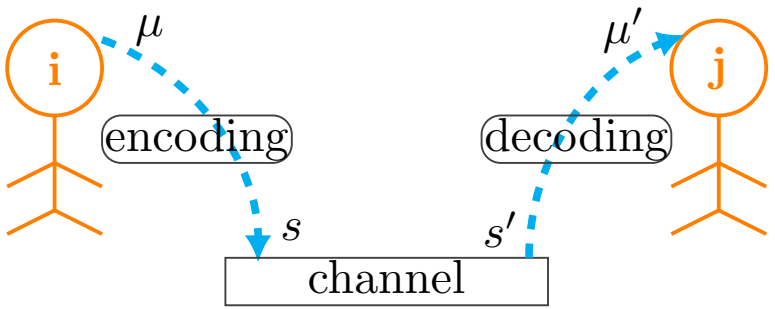
Definitions

Sets

- set of agents
  $\mathcal{P} \triangleq \{1, \cdots, i, j, \cdots, M\}$
- set of meanings of i
  $\mathcal{M}^{(i)} \triangleq \{1, \cdots, \mu, \cdots, M\}$
- set of symbols
  $\mathcal{S}^{(i)} \triangleq \{1, \cdots, s, \cdots, S\}$

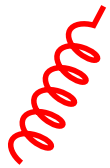
Questions

- $\mathcal{M}^{(i)} \stackrel{?}{=} \mathcal{M}^{(j)}$
- $\mathcal{S}^{(i)} \stackrel{?}{=} \mathcal{S}^{(j)}$
- encoding?
- decoding?



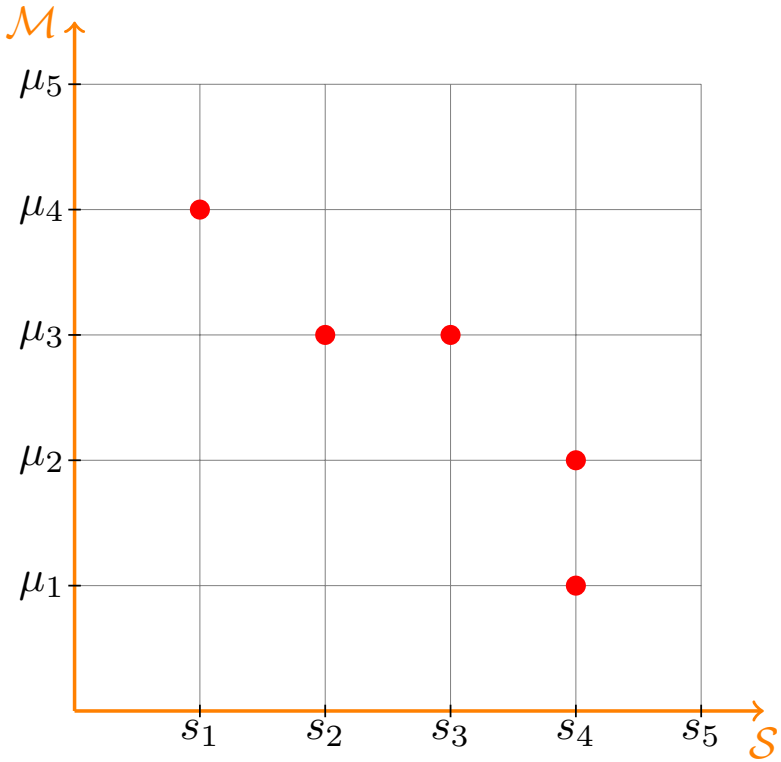
Naming

What is this?



- Learning
  - obtaining meaning-symbol associations

Meaning-symbol association



[Steels, 1995, Hurford, 1989, Nowak and Krakauer, 1999, Nowak et al., 1999]

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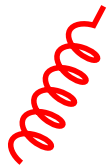
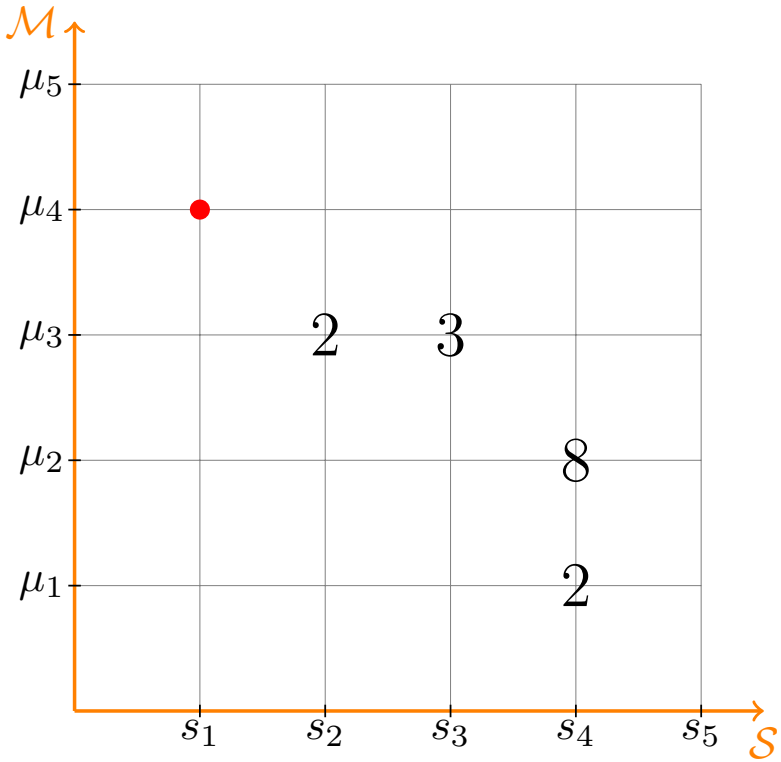
What is this? 

- encoding
  $\text{Prob}\{\mu_6 \to s_1\} = 1$
  $\text{Prob}\{\mu_5 \to s_2\} = 2/5$
- decoding
  $\text{Prob}\{s_1 \to \mu_6\} = 1$
  $\text{Prob}\{s_7 \to \mu_2\} = 8/10$

Questions

- Symbol for μ_5?
- Meaning for s_5?

Meaning-symbol association



[Steels, 1995, Hurford, 1989, Nowak and Krakauer, 1999, Nowak et al., 1999]

Model

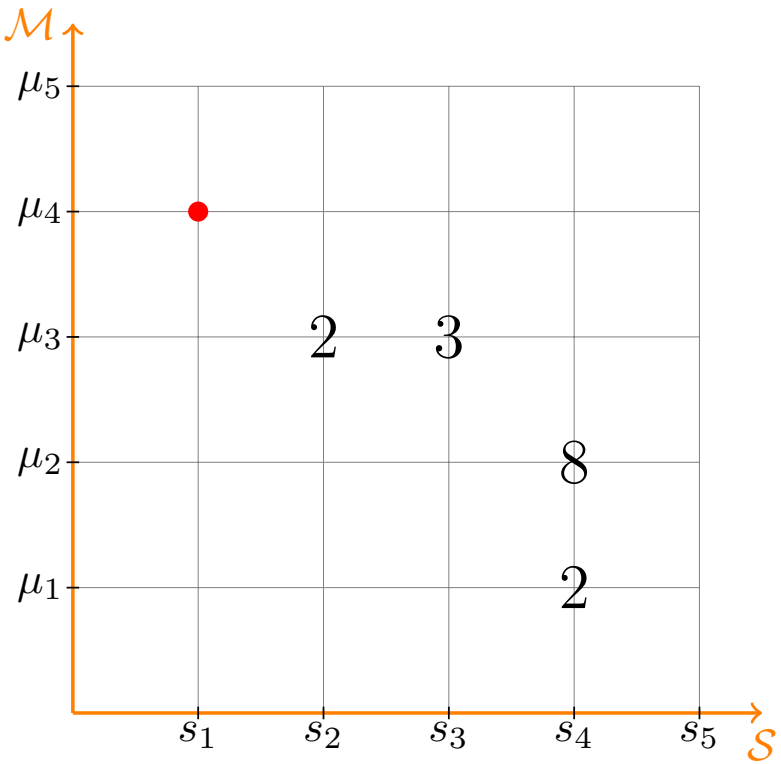
- $\mathbf{A} = [a_{\mu s}]$: association matrix
  - $a_{\mu s} \triangleq$ frequency of $\mu \to s$
- $\mathbf{E} = [e_{\mu s}]$: encryption matrix

$$e_{\mu s} \triangleq \text{Prob}\{\mu \to s\} \triangleq \frac{a_{\mu s}}{\sum_{s'=1}^{S} a_{\mu s'}}$$

- $\mathbf{D} = [d_{\mu s}]$: decryption matrix

$$d_{\mu s} \triangleq \text{Prob}\{s \to \mu\} \triangleq \frac{a_{\mu s}}{\sum_{\mu'=1}^{M} a_{\mu' s}}$$

Meaning-symbol association

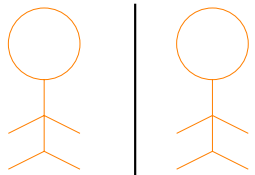


[Steels, 1995, Hurford, 1989, Nowak and Krakauer, 1999, Nowak et al., 1999]

Model

2-person language

- 2 different association matrices
- successfully communicating μ
  $\text{Prob}\{\mu \to \mu\} \triangleq \sum_{s=1}^{S} e_{\mu s}^{(i)} d_{s\mu}^{(j)}$
- (average) comprehension
  from i to j
  $F(i \to j) \triangleq \frac{1}{M} \sum_{\mu=1}^{M} \sum_{s=1}^{S} e_{\mu s}^{(i)} d_{s\mu}^{(j)}$
- (average) mutual comprehension
  from i to j
  $F(i \leftrightarrow j) \triangleq \frac{1}{2}(F(i \to j) + F(j \to i))$



agent	i	j
language	$L^{(i)}$	$L^{(j)}$
association	$\mathbf{A}^{(i)}$	$\mathbf{A}^{(j)}$
encoding	$\mathbf{E}^{(i)}$	$\mathbf{E}^{(j)}$
decoding	$\mathbf{D}^{(i)}$	$\mathbf{D}^{(j)}$

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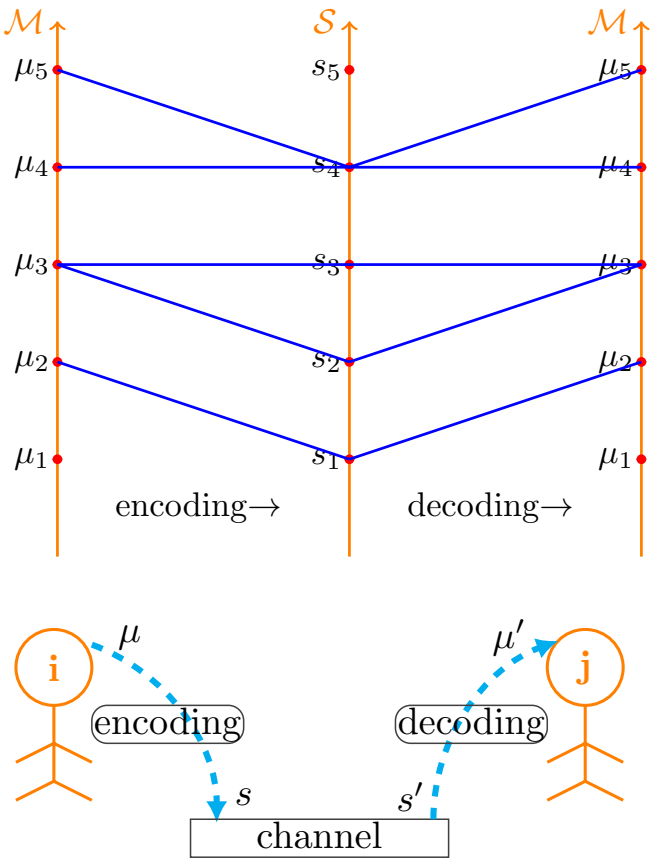

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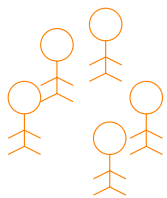
N-person language

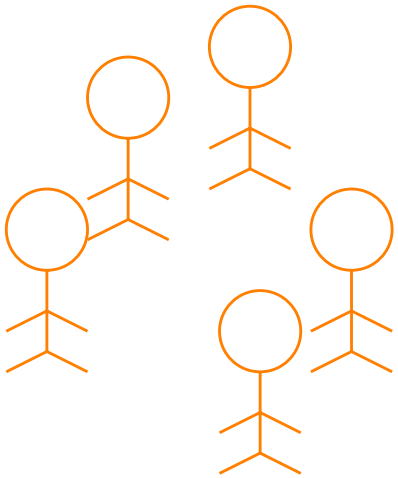
- N different association matrices
- $\binom{N}{2}$ mutual comprehensions
- within community comprehension for $\mathcal{C} \subseteq \mathcal{P}$
  $W(\mathcal{C}) \triangleq \frac{1}{2\binom{|\mathcal{C}|}{2}} \sum_{i \in \mathcal{C}} \sum_{\substack{j \in \mathcal{C} \\ j \neq i}} F(i \leftrightarrow j)$



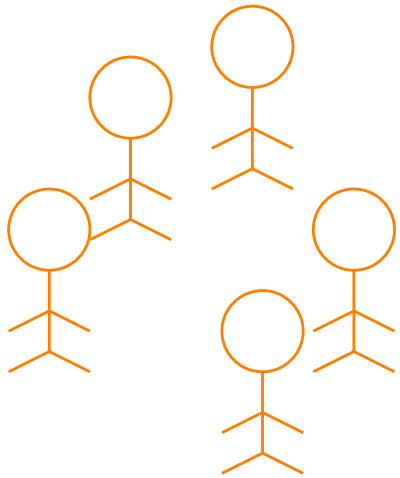
[Hurford, 1989, Nowak and Krakauer, 1999, Nowak et al., 1999]

Evolutionary Dynamics

Evolutionary Dynamics



Generation G_i



Generation G_{i+1}

fitness

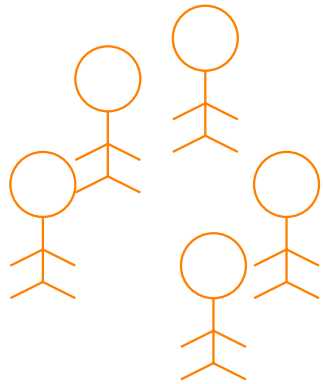
natural selection

reproduction

Fitness

Assumption

- Language ability increases fitness



"able to speak" should increase fitness:

fitness $\nearrow$ as

- language $\nearrow$
- mutual comprehensions $F(i \leftrightarrow j) \nearrow$
- within community comprehension $W(\mathcal{C}) \nearrow$

Learning

"Parent Oriented Teacher Selection Causes Language Diversity"
Journal of Theoretical Biology, 429, 2017

[Cimentepe and Bingol, 2017]

Teacher Selection

Assumptions

- Child learns language of parent p or someone "close" to parents
- Child learns from single teacher t

Language-wise close (Model-A)

- Select R agents language-wise closest to parent p

Physically close (Model-B)

- Select R agents physically closest to parent p
- Use 1D ring lattice for physical distance

- This R-set is called the imitation set $\mathcal{L}_p$ of p. Select ℓ as t among R with probability

$$\frac{F(p \leftrightarrow \ell)}{\sum_{j \in \mathcal{L}_p} F(p \leftrightarrow \ell)}$$

Child Learns from Teacher

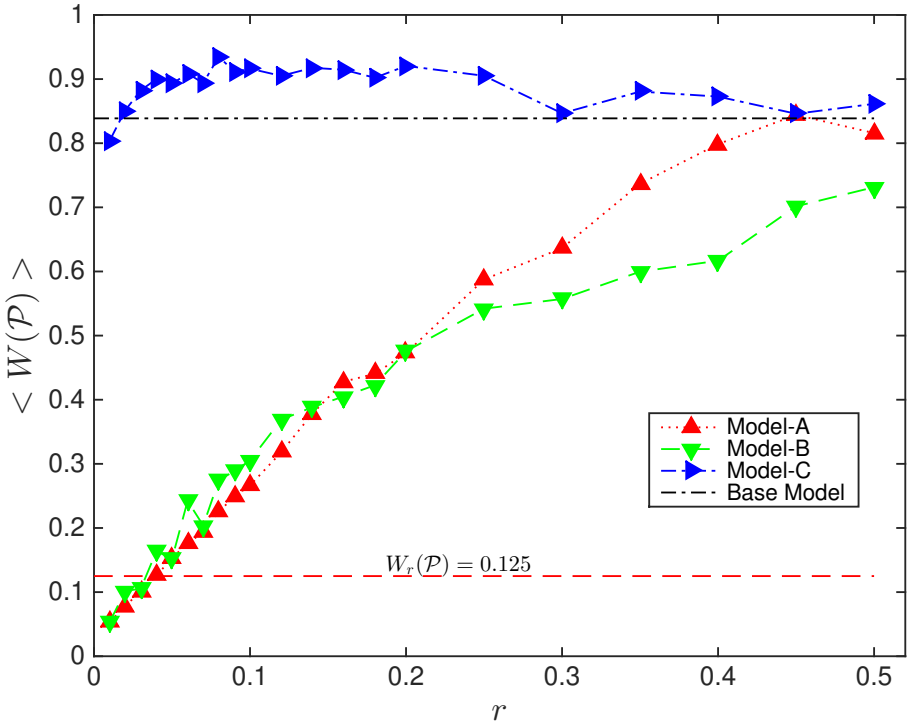
- Initially child has an empty association matrix **A**
- Child learns by means of sampling
  - Child asks Q questions for each meaning μ
  - Teacher answers symbols s
  - Child populates her association matrix entry $a_{\mu s}$

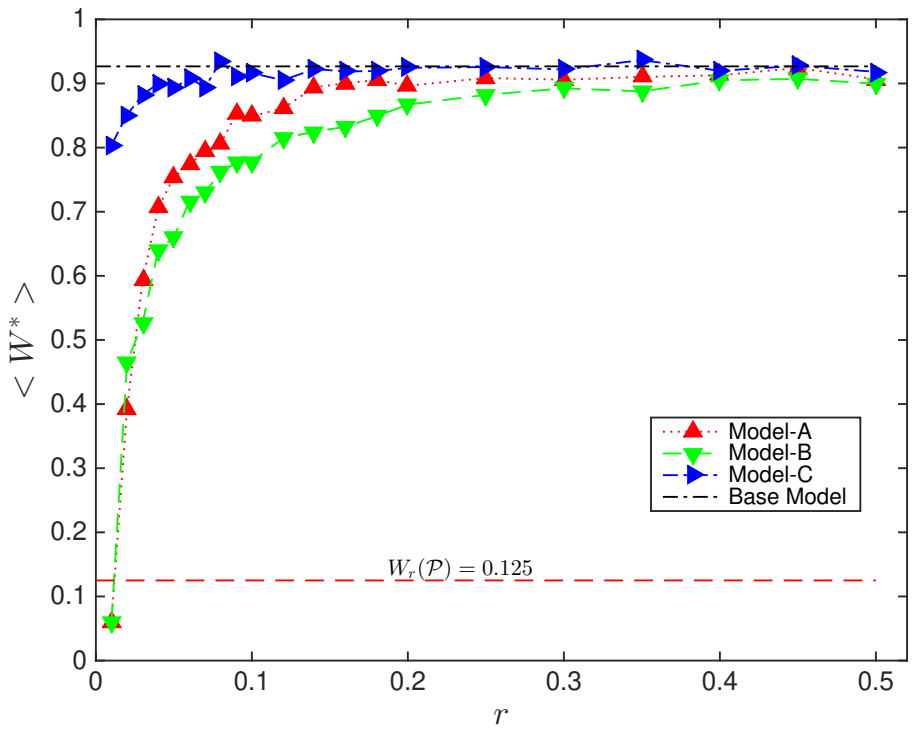
Findings

Teacher selection causes language diversification

[Cimentepe and Bingol, 2017]

No Global Language





Overall comprehension $W(\mathcal{P})$ is not good

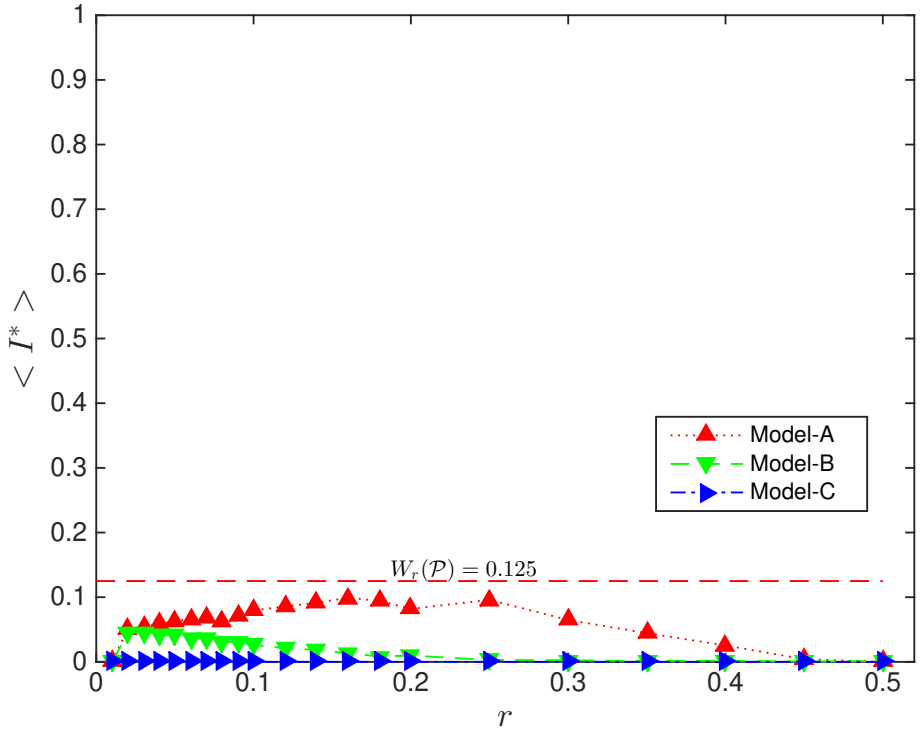
- No single language

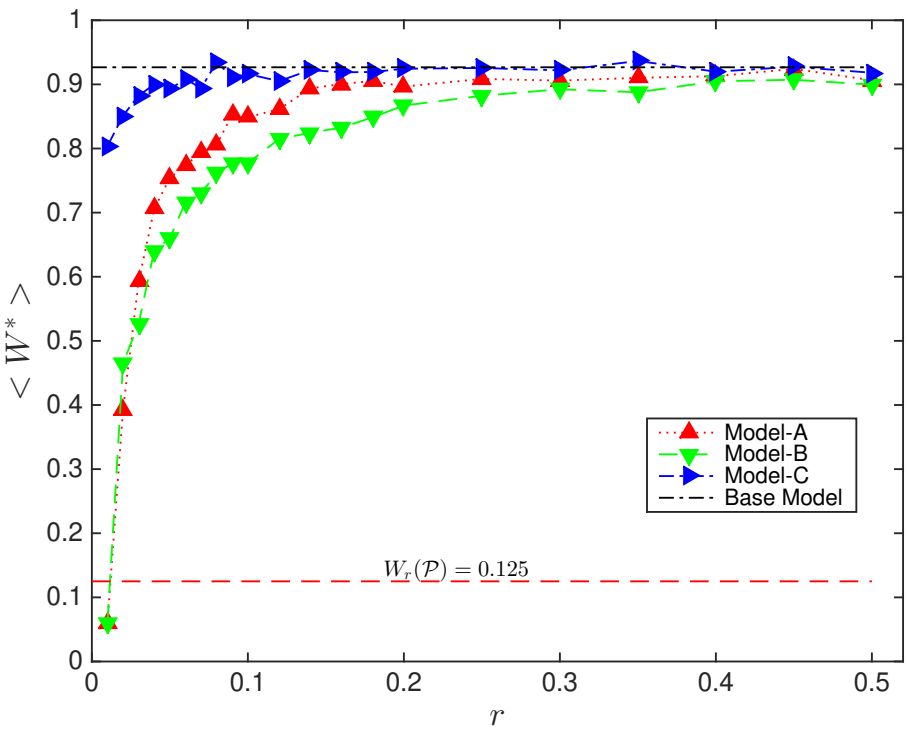
Within-community comprehension $< W^* >$ is good

- "Dialects" in communities

Inter-community Comprehension

High within-community, low inter-community comprehension





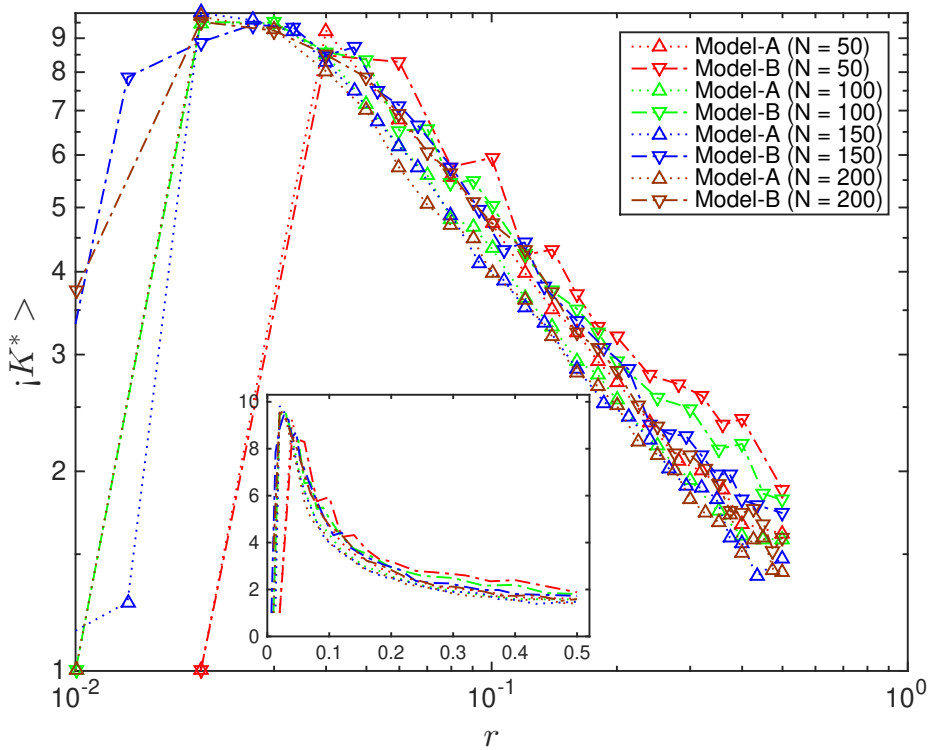
Inter-community Comprehensions $< I^* >$ is low

- It should be low

Within-community comprehension $< W^* >$ is good

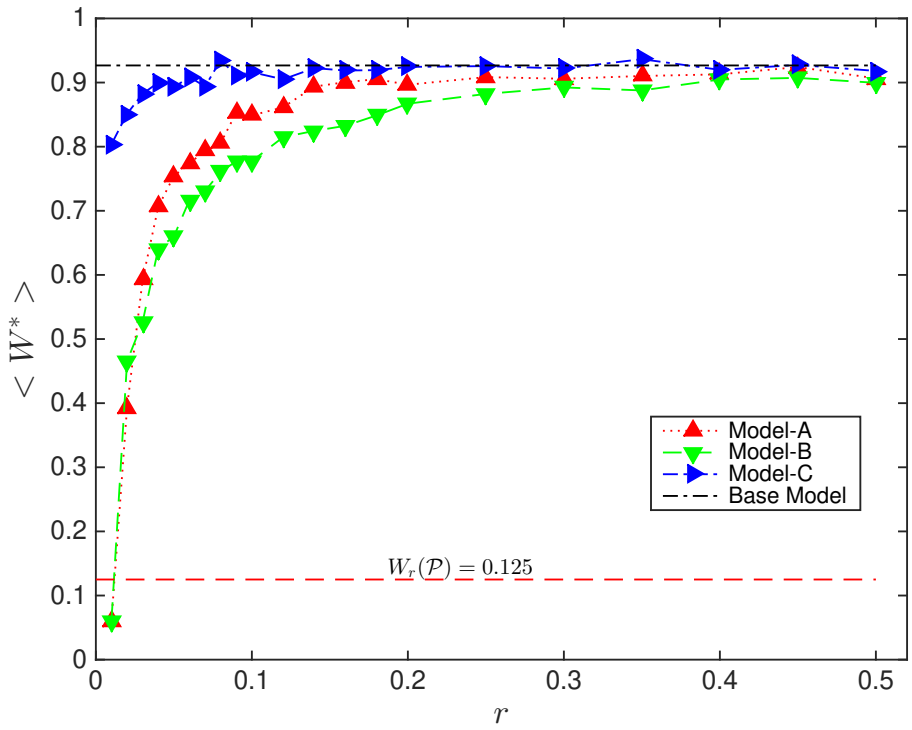
- "Dialects" in communities

Many Local Languages



Number of communities $< K^* >$

- Many language communities



Within-community comprehension $< W^* >$ is good

- "Dialects" in communities

Finding Optimum Language Clusters

(Details)

- K-partition of $\mathcal{P}$
  $\mathbb{P}_K = \{\mathcal{C}_1, \mathcal{C}_2, \cdots, \mathcal{C}_K\}$
- Average within-community comprehension
  $W(\mathbb{P}_K) = \frac{1}{K} \sum_{\alpha=1}^{K} W\mathcal{C}_\alpha$

Using k-means clustering

- Partition with the maximum average within-community comprehension
  $\overline{\mathbb{P}_K} = \arg\max_K W(\mathbb{P}_K)$.
- Optimum K
  $K^* = \arg\max_K W(\mathbb{P}_K)$
- Optimum within-community comprehension
  $W^* = W(\overline{\mathbb{P}_K})$

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source: https://github.com/halukbingol/presentationLanguage.git