Agent-based modeling:

Agents with a complex cognitive architecture
(A tutorial)

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Network Theory and Computer Modeling in the Study of Religion
September 1, 2016

Sentential negation (Jespersen's cycle)

	pre-verbal	discontinuous	post-verbal
French	Jeo ne dis	Je ne dis pas	Je dis pas
English	Ic ne secge	Ic ne seye not	I say not
	1. *SN V*	2. *SN V SN*	3. *V SN*

To explain:

- Typology: pre-verbal, discontinuous, post-verbal,
- ... as well as mixed types.
- Diachronic change (a.k.a. language evolution).

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Sentential negation (Jespersen's cycle)

Research questions:

- Why does this language change happen?
- What drives change?
  "Performance errors" as a driving force behind language change?

Methodology:

- Multi-agent simulations

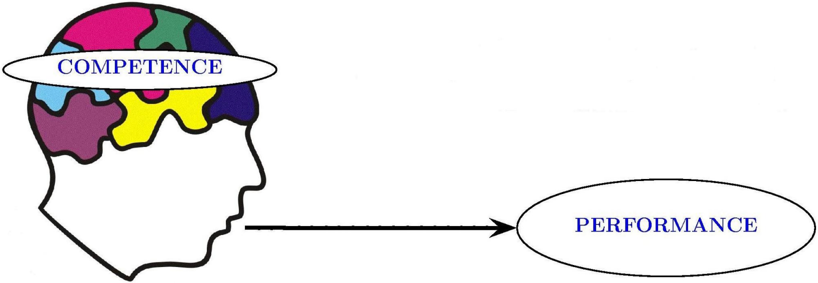
Reference

- A. Lopopolo and T. Biró. 'Language Evolution and SA-OT: The case of sentential negation'. *Computational Linguistics in the Netherlands Journal* 1(2011):21–40.

Learning (what CSR misses from CogSci)

- **Learning:** the algorithm behind / modeling acquisition. A central topic in linguistics and cognitive science, but missing in CSR. See also *machine learning*.

Errors of the mental computation



static knowledge processes in the brain

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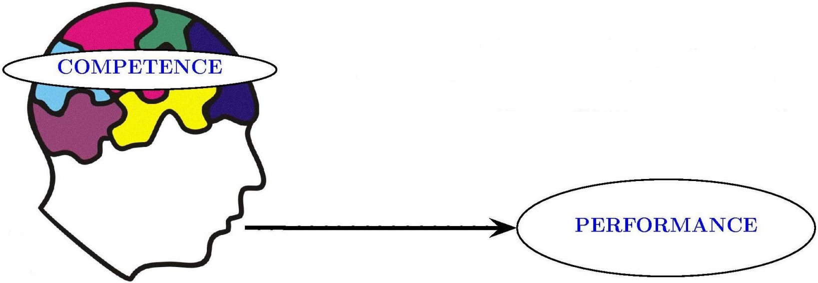

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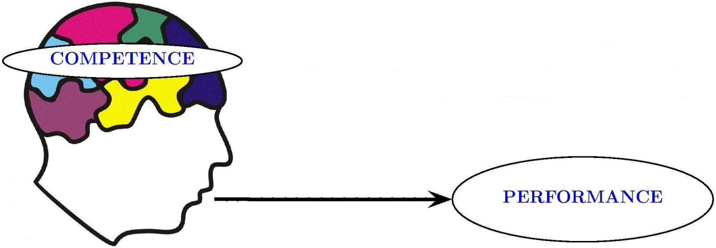
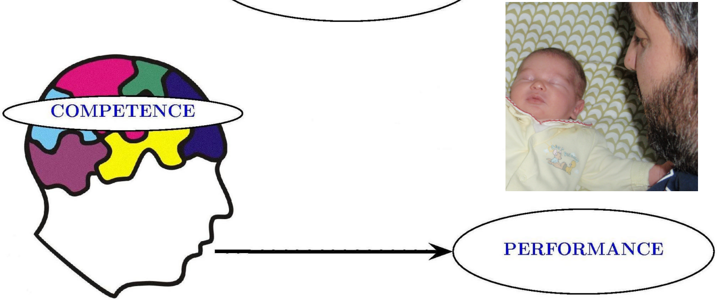
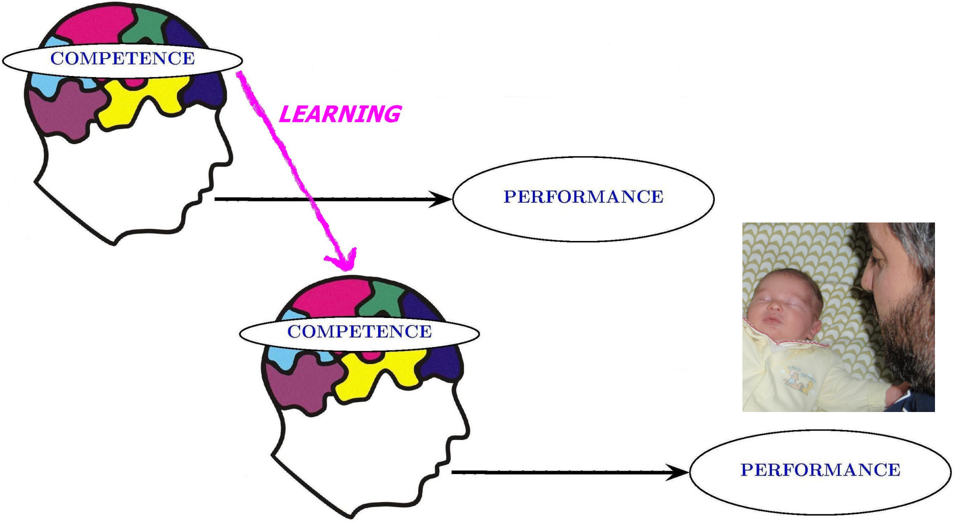
The language acquisition problem

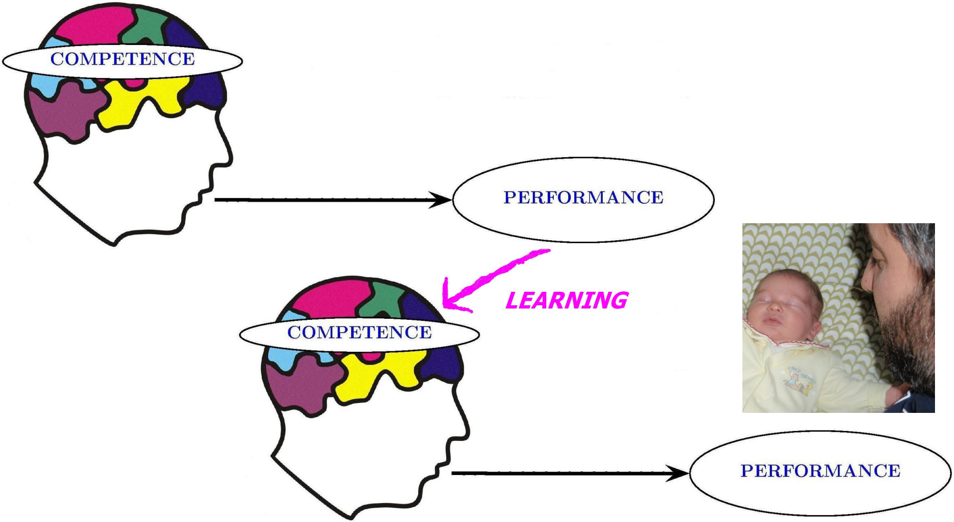




Learning from competence?



Learning from performance!



The *Iterative Learning Model*

- **Learning:** the algorithm behind / modeling acquisition.
  A central topic in linguistics and cognitive science,
  but missing in CSR. See also *machine learning*.
- **Iterative learning:**

  Gen-0 ⟶ *Gen-1* ⟶ *Gen-2* ⟶ *Gen-3* ⟶

- Simon Kirby at al.: language evolution (in biological evolution's timescale). "Learning bottleneck" creates linguistic structure.
- Others: language change (in historical timescale).
  Assumption: language change takes place from generation to generation, due to imperfect acquisition. (Only partly true.)

(Possible) components of the model

Who learns from whom?

- N agents in **one generation.**
- **Series of generations:** language produced by agents in Generation k used as learning data by agents in Gen. $k+1$.

Generation k: a1 a2 a3 a4

Generation $k+1$: b1 b2 b3 b4

- Note the strict intergenerational structure: no learning from grandparents, elder siblings or peers.
- Social structure? More learning data from parents? Learning data with more weight from people with prestige?

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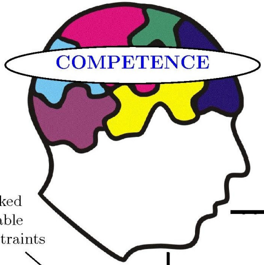
(Possible) components of the model

Who learns at all?

An agent composed of:

- **Knowledge**: a.k.a. competence, grammar, etc.
  Here: Optimality Theory (Prince and Smolensky 1993/2006)
- **Production**: a.k.a. performance, etc.
  Here: Simulated Annealing for Optimality Theory (Biró 2006)
- **Learning**: a.k.a. acquisition, etc.
  Here: online learning algorithms for Optimality Theory (Boersma and Hayes 2001; Magri 2012)

Errors of the mental computation



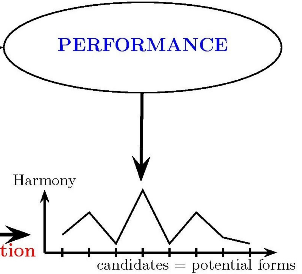
A grammar is a Harmony function on the candidate set, defined by the ranked constraints.
Global optimum: more harmonic than all other candidates.
Local optimum: more harmonic than its neighbours.

Ranked violable constraints

Candidates (potential forms)

/aat/	NoCoda	Parse	Onset
☞ [a.a<t>]		*	**
[a.at]	*!		**
[<a>at]	*!	*	*

implementation



Optimality Theory
grammar
competence model
grammatical form = ☞ (globally) optimal candidate

SA-OT
implementation
performance model
produced forms = globally or locally optimal candidates

Sentential negation: Jespersen's cycle

Generation 1:

- Competence: grammatical form is [SN V].
  Grammar: *NEGATION ≫ NEGATIONFIRST ≫ NEGATIONLAST
- Performance: 100% [SN V].

Generation 2 learning from performance pattern of Generation 1:

- Competence: grammatical form is [SN V].
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- Performance: 90% [SN V], and 10% [SN [V SN]].

Generation 3 learning from performance pattern of Generation 2. Etc.

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1. Has the learning been successful?
   1. grammaticality judgement; 2. grammar; 3. performance pattern.
2. A way to model diachronic change?
3. Learner hears "SN V SN": is it [[SN V] SN] or [SN [V SN]]?

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Modelling linguistic competence

FAITH[NEG] $\gg$ *NEGATION $\gg$ NEGATIONFIRST $\gg$ NEGATIONLAST

	/pol = neg/	Faith[Neg]	*Neg	NegFirst	NegLast
	[V]	*		*	*
☞	[SN V]		*		*
	[V SN]		*	*	
	[SN V SN]		**		
	[V SN SN]		**	*	
	[SN SN V]		**		*
	[SN V SN SN]		***		
	...				

Lopopolo and Biró (2011), based on Henriëtte de Swart (2010).

Modelling linguistic competence

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	/pol = neg/	Faith[Neg]	NegFirst	*Neg	NegLast
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	[V SN]		*	*	
	[SN V SN]			**	
	[V SN SN]		*	**	
	[SN SN V]			**	*
	[SN V SN SN]			***	
	...				

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Global optimum: more harmonic than all other candidates.
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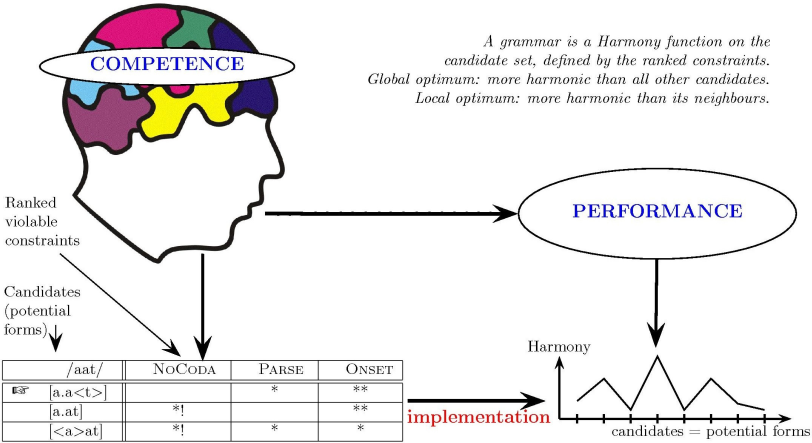

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Optimality Theory
grammar
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grammatical form = ☞ (globally) optimal candidate

SA-OT
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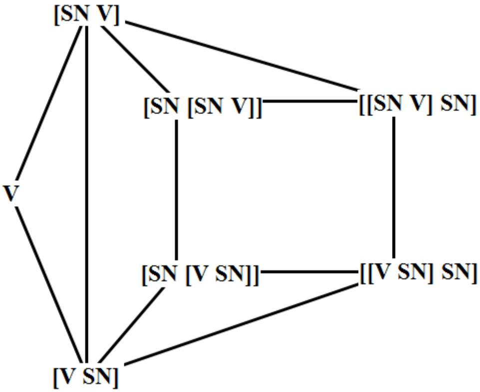
produced forms = globally or locally optimal candidates

Modelling linguistic performance

A topology (neighborhood structure) on the candidate set:



Locally optimal forms: are predicted to be the produced forms.

Modelling linguistic performance

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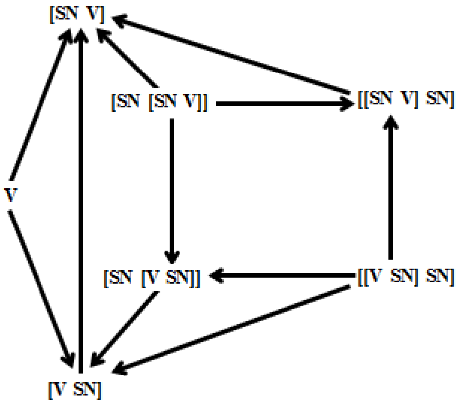

Hierarchy 1: *Neg >> NegFirst >> NegLast

Locally optimal forms: ☞ [SN V].

Modelling linguistic performance

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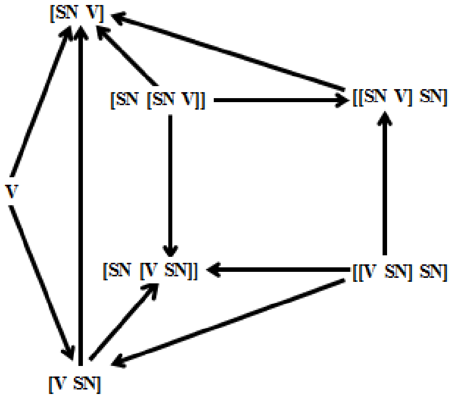

Hierarchy 2: NegFirst >> *Neg >> NegLast

Locally optimal forms: ☞ [SN V] and $\sim$ [SN [V SN]].

	Hierarchy	competence	performance
1.	*Neg $\gg$ NegFirst $\gg$ NegLast	pre-verbal	pre-verbal
2.	NegFirst $\gg$ *Neg $\gg$ NegLast	pre-verbal	pre-V and discont.
3.	NegFirst $\gg$ NegLast $\gg$ *Neg	discontinuous	discontinuous
4.	NegLast $\gg$ NegFirst $\gg$ *Neg	discontinuous	discontinuous
5.	NegLast $\gg$ *Neg $\gg$ NegFirst	post-verbal	discont. and post-V
6.	*Neg $\gg$ NegLast $\gg$ NegFirst	post-verbal	post-verbal

Observerd typology: 3 pure types and 2 mixed types.
Predicted typology:

- Traditional OT (H. de Swart): 3 pure types.
- Stochastic OT (H. de Swart): 3 pure types and 3 mixed types.
- SA-OT (Lopopolo and Biró): 3 pure types and 2 mixed types.

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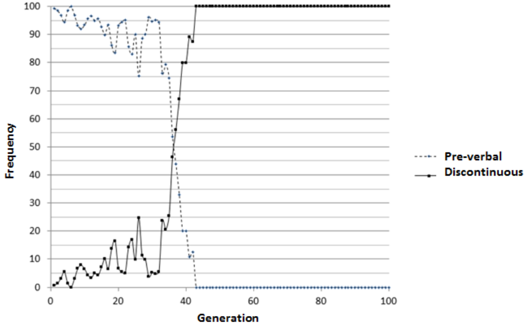
Iterated learning: reproducing language change (?)

Five agents in each generation. Generations 0 to 100.
Each agent learns from every agent in the previous generation.
Negation types in the “simulated historical corpus”:



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Conclusions

What is the question / interest:

- **Proceed from the phenomenon:** explaining Jespersen's cycle.
- **Proceed from theory:** role of *errors* $=$ results of imperfect mental computation in language change.
- **Proceed from framework:** the behavior of a certain theoretical, computational, mathematical framework.

Conclusions

Model:

- Agents $\rightarrow$ (un)structured population $\rightarrow$ generation.
- Agents $\rightarrow$ knowledge (competence), production (performance) and learning (acquisition).
- Iterative learning model

Practicalities

Practicalities:

- Developed in own software *OTKit* (`http://www.birot.hu/OTKit/`).
- The more complex a model: the more parameters.
- The convincing force of a complex, still abstract and oversimplified computational model?

Thank you for your attention!

Tamás Biró:

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OT KIT

Tools for Optimality Theory

`http://www.birot.hu/OTKit/`

Work supported by:

MARIE CURIE ACTIONS

Amsterdam Center for Language and Communication ACLC

NWO Netherlands Organisation for Scientific Research