A Unifying Account of Cognitive Aging as Enrichment

Thomas Hills
University of Warwick

With collaborators: Dirk Wulff, Rui Mata, Simon De Deyne, Haim Dubossarsky

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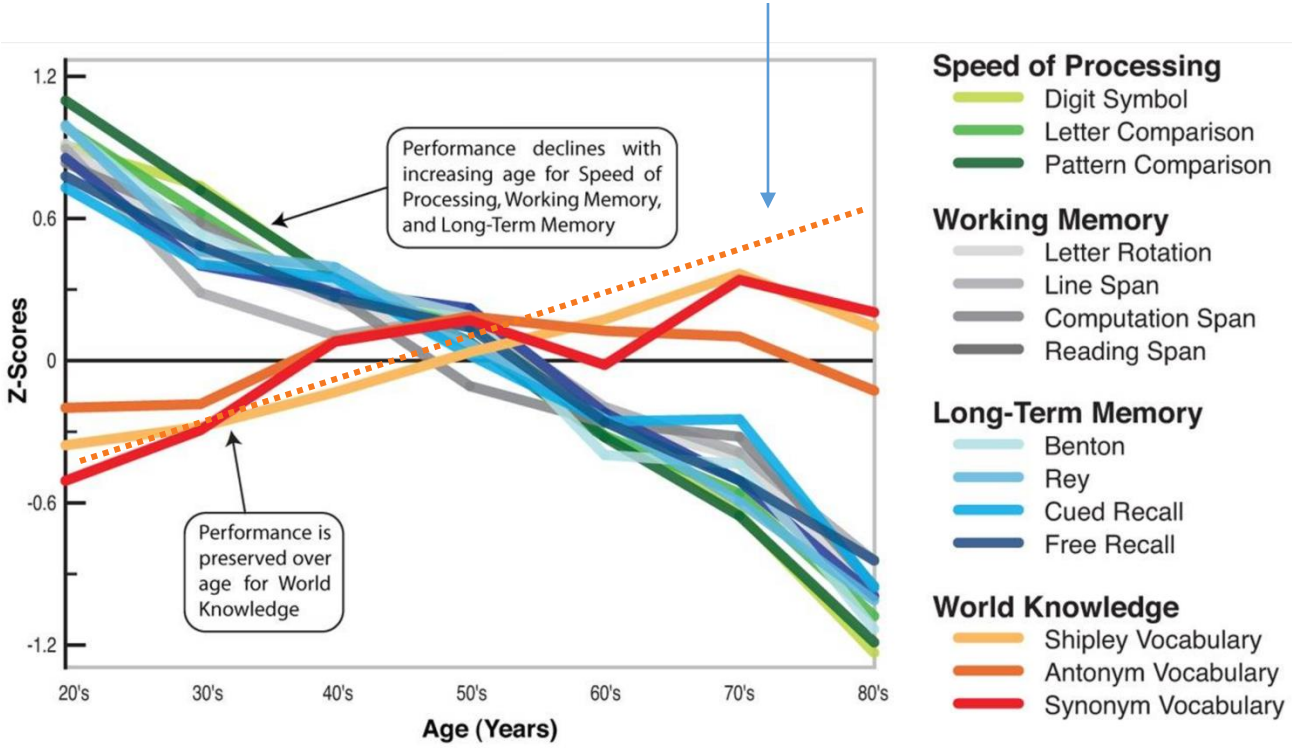
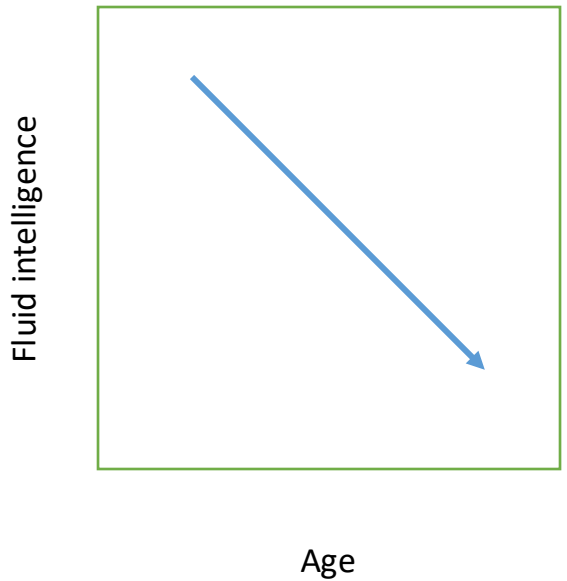
Stylized facts about ‘intelligence’ across the lifespan:

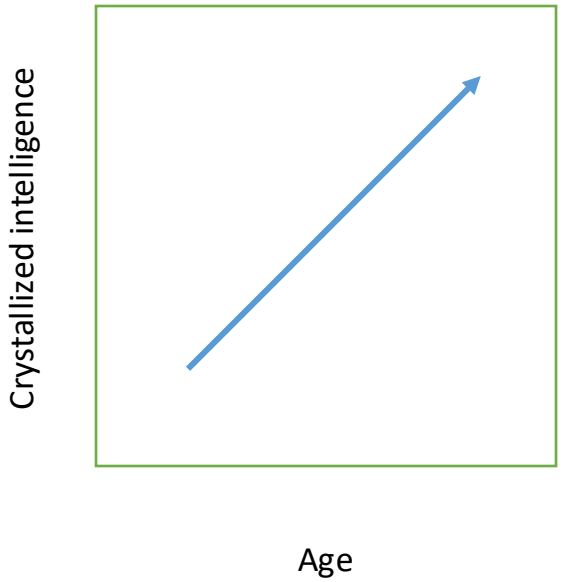
Brysbaert et al., 2016 (~180 new lemmas per year in adult life)



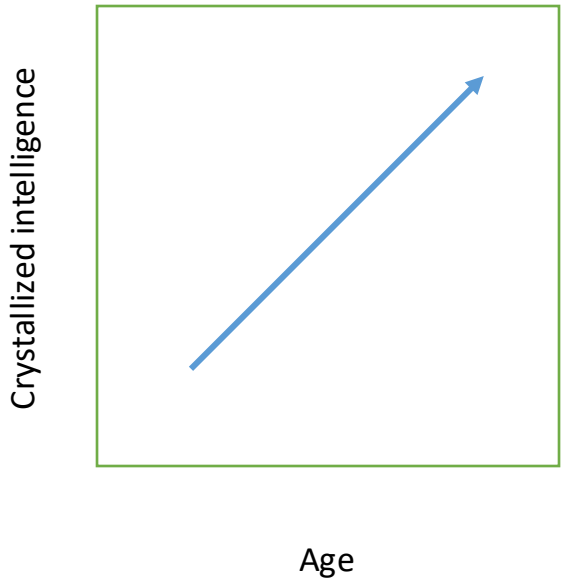
Park & Reuter-Lorenz 2009

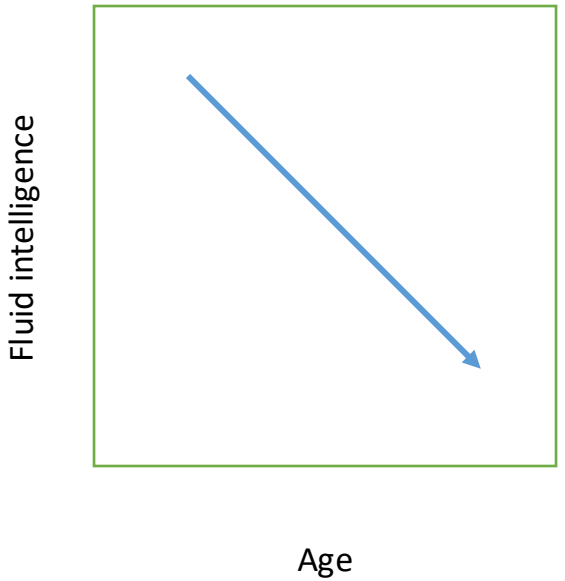
These are usually considered independently





But we might ask how one could cause the other?





Learning is something that we know happens and we understand well the processes that drive it.

How could 'learning' create a decline in fluid intelligence?

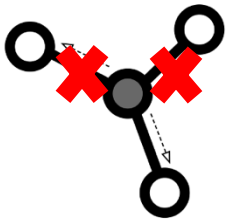
The Aging Mind—A common explanation

- *Common cause theory of aging*

The Aging Mind—

Common cause theory of cognitive aging

- Biological and cognitive degradation share a common cause (e.g., oxidative stress and telomere length).
- Salthouse (2013) explains some putative causes of slowing as including “a slower speed of transmission along single (e.g., loss of myelination) or multiple (e.g., loss of functional cells dictating circuitous linkages) pathways, or. . . delayed propagation at the connections between neural units (e.g., impairment in functioning of neurotransmitters, reduced synchronization of activation patterns)” (p. 116).
- In other words, the brain is breaking down.



Other sources of evidence for potential degradation:

1. Declining fluid intelligence
2. Rising entropy in responses in late life
3. Declining similarity in similarity judgments in late life

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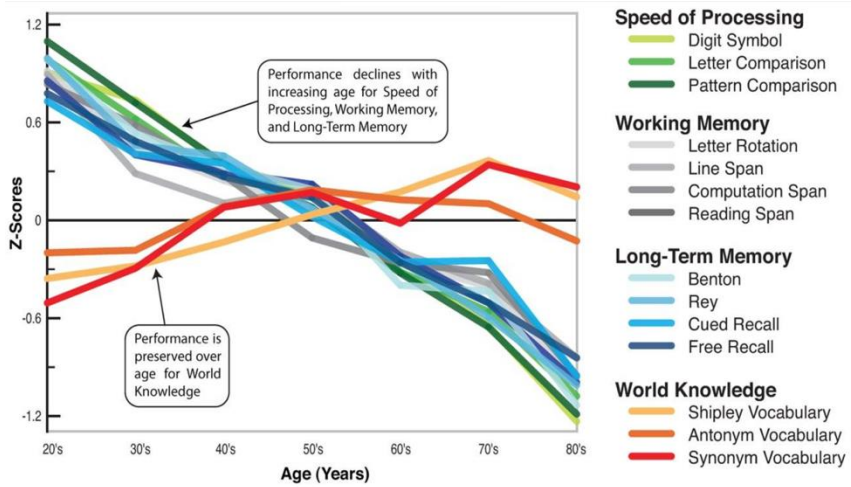


Park & Reuter-Lorenz 2009

Other sources of evidence for potential degradation:

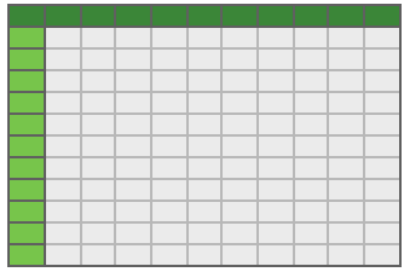
1. Declining fluid intelligence
2. Rising entropy in associations in late life
3. Declining similarity in similarity judgments in late life

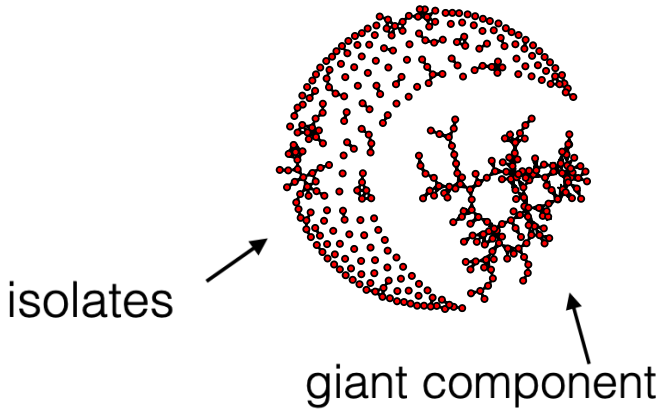
- Study of more than 8000 individuals reporting free associations for 420 words across the lifespan.
- We show people cues, they provide targets.

	Target 1: animal	Target 2: dog	…	Target 3:read
Cue 1:cat	104	53	…	0
Cue 2:book	0	0	…	492
…	…	…	…	…
Cue 420: happy	0	2	…	0

$$w_{ij} = \sum_{i=1}^{P} \frac{w_{i,p}}{N_p - 1}$$

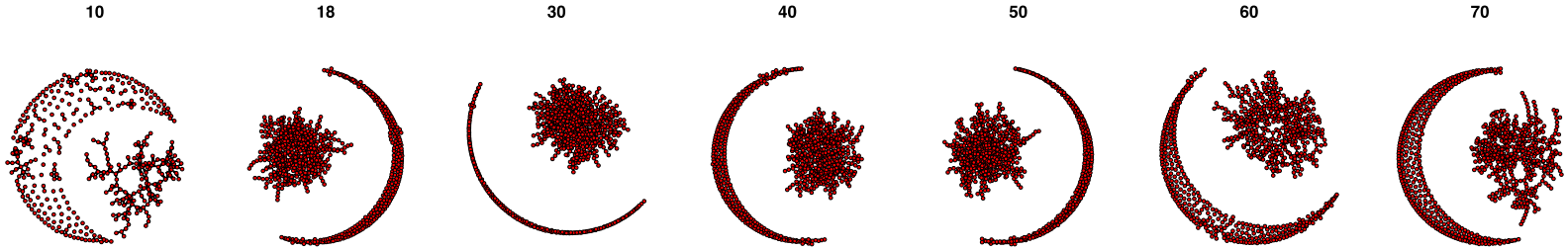
cue x cue matrix





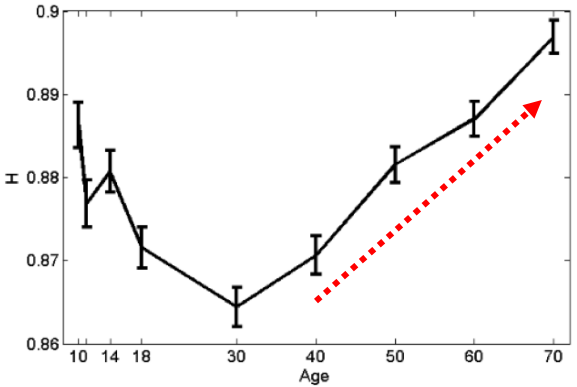
Dubbosarsky, De Deyne, and Hills (2017). *Developmental Psychology*

The changing lexicon across the lifespan



Networks representing similarity between 420 cue words (based on similarity among associates))

$$H = -\sum_{i=1}^{n} \frac{p(x_i) log_b(p(x_i))}{log_b(n)}$$



Is rising entropy consistent with degradation?

Other sources of evidence for potential degradation:

1. Declining fluid intelligence
2. Rising entropy in associations in late life
3. Declining similarity in similarity judgments in late life

Similarity judgments decline with age

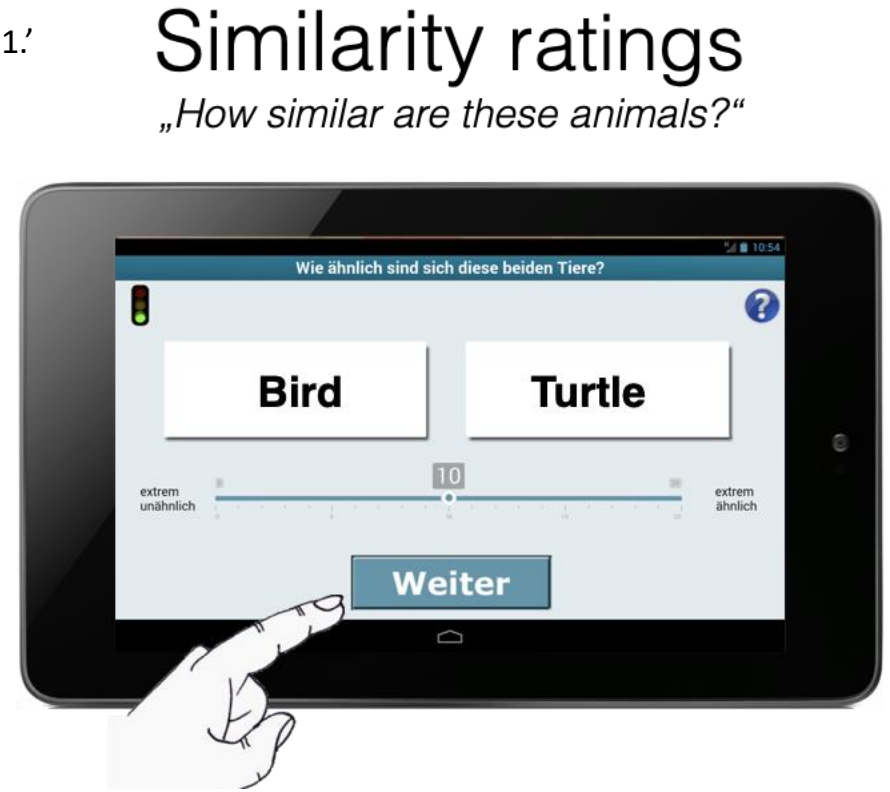
‘How similar is “cat” and “giraffe” on a scale from 0 to 1.’

36 old and 36 young participants

Provided pairwise similarity ratings for 77 animals

~2000 ratings for every pair of 63 animals

Ratings on a scale **from 1 to 20** over the course of 7-14 days



Wulff, Hills, Mata 2022, *Scientific Reports*

Similarity judgments decline with age

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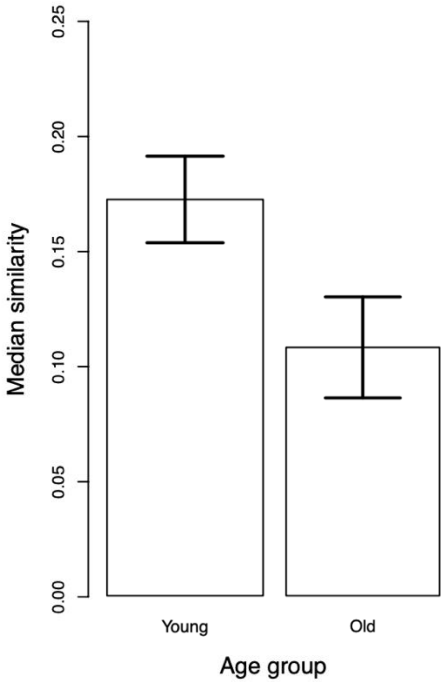
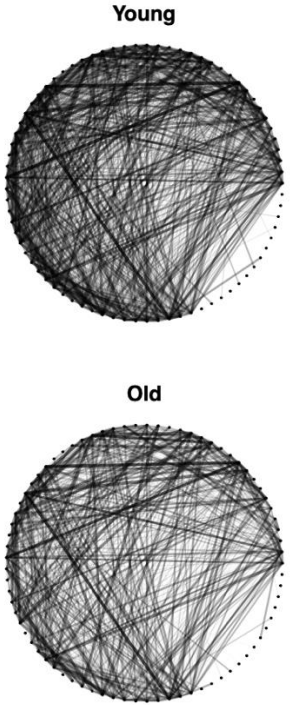




1. Declining fluid intelligence
2. Rising entropy in responses in late life
3. Declining similarity in similarity judgments in late life

But are these really sources of evidence for degradation?

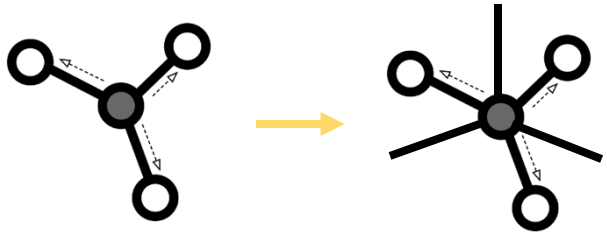
What's the alternative?

The Aging Mind—two competing explanations

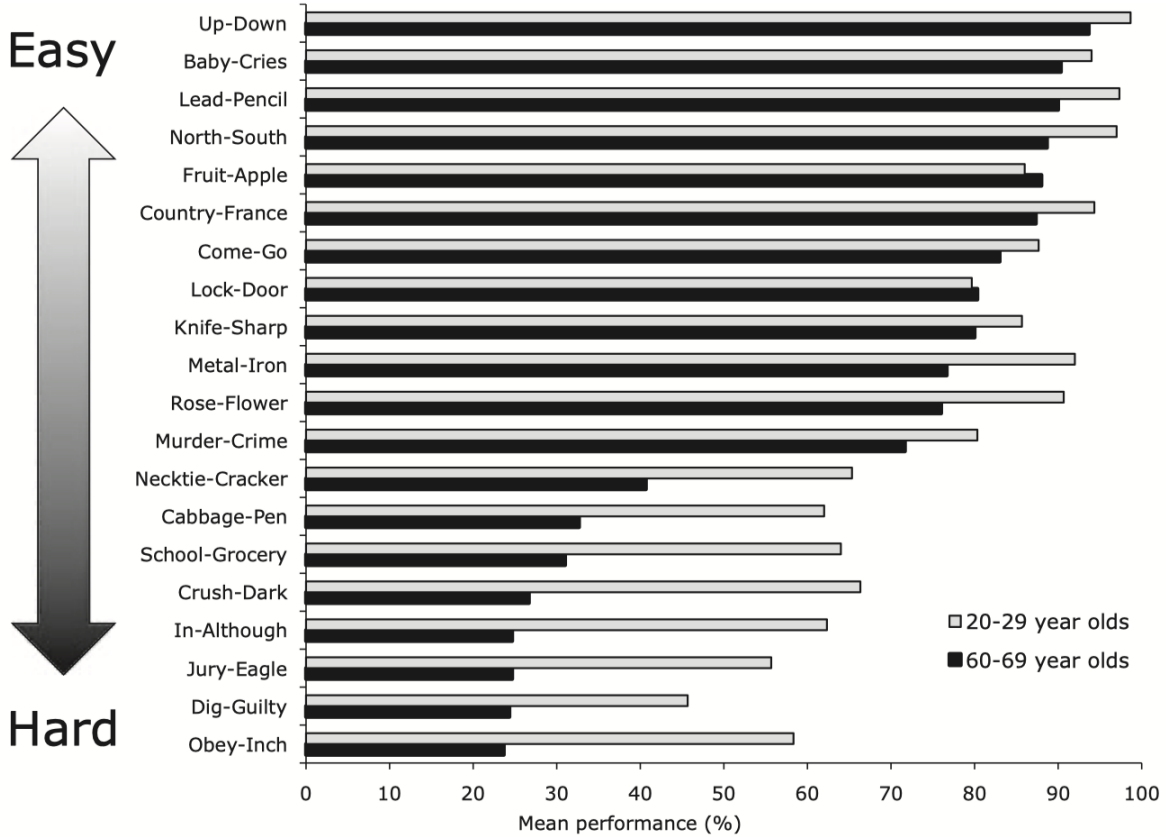
- *Common cause theory of aging*
- *Enrichment*

The Aging Mind—Enrichment

- Aging is overlearning (Ramscar et al, 2014); Older adults learn about 180 new lemmas a year to age 60 (Brysbaert et al 2016)
  - Ramscar et al, 2014: “older adults’ changing performance reflects memory search demands, which escalate as experience grows” (p. 5).

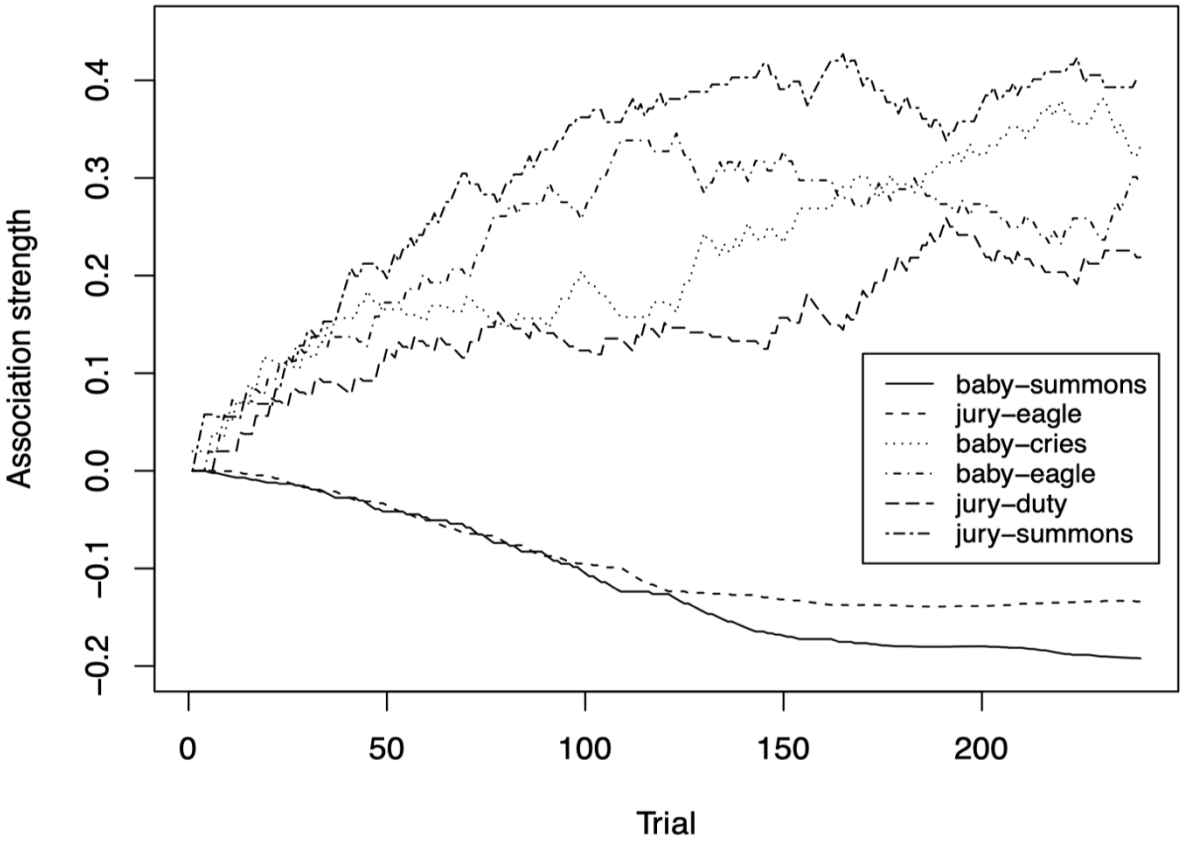


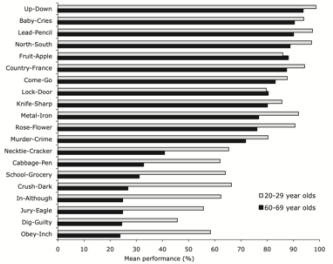
Declining performance in paired association learning is harmed most for uncommon ’hard’ pairs



Ramscar et al. (2017) argue this is a straightforward prediction of learning: “the discriminative processes that produce ‘associative’ learning teaches English speakers not only which words go together, but also which words do not go together. This process both increasingly differentiates meaningful and meaningless word pairs and makes meaningless pairs harder to learn”, p. 3).

Rescorla-Wagner predicts paired-associate learning deficits





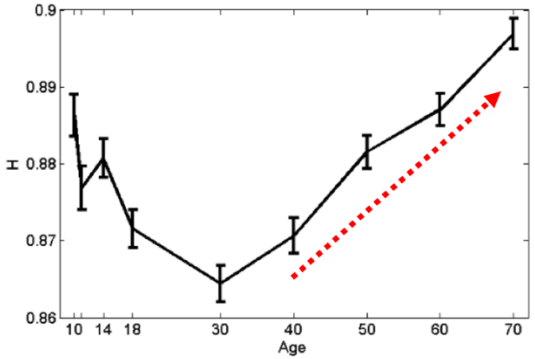
Train model with ‘baby-cries’,
‘baby-eagle’,
‘jury-duty’,
‘jury-summons’

Non-learned associates grow apart:
Baby-summons
Jury-eagle

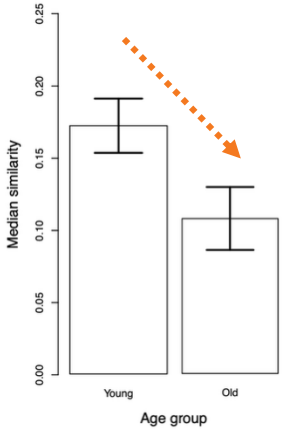
Rescorla, R. A. (1988). Pavlovian conditioning: It’s not what you think it is. American Psychologist,

Can a lifetime of learning explain rising entropy and falling similarity?

Rising entropy

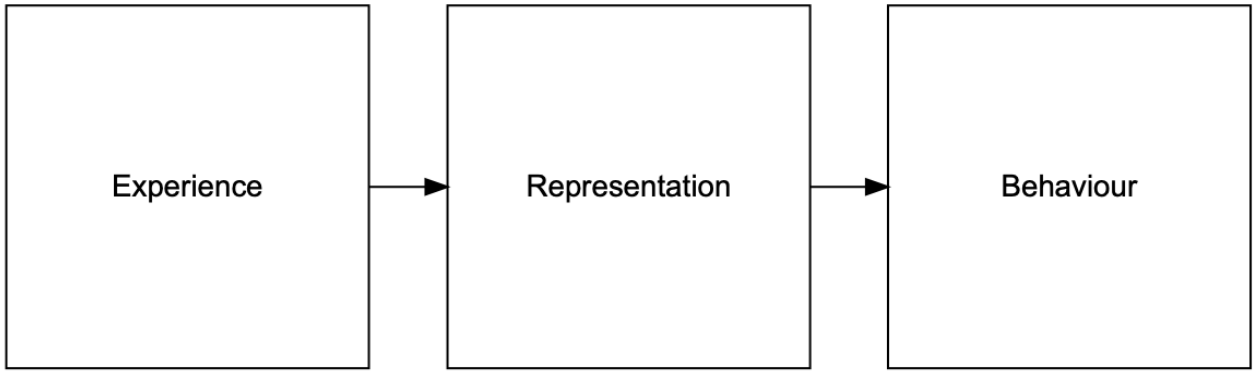


Falling similarity



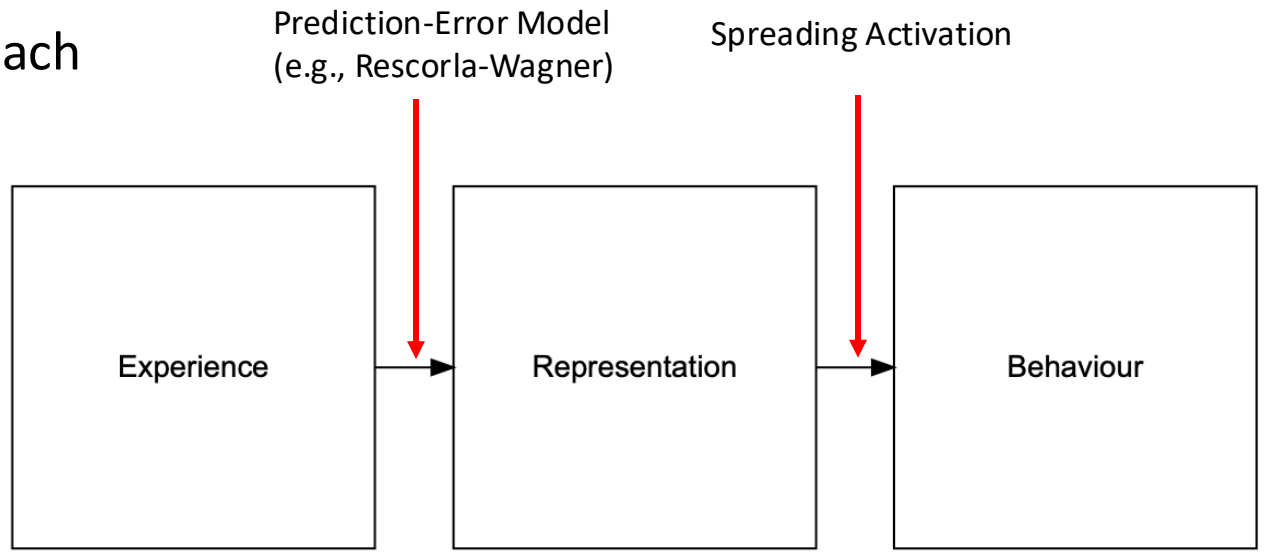
The approach

- Model *experience* as a network of possible associations
- Model *representation* as Rescorla-Wagner learning from experience
- Model *behavior*: entropy and similarity judgments.



Hills (In press)

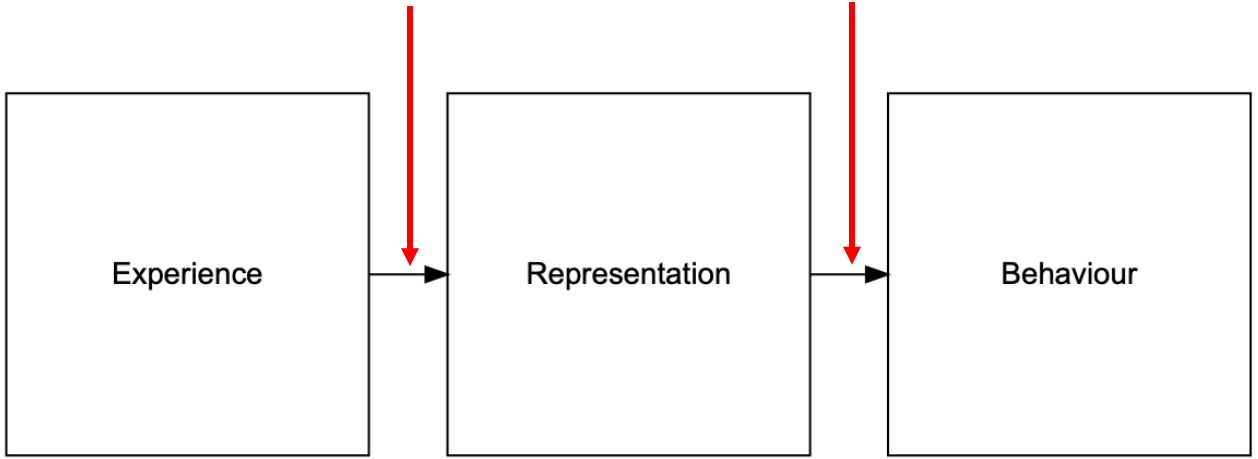
The approach

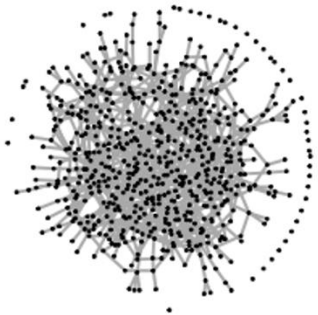


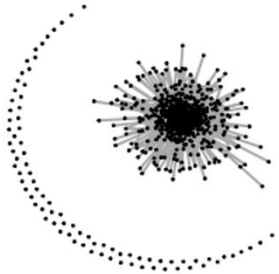
The approach

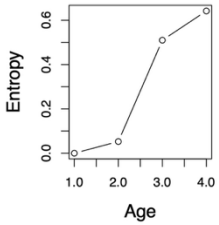
Prediction-Error Model
(e.g., Rescorla-Wagner)

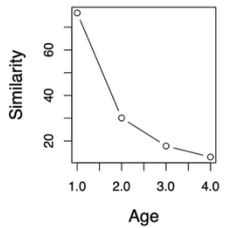
Spreading Activation

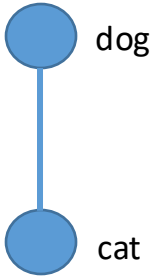








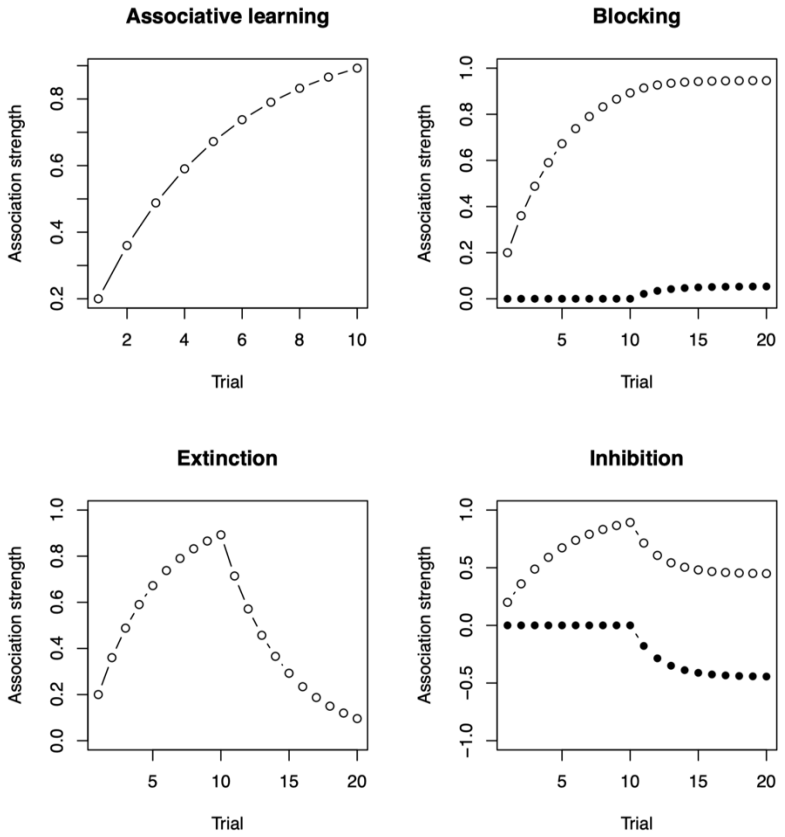




- Rescorla-Wagner model
- Cue outcome association (cue predicts unconditioned stimuli): $V_{C \to U}$
- True outcome: λ_U
- Prediction error: $\Delta V_{C \to U} = \alpha_C \beta_U (\lambda_U - V_{C \to U})$
- Value updating: $V_{C \to U, t+1} = V_{C \to U, t} + \Delta V_{C \to U, t}$

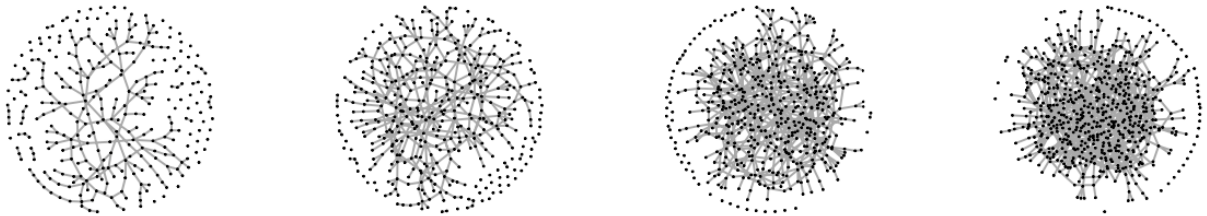
- Rescorla-Wagner predicts all the usual associative learning effects

- Associative learning: $C \rightarrow U$.
- Blocking: $C \rightarrow U$ followed by $CN \rightarrow U$,
- Extinction: $C \rightarrow U$ followed by $C \rightarrow 0$.
- Inhibition: $C \rightarrow U$ followed by $CN \rightarrow 0$.



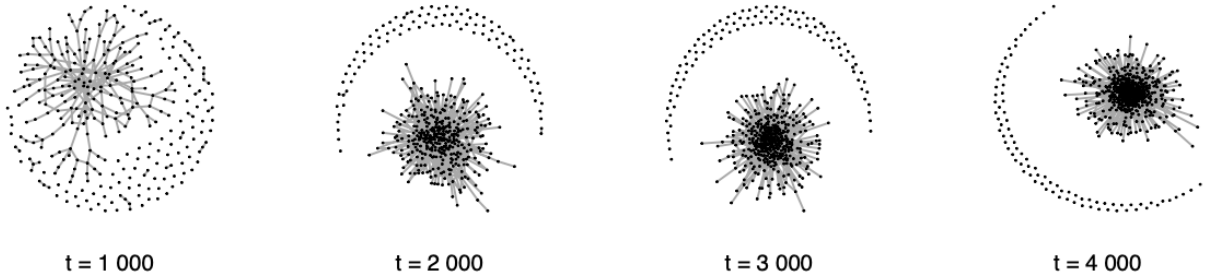
Experience and Representation

Experienced lexicon



Fitness based network with 1000 edges produced in each generation, words (nodes) increase at each age

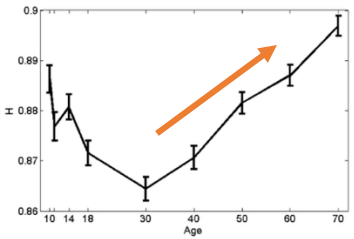
Learned lexicon



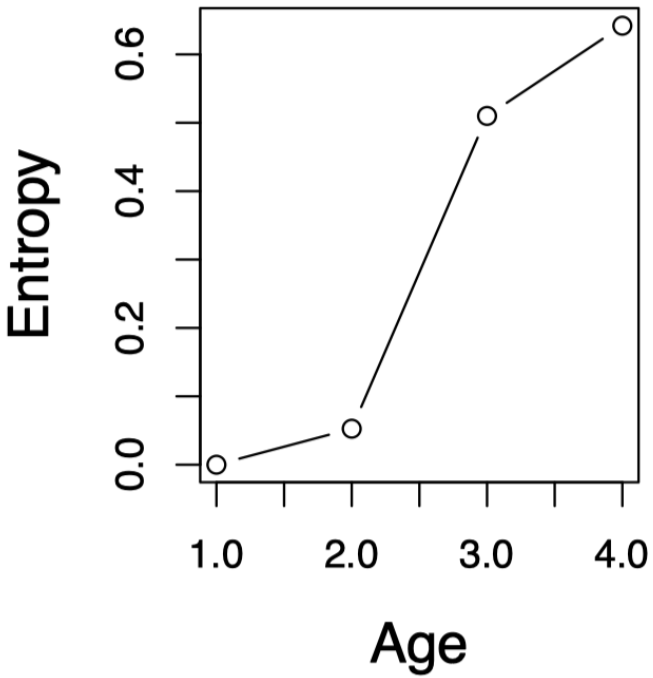
Learned lexicon is created by learning 1000 cue-target relationships in each generation

Entropy increases with age

$$H = -\sum_{i=1}^{n} \frac{p(x_i) log_b(p(x_i))}{log_b(n)}$$



Simulation results



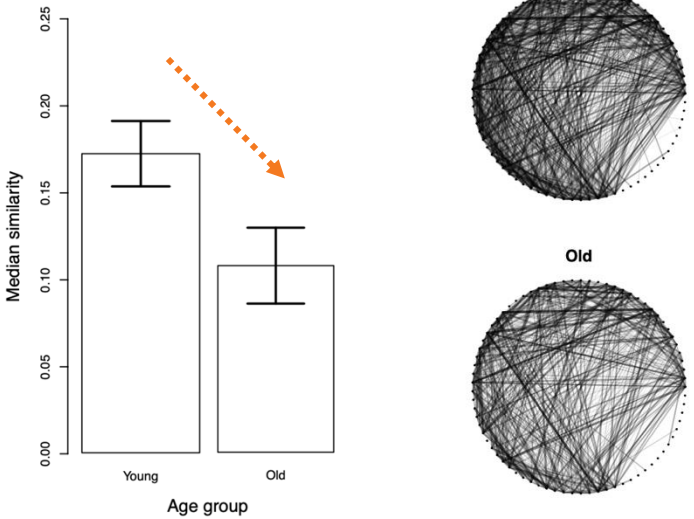
Hills, forthcoming.

Similarity falls with age

Spreading activation from one node to the other, and vice versa

$$S = A_{j \to k} + A_{j \to k}$$

Falling similarity



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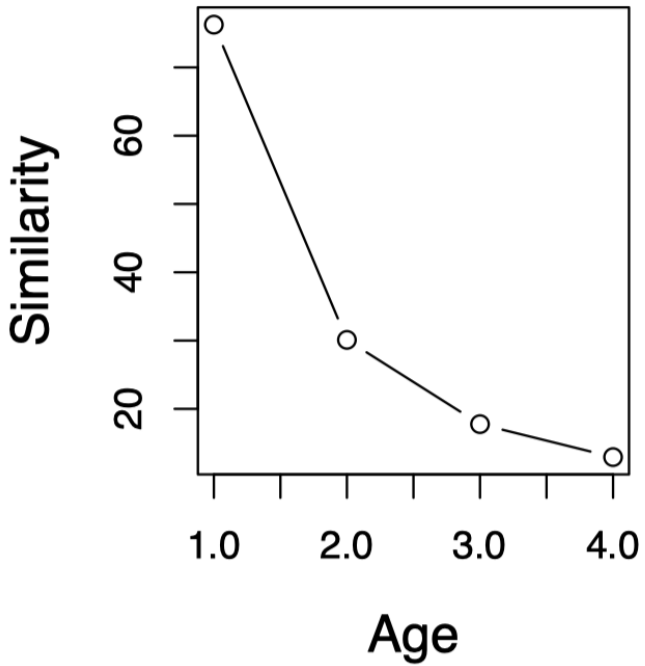
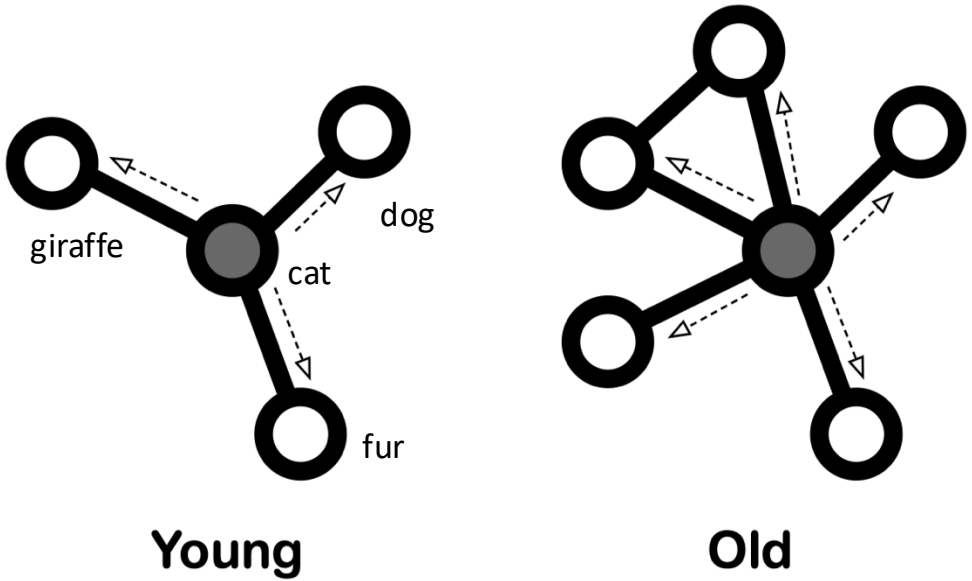


Hills, forthcoming.

The enrichment model of aging

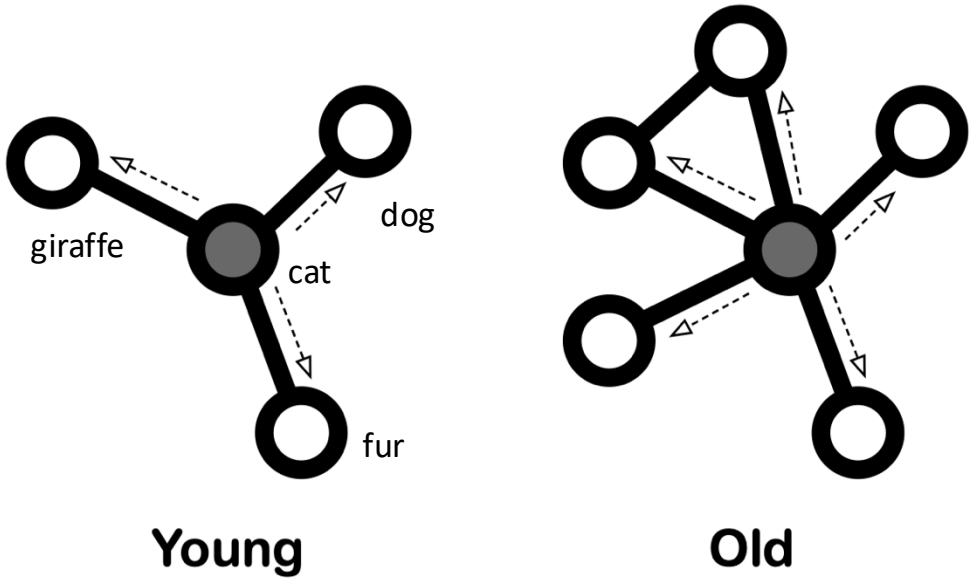
As individuals age, the enrichment among relations in their lexical network increases dispersion of spreading activation.



The enrichment model of aging

This explains:

1. Declining fluid intelligence
2. Rising entropy in responses in late life
3. Declining similarity in similarity judgments in late life



Conclusions

With age and learning…

1. Associations become less predictable (entropy rises)
2. Similarity falls

Take home message:

Learning produces some of the dominant effects of aging.

Speculation:

Perhaps learning produces *most* of the effects of healthy cognitive aging.

Thank you