Generalization over distinct associative substrates with a dynamic associative net

Kevin Shabahang, Hyungwook Yim, Simon Dennis

Some simple associations

eagles - fly

eagles - feathers

falcons - fly

What may be inferred?

eagles - fly

eagles - feathers

falcons - fly

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falcons - feathers?

What may be inferred?

eagles - fly

eagles - feathers

falcons - fly

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falcons - feathers?

falcons - eagles?

Generalization

eagles - fly

eagles - feathers

falcons - fly

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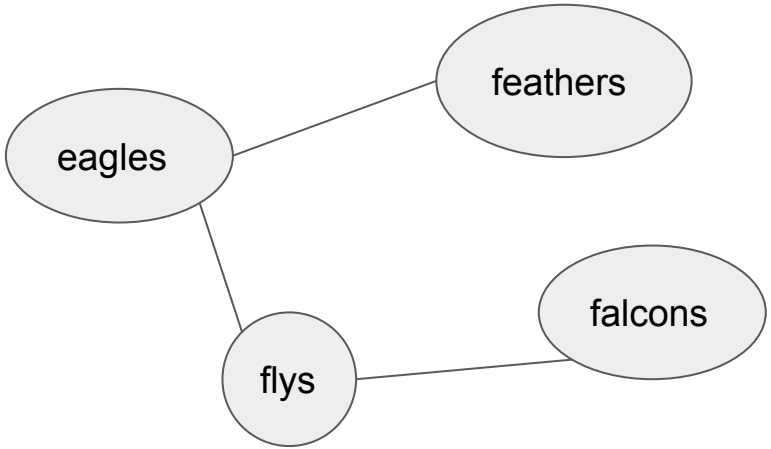
falcons - feathers?

falcons - eagles?



Generalization

eagles - fly

eagles - feathers

falcons - fly

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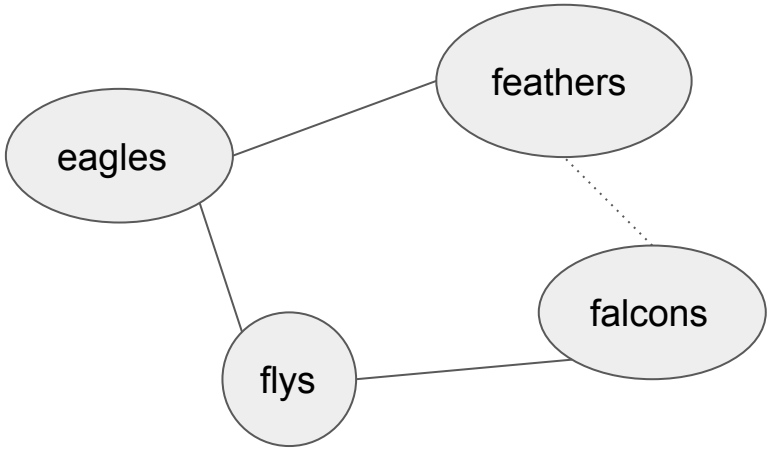
falcons - feathers?

falcons - eagles?



Generalization

eagles - fly

eagles - feathers

falcons - fly

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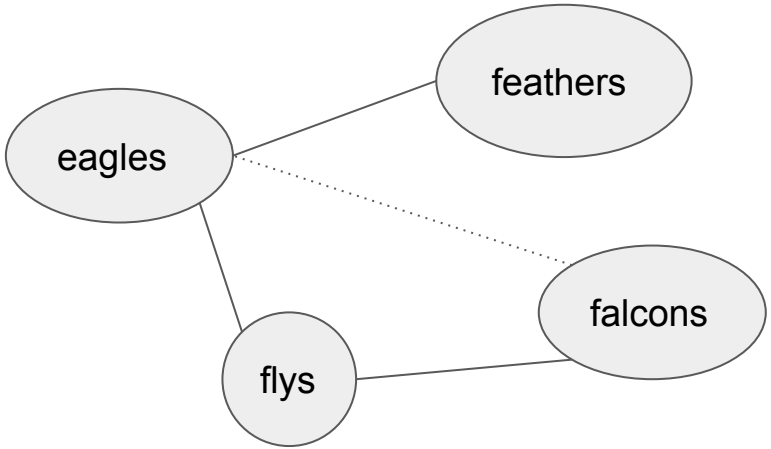
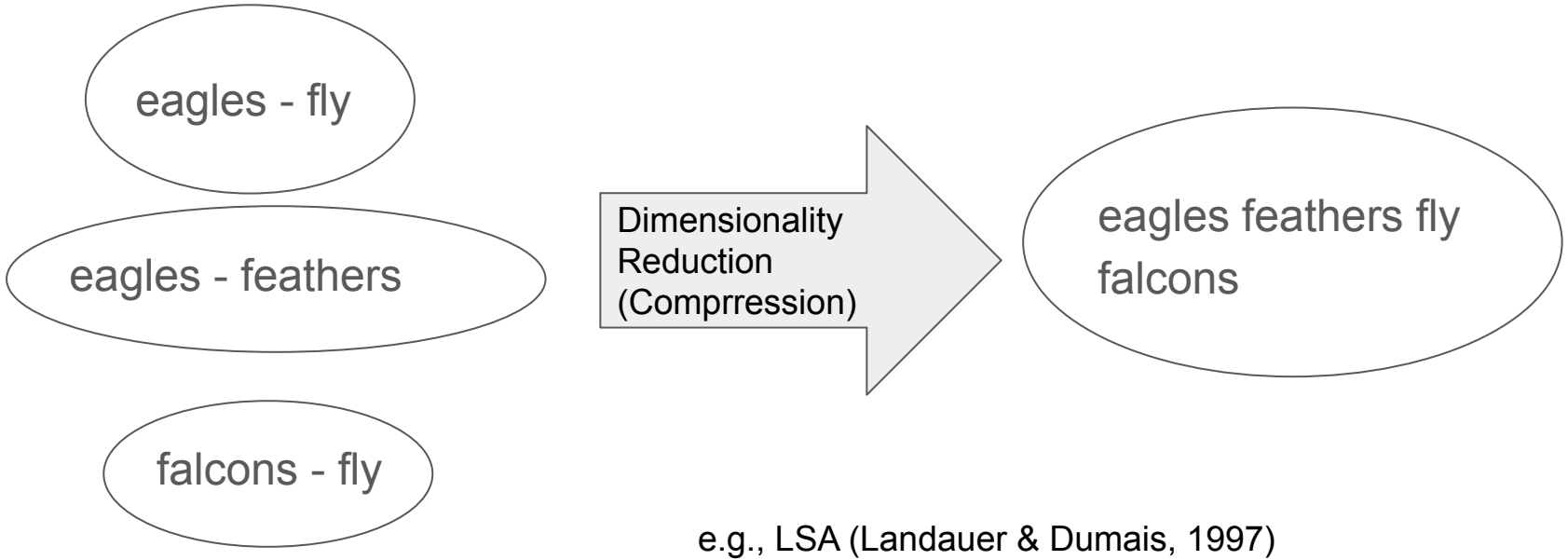
falcons - feathers?

falcons - eagles?



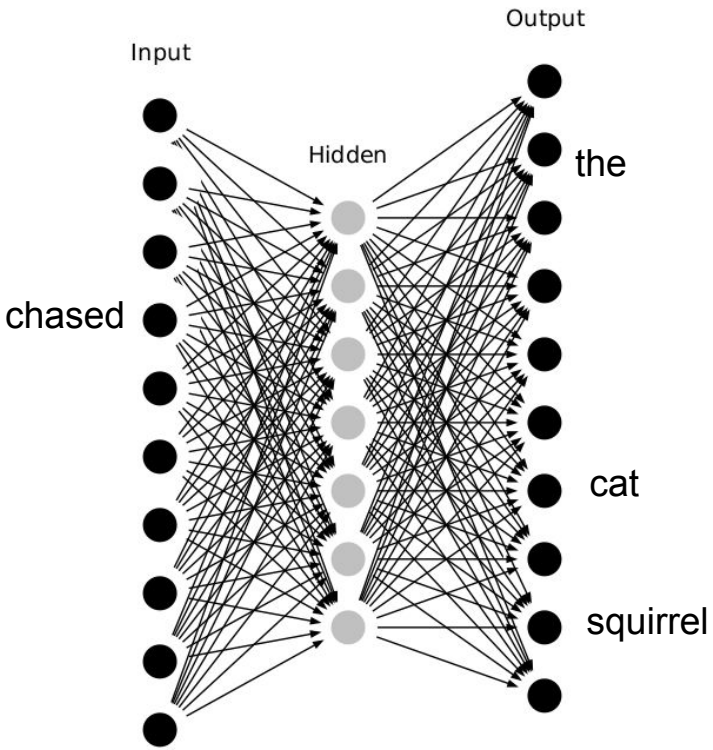
Generalization at encoding



e.g., LSA (Landauer & Dumais, 1997)

word2vec (Mikolov et al. 2013; Skipgram)

The cat <u>chased</u> the squirrel



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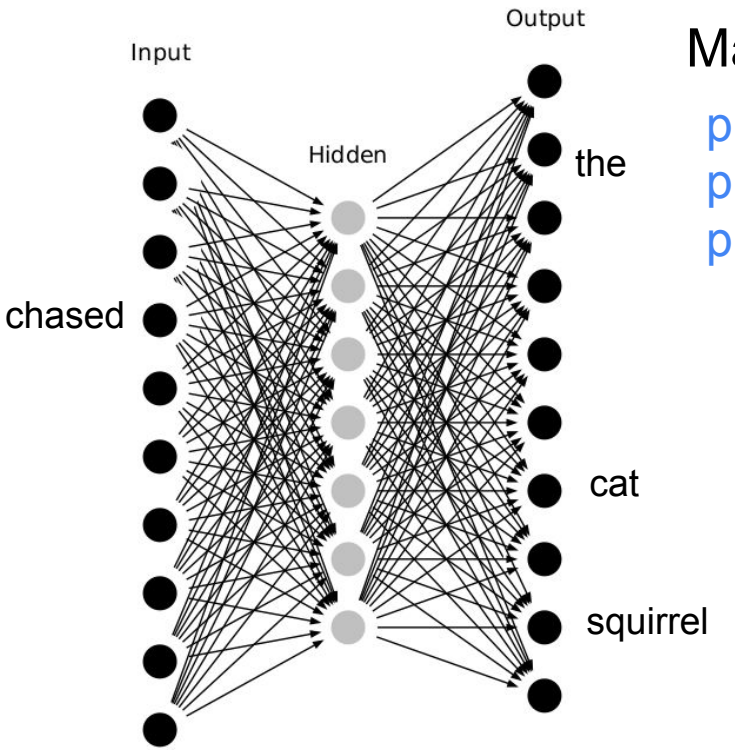
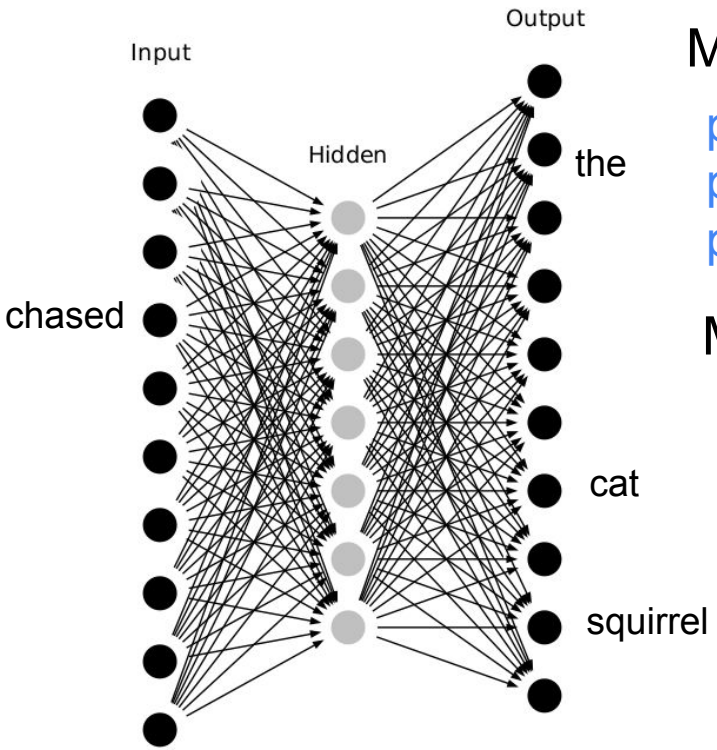


Maximize

p(the | chased)
p(cat | chased)
p(squirrel | chased)

word2vec (Mikolov et al. 2013; Skipgram)

The cat <u>chased</u> the squirrel



Maximize

p(the | chased)
p(cat | chased)
p(squirrel | chased)

Minimize

p(sky | chased)
p(tree | chased)
p(fridge | chased)
.
.
.

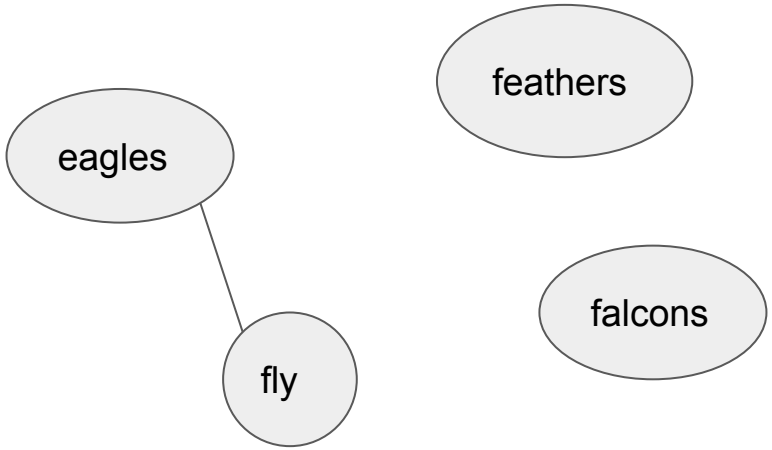
k

Problems with dimensionality reduction

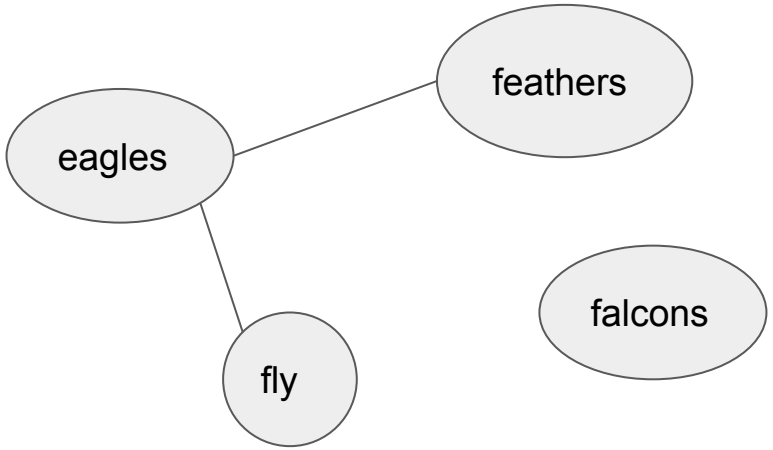
- Catastrophic interference
  - Compressing the original patterns increases overlap
- Lack of one-shot learning
  - People can learn a new association with a single exposure

Hebbian learning in an associative net

eagles - fly



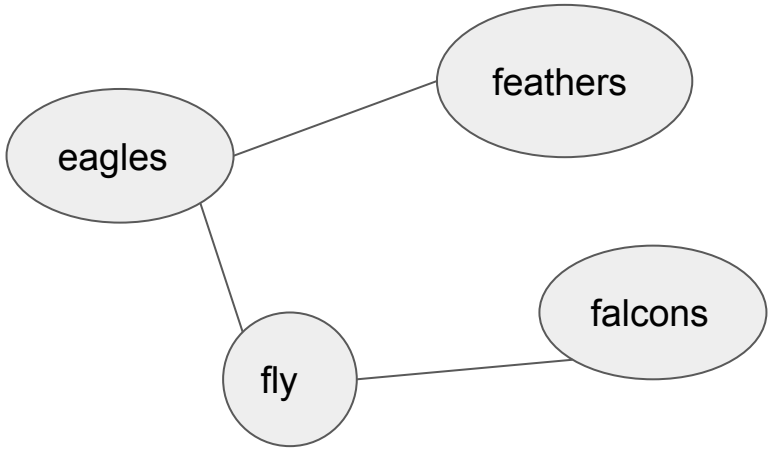
Hebbian learning in an associative net



eagles - fly

eagles - feathers

Hebbian learning in an associative net

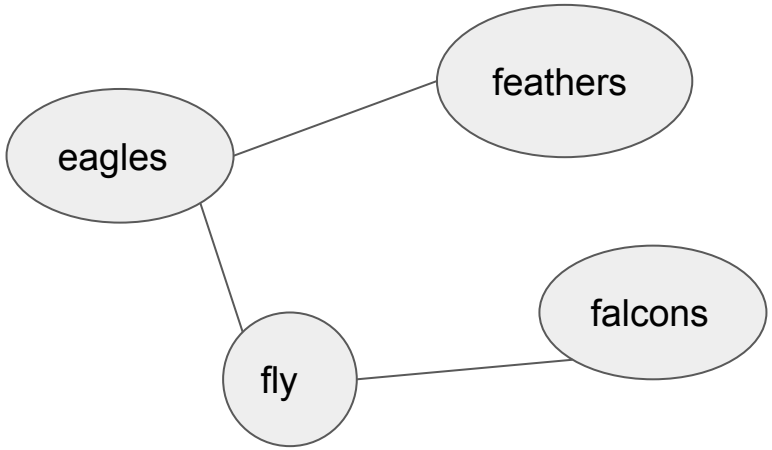


eagles - fly

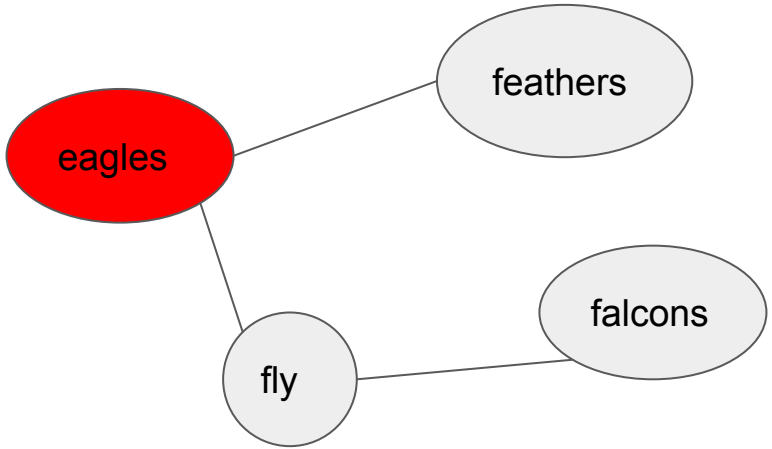
eagles - feathers

falcons - fly

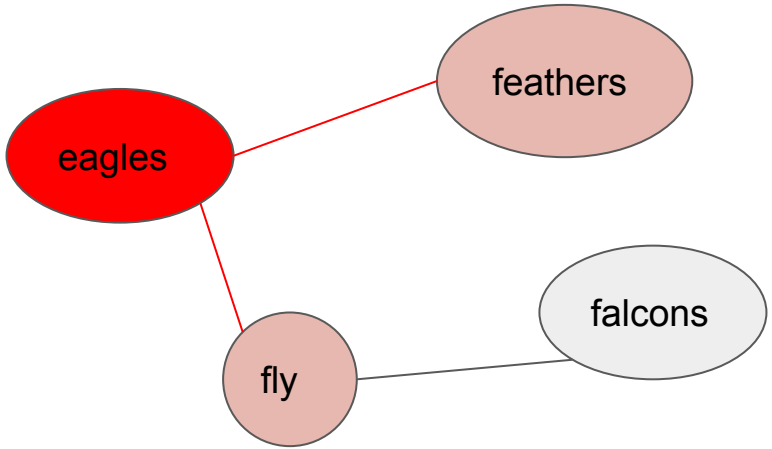
Generalization at retrieval with spreading activation



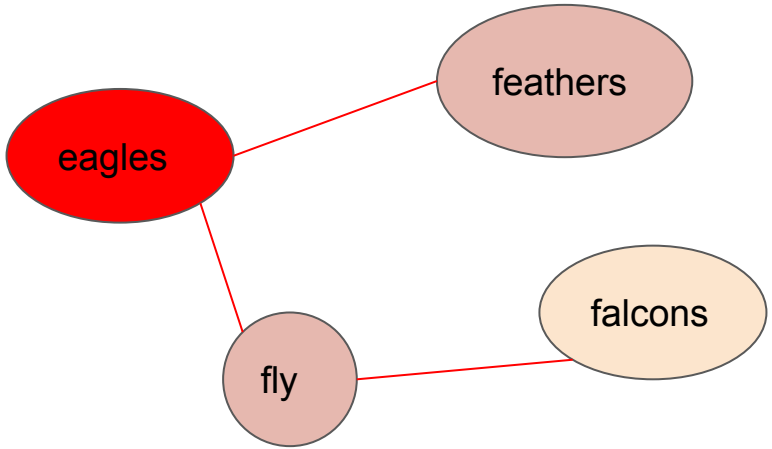
Generalization at retrieval with spreading activation



Generalization at retrieval with spreading activation



Generalization at retrieval with spreading activation

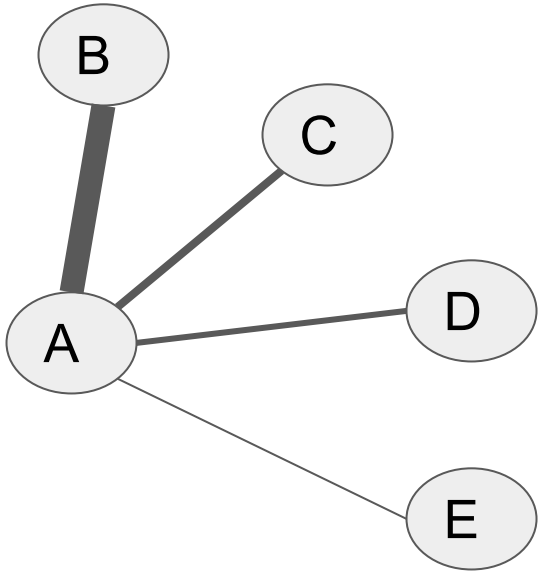


…”eagles” activates “falcons” without a direct association

Generalization at retrieval

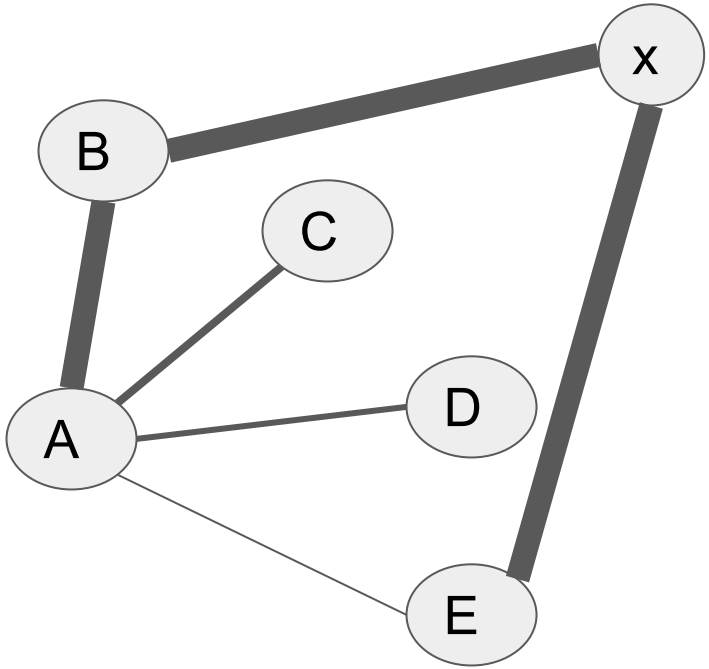
- Event-specific details (co-occurrence) are stored directly
  - Capable of one-shot learning
- Generalization occurs during memory retrieval
  - More dynamic
  - Context-dependent

Generalization through spreading activation



Activation and connection strengths should align

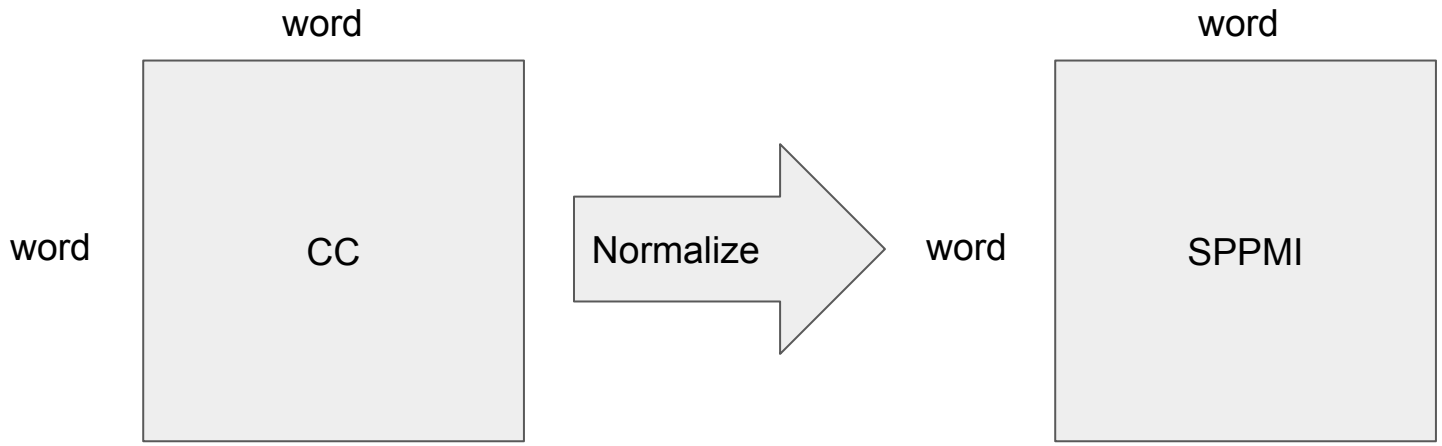
Generalization through spreading activation



Activation and connection strengths should not align

Representation: associative network

... shambled after **as** i 've been doing all my lifeafter people who interest me , because the only people for me are the mad ones , the ones who are mad to live , mad to talk , mad to be saved , desirous of everything at the same time , the ones who never yawn or say a commonplace thing , but burn , burn , burn like fabulous yellow roman candles...



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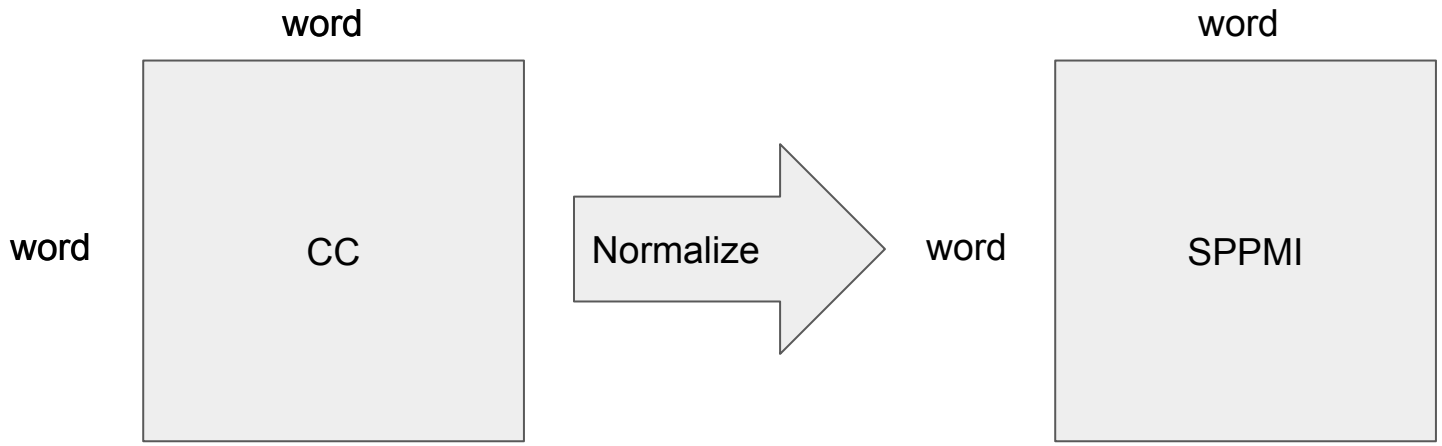

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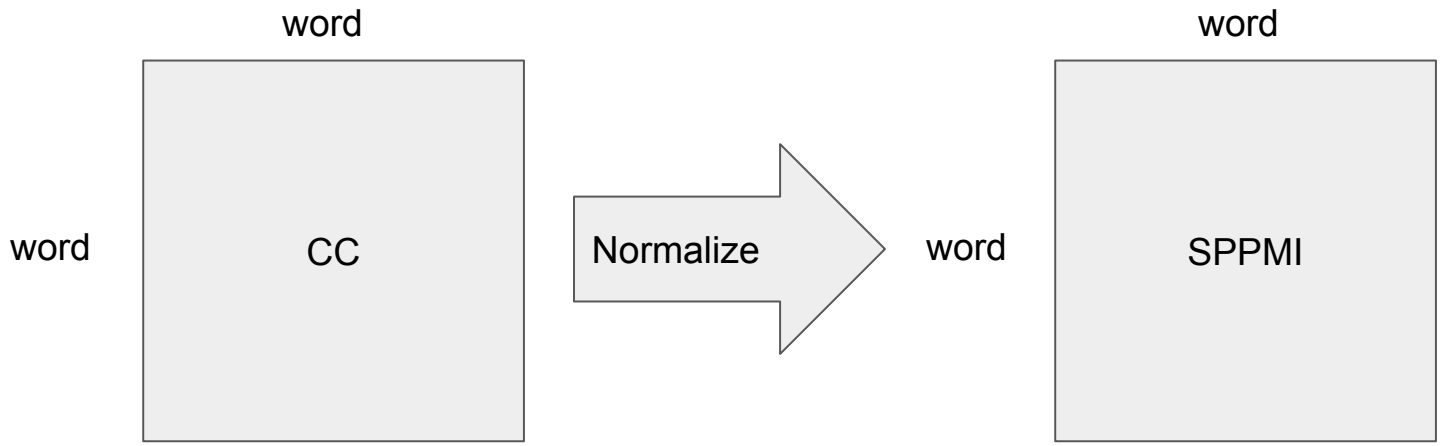
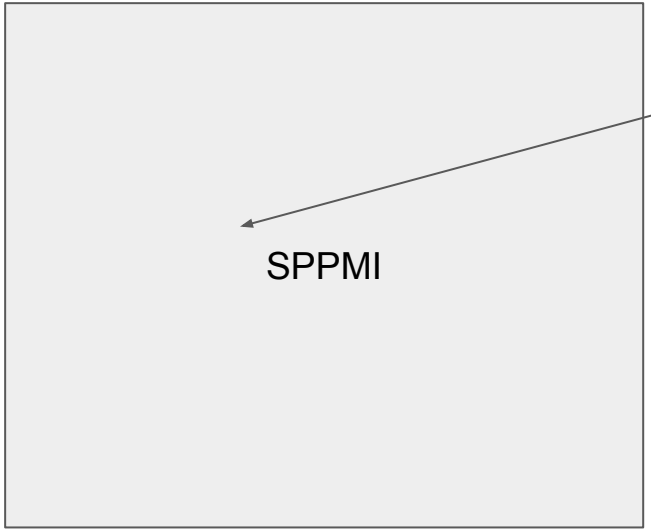


Representation: associative network

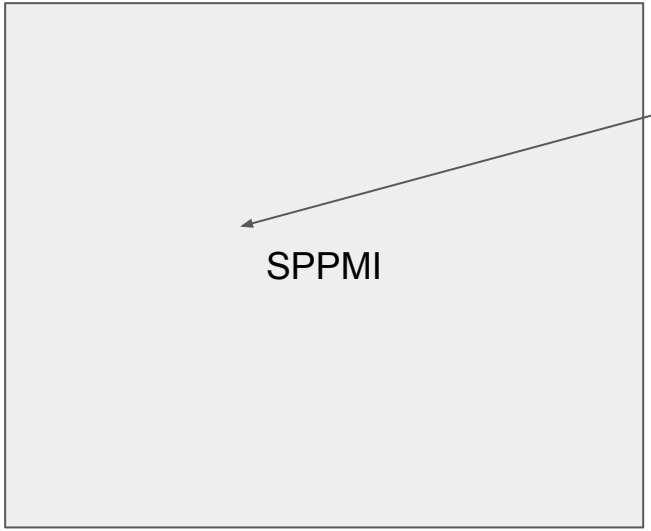
Shifted Positive Pointwise Mutual Information



$$SPPMI_{ij} = (\log(\frac{\hat{p_{ij}}}{\hat{p_i}\hat{p_j}}) - \log(k))^+$$

Representation: associative network

Shifted Positive Pointwise Mutual Information



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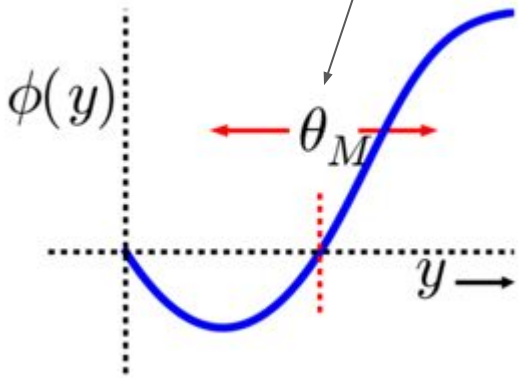


Bienenstock, Cooper, and Munro 1982

cf Barlow's "Suspiscious Coincidence Detector"

Process: Dynamic Eigen Net

$$\mathbf{x}_{t+1}^T = \frac{\mathbf{x}_t^T(\mathbf{W} + \mathbf{x}_0\mathbf{x}_0^T)}{\|\mathbf{x}_t^T(\mathbf{W} + \mathbf{x}_0\mathbf{x}_0^T)\|}$$

$$\mathbf{x}^T_{t+1} = \mathbf{x}^T_t(\mathbf{W} + \mathbf{x}_0\mathbf{x}^T_0) = \Sigma[(\lambda_i\mathbf{x}^T_t\mathbf{e}_i)\mathbf{e}^T_i] + (\mathbf{x}^T_t\mathbf{x}_0)\mathbf{x}^T_0$$

Let $\mathbf{e}'_{max}$ be the primary eigenvector of $(\mathbf{W} + \mathbf{x}_0\mathbf{x}^T_0)$
and λ'_{max} be the corresponding eigenvalue

Then,

$$\Sigma[(\lambda_i\mathbf{x}^T_\infty\mathbf{e}_i)\mathbf{e}^T_i] + (\mathbf{x}_\infty{}^T\mathbf{x}_0)\mathbf{x}^T_0 = \lambda'_{max}\mathbf{e}'_{max}$$

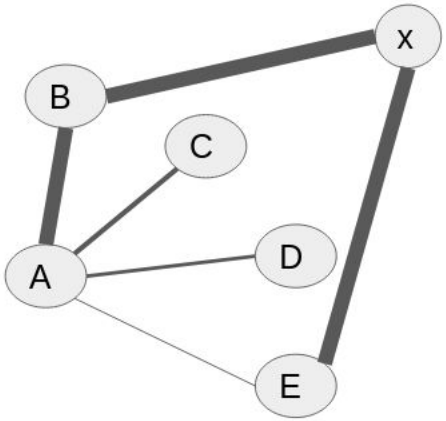
Word relatedness and/or similarity judgements

- Similarity
  - coffee - tea (↑)
  - midday - noon (↑)
  - coffee - cup (↓)
- Relatedness
  - coffee - cup (↑)
  - computer - software(↑)
  - media - gain (↓)

Word relatedness and/or similarity judgements

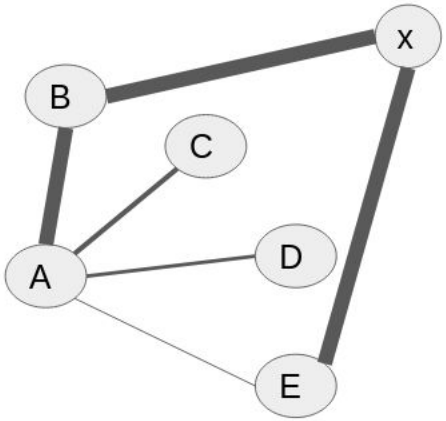
MC-S (30)	Miller, George A., Charles, & Walter G. (1991).
MEN-S (3000)	Bruni, Elia, Tran, Nam-Kahn, & Baroni, Marco. (2013).
MKTurk-SR (287)	Radinsky, K., Agichtein, E., Gabrilovich, E., & Markovitch, S. (2011).
MKTurk-S (771)	Halawi, Guy, Dror, Gideon, Gabrilovich, Evgeniy, & Koren, Yehuda. (2012).
RareWord-S (2034)	Luong, Minh-Thang, Socher, Richard, & Manning, Christopher, D. (2013).
RG-S (65)	Rubenstein, Herbert, & Goodenough, John, B. (1965).
SimLex-S (999)	Hill, Felix, Reichart, Roi, & Korhonen, Anna. (2016).
SimVerb-S (3500)	Gerz, Daniela, Ivan Vulić, Felix Hill, Roi Reichart, & Korhonen, Anna. (2016).
YP-S (130)	Yang, Dongqiang, & Powers, David, Martin. (2006).
WS1-S (353)	Finkelstein, L., Gabrilovich, E., Matias, Y., Rivlin, E., Solan, Z., Wolfman, G., & Ruppin, E. (2001).
WS2-R (353)	Agirre, E., Alfonseca, E., Hall, K., Kravalova, J., Paşca, M., & Soroa, A. (2009).

Steady-states versus direct associations



birds - insects 37.0

Steady-states versus direct associations

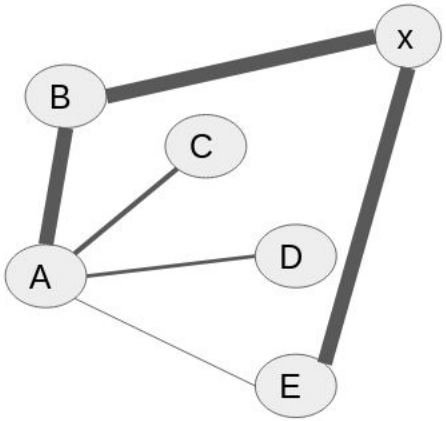


birds - insects 37.0

Direct 8

chirping	nests	mammals	nest	flock	carrion	singing	<u>insects</u>	flocks
0.0051	0.0048	0.0047	0.0046	0.0046	0.0045	0.0043	0.0043	0.0042

Steady-states versus direct associations



birds - insects 37.0

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chirping	nests	mammals	nest	flock	carrion	singing	<u>insects</u>	flocks
0.0051	0.0048	0.0047	0.0046	0.0046	0.0045	0.0043	0.0043	0.0042

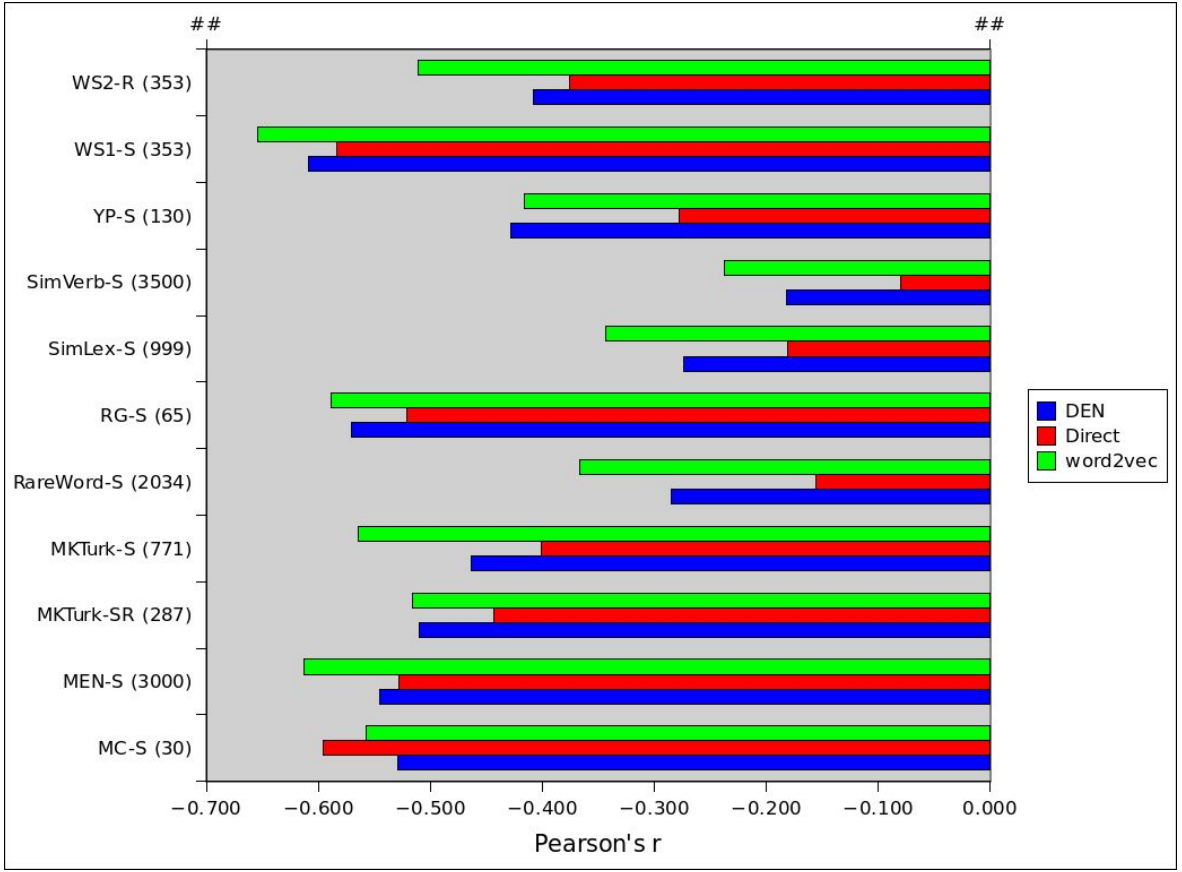
DEN 6

chirping	nests	mammals	nest	flock	<u>insects</u>	carrion	singing	flocks
0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004

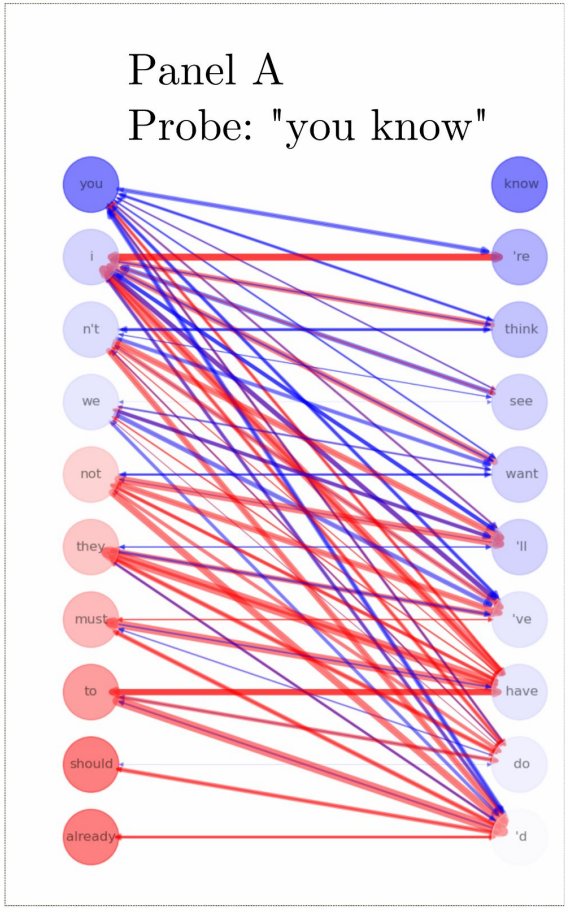
Free associations (USF)

Model	%First	Median Rank
word2vec	16.40	14
DEN	15.86	15
Direct	14.85	17
Topics	15.68	17
BEAGLE	13.29	45
LSA	11.56	28

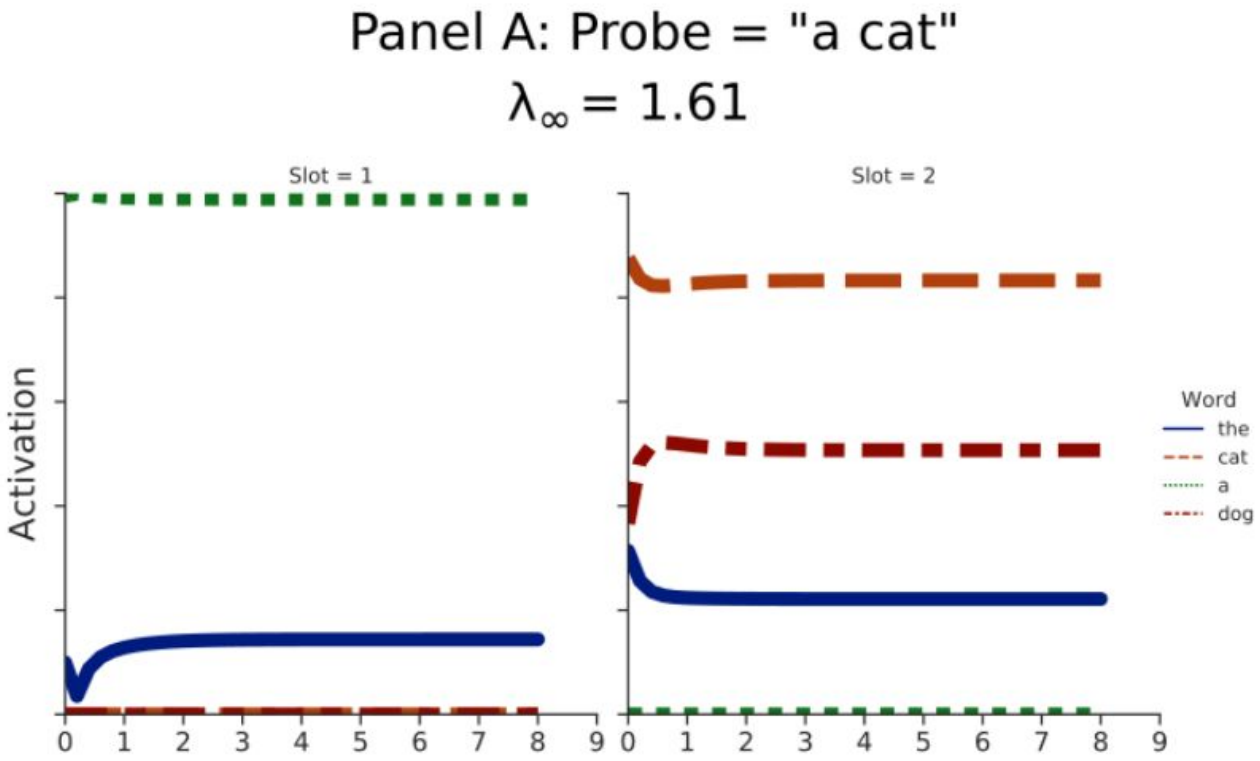
Word similarity/relatedness judgements



Serial order associations



Generalization over serially ordered associations



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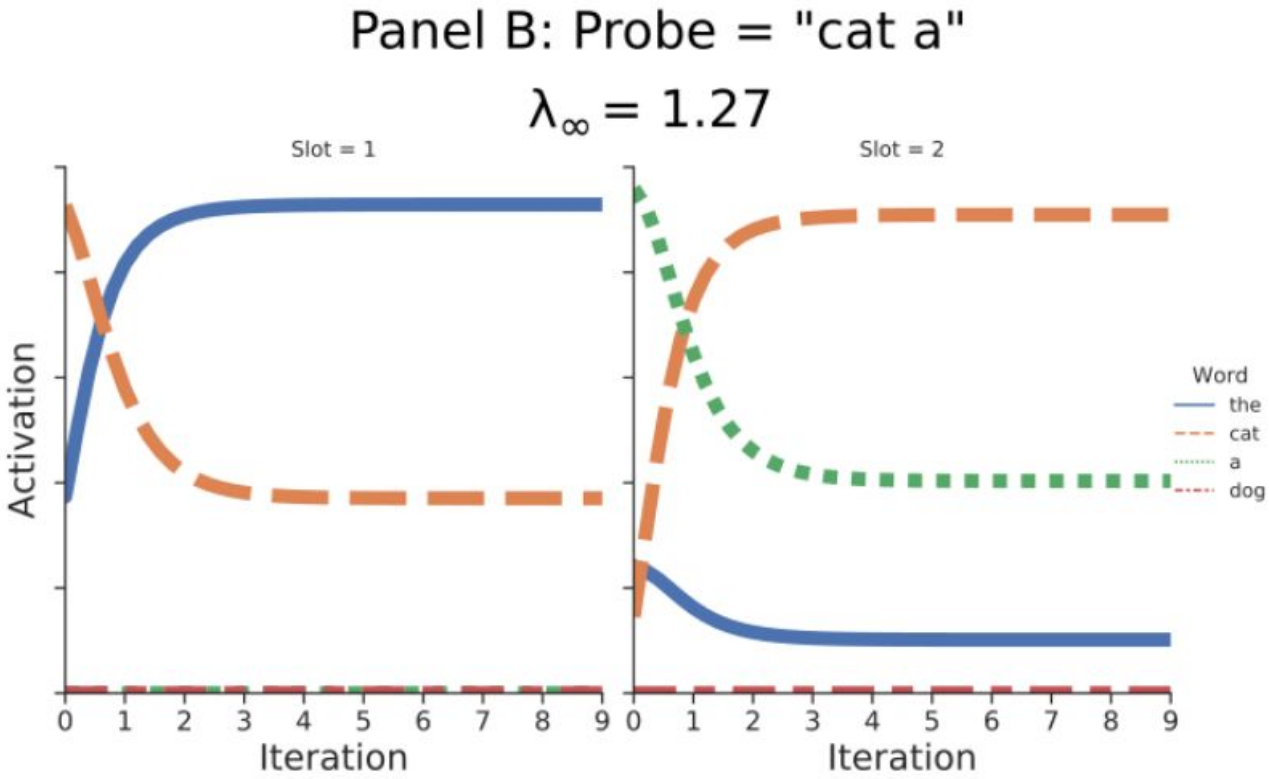

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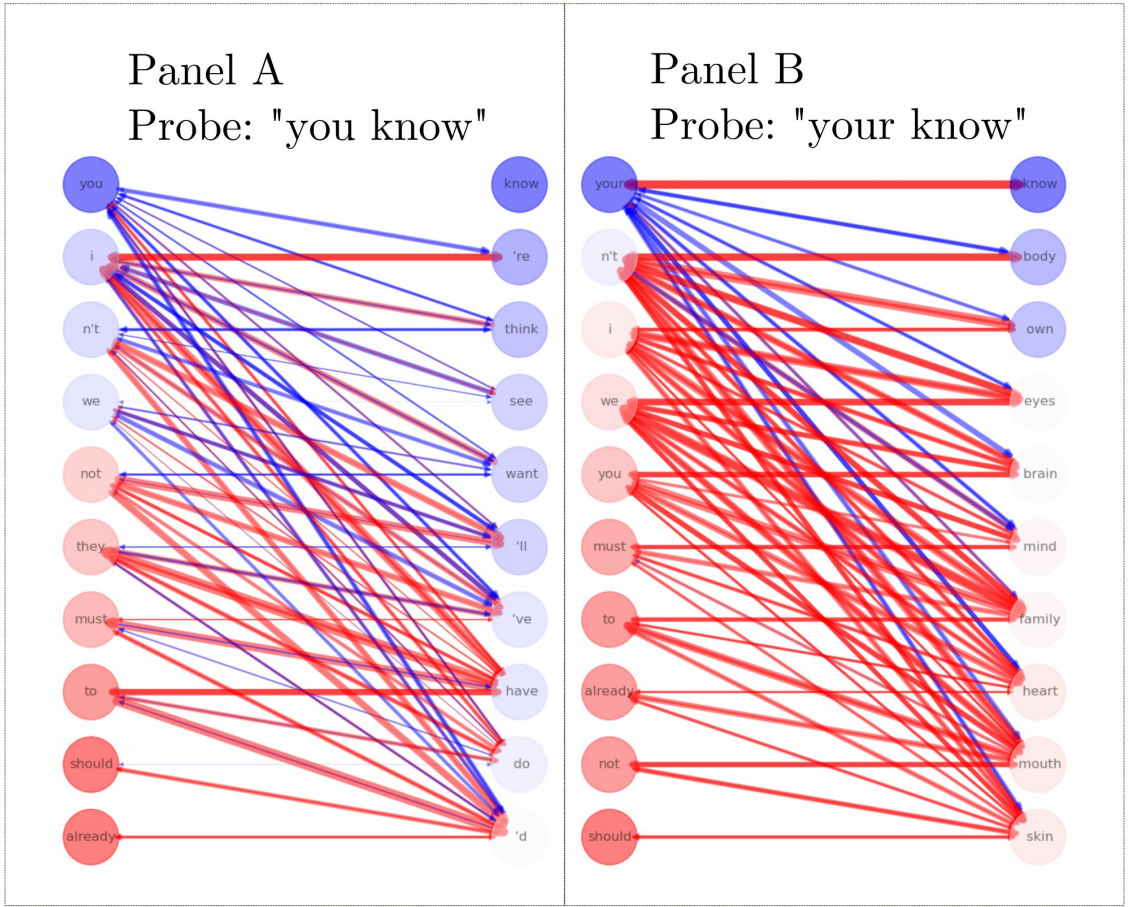
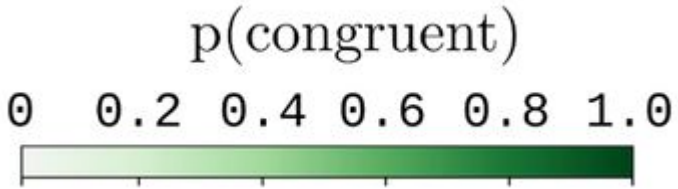


Combinatorial generalization



$$\mathbf{x}_{t+1}^T = S(\mathbf{x}_t^T \mathbf{W} + \mathbf{x}_0^T)$$

$$S(\mathbf{x}_i) = \begin{cases} 1 & \mathbf{x}_i \geq 1 \\ \mathbf{x}_i & -1 < \mathbf{x}_i < 1 \\ -1 & \mathbf{x}_i \leq -1 \end{cases}$$

BSB

	Intact									Lesioned								
	POSS-VERB(pres) NOUN-DET	PREP-VERB(pres) NOUN-ADJ	NOUN-VERB(pres) PRON-NOUN	ADV(comp)-VERB NOUN-VERB(pres)	PREP-NOUN	POSS-VERB(pres) NOUN-DET	PREP-VERB(pres) NOUN-ADJ	NOUN-VERB(pres) PRON-NOUN	ADV(comp)-VERB NOUN-VERB(pres)	PREP-NOUN
DET-NOUN	0.21	0.19	0.47	0.33	0.31	0.61	0.53	0.61	0.69	0.21	0.18	0.46	0.33	0.31	0.61	0.53	0.61	0.69
PRON-VERB(pres)	0.59	0.61	0.73	0.61	0.52	0.76	0.75	0.76	0.65	0.59	0.60	0.73	0.61	0.52	0.76	0.75	0.76	0.65
ADJ-NOUN	0.34	0.31	0.48	0.49	0.25	0.51	0.41	0.51	0.60	0.34	0.31	0.48	0.50	0.25	0.51	0.41	0.51	0.60
PREP-VERB(ing)	0.28	0.25	0.51	0.43	0.28	0.61	0.53	0.61	0.62	0.28	0.26	0.51	0.43	0.28	0.61	0.53	0.61	0.62
POSS-NOUN	0.40	0.38	0.59	0.58	0.32	0.63	0.57	0.63	0.67	0.41	0.38	0.59	0.59	0.32	0.63	0.56	0.63	0.68
NOUN(s)-VERB(pres)	0.46	0.45	0.52	0.48	0.34	0.50	0.43	0.50	0.49	0.46	0.44	0.52	0.48	0.34	0.50	0.44	0.50	0.49
VERB-ADV(comp)	0.28	0.29	0.48	0.40	0.20	0.56	0.38	0.56	0.46	0.28	0.28	0.48	0.40	0.20	0.55	0.38	0.55	0.46
NOUN-VERB(sing/3rd)	0.26	0.27	0.36	0.27	0.19	0.38	0.25	0.38	0.28	0.26	0.26	0.36	0.27	0.19	0.38	0.25	0.38	0.28
NOUN-PREP	0.41	0.44	0.61	0.52	0.41	0.66	0.62	0.66	0.70	0.40	0.43	0.61	0.52	0.41	0.66	0.62	0.66	0.70

Combinatorial generalization

p(congruent)

0 0.2 0.4 0.6 0.8 1.0

$$\mathbf{x}_{t+1}^T = \frac{\mathbf{x}_t^T \mathbf{W} + \mathbf{x}_0^T}{\|\mathbf{x}_t^T \mathbf{W} + \mathbf{x}_0^T\|}$$

pLAN

	Intact									Lesioned								
	NOUN-DET	POSS-VERB(pres)	NOUN-ADJ	PREP-VERB(pres)	PRON-NOUN	NOUN-VERB(pres)	ADV(comp)-VERB	NOUN-VERB(pres)	PREP-NOUN	NOUN-DET	POSS-VERB(pres)	NOUN-ADJ	PREP-VERB(pres)	PRON-NOUN	NOUN-VERB(pres)	ADV(comp)-VERB	NOUN-VERB(pres)	PREP-NOUN
DET-NOUN	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.95	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.97
PRON-VERB(pres)	0.23	1.00	1.00	0.85	0.99	1.00	1.00	1.00	0.46	0.21	1.00	1.00	0.79	0.96	1.00	1.00	1.00	0.40
ADJ-NOUN	0.03	0.99	0.99	0.64	0.91	1.00	1.00	1.00	0.15	0.01	0.53	0.81	0.21	0.35	0.66	0.72	0.66	0.03
PREP-VERB(ing)	0.17	1.00	1.00	0.79	0.96	1.00	1.00	1.00	0.36	0.12	0.93	0.97	0.65	0.84	0.95	0.97	0.95	0.26
POSS-NOUN	0.11	1.00	1.00	0.80	0.98	1.00	1.00	1.00	0.31	0.05	0.95	0.98	0.60	0.84	0.98	0.98	0.98	0.16
NOUN(s)-VERB(pres)	0.01	0.89	0.94	0.39	0.67	0.93	0.92	0.93	0.04	0.00	0.37	0.72	0.11	0.21	0.54	0.58	0.54	0.02
VERB-ADV(comp)	0.01	0.79	0.92	0.37	0.58	0.86	0.91	0.86	0.05	0.01	0.59	0.86	0.27	0.42	0.71	0.81	0.71	0.05
NOUN-VERB(sing/3rd)	0.00	0.85	0.92	0.34	0.59	0.90	0.89	0.90	0.02	0.00	0.19	0.63	0.02	0.08	0.40	0.42	0.40	0.01
NOUN-PREP	0.76	1.00	1.00	0.97	1.00	1.00	1.00	1.00	0.88	0.51	0.99	1.00	0.91	0.98	0.99	1.00	0.99	0.69

Combinatorial generalization

p(congruent)

0 0.2 0.4 0.6 0.8 1.0

$$\mathbf{x}_{t+1}^T = \frac{\mathbf{x}_t^T(\mathbf{W} + \mathbf{x}_0\mathbf{x}_0^T)}{\|\mathbf{x}_t^T(\mathbf{W} + \mathbf{x}_0\mathbf{x}_0^T)\|}$$

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	NOUN-DET	POSS-VERB(pres)	NOUN-ADJ	PREP-VERB(pres)	PRON-NOUN	NOUN-VERB(pres)	ADV(comp)-VERB	NOUN-VERB(pres)	PREP-NOUN	NOUN-DET	POSS-VERB(pres)	NOUN-ADJ	PREP-VERB(pres)	PRON-NOUN	NOUN-VERB(pres)	ADV(comp)-VERB	NOUN-VERB(pres)	PREP-NOUN
DET-NOUN	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97
PRON-VERB(pres)	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.66	0.76	1.00	1.00	0.97	0.99	0.98	1.00	0.98	0.50
ADJ-NOUN	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.66	0.15	0.94	0.91	0.78	0.87	0.66	0.94	0.66	0.14
PREP-VERB(ing)	0.92	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.56	0.54	0.99	0.98	0.93	0.96	0.89	0.98	0.89	0.35
POSS-NOUN	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.77	0.55	0.99	0.99	0.94	0.97	0.94	0.99	0.94	0.33
NOUN(s)-VERB(pres)	0.64	1.00	1.00	0.98	0.99	0.99	1.00	0.99	0.29	0.07	0.92	0.87	0.72	0.83	0.55	0.91	0.55	0.10
VERB-ADV(comp)	0.26	0.97	0.96	0.86	0.93	0.80	0.97	0.80	0.19	0.18	0.92	0.89	0.76	0.85	0.63	0.93	0.63	0.14
NOUN-VERB(sing/3rd)	0.60	1.00	1.00	0.98	0.99	0.99	1.00	0.99	0.27	0.03	0.88	0.83	0.66	0.77	0.44	0.89	0.44	0.07
NOUN-PREP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.93	1.00	1.00	0.99	1.00	0.99	1.00	0.99	0.72

Conclusions

- Word similarities and free associations are **better** captured through **steady state activations** over direct associations
- **Generalization** may be done during retrieval instead of encoding **through spreading activation**
- The **Dynamic Eigen Net** works well with a **variant of PMI** to **drive generalization** in both **order-independent** and **serially ordered** domains
- **Dynamic Eigen Net <u>slightly</u> trails behind word2vec**, leaving open the question as to whether **dimensionality reduction** is necessary