Being stressed by stress

Competence, performance and learning of metrical stress in Optimality Theory

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How to observe stress pattern in (Dutch) fast speech?

Quiz item:

Q4	*President Bush is een typische*	'President Bush is a typical'
A1	*intellectueel*	'intellectual'
A2	*amerikaan*	'American'
A3	*taalkundige*	'linguist'

Maartje Schreuder and Dicky Gilbers (2004). 'The Influence of Speech Rate on Rhythm Patterns'. In: *On the Boundaries of Phonology and Phonetics*. Groningen.

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Forms and frequencies observed by Schreuder and Gilbers:

fo.to.toe.stel 'camera'	*uit.ge.ve.rij* 'publisher'	*stu.die.toe.la.ge* 'study grant'	*per.fec.tio.nist* 'perfectionist'
susu	ssus	susuu	usus
fó.to.tòe.stel fast: slow:	*ùit.gè.ve.ríj* fast: **0.67** slow: **0.96**	*stú.die.tòe.la.ge* fast: **0.38** slow: **0.81**	*per.fèc.tio.níst* fast: **0.13** slow: **0.20**
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shift to right	beat reduction	shift to right	shift to left

Stressing questions

- Account for stress patterns within some linguistic framework.
- Account for changing patterns: normal *vs.* fast speech.
  - Account for fast speech forms. Account for their frequencies.
  - Both forms present. Different word types have different frequencies.
  - Gradual change between 'normal' and 'fast'.
- Account for language acquisition:
  - Despite difficulties caused by framework (*viz.* feet).
  - (Despite difficulties caused by speech errors.)
- (Account for language change: iterated learning.)

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Overview

1. Optimality Theory: competence
2. Simulated Annealing for Optimality Theory: performance
3. Learning in Optimality Theory: problems
4. Conclusions

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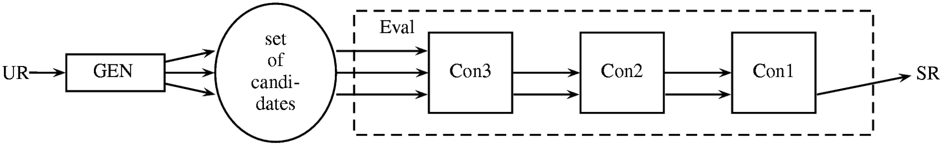
Traditional Optimality Theory

- Underlying form $\mapsto$ a set of candidates (potential surface forms).
- Constraints: elementary functions defined on the candidate set.
- Grammatical form predicted by this grammar:
  candidate that violates the highest ranked constraints the least.
- Serial evaluation approach:



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Grammar = constraint hierarchy

- Optimality Theory is a P&P-style model of competence.
- Constraints are universal "principles".
- Constraint ranking is language-dependent "parameter".

Traditional Optimality Theory

Prosodic phonology:

$$\Big[_{\mathrm{IP}}\ \Big[_{\mathrm{Wd}}\ \sigma\ [\grave{\sigma}\sigma]\ [\grave{\sigma}]\ \sigma\ [\sigma\acute{\sigma}]\ \Big]\ \Big]$$

- Intonational Phrase $\rightarrow$ Prosodic Word $\rightarrow$ Foot $\rightarrow$ Syllable $\rightarrow$ ...
- Stressed syllable: head (‘strong’) syllable of a word.
- Main stress: head syllable of head (‘strong’) foot.

Traditional Optimality Theory

Proposal of Schreuder and Gilbers:

Andante speech:

/*foto+toestel*/	OUTPUT-OUTPUT CORRESPONDENCE	FOOT REPULSION	PARSE SYLLABLE
☞ (fóto)(tòestel)		*	
(fóto)toe(s̀tel)	*!		*

NB: Further output forms in the language: *fóto* and *tóestel*.

Traditional Optimality Theory

Proposal of Schreuder and Gilbers:

Allegro speech:

/*foto+toestel*/	FOOT REPULSION	OUTPUT-OUTPUT CORRESPONDENCE	PARSE SYLLABLE
(fóto)(tòestel)	*!		
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Traditional Optimality Theory

Grammar = constraint hierarchy

- Different grammar for fast speech.
  Hence, different competence in fast speech?
- How to account for both forms produced?
  - frequencies depending on speech rate, and
  - frequencies depending on word.

Constraint re-ranking

- Ad hoc re-ranking, motivated by analogy in music.
- Principled framework: Boersma's *Stochastic Optimality Theory*.

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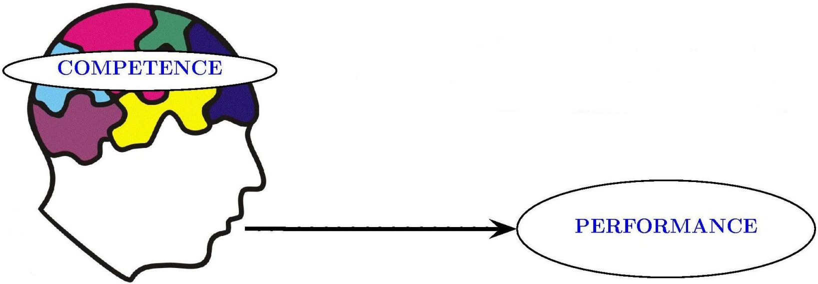
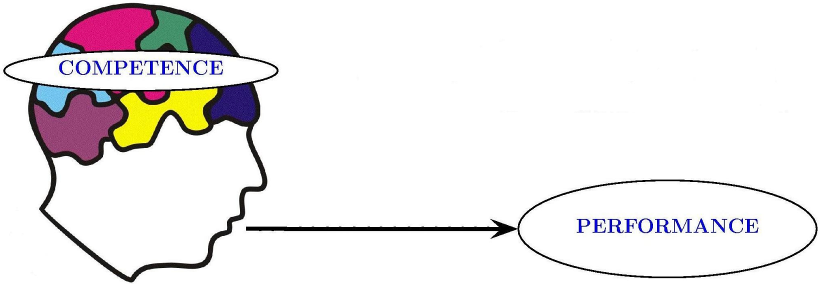
Errors of the mental computation



static knowledge | processing in the brain
Optimality Theory | Simulated Annealing for OT

Errors of the mental computation



static knowledge processing in the brain

Optimality Theory Simulated Annealing for OT

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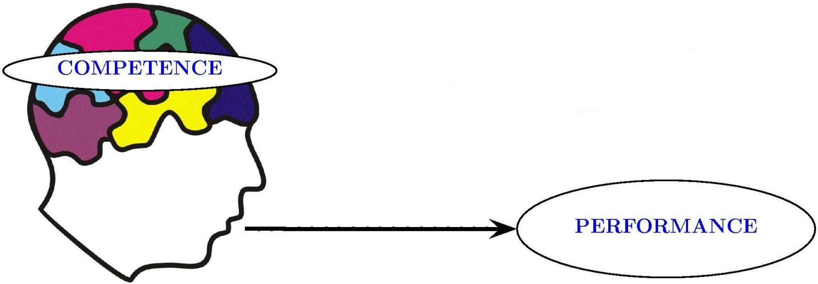
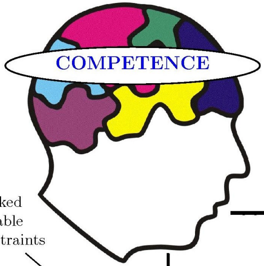


static knowledge — processing in the brain

Optimality Theory — Simulated Annealing for OT

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.

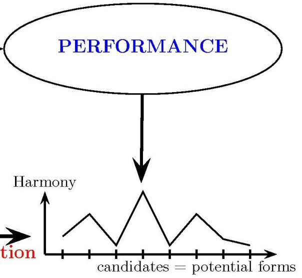


Ranked violable constraints

Candidates (potential forms)

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

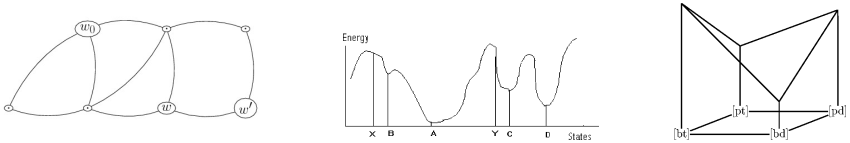
implementation



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

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

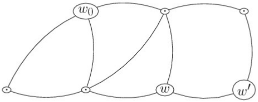
Basic idea of Simulated Annealing

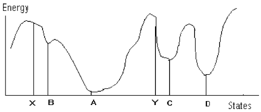


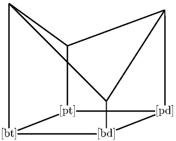
Step 1 – introducing landscape:

- Horizontal: universal *neighbourhood structure* (a.k.a. *topology*) on the universal candidate set.
- Vertical: grammar-dependent harmony (violation profile of the constraints).
- Random walk in this landscape.

Basic idea of Simulated Annealing



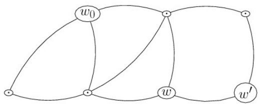


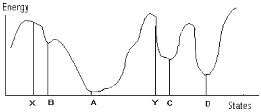


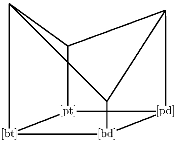
Step 2 – walking in this landscape:

- Pick a random neighbour of your position.
- If neighbour is more optimal: move.
- If less optimal: move in the beginning, don't move later.
  (Exponential expression applied to vector-valued target function.)

Basic idea of Simulated Annealing



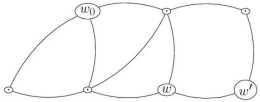


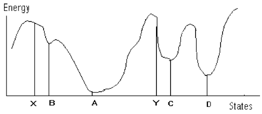


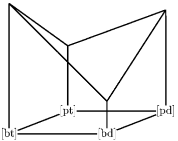
Step 3 – performing a random walk on this landscape:

- Start random walk from some initial position.
- End position returned as output of the algorithm: produced form.
- Hopefully, global optimum (grammatical form) is found. Yet...
- Neighbourhood structure → local optima, where random walker can get stuck. Performance errors.

Basic idea of Simulated Annealing







Step 4 – Precision of the algorithm

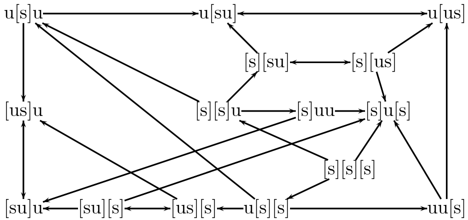
- **Precision** of the algorithm: chance of ending up in global optimum, and hence returning grammatical form.
- Precision of the algorithm depends on its speed.
- Trade precision for speed – just like human mind!

Basic idea of Simulated Annealing

Level	its product	its model	the product in the model
Competence in narrow sense: static knowledge of the language	grammatical form	standard OT grammar	globally optimal candidate
Dynamic language production process	acceptable or attested forms	SA-OT algorithm	local optima
Performance in its outmost sense	acoustic signal, etc.	(phonetics, pragmatics)	??

How to predict stress pattern in (Dutch) fast speech?

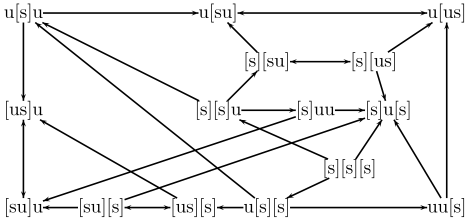
Landscape:



Basic steps that connect neighbours:

- Move foot boundary: [s] ⇔ [su]; [s] ⇔ [us].
- Change head of foot: [su] ⇔ [us].
- Insert/delete monosyllabic foot: [s] ⇔ u

How to predict stress pattern in (Dutch) fast speech?



Hierarchy:

ALIGN-LEFT $\gg$ $\text{OOC}_{z=2}$ $\gg$ FOOTREPULSION $\gg$ PARSESYLL $\gg$ TROCHAIC

- Global optimum: [s]u[su].
- Local optima: [s]u[su] and [su]u[s].
- Local optimum [su]u[s] has less harmonic neighbours: [su]uu, [su][s][s], [us]u[s], [s]uu[s], [su][us].

How to predict stress pattern in (Dutch) fast speech?

Local optimum [su]u[s] has less harmonic neighbours:
[su]uu, [su][s][s], [us]u[s], [s]uu[s], [su][us].

/fototoestel/	ALIGN-LEFT	$\text{OOC}_{z=2}$	FTREPULS	PARSES	TROCHAIC
∼ [su]u[s]	0	2	0	1	0
[su]uu	0	3	0	2	0
[su][s][s]	0	3	2	0	0
[us]u[s]	0	4	0	1	1
[s]uu[s]	0	2	0	2	0
[su][us]	0	2	1	0	1

How to predict stress pattern in (Dutch) fast speech?

`http://www.birot.hu/sa-ot/`

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Simulated / **observed** (Schreuder) frequencies.

In the simulations, $T_{step} = 3$ used for fast speech and $T_{step} = 0.1$ for slow speech.

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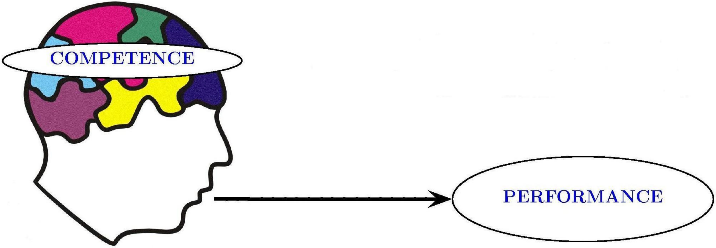
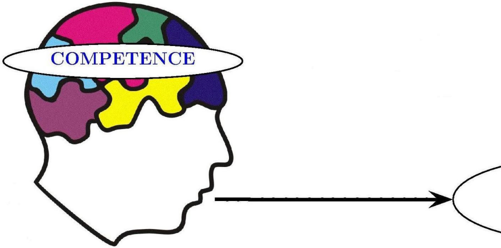
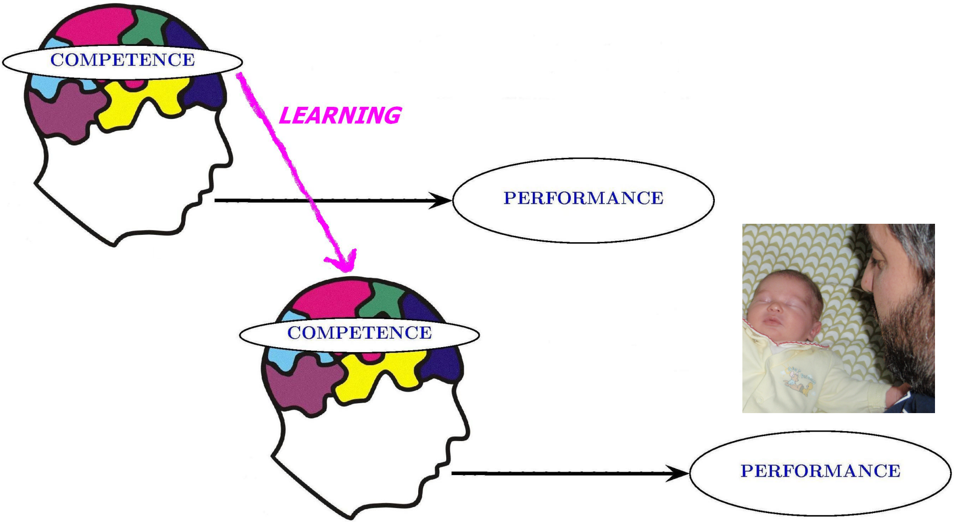
The language acquisition problem

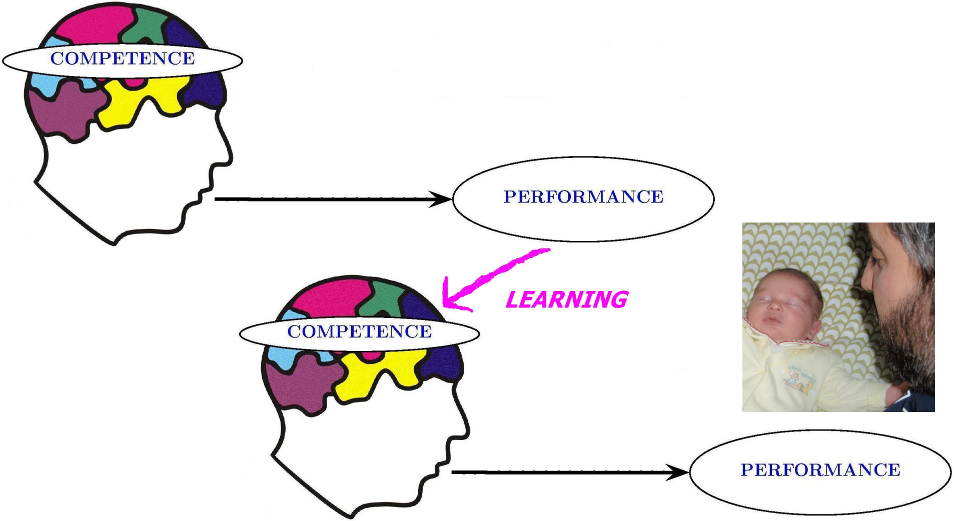




Learning from competence?



Learning from performance!



Learning in Optimality Theory

General idea:

- Speaker-teacher wants to say *underlying form* uf.
- Speaker-teacher's grammar produces *surface form* sf.
- Listener-learner hears *surface form* sf = *winner form* w.
- Listener-learner's grammar would produce uf as *loser form* l.
- Listener-learner updates her grammar,
  in order to produce w, and not l:

  Winner-preferring constraints are promoted and loser-preferring constraints are demoted in hierarchy hypothesized by the learner.

Learning hidden structures (e.g., metrical feet)

But foot boundaries are not pronounced:

- Speaker-teacher wants to say: *ab.ra.ka.dab.ra* (underlying form).
- Speaker-teacher's grammar produces:
  [àb.ra].ka.[dáb.ra] (surface form).
- Speaker-teacher utters: *àb.ra.ka.dáb.ra* (overt form).
- Listener-learner hears: *àb.ra.ka.dáb.ra* (overt form).
- Listener-learner hesitates:
  what is the grammatical surface form in the target languages?

[àb].ra.ka.[dáb].ra, *[àb.ra].ka.[dáb].ra*
[àb].ra.[ka.dáb].ra, *[àb].ra.ka.[dáb.ra]*, etc.?

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Robust Interpretive Parsing (Tesar and Smolensky)

		/ab.ra.ka.dab.ra/	NonFinal	Trochaic	FootRepulsion
l	1.	*ab.ra.[ka.dáb].ra*		*	
w	2.	*[àb.ra].[ka.dáb].ra*		*	*
☞	3.	*[àb.ra].ka.[dáb.ra]*	*		

- Teacher: FootRepulsion ≫ Trochaic ≫ NonFinal, producing grammatical form ☞: *[àb.ra].ka.[dáb.ra]*.
- Learner: NonFinal ≫ Trochaic ≫ FootRepulsion, producing loser: *ab.ra.[ka.dáb].ra*.
- Learner hears *àb.ra.ka.dáb.ra*. Two possible candidates. The winner must have been, the best one, *[àb.ra].[ka.dáb].ra*.
- Compare w and l. Promote w-preferring constraints: none. Demote l-preferring constraints: FootRepulsion → deadlock!

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- Teacher: FOOTREPULSION ≫ TROCHAIC ≫ NONFINAL, producing grammatical form ☞: *[àb.ra].ka.[dáb.ra]*.
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- Learner hears *àb.ra.ka.dáb.ra*. Two possible candidates. The winner must have been, the best one, *[àb.ra].[ka.dáb].ra*.
- Compare w and l. Promote w-preferring constraints: none. Demote l-preferring constraints: FOOTREPULSION → deadlock!

Robust Interpretive Parsing (Tesar and Smolensky)

		/ab.ra.ka.dab.ra/	NonFinal	Trochaic	FootRepulsion
l	1.	*ab.ra.[ka.dáb].ra*		*	
w	2.	*[àb.ra].[ka.dáb].ra*		*	*
☞	3.	*[àb.ra].ka.[dáb.ra]*	*		

- Teacher: FootRepulsion ≫ Trochaic ≫ NonFinal, producing grammatical form ☞: *[àb.ra].ka.[dáb.ra]*.
- Learner: NonFinal ≫ Trochaic ≫ FootRepulsion, producing loser: *ab.ra.[ka.dáb].ra*.
- Learner hears *àb.ra.ka.dáb.ra*. Two possible candidates. The winner must have been, the best one, *[àb.ra].[ka.dáb].ra*.
- Compare w and l. Promote w-preferring constraints: none. Demote l-preferring constraints: FootRepulsion → deadlock!

Revised *Robust Interpretive Parsing* (Biró, under review)

		/ab.ra.ka.dab.ra/	NONFINAL	TROCHAIC	FOOTREPULSION
l	1.	*ab.ra.[ka.dáb].ra*		*	
	2.	*[àb.ra].[ka.dáb].ra*		*	*
☞	3.	*[àb.ra].ka.[dáb.ra]*	*		
w			0.5	0.5	0.5

- Teacher: FOOTREPULSION ≫ TROCHAIC ≫ NONFINAL, → ☞*[àb.ra].ka.[dáb.ra]*.
- Learner: NONFINAL ≫ TROCHAIC ≫ FOOTREPULSION, → l *ab.ra.[ka.dáb].ra*.
- Learner: w is either *[àb.ra].[ka.dáb].ra* or *[àb.ra].ka.[dáb.ra]*.
- Calculate (weighted) average, as *winner violation profile*. Compare it to loser. Promote w-preferring constraints: TROCHAIC. Demote l-preferring constraints: FOOTREPULSION and NONFINAL.
- → solution: TROCHAIC ≫ NONFINAL ≫ FOOTREPULSION. *Learner's new grammar different from, but equivalent to teacher's!*

Revised *Robust Interpretive Parsing* (Biró, under review)

/ab.ra.ka.dab.ra/			NONFINAL	TROCHAIC	FOOTREPULSION
l	1.	*ab.ra.[ka.dáb].ra*		*	
	2.	*[àb.ra].[ka.dáb].ra*		*	*
☞	3.	*[àb.ra].ka.[dáb.ra]*	*		
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- Learner: NONFINAL ≫ TROCHAIC ≫ FOOTREPULSION, → l *ab.ra.[ka.dáb].ra*.
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Revised *Robust Interpretive Parsing* (Biró, under review)

	/ab.ra.ka.dab.ra/	NonFinal	Trochaic	FootRepulsion
l 1.	*ab.ra.[ka.dáb].ra*		*	
2.	*[àb.ra].[ka.dáb].ra*		*	*
☞ 3.	*[àb.ra].ka.[dáb.ra]*	*		
w		0.5	0.5	0.5

- Teacher: FootRepulsion ≫ Trochaic ≫ NonFinal, → ☞*[àb.ra].ka.[dáb.ra]*.
- Learner: NonFinal ≫ Trochaic ≫ FootRepulsion, → l *ab.ra.[ka.dáb].ra*.
- Learner: w is either *[àb.ra].[ka.dáb].ra* or *[àb.ra].ka.[dáb.ra]*.
- Calculate (weighted) average, as *winner violation profile*.
  Compare it to loser. Promote w-preferring constraints: Trochaic.
  Demote l-preferring constraints: FootRepulsion and NonFinal.
- → solution: Trochaic ≫ NonFinal ≫ FootRepulsion.
  Learner's new grammar different from, but equivalent to teacher's!

Revised *Robust Interpretive Parsing* (Biró, under review)

	/ab.ra.ka.dab.ra/	NONFINAL	TROCHAIC	FOOTREPULSION
l	1. *ab.ra.[ka.dáb].ra*		*	
	2. *[àb.ra].[ka.dáb].ra*		*	*
☞	3. *[àb.ra].ka.[dáb.ra]*	*		
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- Learner: w is either *[àb.ra].[ka.dáb].ra* or *[àb.ra].ka.[dáb.ra]*.
- Calculate (weighted) average, as *winner violation profile*. Compare it to loser. Promote w-preferring constraints: TROCHAIC. Demote l-preferring constraints: FOOTREPULSION and NONFINAL.
- → solution: TROCHAIC ≫ NONFINAL ≫ FOOTREPULSION. *Learner's new grammar different from, but equivalent to teacher's!*

Revised *Robust Interpretive Parsing* (Biró, under review)

	/ab.ra.ka.dab.ra/	NonFinal	Trochaic	FootRepulsion
l 1.	*ab.ra.[ka.dáb].ra*		*	
2.	*[àb.ra].[ka.dáb].ra*		*	*
☞ 3.	*[àb.ra].ka.[dáb.ra]*	*		
w		0.5	0.5	0.5

- Teacher: FootRepulsion $\gg$ Trochaic $\gg$ NonFinal, $\rightarrow$ ☞ *[àb.ra].ka.[dáb.ra]*.
- Learner: NonFinal $\gg$ Trochaic $\gg$ FootRepulsion, $\rightarrow$ l *ab.ra.[ka.dáb].ra*.
- Learner: w is either *[àb.ra].[ka.dáb].ra* or *[àb.ra].ka.[dáb.ra]*.
- Calculate (weighted) average, as *winner violation profile*. Compare it to loser. Promote w-preferring constraints: Trochaic. Demote l-preferring constraints: FootRepulsion and NonFinal.
- $\rightarrow$ solution: Trochaic $\gg$ NonFinal $\gg$ FootRepulsion.
  Learner's new grammar different from, but equivalent to teacher's!

Revised *Robust Interpretive Parsing* (Biró, under review)

/ab.ra.ka.dab.ra/	NONFINAL	TROCHAIC	FOOTREPULSION
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2. *[àb.ra].[ka.dáb].ra*		*	*
☞ 3. *[àb.ra].ka.[dáb.ra]*	*		
w	0.5	0.5	0.5

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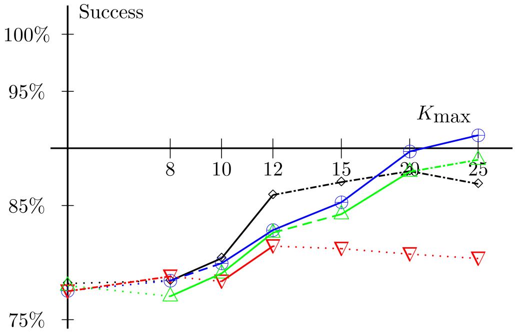
Revised *Robust Interpretive Parsing* (Biró, under review)



Success rate of learning a random target grammar, as a function of parameter K_{max}, for different update rules. Random initial grammar and random target grammar, with twelve constraints.

Overview

1. Optimality Theory: competence
2. Simulated Annealing for Optimality Theory: performance
3. Learning in Optimality Theory: problems
4. Conclusions

Conclusions

- *Optimality Theory:* model of linguistic competence.
  Grammatical form = (globally) optimal candidate.
- *Simulated Annealing for Optimality Theory:* model of performance.
  Produced form = locally optimal candidate.
  Predicting frequencies. More error, if SA-OT is run faster.
- Learning an OT grammar poses challenges,
  e.g., due to hidden structures. But solutions exists!
- (Omitted from this talk: OT in other domains (e.g., syntax),
  learning in presence of performance errors, iterated learning.)

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Thank you for your attention!

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