Bootstrapping into Filler-Gap: An Acquisition Story

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Background

Filler-Gap

A non-local dependency that potentially spans an unbounded # of lexemes.

e.g. That's {the ball} John kicked ___.
e.g. That's {the ball} Mary said John kicked ___.

This is hard because:

- Filler must be remembered
- Where is the gap?

Motivation

How could children learn this?

Goal

- Simple model of filler-gap

Types of Filler-Gap (for us)

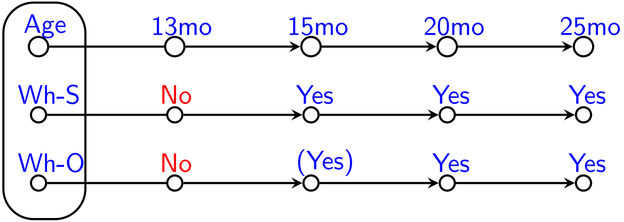
Questions

Wh-S: {What} ___ ate the apple?
Wh-O: {What} did the monkey eat ___?

Relatives

Wh-rS: Find {the boy} who ___ bumped the girl.
Wh-rO: Find {the boy} who the girl bumped ___.
That-rS: Find {the boy} that ___ bumped the girl.
That-rO: Find {the boy} that the girl bumped ___.

Acquisition Pattern



Developmental timeline of wh- question comprehension

Parentheses = marginal comprehension

That-relatives acquired slower than wh-relatives

[Seidl et al., 2003, Gagliardi et al., 2014]

Acquisition Pattern

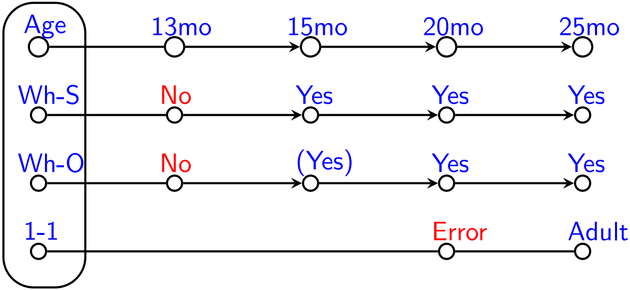
1-1 Role Bias

Subject Object

- John gorped
- Mary gorped John
- John and Mary gorped

Interpreted by Gertner and Fisher (2012) as 'Agent-first bias'
But we will show: can be modeled as 1-1 role bias

Acquisition Pattern



Developmental timeline of 1-1 role bias errors (21, 25)
Children stop this error by 25 months
[Naigles, 1990, Gertner and Fisher, 2012]

Model Motivation

What are children learning?

Complex Grammatical Constraints

Under certain conditions:

Arguments may occur in non-canonical syntactic positions.

e.g., questions introduce an expected future gap (SLASH, A-bar).

Problem:

Syntax isn't great yet

- Role conjunction not comprehended

  [Gertner and Fisher, 2012]

- Ditransitives not generalized until later

  [Goldberg et al., 2004, Bello, 2012]

Model Motivation

What are children learning?

Different Possible Orderings

The flower **hit** the apple.
What **hit** the apple.
What did the flower **hit**?

Plausible:
Word ordering patterns are fairly widespread (e.g. SOV, SVO, etc)

Previously used in BabySRL [Connor et al., 2008, 2009, 2010]

Model

- Inspired by Gradual Learning Algorithm [Boersma, 1997]
- Structure mapping: nouns used to learn verbs [Yuan et al., 2012]
- Roles assigned via ordered, latent distributions

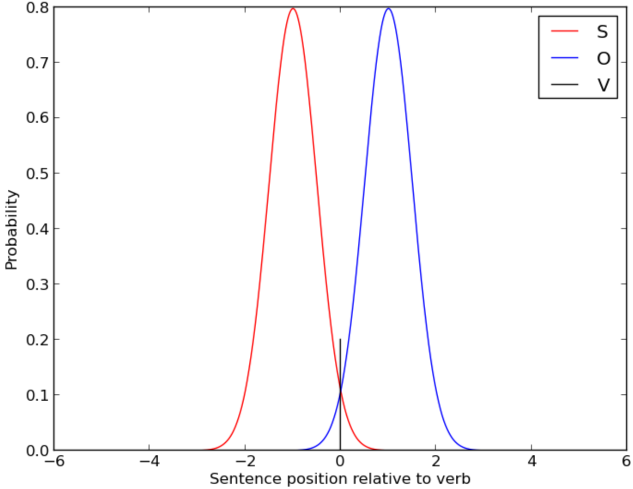
Assumptions

- (14m) Children can chunk nouns [Waxman and Booth, 2001]
- (pre-25m) Ns and roles are 1-to-1 [Gertner and Fisher, 2012]
- (9m) Abstract factors (#N) are used by learners [Xu, 2002]
- (4-5y) Children are bad at recursion [Diessel and Tomasello, 2001]

Implementation Assumptions

- Generate position of arguments relative to verb
- Sampled from Gaussian distributions
- Samples assumed to be independent

Model



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Probability
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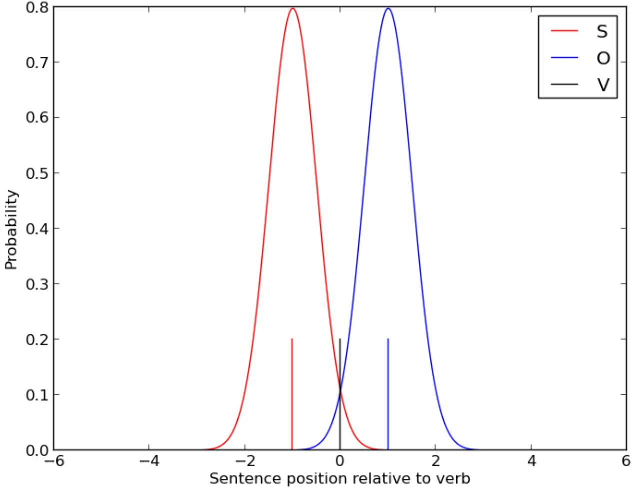
Sentence position relative to verb
S
O
V

Model



$P(-1 \mid S) \cdot P(1 \mid O)$

The cat bumped the dog.

Model

Possible parses...

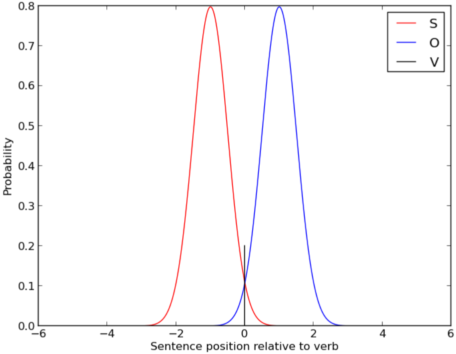
P(SVO) = P(−1 | S) · P(1 | O)
The cat bumped the dog.

P(OVS) = P(−1 | O) · P(1 | S)
The cat bumped the dog.

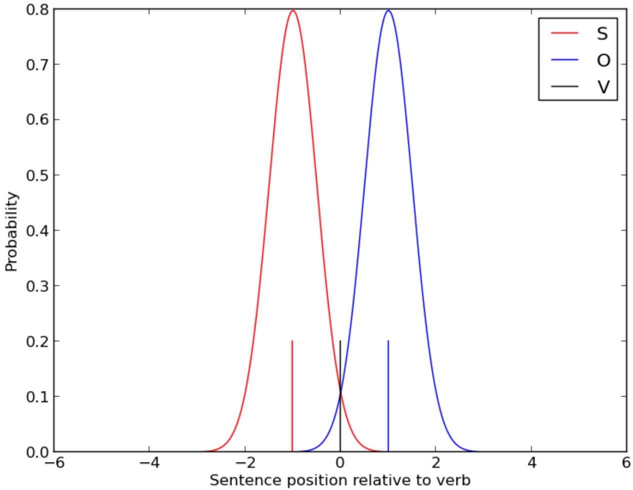
P(VO) = P(−1 | skip) · P(1 | O)
The cat bumped the dog.

P(SV) = P(−1 | S) · P(1 | skip)
The cat bumped the dog.

...



Model



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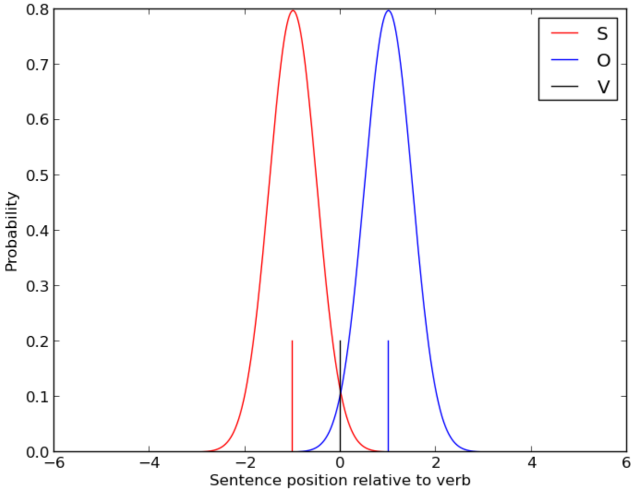
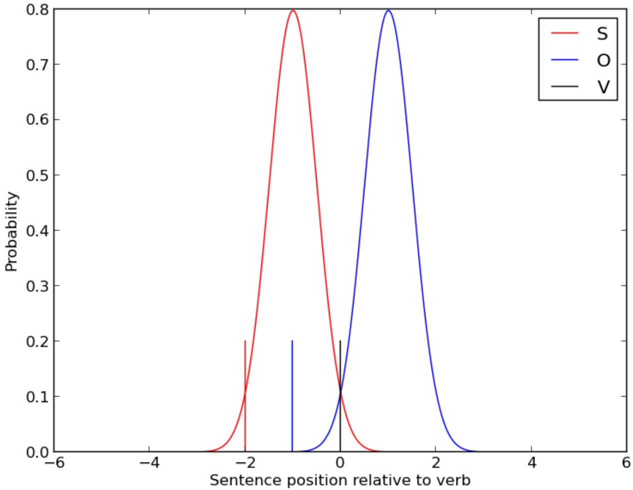


$$P(-1 \mid S) \cdot P(1 \mid O)$$

Wh-S: Which cat bumped the dog?

Model



$P(-3 \mid S) \cdot P(-1 \mid O)$

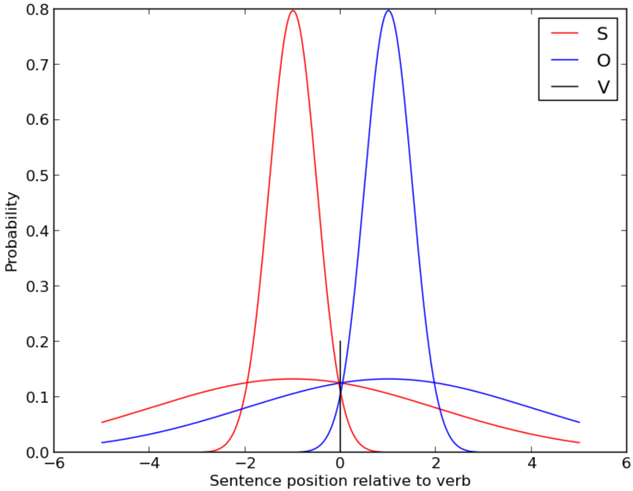
Wh-O: Which cat did the dog bump?*

Model

Initialization 2.0

- Split distributions into mixtures of distributions
  - 1) strong due to canonical evidence
  - 2) weak, but finds arguments from anywhere

Model



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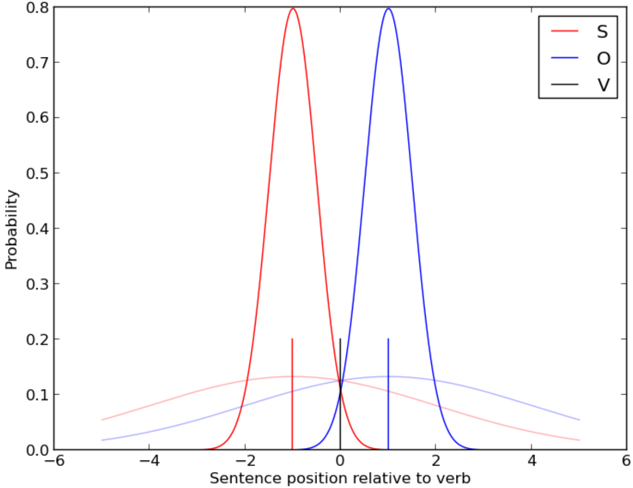
Sentence position relative to verb
S
O
V

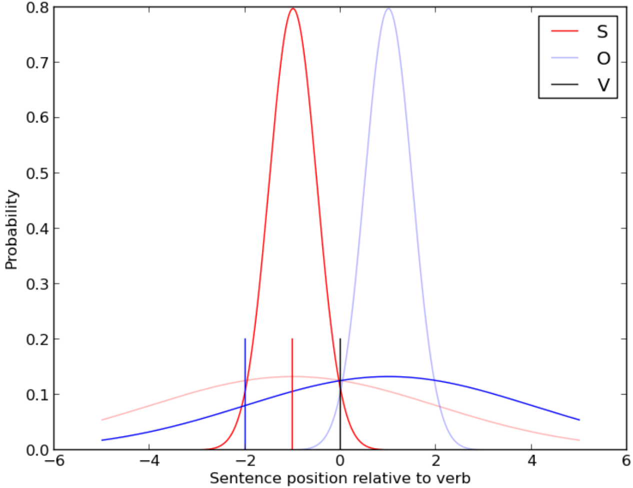
Model



$$P(-1 \mid S_C) \cdot P(1 \mid O_C)$$

Wh-S: Which cat bumped the dog?

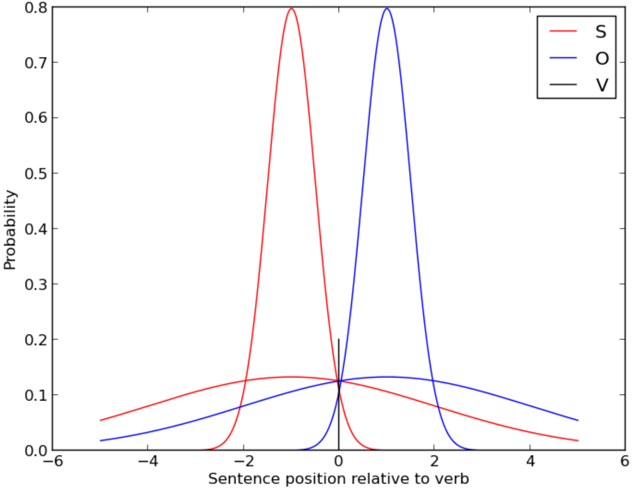
Model



$$P(-3 \mid O_N) \cdot P(-1 \mid S_C)$$

Wh-O: Which cat did the dog bump?

Model



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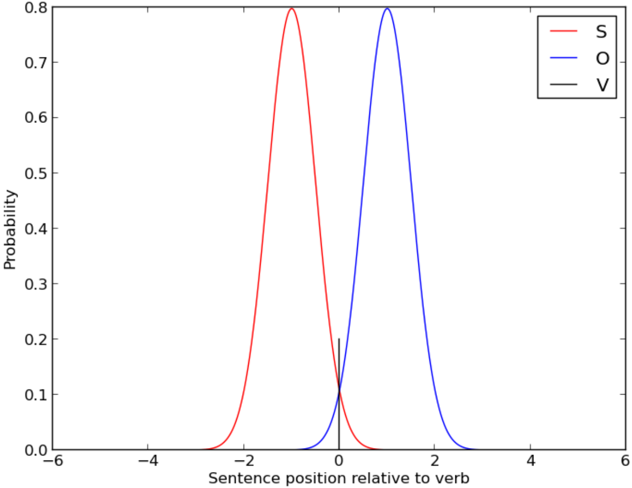
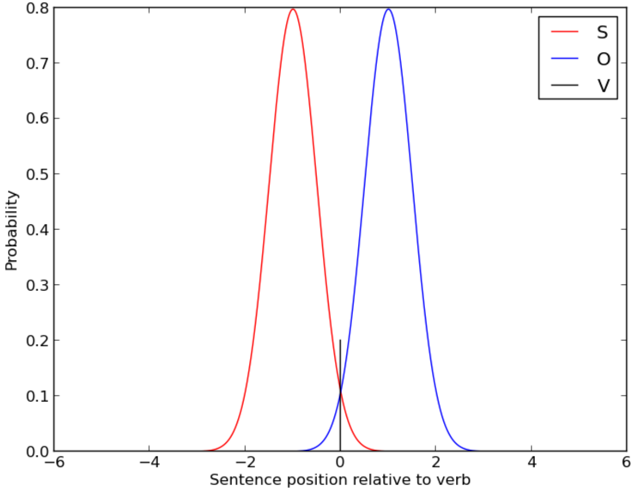


With priors, our initial model looks like this.

Evaluation

1. Extract CDS from Eve corpus
   (‘you’, ‘S’) (‘get’, ‘V’) (‘one’, ‘O’) .
   (‘what’, ‘O’) are (‘you’, ‘S’) (‘doing’, ‘V’) ?
   (‘you’, ‘S’) (‘have’, ‘V’) another cookie right on the table .
2. Chunk nouns (NLTK)
   (N;you)(V;get)(N;one) .
   (N;what)(X;are)(N;you)(V;doing) ?
   (N;you)(V;have)(N;cookie)(X;right)(X;on)(N;table) .
3. Run inference (EM)
   - Estimate labels using distributions over previous observations
   - Estimate new distributions using labelled data

Results



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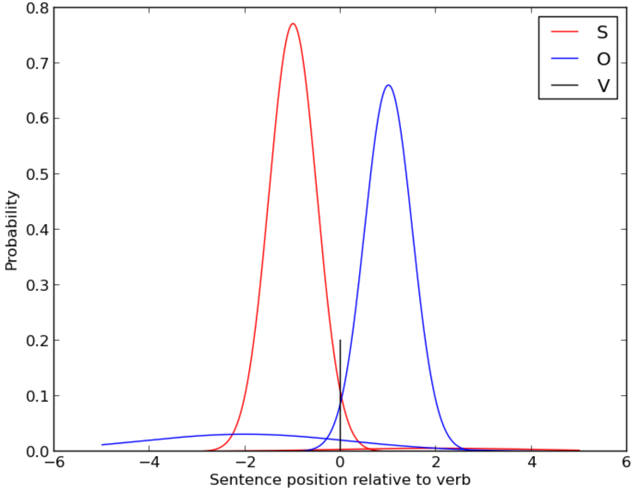
Sentence position relative to verb

Results



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Results: Quantitative

Overall Accuracy

Arguments correctly labelled

	P	R	F
Initial	**.56**	.66	.60
Trained	.54	**.71**	**.61***

Eve (n = 4820)

	P	R	F
Initial	**.55**	.62	.58
Trained	.53	**.67**	**.59***

Adam (n = 4461)

* ($p < .01$)

Results: Quantitative

But those numbers reflect overall performance...

We can try a coarse filler-gap filter.

Extract sentences where either:

- O precedes V
- S not immediately followed by V

Filler-gap Corpora

	P	R	F
Initial	.53	.57	.55
Trained	**.55**	**.67**	**.61***

Eve FG (n = 1345)

	P	R	F
Initial	.53	.52	.52
Trained	**.54**	**.63**	**.58***

Adam FG (n = 1287)

* ($p < .01$)

Results: Quantitative

Eve FG Corpus

Subject/Object

	P	R	F
Initial	**.66**	**.83**	**.74**
Trained	.64	.84	.72†

Subject (n = 691)

	P	R	F
Initial	.35	.31	.33
Trained	**.45**	**.52**	**.48***

Object (n = 654)

That/Wh-

	P	R	F
Initial	.63	.45	.53
Trained	**.73**	**.75**	**.74***

Wh- (n = 689)

	P	R	F
Initial	.43	.48	.45
Trained	**.44**	**.57**	**.50†**

That (n = 125)

* ($p < .01$) † ($p < .05$)

1-1 Role Bias

How often is NNV labelled as SOV? (1-1 role bias error)

- Connor et al (2008, 2009): 63-82% error (agent-first bias)
- Our initial model: 66% error (1-1 bias)

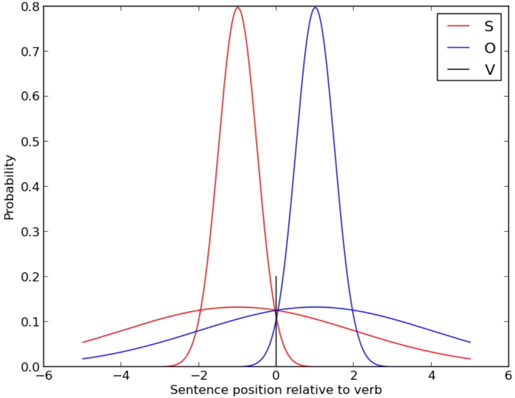
Current model is comparable to Baby SRL

Initialization Analysis

Very Robust

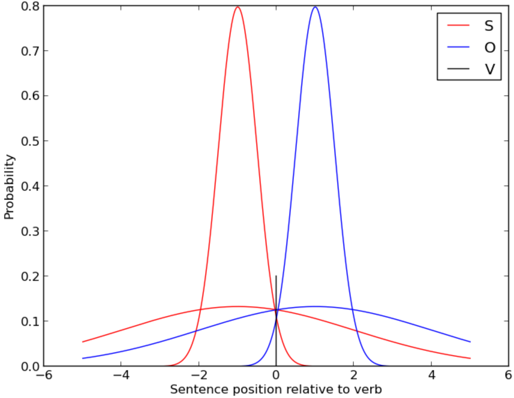
- positions: -3,3 ; -1,1 ; -0.1,0.1
- variance: 0.5 – 4
- caveat: filler preverbal prob must outweigh skip-penalty

Model Selection



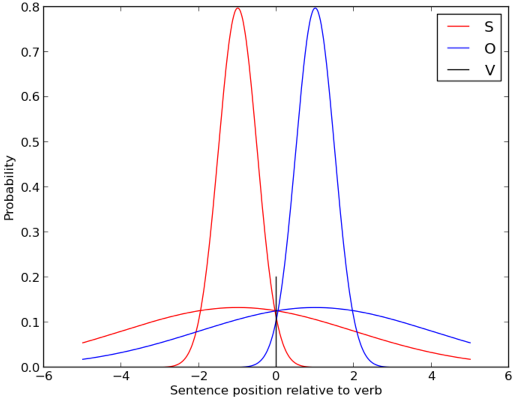
Do we really want this setup?

Model Selection



Is the non-canonical subject useful? (According to BIC)

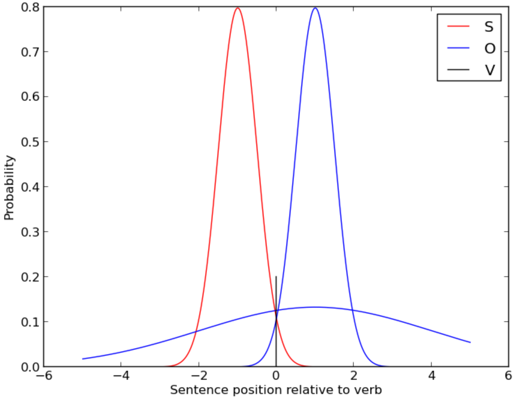
Model Selection



"Helps" capture imperatives...
But kids know imperatives...

'Put the cookie on the table!'
'[You] put the cookie on the table!'

Model Selection



Then non-canonical subject isn't useful (according to BIC)

Suggests dynamic Gaussian generation is possible

Future Work

- Add lexicalization
- Dynamically generate Gaussians
- Model non-English (verb-medial) languages
- Bootstrap linear grammar into hierarchic grammar

Conclusion

It is possible to acquire filler-gap without (complex) syntax.
The current model offers additional benefits:

- Reflects developmental S-O asymmetry
- Reflects developmental That-Wh asymmetry
- Robust to varied initializations

Questions?

Thanks to:

- Peter Culicover
- William Schuler
- Laura Wagner
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Results: 1-1 bias

How often NNV is labelled SOV

Current Model

	Error Rate
Initial	.66
Trained	.13

(n = 1000)

Trained Baby SRL

	Error Rate
Arg-Arg	.65
Arg-Verb	0

[Connor et al., 2008]

	Error Rate
Arg-Arg	.82
Arg-Verb	.63

[Connor et al., 2009]

Results: 1-1 bias

Agent Prediction

	Recall
Initial	.67
Trained	.65

Transitive (n = 1000)

	Recall
Initial	1
Trained	.96

Intransitive (n = 1000)

[Connor et al., 2010]

	Recall
Weak (10) lexical	.71
Strong (365) lexical	.74
Gold Args	.77

Transitive

	Recall
Weak (10) lexical	.59
Strong (365) lexical	.41
Gold Args	.58

Intransitive

1-1 Role Bias Summary

How often is the agent correctly labelled?

Transitives (1173 sents)

- Connor et al. (2010): 71-77%
  - Lexicalization helps
- Initial current model: 67%
  Trained current model: 65%
  - Completely unlexicalized

Intransitives (1513 sents)

- Connor et al. (2010): 41-59%
- Initial current model: 100%
  Trained current model: 96%

Current model is comparable to Baby SRL for transitives
Current model does much better on intransitives

Gertner and Fisher (2012)

[Gertner and Fisher, 2012]

The boy/girl is gorping.

Gertner and Fisher (2012)

[Gertner and Fisher, 2012]

The girl is gorping the boy.

Gertner and Fisher (2012)

[Gertner and Fisher, 2012]

The girl and the boy are gorping.

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