Distributed Connectionist Modeling of Morphological Priming in Hebrew

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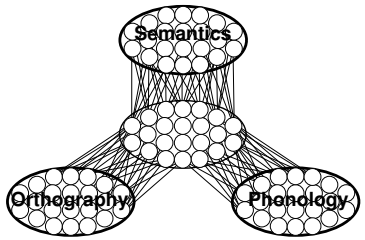
Alternative perspectives on morphology

Traditional perspective

- Word are built out of discrete units called *morphemes* (WALKED = WALK + -ED; TEACHER = TEACH + -ER) that contribute systematically to grammar/meaning
- Exceptional/opaque forms (SING ⇒ SANG; CORNER ≠ CORN + -ER) are handled as whole, undecomposed forms

Distributed connectionist perspective

- Morphology is a characterization of learned sensitivity to systematic relationships within and among surface forms of words (phonology, orthography) and their meanings (semantics)
- Properties of morphology *derive from* the nature of semantics, phonology, orthography and their interrelationships in a given language
- Provides natural instantiation of *partial* decomposition (DRESSER ≈? DRESS + -ER)



Hebrew derivational morphology

- Most words formed by interleaving three-consonant *root* into vowel/consonant *word pattern*

Root		Word Pattern		Phonology	Orthography	Meaning
ZMR	+	_a_a_	=	/zamar/	ZMR	singer (male)
		_a_e_et	=	/zameret/	ZMRT	singer (female)
		_e_e_	=	/zemer/	ZMR	song
		_a_i_	=	/zamir/	ZMYR	nightingale
		ti__o_et	=	/tizmoret/	TZMVRT	orchestra
		mi__o_	=	/mizmor/	MZMVR	psalm
		_a_a_ut	=	/zamarut/	ZMRVT	singing profession

  - Roots carry core meaning (with exceptions/subfamilies); word patterns carry grammatical/word-class information and very broad semantic distinctions
- Nouns formed from 100+ word patterns; verbs formed from 7 word patterns with distinct syntactic/semantic implications
- "Weak" roots (≈ 10%) drop/alter specific consonants in particular verbal forms

Root		Word Pattern		Phonology	Orthography	Meaning
NPL	+	hi__i_	=	/hipil/	HPYL	he overthrew
QVM	+	hi__i_	=	/heqim/	HQYM	he raised
YRD	+	hi__i_	=	/horid/	HVRYD	he went down

Summary of empirical findings in Hebrew

Nouns (Frost, Forster, & Deutsch, 1997, *JEP:LMC*)

- Root priming from isolated roots (11–14 ms) or from derived words with same root but different word pattern when semantically related (15 ms) or unrelated (11 ms)
- No (or weak) semantic priming from semantic but not morphologically related primes (–3 ms n.s., but reliable 10% difference in error rates)
- No word-pattern priming from derived words with same word pattern but different root (1–3 ms, n.s.)
- No pseudo-derived priming from derived nonwords with same root (4 ms n.s.)

Verbs (Deutsch, Frost, & Forster, 1998, *JEP:LMC*; Frost, Deutsch, & Forster, 2000, *JEP:LMC*)

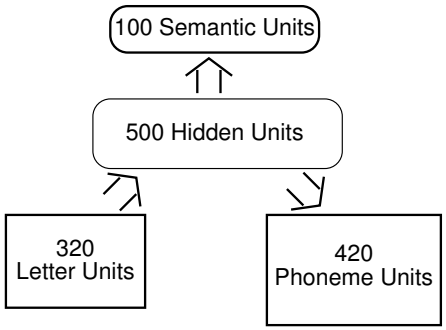
- Root priming from derived words with same root (9–13 ms)
- Word-pattern priming with full roots from derived words or nonwords with real roots (11–17 ms) or pseudo-roots (11–14 ms)
- No word-pattern priming with weak roots from derived words with same word pattern but missing/defective root consonant (6 ms n.s.)

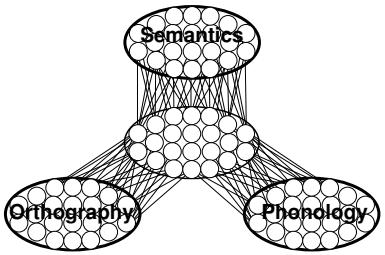
Challenges of Hebrew for connectionist approach

- Non-concatenative morphology
- Morphological priming from semantically unrelated (and formally matched) primes
  - But M+S− priming can arise from morphological organization induced by M+S+ items in languages with rich morphologies (Plaut & Gonnerman, 2000, *LCP*)
- Differences between nouns and verbs
  - Word-pattern priming for verbs but not nouns
  - Word-pattern priming for pseudo-verbs but no root priming for pseudo-nouns
- Sensitivity of morphological priming to "structural" manipulations
  - Word-pattern priming eliminated with weak roots
  - Reinstated if random consonant is "place-holder" for missing root consonant

Simulation: Network architecture

- Feedforward network mapping Orthography to Semantics and Phonology via common set of internal (hidden) units (421,020 total connections)





Simulation: Vocabulary

"Pseudo-Hebrew"

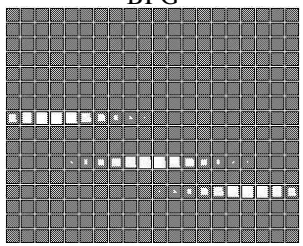
- 60 word patterns of experimental stimuli (53 for nouns; 7 for verbs)
- 200 roots from random triples of 16 consonants (6 also in word patterns)
  - 10% are "weak" (drop a particular letter in some verb word patterns)
- Words selected from all possible combinations of roots and word patterns
  - 2084 nouns (20% of 200 roots x 53 word patterns)
  - 1109 verbs (80% of 200 roots x 7 word patterns)
- Pseudo-nouns are novel combinations of known roots and noun word patterns
- Pseudo-verbs are combinations of novel roots (unfamiliar triples of 16 consonants) and verb word patterns

Simulation: Representations

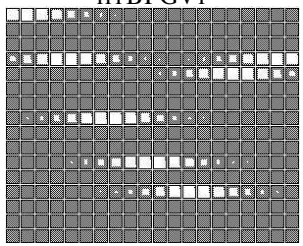
Orthography

- Letters in words presented as Gaussian "bumps" of activity in banks of letter units (16 letters, one row per letter; 20 units wide)

BFG



HTBFGVT



Phonology

- Analogous to Orthography but also including vowels (21 phonemes; 20 units wide)
  e.g., BAFAG, HITBAFGUT

Simulation: Representations

Semantics (following Plaut & Gonnerman, 2000, *LCP*)

- Each root and word pattern assigned random prototype pattern over 100 semantic/syntactic "features" (10 features for roots; 5 for word patterns)
- Each word's meaning is created by combining features derived from its root and features derived from its word pattern
  - 80% of words derived from a root are related (keep 4/10 features of root prototype)
  - 20% of words are unrelated (root contributes random 10 features)
  - Nouns have random 1/5 features of word pattern prototype
  - Verbs have random 4/5 features of word pattern prototype
- Words sharing root or word pattern tend to have greater semantic overlap
  - Only for 80% of root derivatives
  - More for verb than noun word pattern derivatives

Simulation: Training and testing

Training procedure: Back-propagation

- Batch learning, adaptive connection-specific learning rates (Jacobs, 1988)
- Error tolerance of 0.05 for "off" features; 0.1 for "on" features
- Trained for 2000 sweeps through 3193 words
  - Semantics: at most 1 feature >0.2 from target for all words (mean SSE/unit = 0.00756)
  - Phonology: highly accurate (mean SSE/unit = 0.00025)

Testing procedure: Priming

- RTs of network determined by *cascading* unit activations ($\tau = 0.01$) and applying stability criterion (mean change < 0.01)
- Priming measured by change in RT to target when preceded by different primes
  - Prime presented and processed for 0.5 units of time (50 updates)
  - Target replaces prime over Orthography; other activations unchanged
  - Network processes target until stability criterion is met (over Hidden and Semantic units)

Experimental design

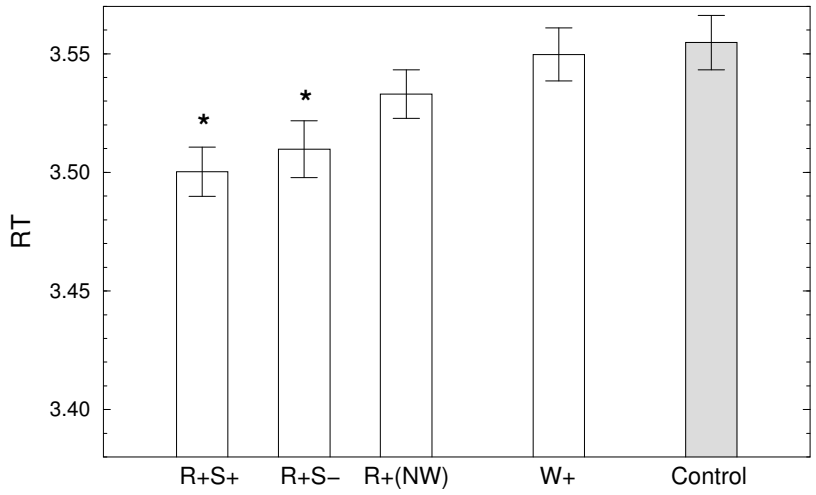
- All prime-target pairs have the same length and overlap in 3 letters
- Pairs categorized on four factors
  - **R+**: prime and target share root
  - **S+**: R+ and semantics of root in both prime and target is related to root prototype
  - **F+**: Root is full (not "weak")
  - **W+**: prime and target share word pattern
- Comparisons

Control condition	R−S−F+W−	
Root priming	R+S+F+W− (related)	R+S−F+W− (unrelated)
Word-pattern priming	R−S−F+W+ (full)	R−S−F−W+ (weak)
Pseudo-derived priming	R+S+F+W− (nouns)	R−S−F+W+ (verbs)

- Results based on random selection of 30 prime-target pairs from each condition (to approximate power in empirical studies)

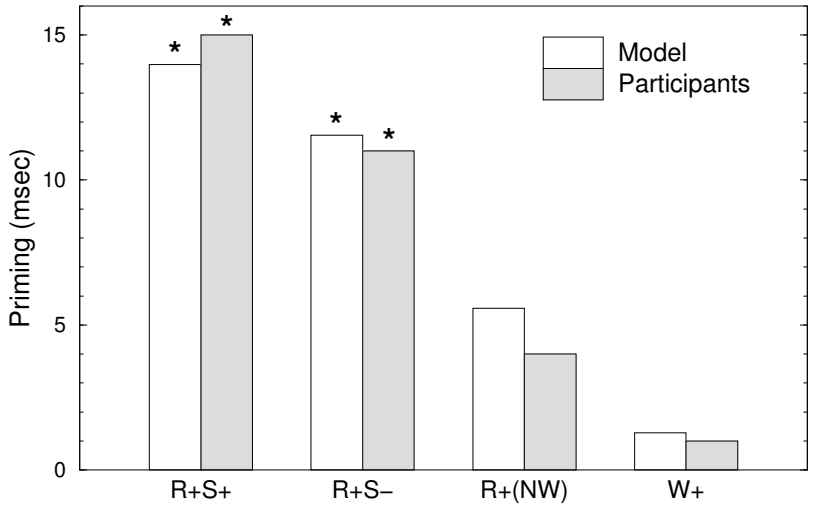
Results: Nouns

Empirical findings: Root priming (related and unrelated); no word-pattern priming, no pseudo-derived priming [Note: cannot test for lack of non-morphological semantic priming]



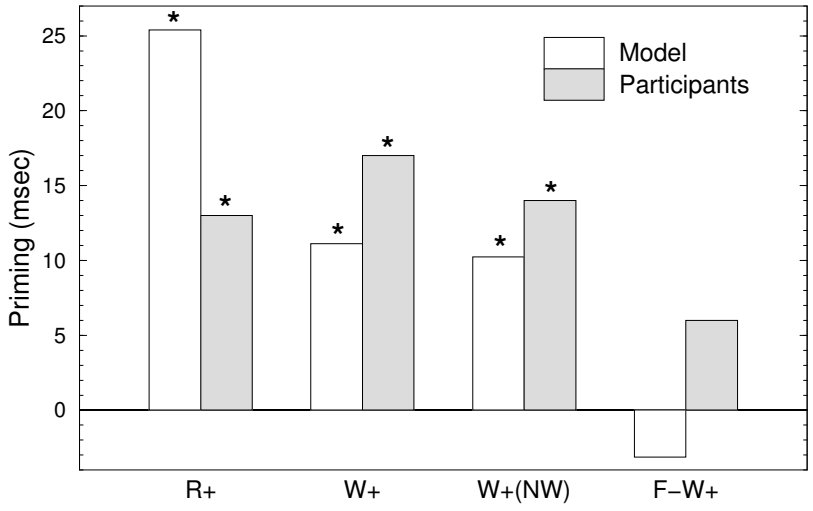
Quantitative comparison with empirical results

Nouns



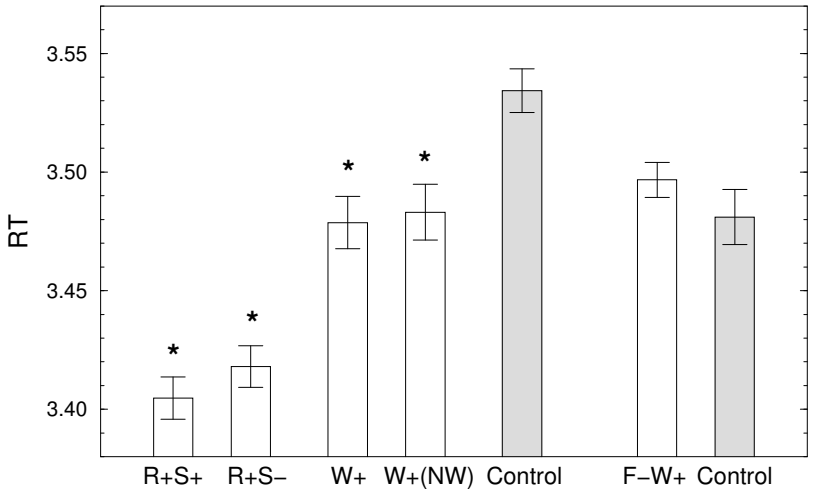
Quantitative comparison with empirical results

Verbs



Results: Verbs

Empirical findings: Root priming; word-pattern priming with full roots (real and pseudo) but not with weak roots



Simulation: Summary

- Reproduces broad patterns of empirical findings
  - Root priming for nouns and verbs irrespective of semantic similarity
  - Word pattern priming only for verbs; eliminated by “weak” roots
  - Word pattern priming from pseudo-verbs but no root priming from pseudo-nouns
- Demonstrates that distributed connectionist approach can capture effects of “structural” manipulations on morphological priming
- Quantitative match is good for nouns but relatively poor for verbs
  - Exaggerated root priming may be due to complete overlap of root letters between primes and targets

Empirical support for connectionist approach

Frost, Plaut, and Hazan (in preparation)

- Some weak roots drop weak letter in **all** derivations (BYN: HABANAH, HEBIN, TBUNAH)
- Other roots drop weak letter only in some derivations (NPL: HAPALAH vs. NEPILAH)
- Connectionist approach predicts sensitivity to distributional properties of root letters

Experiments

- Contrast root priming from consistent letters (BN) vs. from "true" root (BYN)

Results

Prime			
Morph.	Control	Target	
BN	BH	HBNH	13 ms priming
BYN	HNH	HBNH	0 ms priming (n.s.)

Distributed connectionist framework for morphology

- Morphology is a characterization of learned sensitivity to systematic relationships within and among surface forms of words (phonology, orthography) and their meanings (semantics)
- Properties of morphology *derive from* the nature of semantics, phonology, orthography and their interrelationships in a given language
- Provides natural instantiation of *partial* decomposition