# WHERE DOES CREATIVITY COME FROM?

# THOMAS HILLS



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# **TWO QUESTIONS**

- How does the mind generate creative ideas?
- How does executive function work (as a mechanism)?

# THE GENIUS OF DISCOVERY **DEPENDS ALTOGETHER ON THE** NUMBER OF THESE RANDOM **NOTIONS AND GUESSES WHICH** VISIT THE INVESTIGATOR'S MIND. TO **BE FERTILE IN HYPOTHESES IS THE** FIRST REQUISITE.

William James (1880)

# VARIANCE-SELECTION PROCESS (EQUAL-ODDS RULE)

The mind generates alternatives, roughly at random, and then – presumably some other part of the mind – selects the best options.

Some experimental evidence for this exists (Jung et al., 2015), but then 'be creative' also works (Benedek et al., 2020)



### HOW DO PSYCHOLOGISTS MEASURE CREATIVITY?

Guilford (1972): "Since creative talent... is composed of numerous special abilities, and since criteria of creative performance in everyday life are also complex, no one test of a creative ability can be expected to correlate highly with those criteria" (p. 86).

Methods:

- convergent thinking tasks (remote associates, insight tasks)
- divergent thinking tasks (alternative uses tasks (paperclip, brick))
- Self-report measures (achievement, activities)
- Test batteries

### A TALE OF TWO THEORIES

- Associative Theory of Creativity
- Executive Theory of Creativity

ASSOCIATIVE THEORY OF CREATIVITY—WHAT YOU KNOW

#### ASSOCIATIVE THEORY OF CREATIVITY



"The organization of an individual's associations will influence the probability and speed of attainment of a creative solution" (Mednick, 1962, p. 222).

#### VAN GOGH

Van Gogh had an extensive knowledge of the art world, coming from a family of art dealers and working as one.









Van Gogh's painting are often his personal versions of other artist's paintings. Here is 'Raising of Lazarus' (1890) inspired by Rembrandt's etc



Here is Jean-Francois Millet's 'The Sower' (1850) and Van Gogh's 'The Sower (after Millet)' 1889. Of Millet's "Sower", Van Gogh said "art sor

### SEMANTIC NETWORKS OF HIGH AND LOW CREATIVES



Networks from fluency data (60s to produce words to 36 cues)

Data is aggregated by group. Network edges are cosine similarity values that survive a filtering algorithm.

Results: 1. Cosine similarity (HC > LC): 2. Diameter (HC < LC) (things are closer together for high creatives)

Kenett, Anaki, Faust, 2014

Much of 'Associative Theory' or structural explanations are based on getting people to produce (often free associations) or judge things (similarity ratings) and then measuring the distance between them (Olson et al., 2021; Beaty et al., 2021; Benedek et al., 2017)

- Fine, but...
- Every structure has a process story

# EXECUTIVE THEORY OF CREATIVITY

- Top-down control process
- Intelligence and other measures of executive function correlate with creativity measures (Benedek et al., 2014; Nusbaum & Silvia, 2011).
- Higher creatives show greater interconnectivity between the executive control network and the default mode network (Beaty et al., 2014; Evans et al., 2020; Ovando-Tellez, Benedek, et al., 2022):

#### NETWORK EFFICIENCY ('CLOSENESS') BETWEEN ROI INCREASES W CREATIVITY



BEATY ET AL., 2014; OVANDO-TELLEZ ET AL., 2022; CHEN ET AL., 2025

### A TALE OF TWO THEORIES

- Associative Theory of Creativity
- Executive Theory of Creativity

Are these separate ideas? Are they internally consistent?

#### **CORRELATIONS ACROSS MEASURES**



Ovando-Tellez et al., 2022, Communications Biology

#### SUMMARY OF FINDINGS FROM EMPIRICAL LITERATURE

- 1. More rapid production of responses (faster)
- 2. More original responses, on average (further away)
- 3. Report greater similarity between pairs of items
- 4. Have more interconnected semantic networks
- 5. More neural interconnectivity between ECN and DMN
- 6. Creativity correlated with cognitive control

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#### THE RIDDLE OF FASTER-AND-FURTHER

- Being more interconnected and producing greater activation (being faster) in individual nodes violates our understanding of how activation moves through a network.
- Spreading activation models won't do this (Siew, 2019; Collins & Loftus, 1975; Anderson, 1983): Activation is 1/n.
- The fan effect shows people don't do this either (Anderson & Reder, 1999)

Is there a way to get faster and further without resorting to structural differences?



# MHAT IS EXECUTIVE CONTROL

#### HOW DOES EXECUTIVE CONTROL WORK?

- Inhibition, monitoring, updating, retrieval (Miyake et al., 2000)
- Strategic strategy use ()
- Asking people to 'be creative' (Benedek et al., 2020)
- Focused attention (Posner)
- Executive dysfunction (Dopamine, Catecholamines, etc)
- Foraging related neuromodulation to control search across species (Hills, 2006)



Doya, 2002

## DISINHIBITION?

- Cognitive control tunes background neural firing in different areas of the brain to mediate the exploration exploitation trade-off and behavioral flexibility (AstonJones & Cohen, 2005; Avery & Krichmar, 2017; Cools & D'Esposito, 2011; Doya, 2008; Eppinger et al., 2021; Gilbertson & Steele, 2021; Lin & Vartanian, 2018; Pezzulo et al., 2015).
- Behavioral disinhibition requires DA receptor activation (van Gaalen et al., 2006).



Doya, 2002

### SPONTANEOUS ACTIVITY IS PART OF THE SYSTEM AND IT PERFORMS WORK IN THE BRAIN

### SIGNAL AND NOISE IN THE BRAIN

- Tonic activity from the LC increase increases arousal (background firing rates) throughout the brain.
- Spontaneous firing (even in the absence of pre-synaptic transmission) is functional (Häusser et al., 2004; Ermentrout et al., 2008).
- Stochastic resonance is the observation that subthreshold inputs have a better chance of being detected with when noise is added (Lu et al., 2019). This is a feature, not a bug (Rusakov et al., 2020).
- "A dynamic system computationally solved in the presence of noise explores a greater range of network configurations (Deco et al., 2011."
- The brain's 'global signal' (background activation) correlates with neural spike activity, frontopareital control network, negative life outcomes (Uddin et al., 2021). You cannot separate the single from the noise, because the noise is part of the signal.
- Softmax, Luce choice, Boltzman equations all assume probabilistic (noisy) sampling:
- The sensitivity (beta) can be tuned (proposal)
- What are priors in a Bayesian brain? Some kind of probabilistic manifold that favors the activation of some things over others.





Wainstein et al., 2022

# ENTROPY MODULATION THEORY—A MODEL OF SELECTIVE

- I'm going to tell you how the model works
- Then I'm going to show you how the model works

Suppose everyone has the same network



Suppose everyone has the same network

 Activating a node leads to sampling of nearby nodes: P(i) ~ f(1/distance).



P(i)

#### Distance

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- Each sample adds activation + noise:

 $\delta + \xi^*$ 

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- Nodes accumulation activation until they surpass a threshold (race model).

ENTROPY MODULATION



Despite appearances, this is a two-parameter model:





















The number of samples to reach the threshold is the reaction time.

# FOR A POPULATION, WE GET A MEASURE OF ASSOCIATION STRENGTH

We should expect something that looks like this for a given set of parameters:  $au ~ \sigma$ 

















#### NOW TURN UP THE NOISE

modulate C



 $P(w_i) = \frac{M_i^{\beta}}{\sum_{k \in W} M_k^{\beta}}.$ 

20 cue words

## SIMULATE THE MODEL

5000 associates per cue



20 cue words

## SIMULATE THE MODEL

5000 associates per cue





20 cue words

## SIMULATE THE MODEL

5000 associates per cue





20 cue words

# FROM THE SIMULATION 5000 associates per cue



# WE CAN MEASURE THIS IN $EN^{-}E = \sum_{i=1}^{n} p_i \log(p_i)$

**P(i)** 



Distance

# LOWER THE THRESHOLD AND/OR INCREASE THE NOISE



# LOWER THE THRESHOLD AND/OR INCREASE THE NOISE



### SUMMARY OF ENTROPY MODULATION THEORY

- Structural differences in behaviour can arise via processing differences.
- Entropy modulation is one demonstration of this.
- Every structure has a process story.





### SUMMARY

- Creative exploration shows evidence of structural and controlbased origins.
- The control origins lacked formal models
- Entropy modulation theory offers a solution based on evidence for controlled disinhibition.
- Questions?