Using Neural Network Models to Model Cerebral Hemispheric Differences in Processing Ambiguous Words

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Outline

- Background
  - Homographs
  - Left and Right Hemispheres
  - Kawamoto's Model
- Our Model
- Computational Simulations

Examples of Homographs

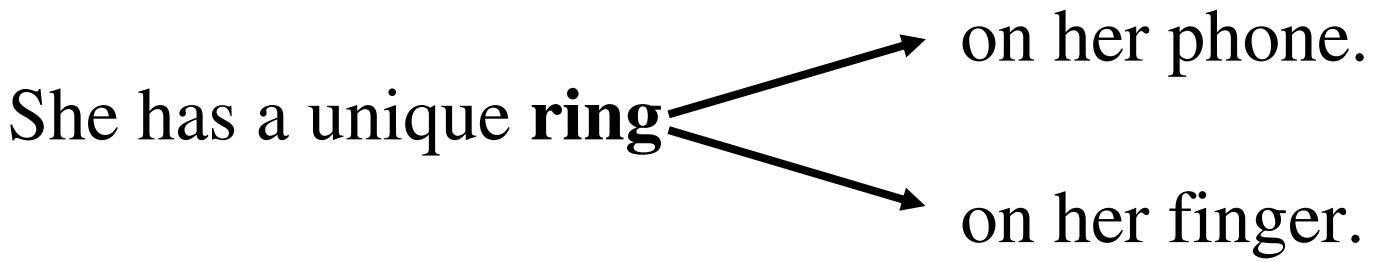
The businessman went to the **bank**.

The fisherman fished on the **bank**.

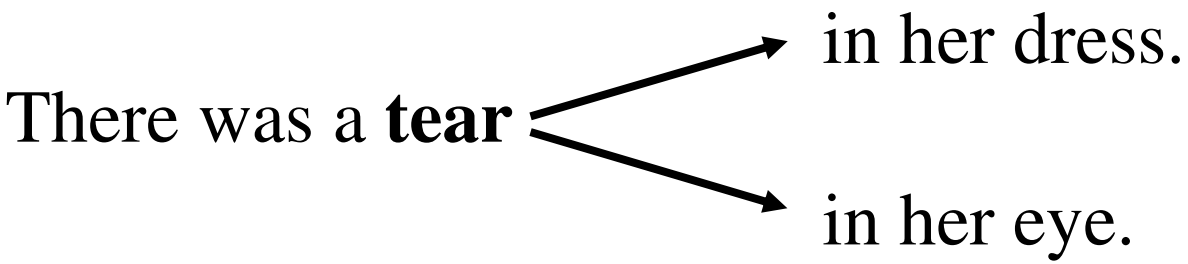
הוא חיפש את **הספר**.

הוא קבע תור אצל **הספר**.

- **Homophonic Homograph**



- **Heterophonic Homograph**



Introduction

- Reading is a complex and highly skilled action that requires the combination of information from different sources

- Do we use phonology when we read silently?

To understand the meaning of the letters “wind” or “ס פ ר” we use:

- Lexical - prior **degree of frequency or familiarity** with the homograph
- Contextual – prior **contextual information**
- Phonological –

orthography → phonology → meaning.

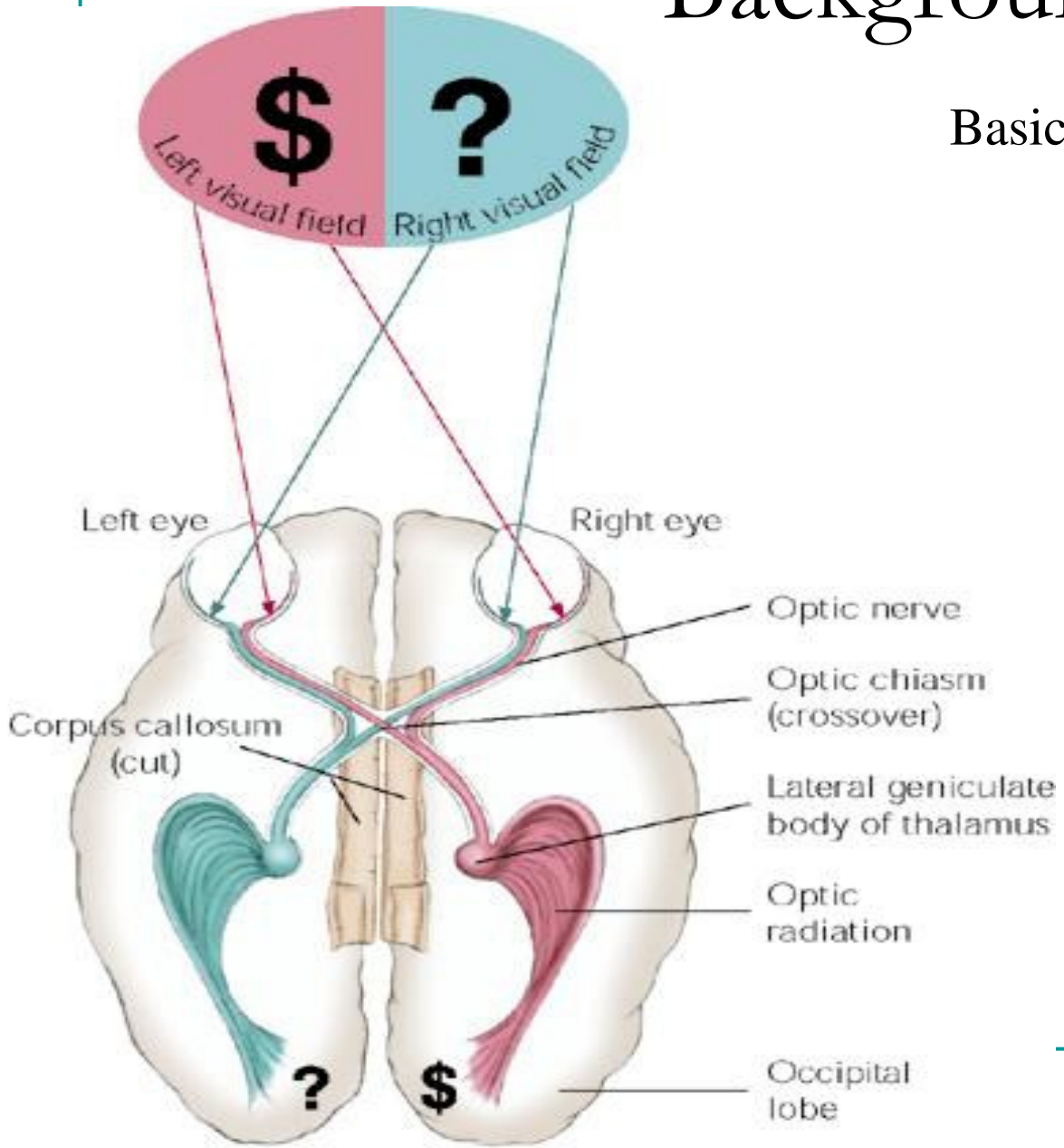
OR

orthography → meaning.

Hebrew

- Common Hebrew script omits vowels
- For example, the letters "ס פ ר" could be
  - Book - סֵפֶר
  - border - סַפָּר
  - barber – סַפָּר
- This ambiguity is not as common in English, especially that of Heterophonic Homographs.

Background



Basic Nerve Pathways of Vision

Notice that the left portion of each eye connects only to the left half of the brain; likewise, the right portion of each eye connects to the right brain. When the corpus callosum is cut, a "split brain" results. Then visual information can be directed to one hemisphere or the other by flashing it in the right or left visual field as the person stares straight ahead.

Coon, Dennis. Psychology: A Modular Approach to Mind and Behavior. Wadsworth Publishing, 2005. p 68.

Split Brain Movie (**Michael Gazzaniga**)

Split Brain

Scientific American Frontiers

http://pbs-saf.virage.com/cgi-bin/visearch?user=pbs-saf&template=template.html&squery=Pieces%2Bof%2BMind

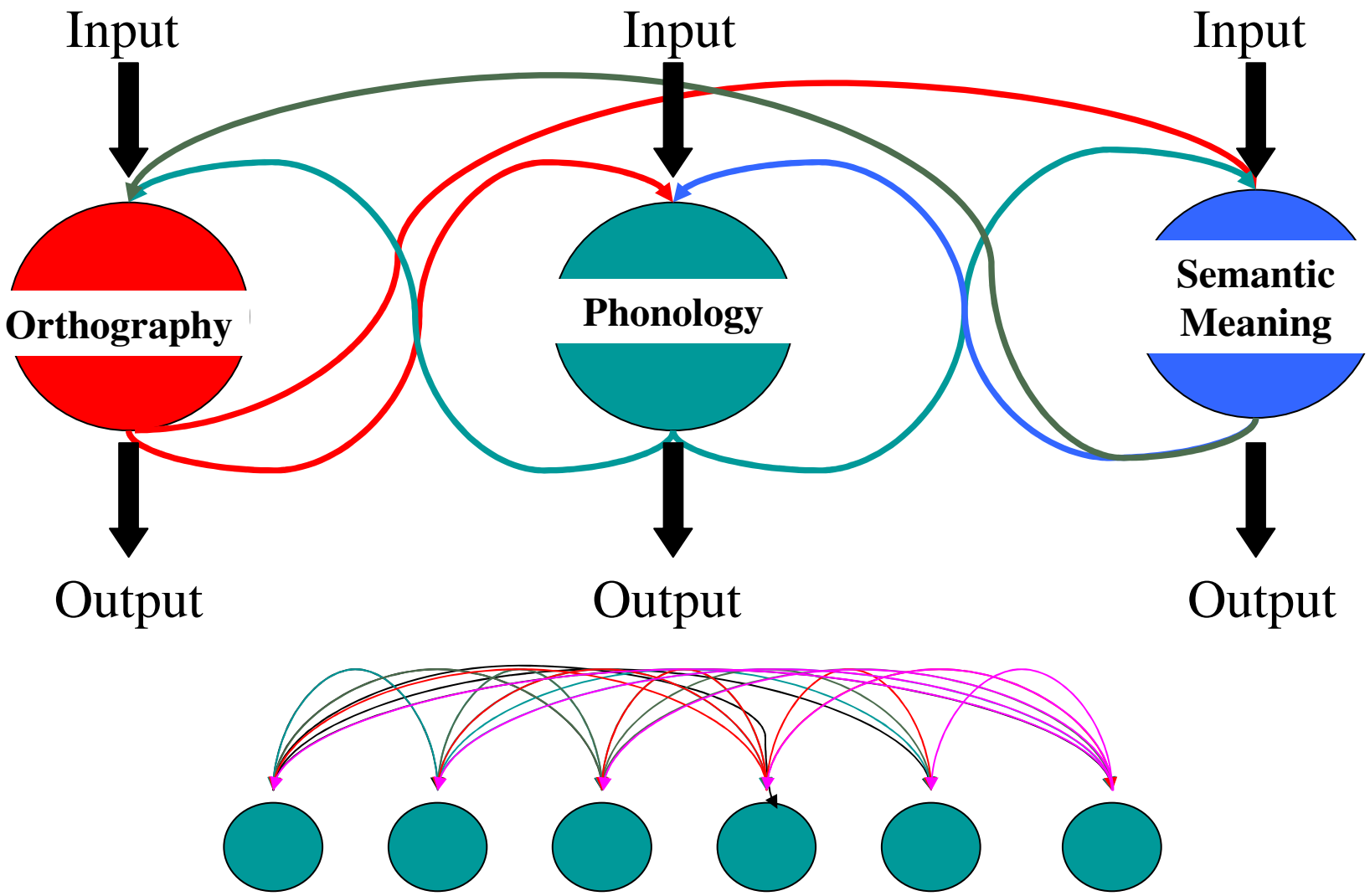
Previous finding

	Left Hemisphere	Right Hemisphere
Language Processing	Faster	Slower and less accurate
Phonological Abilities	Able to derive phonology from print	Unable to derive phonology from print
Frequencies	When encountering a word: The LH quickly focuses on a **narrow** range of **dominant** and closely related meanings	When encountering a word: The RH activates and maintains a **broader** range of **subordinate** and distantly related meanings
Context	Conflicting Findings: some say the RH is more sensitive to context, and vice versa	

- In sum, lateralization studies have reported hemispheric differences in phonological and semantic processing as well as differential sensitivity to frequency and to sentential contexts.

- This study examined the extent to which each hemisphere uses phonological, lexical (frequency) and sentential sources of information to guide the resolution process of heterophonic versus homophonic homographs.

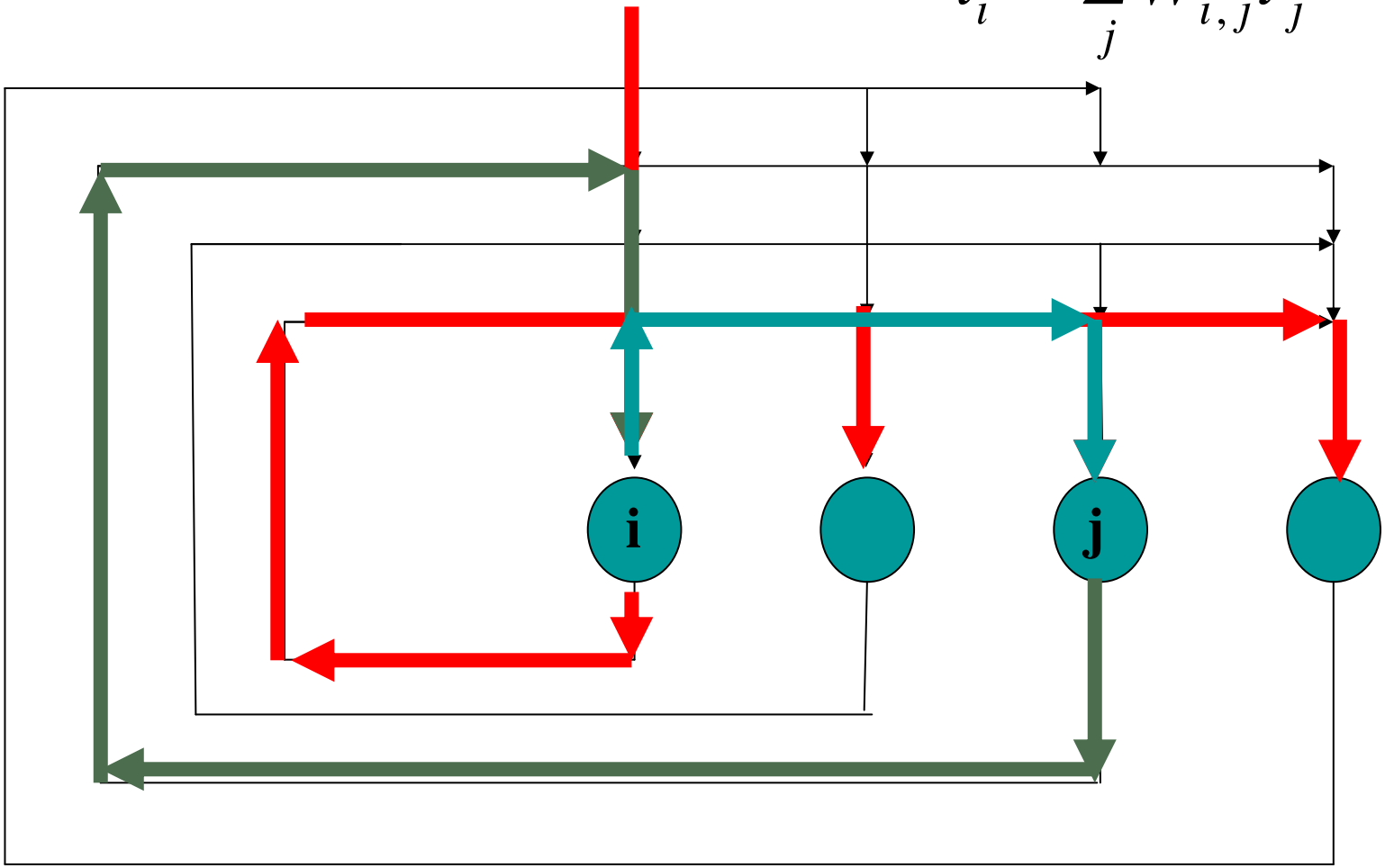
Connectionist Network (following Kawamoto (1993))



Learning Function: Changes in weights

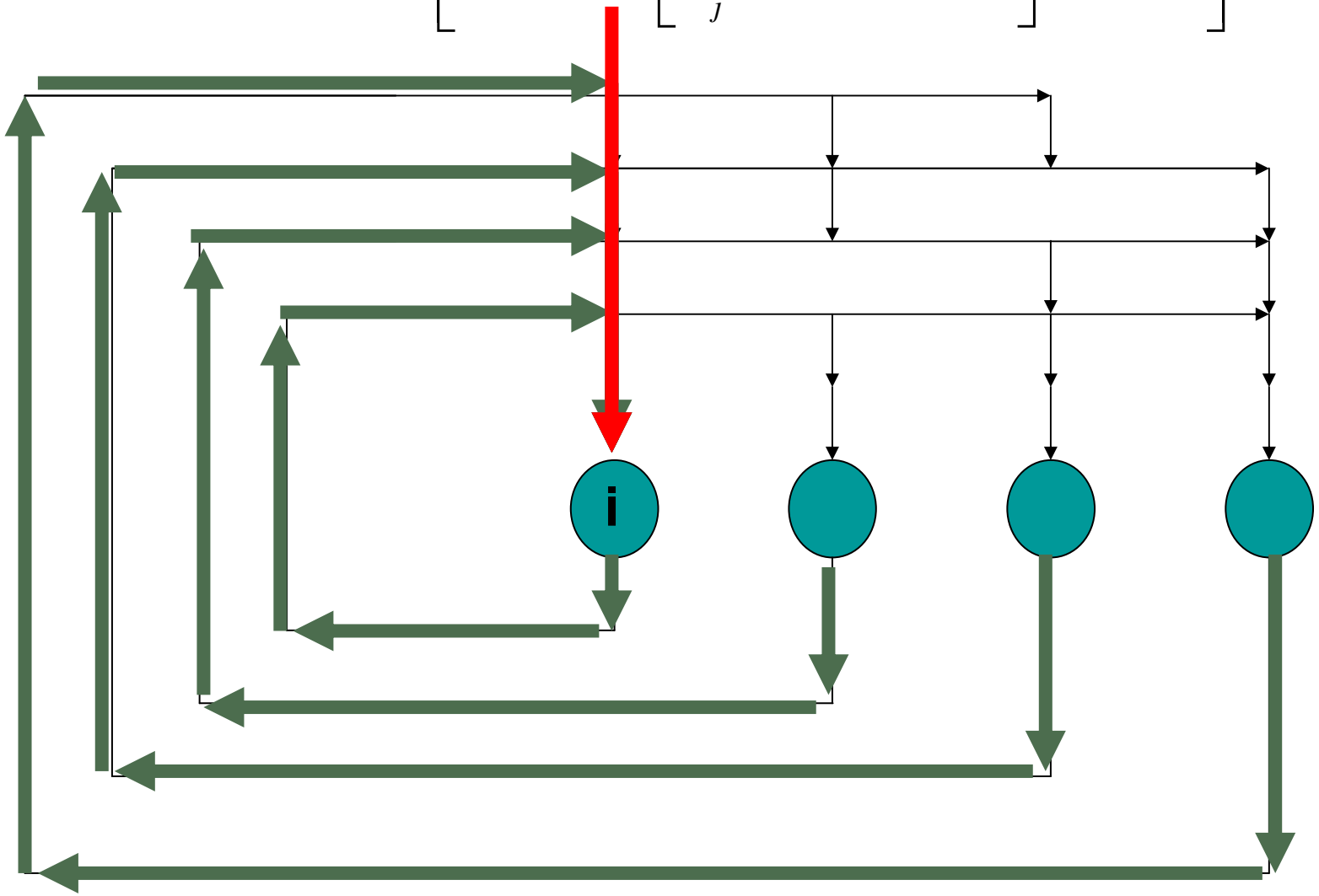
$$\Delta W_{i,j} = \eta(t_i - i_i)t_j$$

$$i_i = \sum_j W_{i,j} t_j$$



Activation Function

$$a_i(t+1) = Limit\left[\delta a_i(t) + \left[\sum_j W_{ij}(t)a_j(t)\right] + s_i(t)\right]$$



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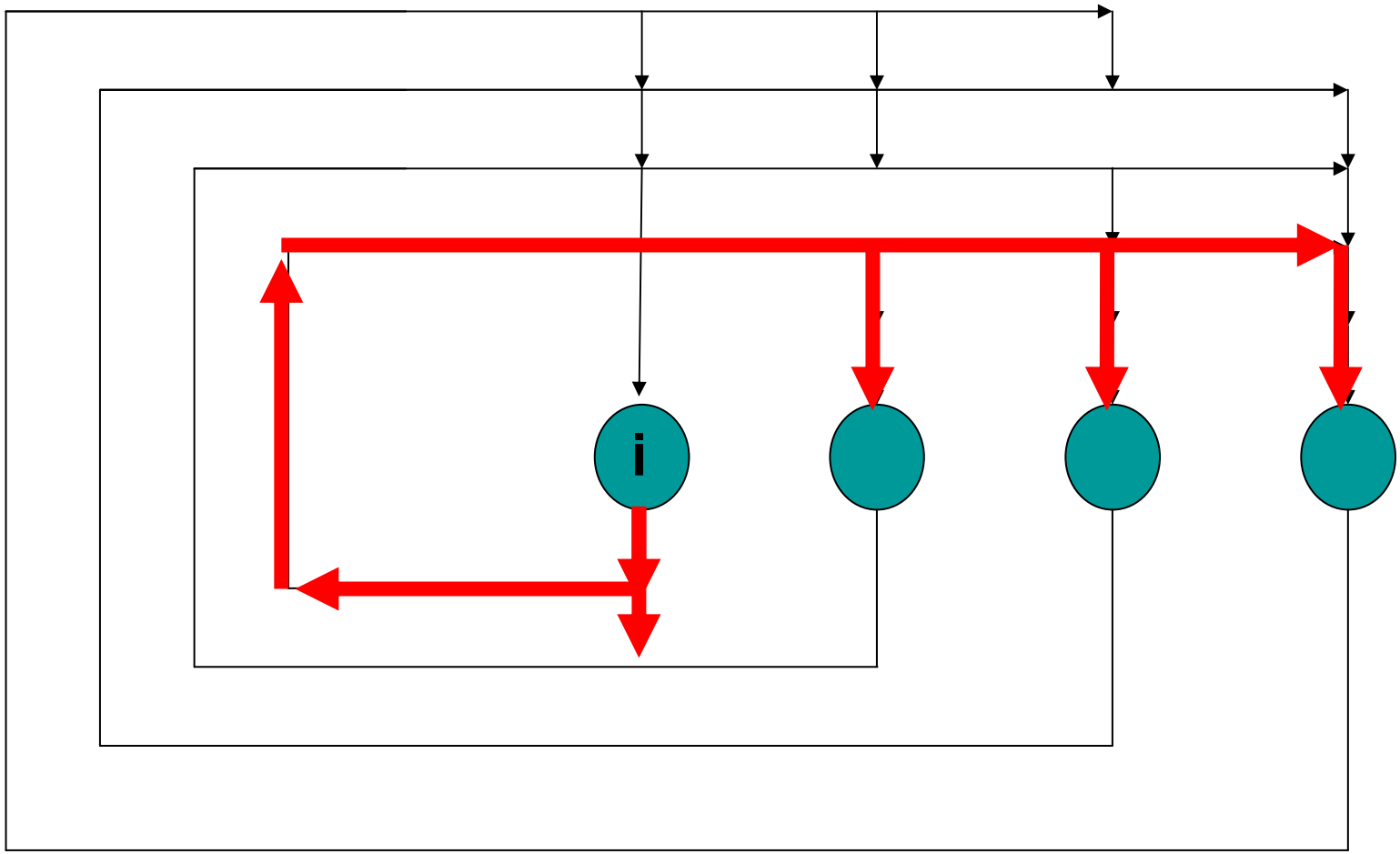
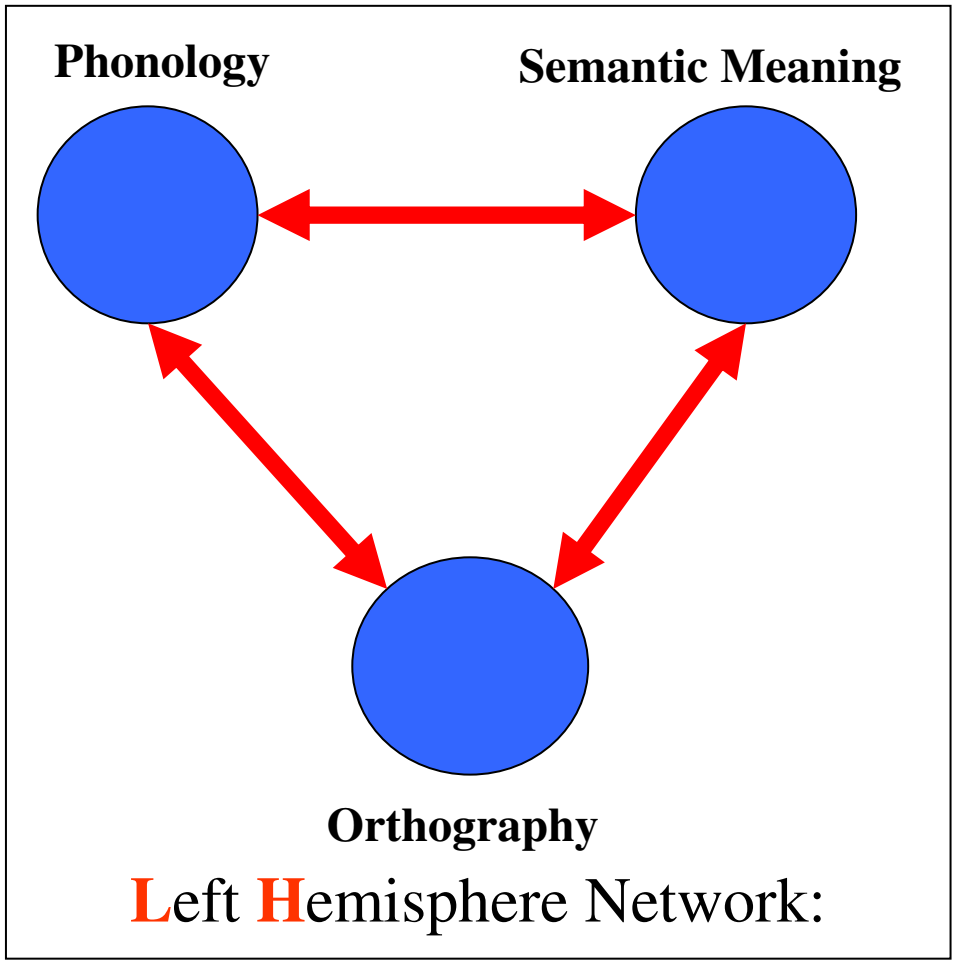
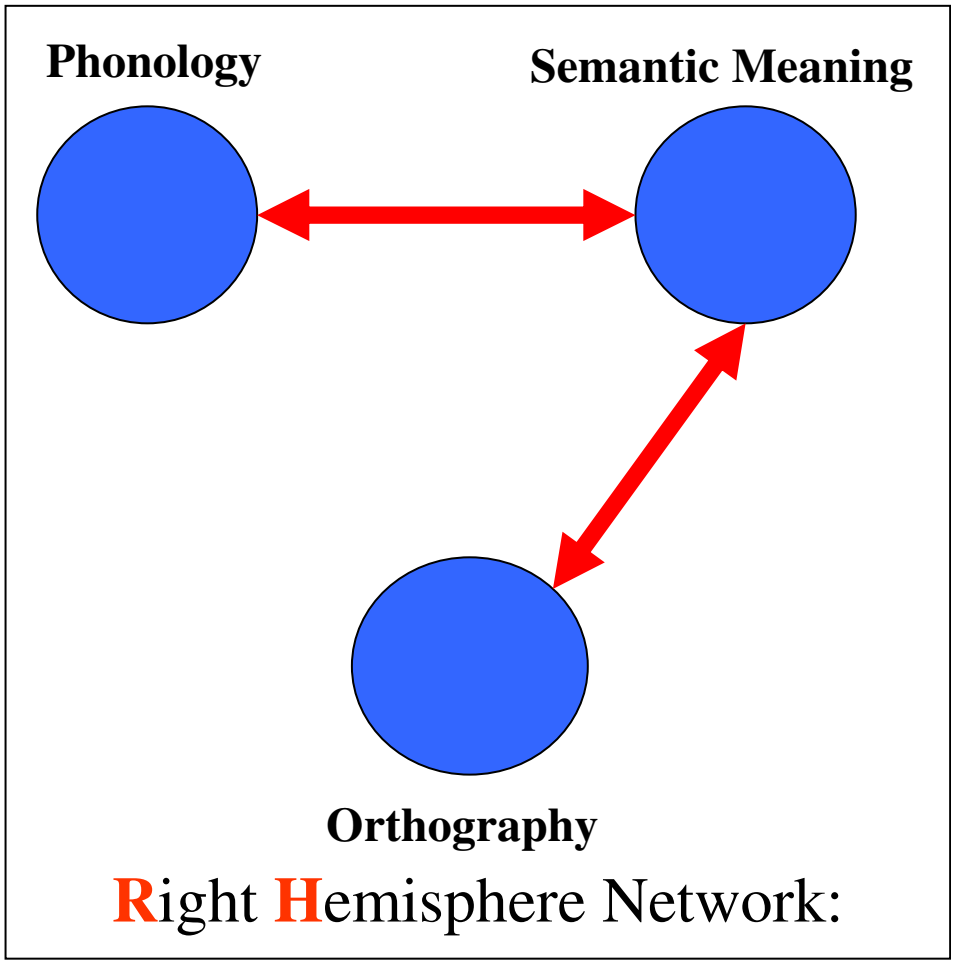


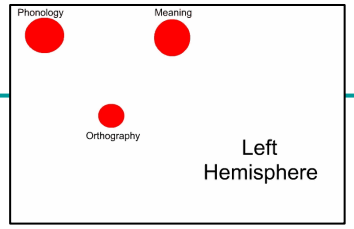
The Split Reading Model

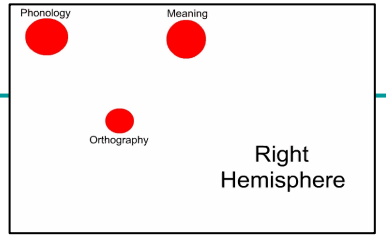


Left Hemisphere Network:

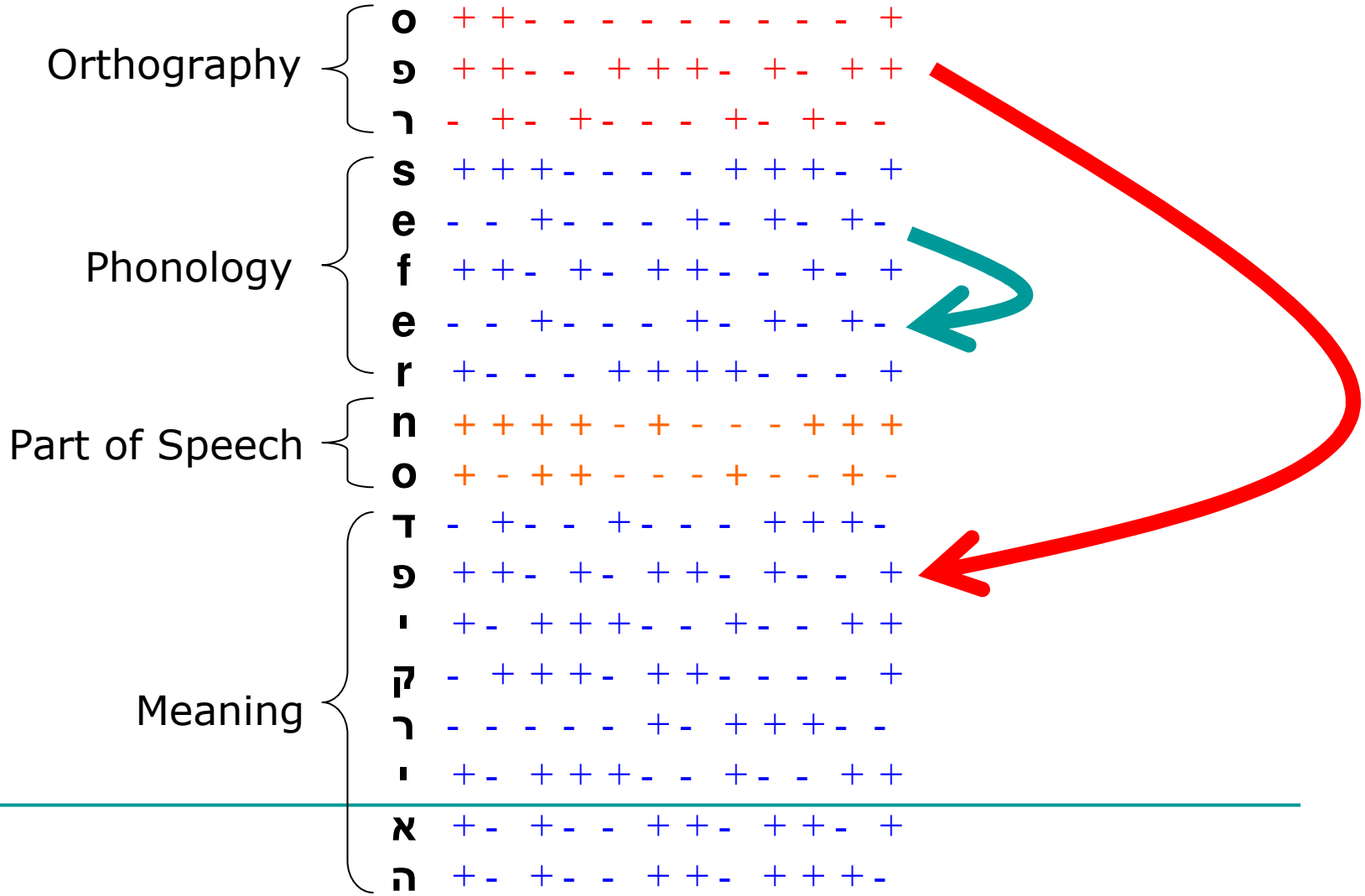


Right Hemisphere Network:





Detailed description of the representation of the dominant sense of "ספר"



Representation

- 24 polarized 3-letter noun homographic pairs:
  - 12 Homophonic
  - 12 Heterophonic

  } 48 Meanings

- Words are represented as distributed patterns of activity over a set of simple processing units.

Representation

The 288 features are grouped into sets of 16:

- 3 character x 16 bit → 48 bit **Spelling**
- 5 character x 16 bit → 80 bit **Pronunciation**
- 2 character x 16 bit → 32 bit **Part of Speech**
- 8 character x 16 bit → 128 bit **Meaning**

For example:

- ספר sefer no דפיקריאה
- ספר sapar no גוזרשיער

Training

- In training the net learns (+) and (–) values only
  - (+) input +1 value
  - (-) input -1 value
- Phase 1:
  - Initially, connections between the units were set to small random values
- Phase 2:
  - Each training session a random homogeneous entry was presented to the network
    - Dominant meanings were selected more than subordinate meanings
  - In total, the network underwent 4,000 training sessions

- **12** identical networks were used to simulate **12 subjects**

Testing

- After training the networks were first tested by presenting only orthographic inputs
  - The following tests included contextual clues which aided in meaning selection

- We tested the net by presenting a vector that contains:
  - +0.25 if the corresponding input feature was (+)
  - -0.25 if the corresponding input feature was (–)
  - 0 if the corresponding input feature was neutral

- Output of the networks were between -1 and +1

Assessment 1: Access to Meaning

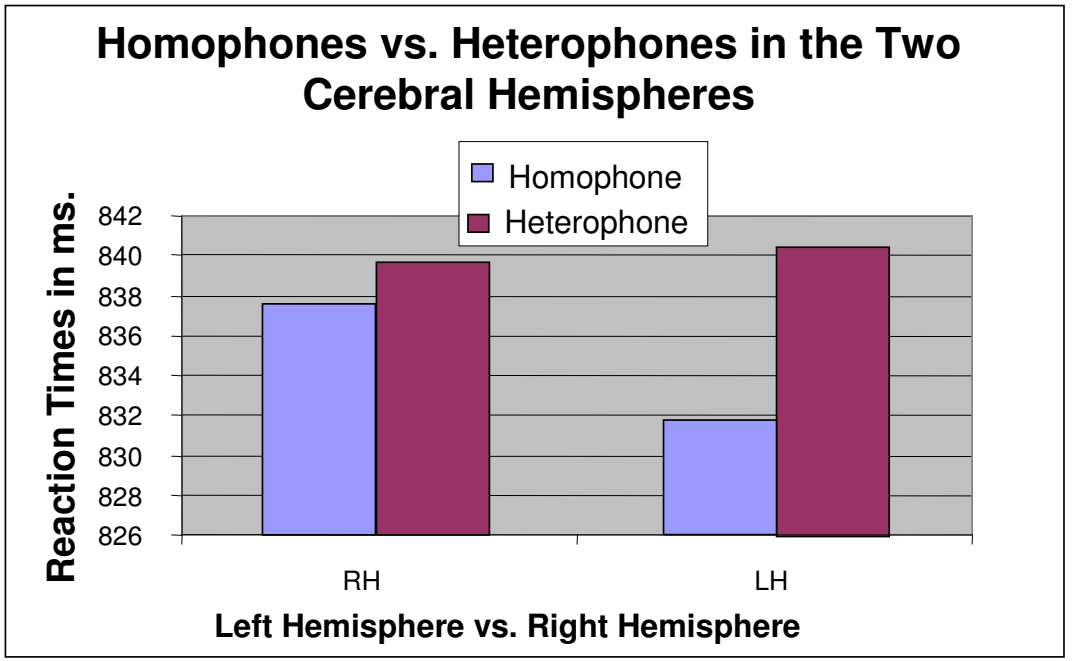
- We measured the network's **number of iterations** for all the units until they became saturated
  - Units in the fields of pronunciation, part of speech, and meaning

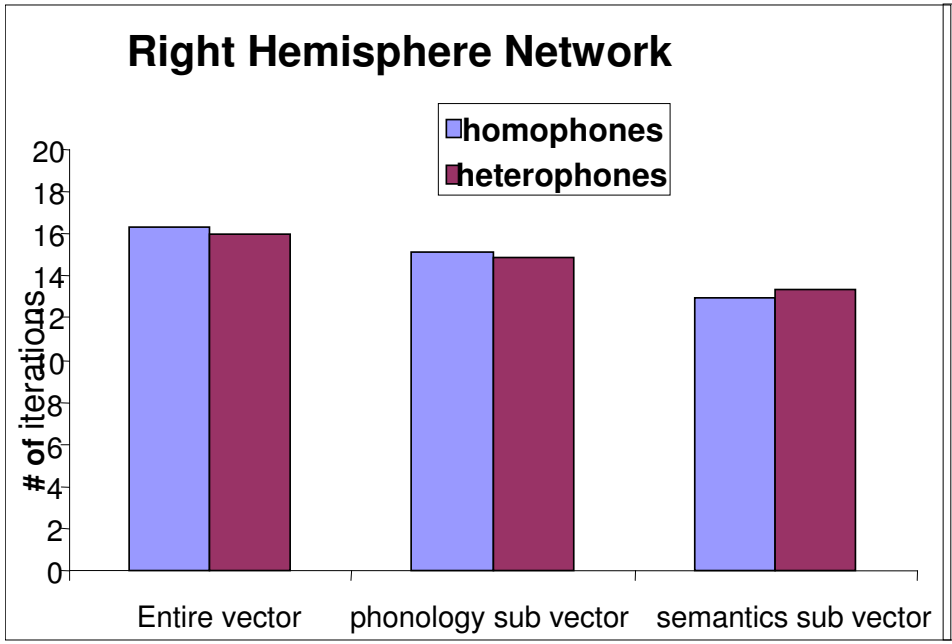
- Error Response:
  - if the pattern of activity did not correspond with the training input

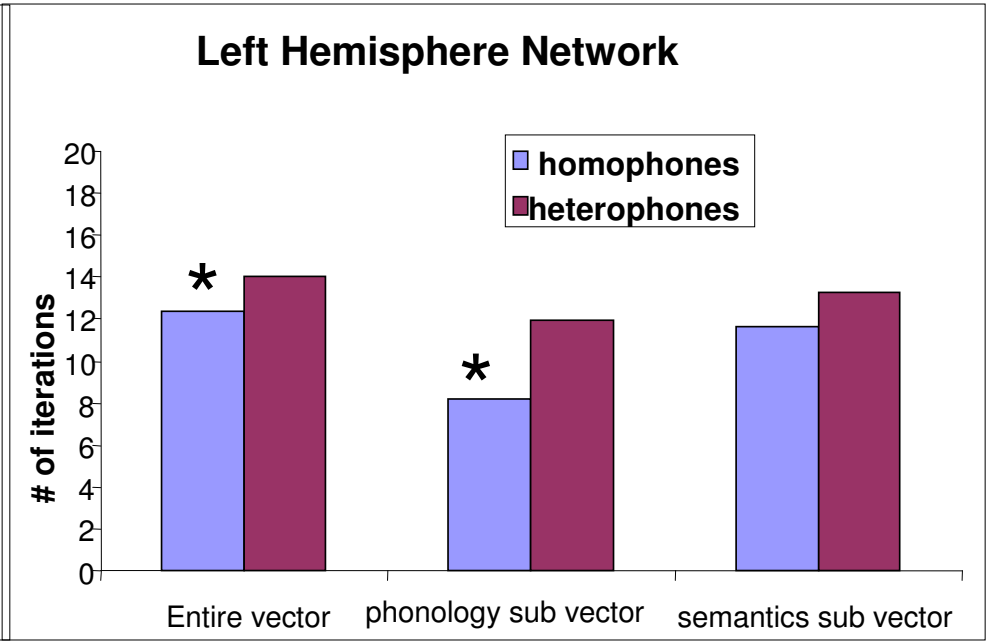
  OR
  - if the units did **not saturate** after 120 iterations.

Results

Human Subjects







Computational Results

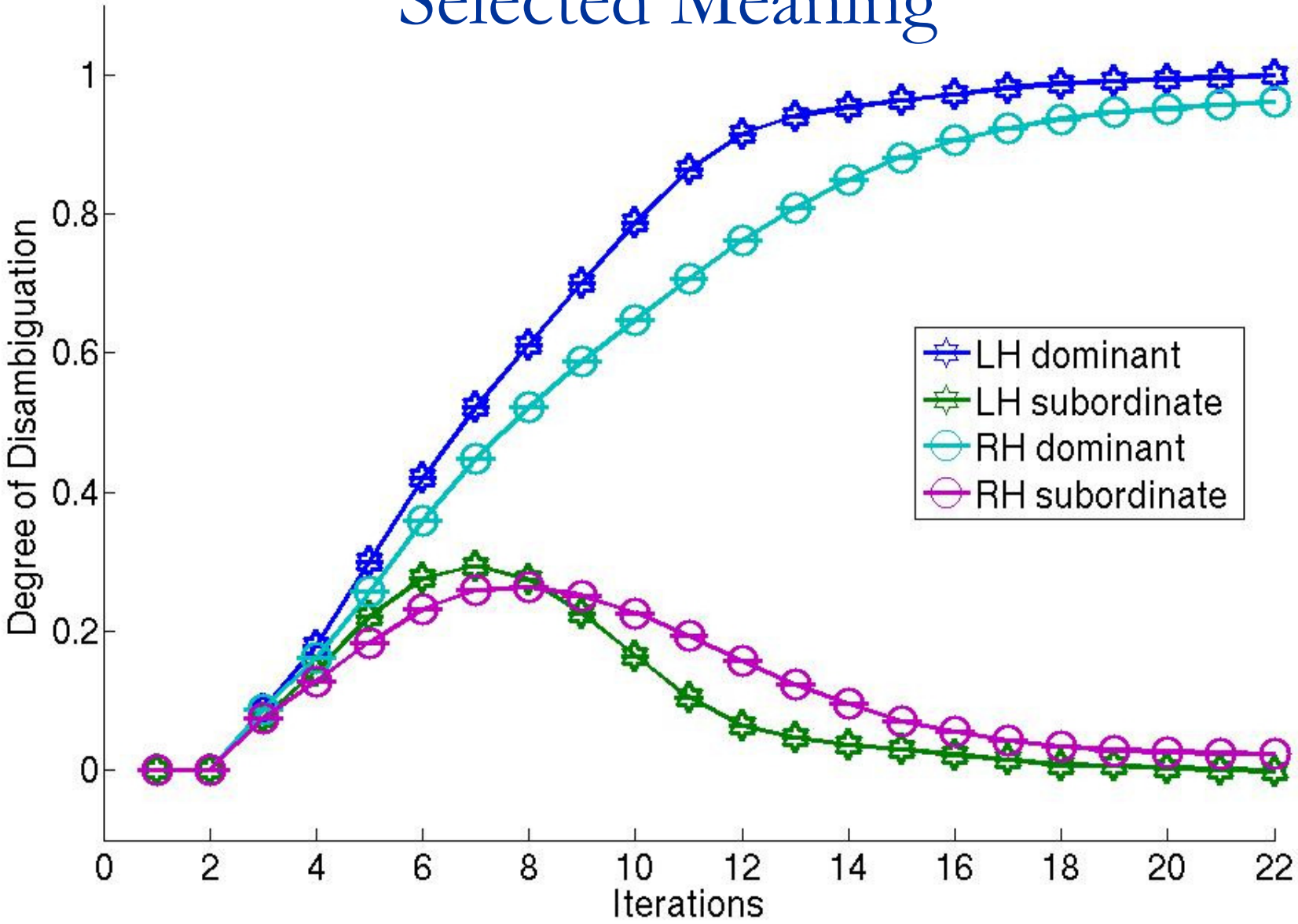
Units	LH		RH	
	Homophone	Heterophone	Homophone	Heterophone
Phonologic	8.89	12.23	13.03	13.57
Semantic	11.49	13.06	14.95	14.60
Entire vector	12.20	14.15	16.28	16.02
Error	0%	0%	9.72%	7.68%

Assessment 2 : Timeline of Access to Meaning

The activation of the meanings of the homographs were also examined as a function of time:

We **compared the pattern** of activity of the RH and LH networks' response corresponding to the dominant and subordinate meaning of a given homograph across the iterations.

Comparison of the LH and RH to the Selected Meaning



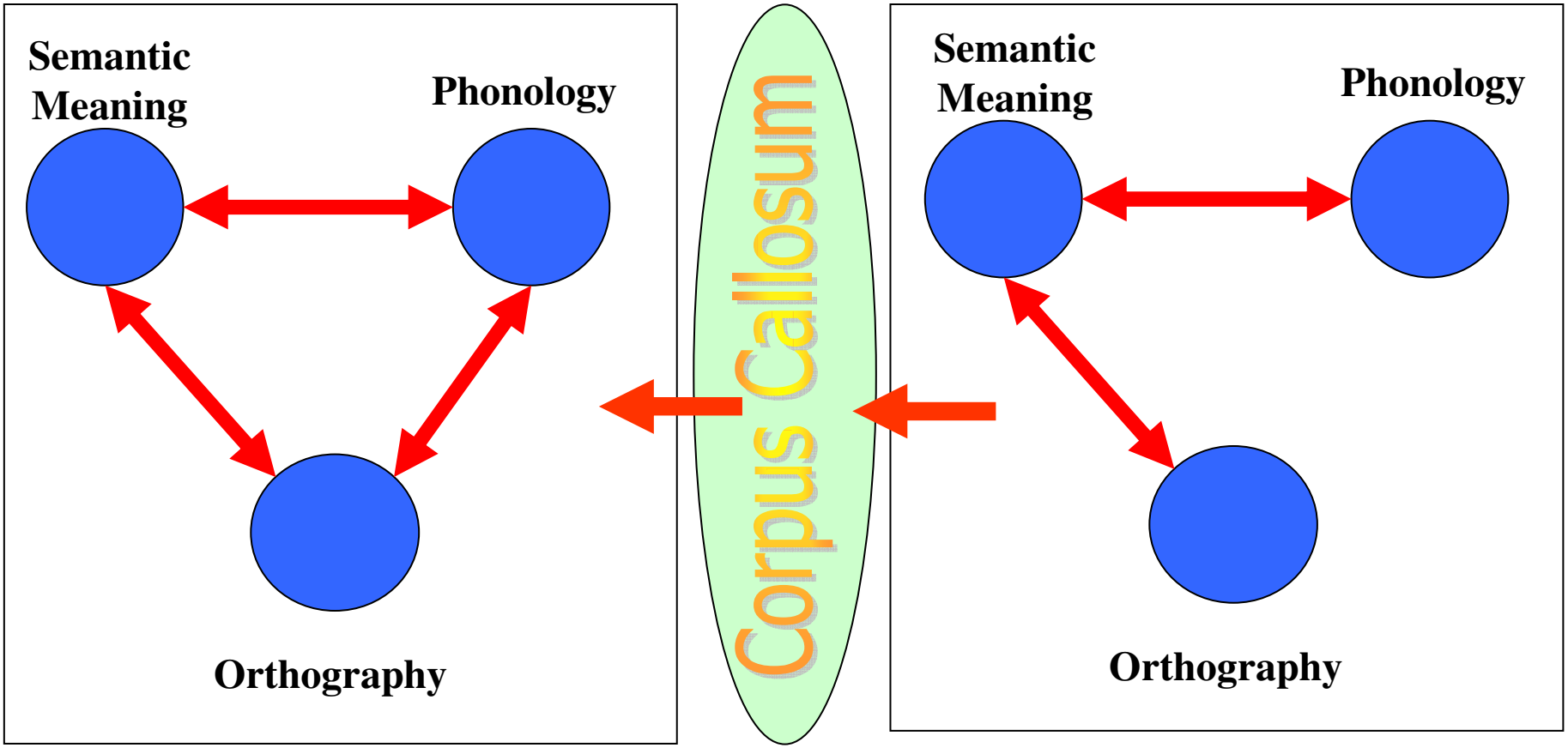
Conclusions

- Left Hemisphere:
  - **All sources** of information (e.g., phonology and semantics) are available immediately
  - As a result, selection processes are **faster** and **more sensitive** to phonological information
- Right Hemisphere:
  - **Not all sources** of information are available immediately
  - As a result, selection processes are **slower** and **less sensitive** to phonological information

The benefits of the two nets…

- LH processing is efficient because it is **fast** and **non-ambiguous**
  - immediate selection of one alternative meaning
- However, while in most cases the rapid LH selection of the dominant meaning is contextually appropriate, there are some cases in which further contextual clues lead to the consideration and selection of the subordinate meaning after the initial selection of the dominant
- This is when RH processing is needed…

Corpus Callosum Model



Left Hemisphere Network:

Right Hemisphere Network:

Results on Corpus Callosum Model

"LH only" - LH receives counter clues **without** intervention from RH.

"RH only" - RH receives counter clues **without** intervention from LH.

"LH+RH"- LH receives counter clues **and** RH phonologic and semantic information.

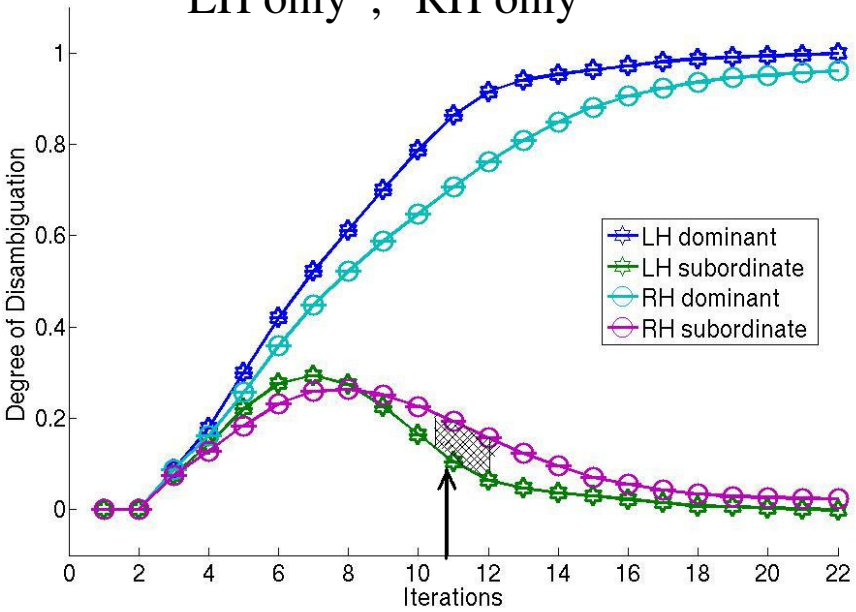
"LH+RH +random" - LH receives counter clues **and** RH phonologic and semantic information containing additional small random values.

	Error / Non-convergence (out of 288)								Speed of convergence (Iteration)			
Method	LH only		RH only		LH+RH		LH+RH +random		LH only	RH only	LH+RH	LH+RH +random
Dominant to Subordinate	49	129	0	114	9	81	0	0	40.75±3.9	25.43±6.68	34.74±6.68	18.1±6.04
Subordinate to Dominant	0	60	0	5	0	60	0	55	26.7±5.3	14.26±2.19	26.48±5.12	22.38±4.67

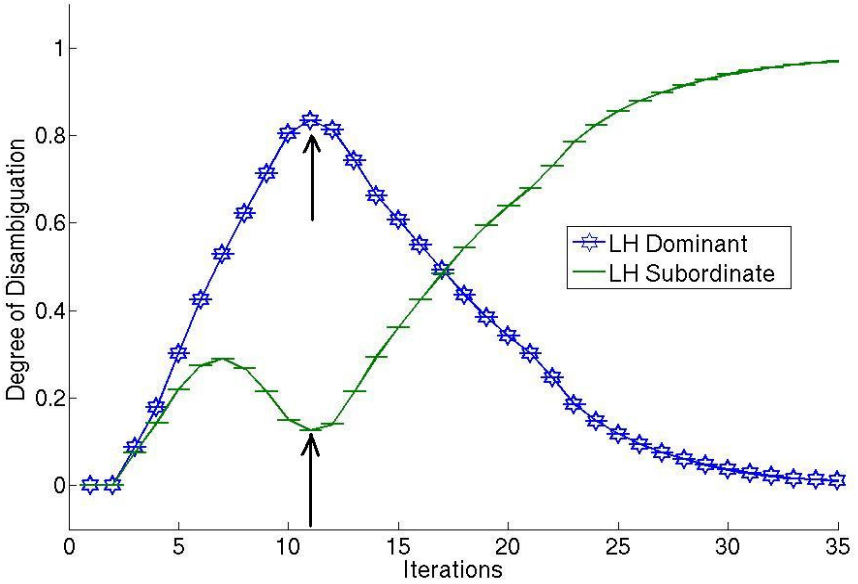
Errors

Non converges

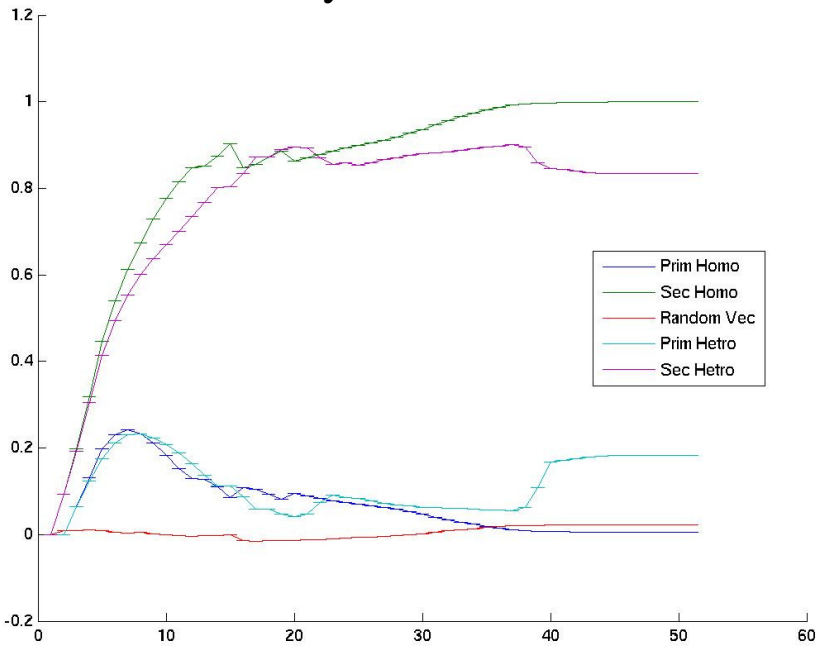
"LH only", "RH only"



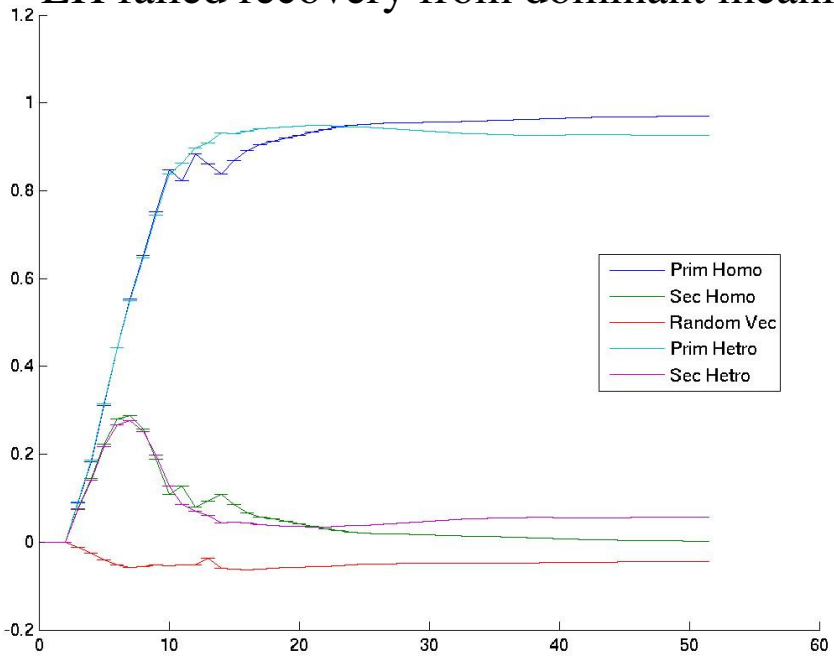
"LH + RH + random"



LH failed recovery from subordinate meaning



LH failed recovery from dominant meaning



Benefits of the Model

- Psychological:
  - Expands the traditional model to include hemispheric differences in understanding words during the reading process
  - Furthers the understanding of Dyslectic deficiencies and enhances the ensuing methods of treatment
  - Validates existing and future behavioral findings
- Computational:
  - Validates assumptions regarding the organization of information in the brain

Thanks to

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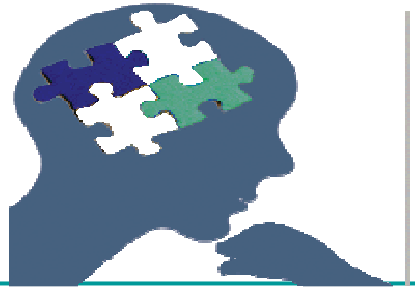

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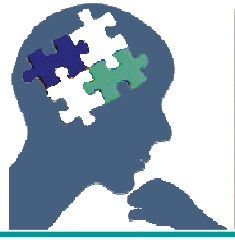

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Thank You