# A Distributed, Large Scale Connectionist Model of the Interaction of Lexical and Semantic Constraints

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# Constraint Based Theories of Sentence Processing

- Focus on the integration of multiple soft constraints:
  - ▷ Syntactic / Structural
  - ▷ Pragmatic
  - ▷ Lexical frequency biases

# Problem: How are Constraints Weighed?

- Claim is that multiple constraints matter, but data suggest that some constraints are weighed more heavily than others
- “Grain” problem: infinite number of possible statistics could be calculated
- Challenge is to specify computational mechanism underlying constraint integration

# Need for Computational Models

- Specify precise weighing of constraints according to:
  - ▷ Informativeness of cue
  - ▷ Prior world knowledge about relationships of objects and events, etc.
  - ▷ Current state of the system: what is and isn’t known from previous words

- Prior computational models (e.g., Christiansen & Chater, 1999; Elman, 1990; Tabor et al., 1997) examined interactions of lexical and contingent frequency constraints, but did not include semantics.
- Semantics crucial to grain problem and constraint based theories in general

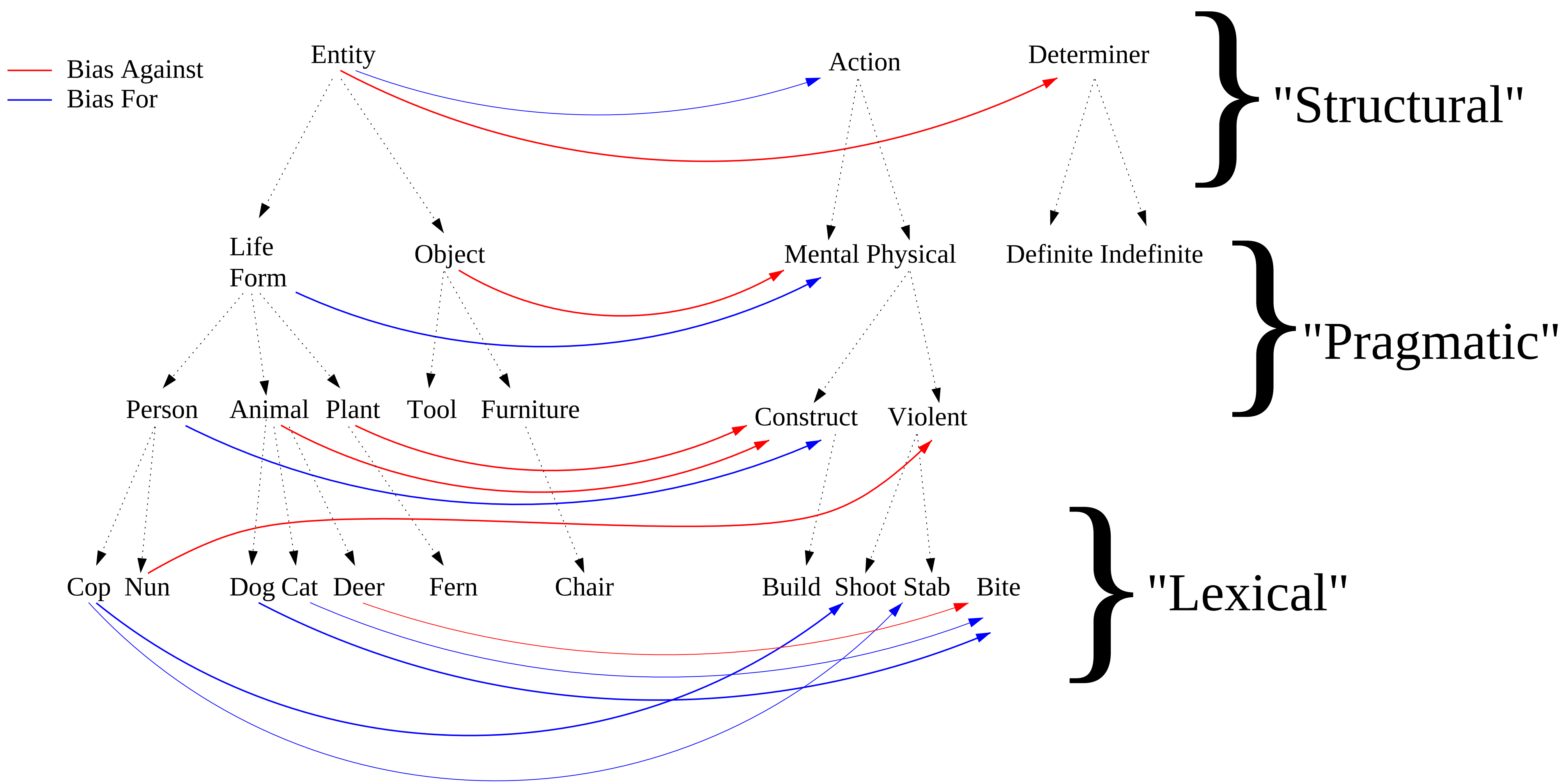
# Goals of Current Work

- Recast grain problem
  - ▷ Not *“Which grain level does the system compute statistics over,”*
  - ▷ But rather: *“What factors affect the relative influence of simple and contingent statistical regularities?”*
- Develop a computational model with distributed semantic representations to investigate complex constraint interactions

# Semantic Specificity and Statistical Regularity

- Distributional regularities over multiple levels of semantic specificity:
  - Structural: regularities over coarse-grained semantics (i.e., object, action) correspond to syntactic categories
  - Pragmatic: regularities over mid-level semantics yield pragmatic constraints. For example, animate objects participate in mental events, etc.
  - Lexical: statistics calculated over fine-grained semantics yield word-specific constraints

# Specificity and Regularity (cont.)



# Example: Syntactic Category Ambiguities

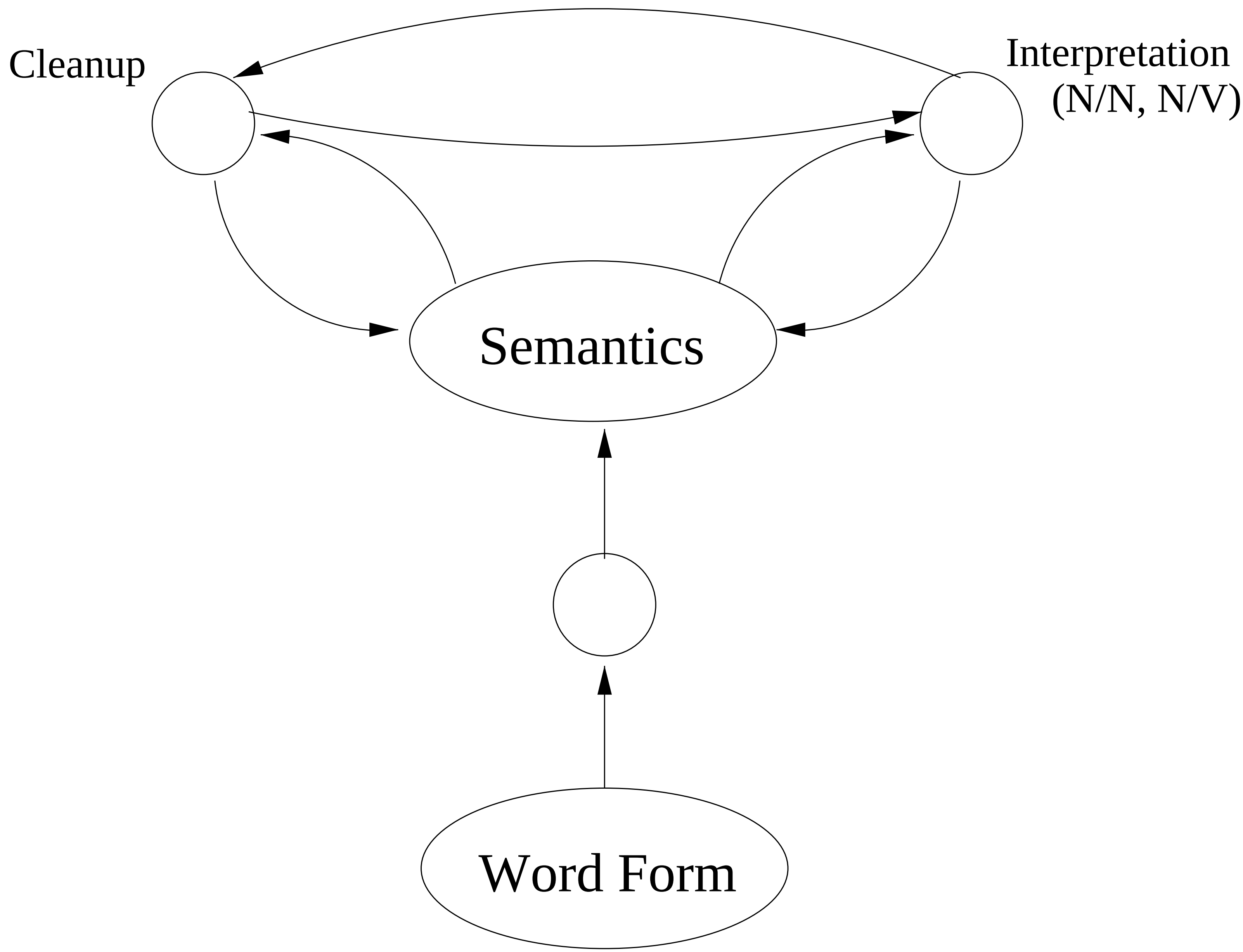
- Good domain to look for local statistical influences
- Rich interactions of lexical and pragmatic biases
  - ▷ *Corporation fires (us/are)*
  - ▷ *Warehouse fires (us/are)*
- Words have lexical frequency biases for head noun versus modifying noun status

- Pragmatics: warehouses burn, corporations fire people
- MacDonald (1993) manipulated frequency bias of first word (bias for modifier or head noun), frequency of co-occurrence of words, and semantic plausibility
- Found effects of all factors. Evidence for online use of multiple sources of information in disambiguating

# Simulating Syntactic Category Ambiguities

- Distributed Semantic Representations
  - ▷ WordNet online semantic database (Miller, 1990)
  - ▷ 8,207 hierarchically structured features, including:
    - ⇒ High-level semantic (entity, modifier, state)
    - ⇒ Mid-level catgory (living thing, tool, plant, human)
    - ⇒ Lexical, item specific
    - ⇒ Morphological (plural, past tense)
- Distributed word form representations
  - ▷ Localist syllables
  - ▷ Morphological affixes
  - ▷ 8,210 word forms, 3,421 features

# Model Architecture




Task: Compute Semantics of Current Word

# Training Set

- Large training set: 20,000 Word triplets from tagged WSJ and Brown corpora
- Tokens fitting NOUN-NOUN-XXX or NOUN-VERB-XXX template
- Broad range of ambiguous items and phrases:
  - ▷ Modifying noun vs. head noun biases ranged from heavily biased to equibiased
    (e.g., *Tax* is very heavily biased to be a modifer. *Tariff* is weak. Semantics are the same.)
  - ▷ Semantic biases ranged from heavy to weak
    (e.g., <mental actions> require an <living> noun. <physical actions> can be performed by <living> or <object> nouns.)

# Training Regime

- Word forms presented one at a time
- Target is semantics for current word
- Interpretation nodes: target is N/N or N/V over whole duration of triplet
- Activity builds up gradually over time using continuous time backprop: 42 samples, 10 units of whole time, one word every 14 samples. Under time pressure
- Trained for 400,000 presentations of randomly selected triplets

# Scoring the Model

- Measured accuracy of semantic features after each word, and error on interpretation nodes at end of triplet
- Mean total semantic error: 0.66 per word
- 99.99% of features correct
- Mean error on interpretation nodes: 0.03

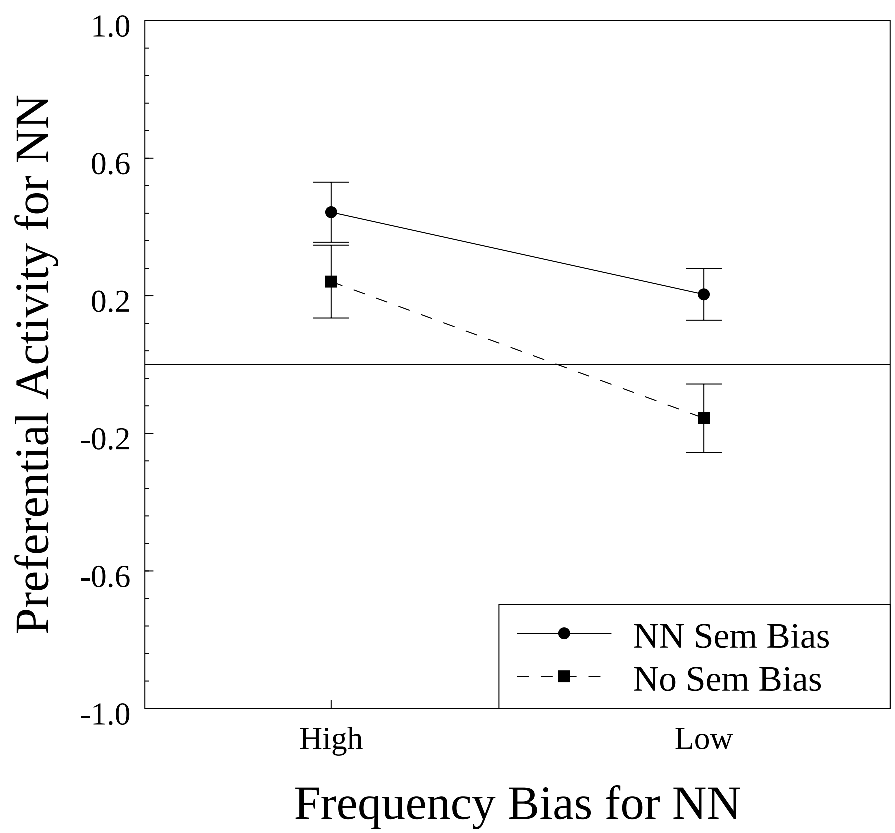
# Behavior of the Model

- Structural constraints: *man dog bites* not coherently assimilated - interpretation nodes unstable. Novel (though perhaps implausible) grammatical phrases (e.g., *truth bites man*) generally are stable
- Pragmatics: *dog bites man* recognized more quickly than *truth bites man*
- Lexical: *tax cuts are* recognized more quickly than *tariff cuts are*

# Replication of MacDonald (1993)

- 2x2 design: selected 24 items, crossed bias of first word (to modifying noun vs. head noun) with combinatorial semantic constraint
- Identified combinatorial semantic constraint by computing conditional entropy of semantic features: degree to which features of both wordsconstrain features of second word (e.g., abstraction -> communication, as in *injury claims* (N/N bias) versus *company claims* (N/V bias))

- Dependent variable: integrated difference in activity of interpretation features for N/N and N/V over time.
- Results: Reliable effect of lexical frequency ($p < 0.003$) and plausibility ($p < 0.007$)



# Conclusions

- Modeling pragmatic effects in empirical studies requires rich semantics
- World knowledge approximated with rich semantics and large training set of real-world utterances
- Potential to look at much more complex phenomena involving deeper world knowledge, e.g., conceptual combination, more complex ambiguities
- Framework allows examination of effects of multiple cues computed at multiple levels. Recasts “grain problem.”

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