Positive Effects of Redundant Descriptions in an Interactive Semantic Speech Interface

Lane Schwartz, Luan Nguyen, Andrew Exley, William Schuler
University of Minnesota

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NSF project: build working interactive model of speech/language processing

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  To artificial agent in 'content creation' domain:
  1. 'Add new folder ***coling***' (fix pronunciation?)
  2. 'Go to the ***coling*** folder and add new item ***semrec***' (fix pronunciation?)
  3. ...
  4. 'Select the ***semrec*** in the ***coling*** folder' (recognition should be reliable)

  Interface uses context to improve recognition, in lieu of training corpus

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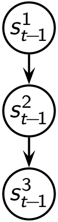
  This talk: extended model allows redundancy to improve accuracy
  (only one semrec, but similar to sentry/timrec/... so add 'in coling')

Probabilistic Time-Series Model

Interactive semantics: Hierarchic Hidden Markov Model (Murphy,Paskin'01)



Elements hold hypoth. stacked-up **incomplete constituents**, dep. on parent (incomplete constituent: e.g. S/VP = sentence lacking verb phrase to come)

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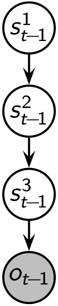

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Hypothesized mem elements generate **observations**: words / acoust. features

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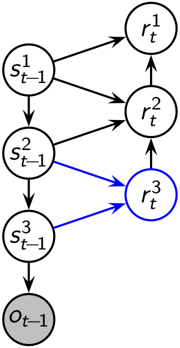

Elements in memory store may be composed (reduced) w. element above

Probability depends on antecedent vars (e.g. Det, Noun reduce to NP)

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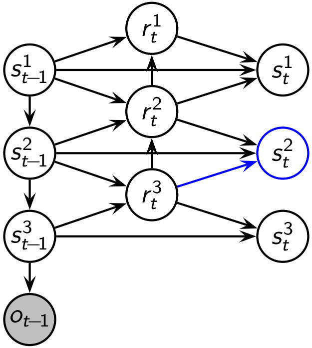

Non-reduced elements carry forward or transition (e.g. NP becomes S/VP)

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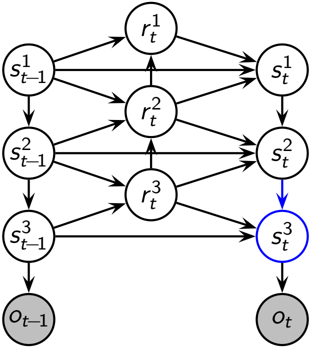

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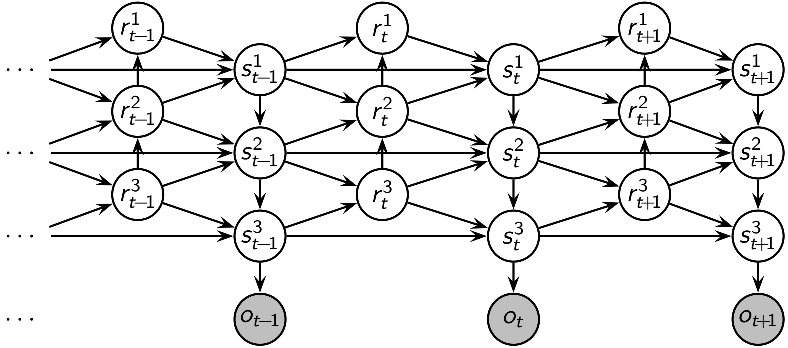

Non-reduced elements carry forward or transition (e.g. NP becomes S/VP)

Reduced elements may be expanded again (e.g. S/VP expands to Verb)

Process continues through time

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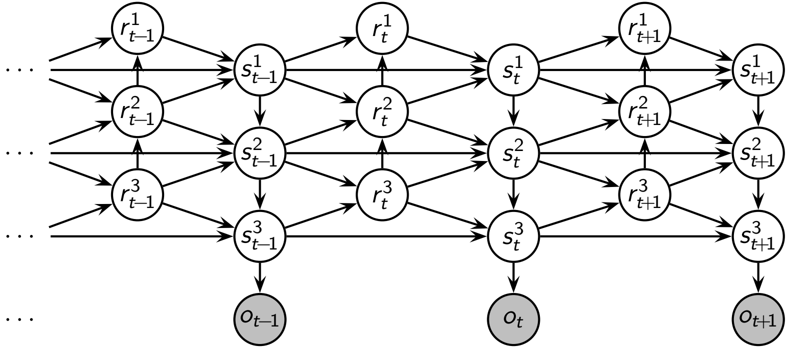

Alternate hypotheses (memory store configurations) compete w. each other:

$$\hat{s}^{1..D}_{1..T} \stackrel{\text{def}}{=} \underset{s^{1..D}_{1..T}}{\text{argmax}} \prod_{t=1}^{T} \mathsf{P}_{\Theta_{\text{LM}}}(s^{1..D}_t \mid s^{1..D}_{t-1}) \cdot \mathsf{P}_{\Theta_{\text{OM}}}(o_t \mid s^{1..D}_t)$$

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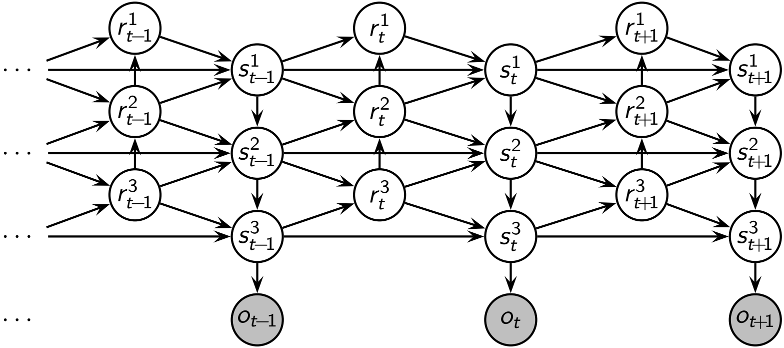
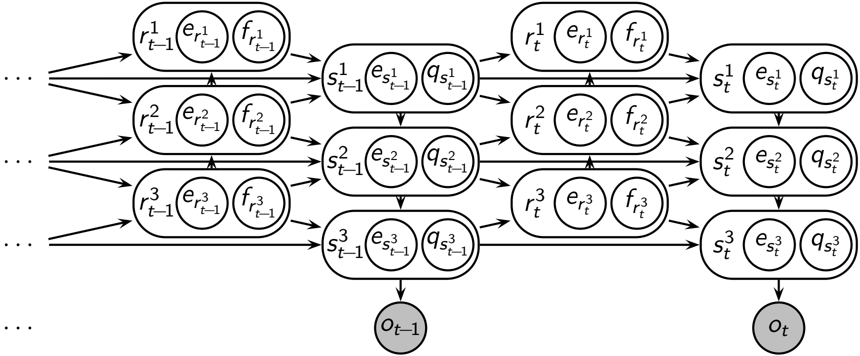


$$\mathsf{P}_{\Theta_{\mathrm{LM}}}(s_t^{1..D} \mid s_{t\text{-}1}^{1..D}) = \sum_{r_t^{1..D}} \mathsf{P}_{\Theta_{\mathrm{Reduce}}}(r_t^{1..D} \mid s_{t\text{-}1}^{1..D}) \cdot \mathsf{P}_{\Theta_{\mathrm{Shift}}}(s_t^{1..D} \mid r_t^{1..D}\ s_{t\text{-}1}^{1..D})$$

$$\stackrel{\mathrm{def}}{=} \sum_{r_t^{1..D}} \prod_{d=1}^{D} \mathsf{P}_{\Theta_\rho}(r_t^d \mid r_t^{d+1} s_{t\text{-}1}^d s_{t\text{-}1}^{d\text{-}1}) \cdot \mathsf{P}_{\Theta_\sigma}(s_t^d \mid r_t^{d+1} r_t^d\ s_{t\text{-}1}^d s_t^{d\text{-}1})$$

Probabilistic Time-Series Model

Add interactive semantics — simply factor HHMM states:



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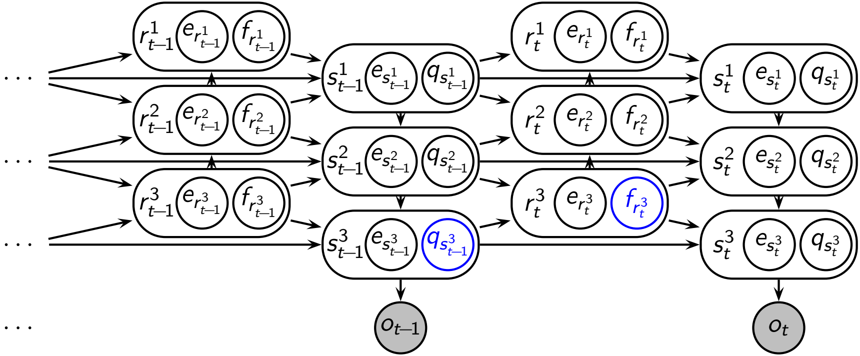

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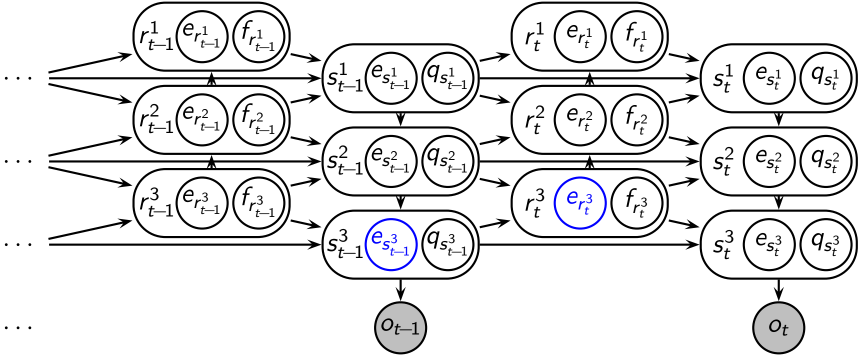


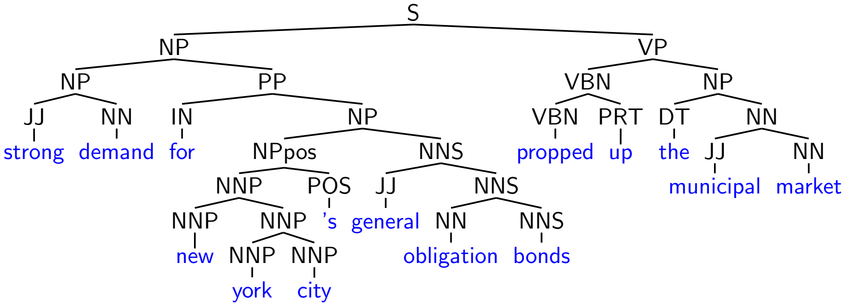
— factor r, s into interdependent syntactic (q/f) and referential (e) states:

- **incomplete syntactic states:** e.g. $q = \mathrm{S/VP}$ (with f as a reduce flag)
- **incomplete referential states:** e.g. $e = \{i_{\mathrm{coling}}, i_{\mathrm{naacl}}\}$ (entity set/class)

Connecting Generative Grammar to Time-Series Model

Sequences of memory stores correspond directly to familiar phrase structure:

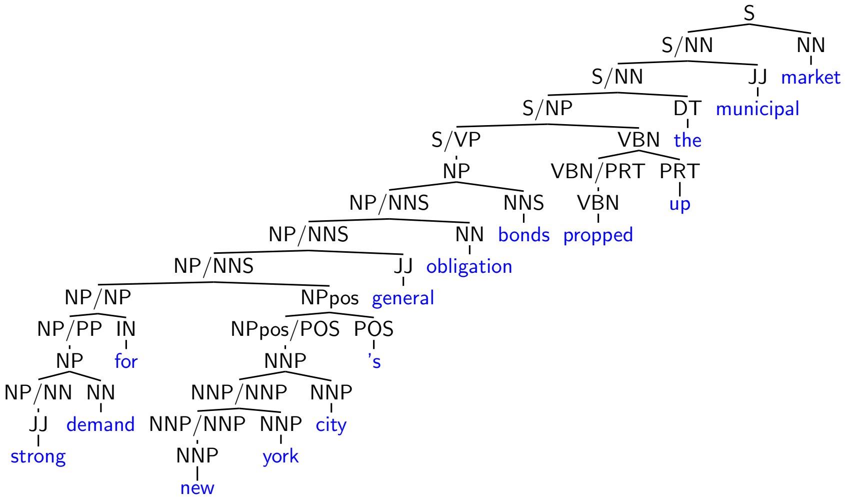
(trees from Penn Treebank, modified to featurize empty categories)



Correspondence requires flatter, more memory-efficient representation...

Connecting Generative Grammar to Time-Series Model

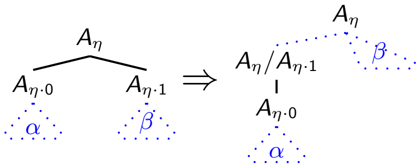
'Right-corner transform' map right-embedded sequence → left-embedded seq. (allows new constituents to be immediately composed)



Right-Corner Transform

Transform is simple — **three cases** on right-embedded sequence:
(η, μ are paths of 0:left/1:right)

Beginning case:



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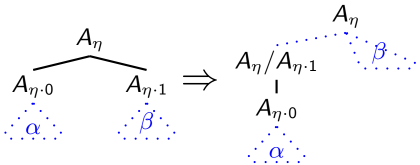
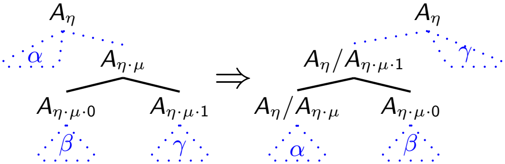


(left child → top/right)

Middle case:



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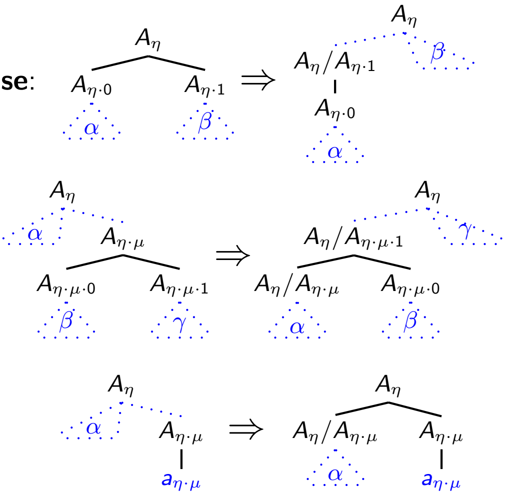

Beginning case: (left child → top/right)

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Ending case: (left child → top/right)

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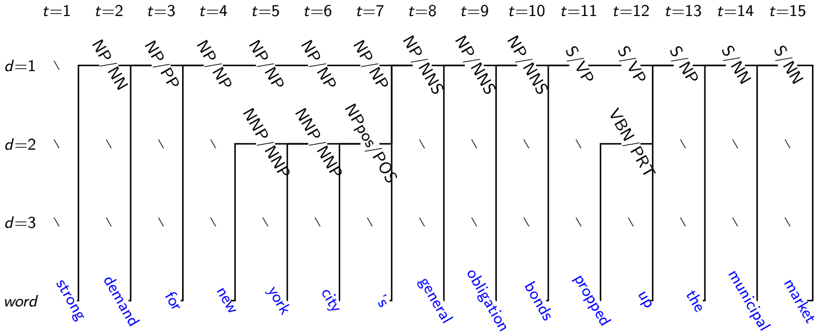
Align levels to a grid, to train HHMM:



Time-order parsing based on familiar phrase structure grammar rules

Interactive Interpretation

Add interactive meaning:

- last year: first-order objects (individual files/directories)
  runs in real time w. 4000 individuals, 4000 words

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- now: redundancy requires second-order objects (sets of individuals)
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  syntax, semantics defined w. familiar grammar rules, set operations
  (someday, by user – fully extensible language model)

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Interactive interpretation defined using $e \rightarrow e$ transitions in HHMM

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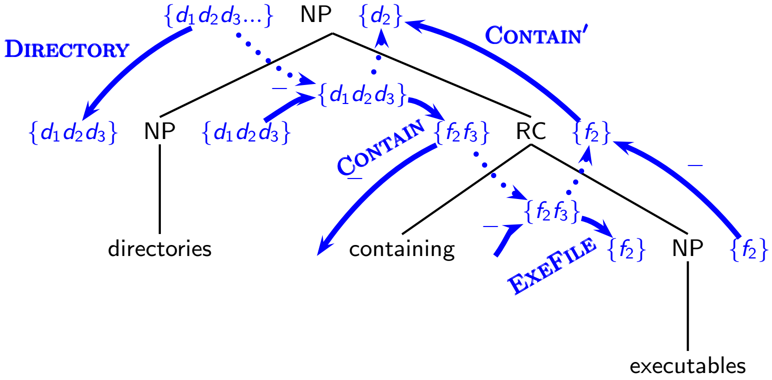
Semantics now 'ride along' through transform as operator/transition chains

Right-Corner Transform on Operator Chains

Operator chains prior to transform (dot arcs show λX dependencies):



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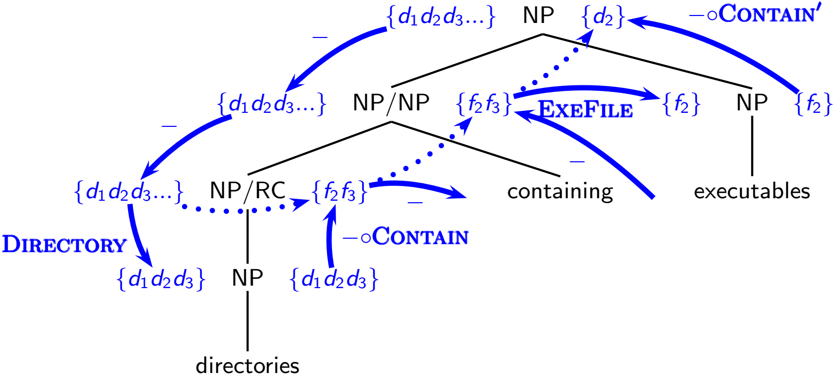
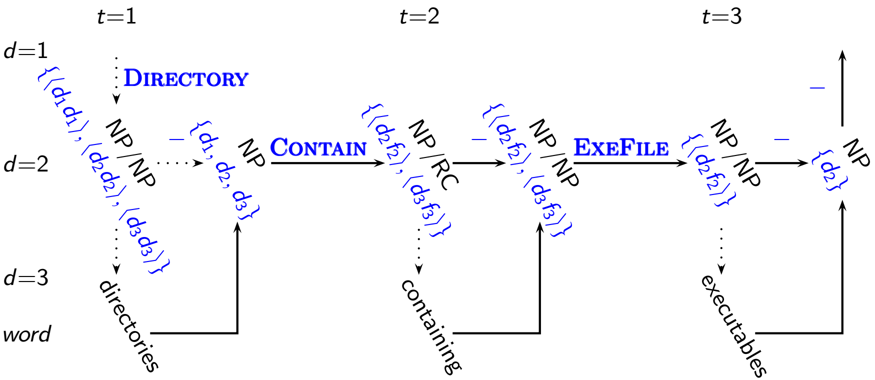
Operator chains following transform:



Left legs turn into right legs, but operators keep order, structure

Right-Corner Transform on Operator Chains

Transformed operations aligned to time-series model:



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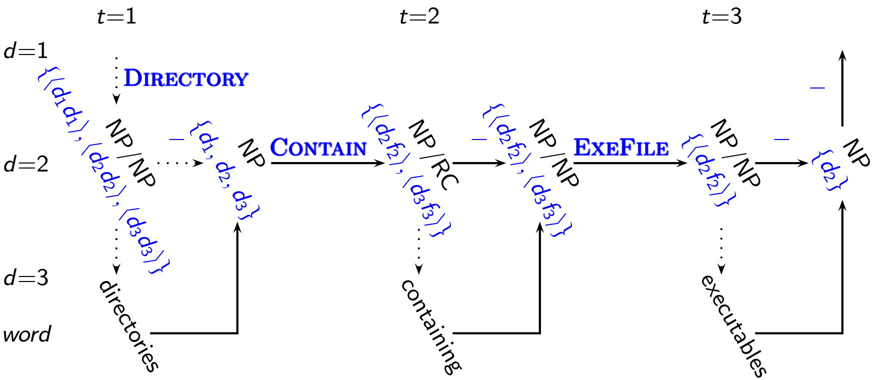


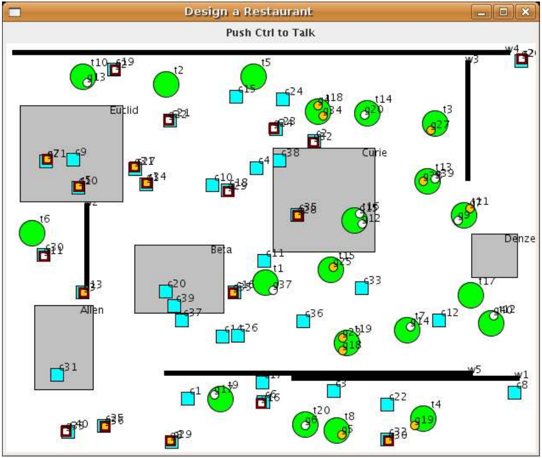
Time-order interpretation from familiar grammar rules, set operations

Interpretations dynamically calculated, then used to rate hypotheses (prob. based on denotation cardinality before and after each operation)

Evaluation: scalable to second-order denotations

Bounded model allows 2ndorder denotations in real time speech (13% SER)

Restaurant domain: 'select the glasses on chairs'



Evaluation: scalable to second-order denotations

Beam=100, Individuals=110, Lexicon=50 — 100 directives test:

Subject	Sentence error rate	Corrected on 1st retry	Corrected on 2nd retry
1	2 / 20	2	-
2	2 / 20	1	1
3	3 / 20	2	1
4	4 / 20	4	-
5	2 / 20	1	1
Total	13%	10	3

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Total	13%	10	3

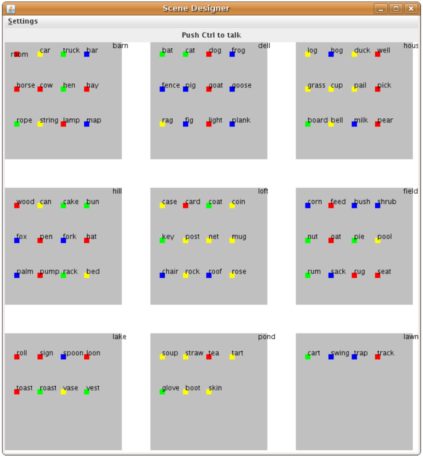
Beam=100, Individuals=110, Lexicon=1000 — 60 directives test:

Subject	Sentence error rate
1	2 / 20
2	1 / 20
3	5 / 20
Total	13%

Evaluation: redundancy improves accuracy

Does interactive model let speaker be redundanct to improve communication?

Monosyllabic domain: 'select the seat [to the right of the rug]'



Evaluation: redundancy improves accuracy

Beam=100, Individuals=100, Lexicon=100 — 1000 directives test:

Subject	Sentence error rate without redundancy	Sentence error rate with redundancy
1	54 / 100	37 / 100
2	32 / 100	21 / 100
3	25 / 100	18 / 100
4	28 / 100	12 / 100
5	24 / 100	15 / 100
All	32.6%	20.6%

Natural model of using redundancy to ensure correct interpretation.

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- Based on familiar notions of phrase structure, semantic composition
- Interactive interpretation lets user be redundant to improve accuracy

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Thank you!