Kognitionspsychologie: Session 2

What is intelligence?

Rui Mata, HS 2024

Version: October 8, 2024

Course structure

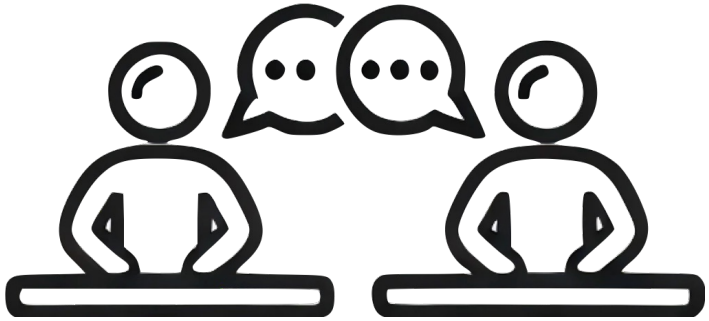
Session information

Sessions take place Tuesdays, 10.15-11.45, Pharmazentrum, Hörsaal 1.

#	Date	Topic	Slides
1	01.10.2024	Session 1: Introduction	pdf
2	08.10.2024	Session 2: Intelligence	
3	15.10.2024	Session 3: Perception	
4	22.10.2024	Session 4: Spatial cognition	
5	29.10.2024	Session 5: Numerical cognition	
6	05.11.2024	Session 6: Language	
7	12.11.2024	Session 7: Knowing	
8	19.11.2024	Session 8: Consciousness	
9	26.11.2024	Session 9: Applications: Reading acquisition	
10	03.12.2024	Session 10: Applications: Study techniques	
11	10.12.2024	Session 11: Applications: Combating misinformation	
12	17.12.2024	Session 12: Wrap-up and Q&A	

WHAT IS INTELLIGENCE?

And how would one study it based on Tinbergen's 4 questions?



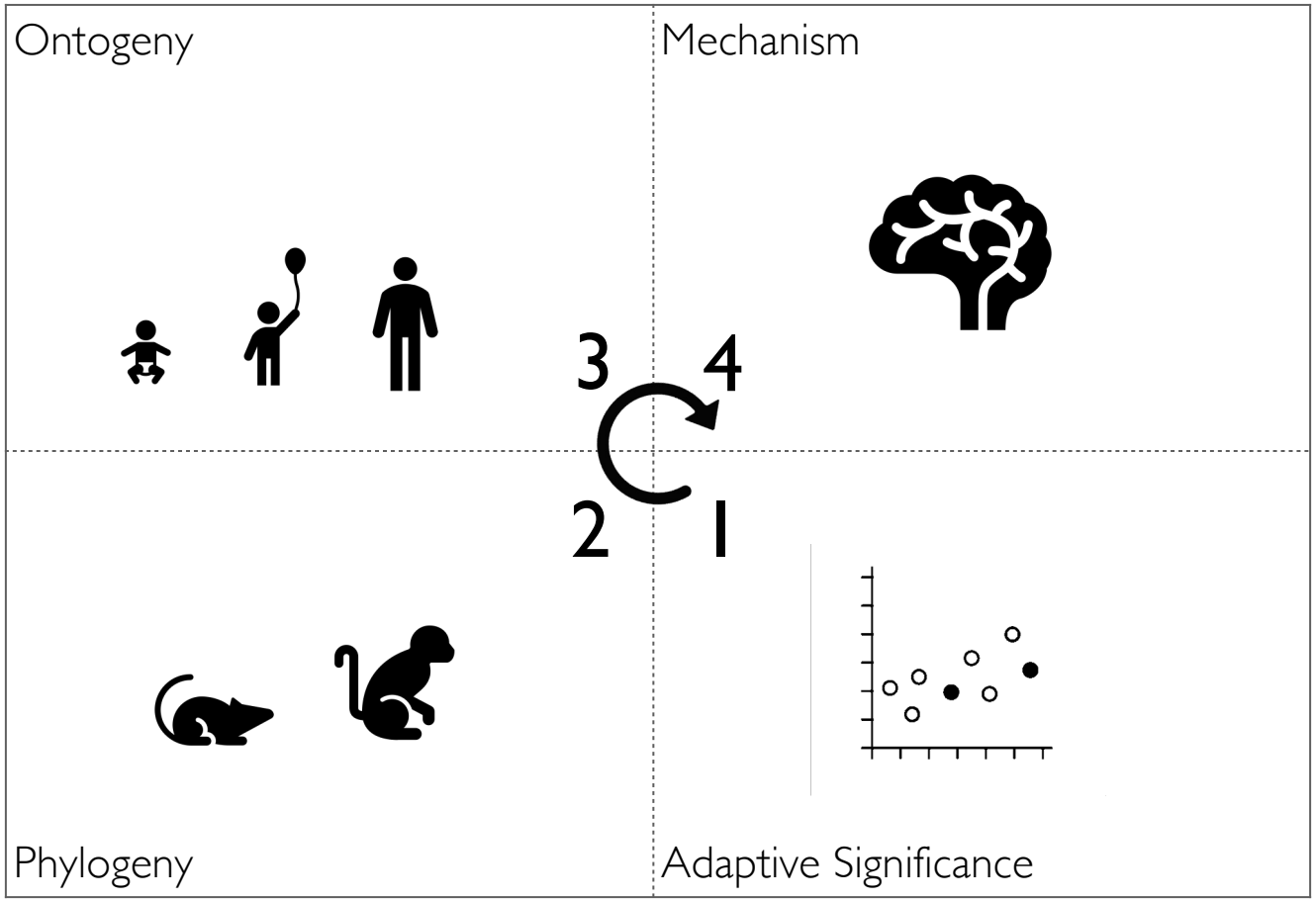
Intelligence: Consensual definition

"Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—"catching on," "making sense" of things, or "figuring out" what to do. Intelligence, so defined, can be measured, and intelligence tests measure it well."

Gottfredson, L. S. (1997) Mainstream science on intelligence: An editorial with 52 signatories, history, and bibliography. Intelligence, 24, 13–23.

[cf. Nisbett, R. E., Aronson, J., Blair, C., Dickens, W., Flynn, J., Halpern, D. F., & Turkheimer, E. (2012). Intelligence: New Findings and Theoretical Developments. *American Psychologist, 67*, 130-159]

Intelligence



Learning Objectives

- Review past debates about the structure of intelligence, and be familiar with the differential approach to intelligence
- Discuss the **adaptive significance** of intelligence
- Learn about **comparative approaches** to intelligence
- Learn about **developmental patterns** in intelligence
- Learn about **neural model**(s) of intelligence
- Discuss potential overlap and conflict between psychometric and neural models of intelligence

Intelligence and Modularity

modularity: i.e., the degree to which a system's components may be separated and recombined; in cognitive science, the thesis of modularity of mind holds that the mind is composed of (at least some) independent, domain-specific processing modules.

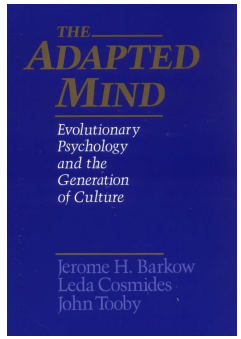
weak modularity

Modularity applies to perceptual modules, which are informationally encapsulated and provide input to higher-order systems.

Jerry Fodor (1935-2017) 1983

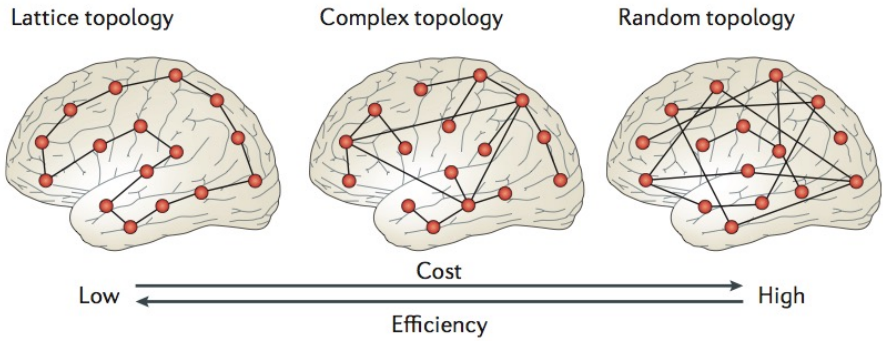
strong modularity

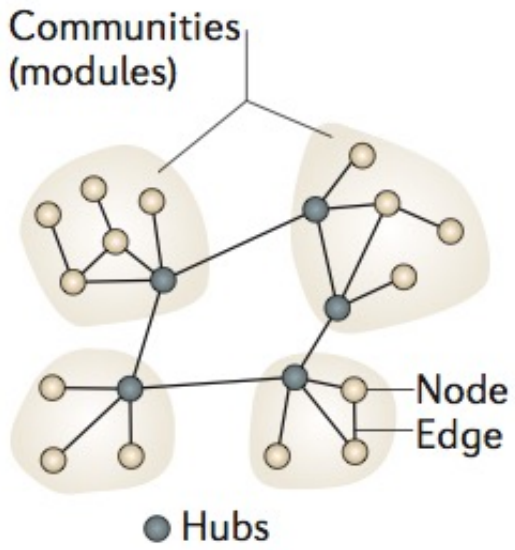
Our cognitive architecture consists of a confederation of hundreds or thousands of domain-specific (function specific) modules designed to solve adaptive problems from our evolution as a species of hunter-gatherers.



John Tooby (1952-2023)
Leda Cosmides (1957-) 1992

Intelligence and Modularity





Advantages of modular organization:

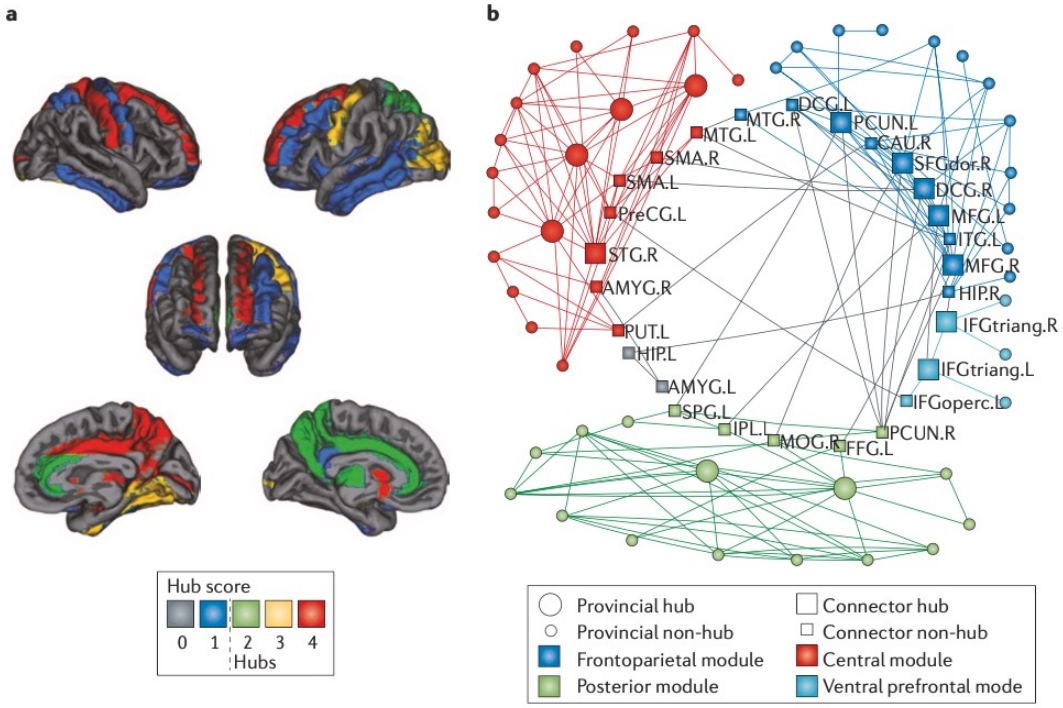
- helps conserve wiring costs and improving the local efficiency of specialized neural computations
- modules offer resilience against dynamic perturbations and small variations in structural connectivity;

Disadvantages of modular organization:

- functional integration between modules requires the addition of high-cost or long-distance axonal projections to interconnect spatially remote brain regions, which gives rise to connector hubs
- Hubs have a high participation index and can serve as a 'bottleneck' in the network.

Bullmore, E. & Sporns, O. (2012). The economy of brain network organization. ***Nature Reviews Neuroscience, 13***(5), 336-349.

Intelligence and Modularity



Novel neuroimaging methods have increasingly allowed for a better empirical estimation of functional and structural connectivity/modularity.

a | In human brain networks, some regions have more connections to the rest of the network, greater clustering and mediate a greater proportion of the shortest path connections between other regions. Such regions are called 'hubs' and include parts of medial parietal cortex, cingulate cortex and superior frontal cortex, indicated here by their 'hub score' (regions with a hub score of 2 or higher are defined as hubs). **b** | Human brain networks are also modular. Brain regions are colour-coded according to their membership in major modules comprising frontal (dark blue), central (red) and posterior (green) brain regions as well as a smaller module of inferior frontal regions (light blue). The connector hubs, which mediate most of the longer-distance inter-modular connections, are shown as a ring of square markers

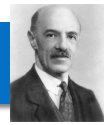
Bullmore, E. & Sporns, O. (2012). The economy of brain network organization. ***Nature Reviews Neuroscience, 13***(5), 336-349.

The Psychometric Approach to Intelligence

Perspectives

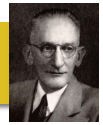
Intelligence as a general ability

Charles E. Spearman (1863-1945)



Intelligence as the product of specific faculties

Louis L. Thurstone (1887-1955)



1900 1925 1950 1975 2000

The Psychometric Approach to Intelligence

Spearman's correlation matrix for six measures of school performance. All the correlations are positive, a phenomenon referred as the *positive manifold*. The bottom row shows the *g* loadings of each performance measure.[5]

	Classics	French	English	Math	Pitch	Music
Classics	-					
French	.83	-				
English	.78	.67	-			
Math	.70	.67	.64	-		
Pitch discrimination	.66	.65	.54	.45	-	
Music	.63	.57	.51	.51	.40	-
g	.958	.882	.803	.750	.673	.646

http://setosa.io/ev/principal-component-analysis/

The Psychometric Approach to Intelligence

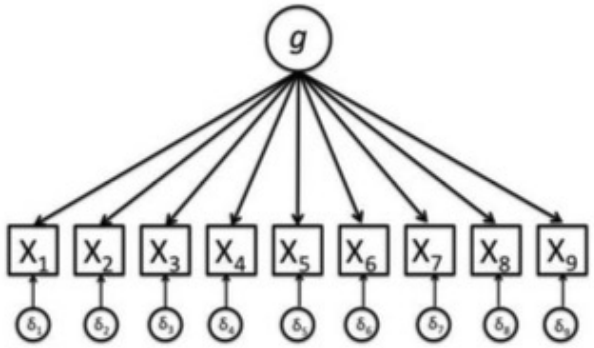


Figure 1. A model depicting Spearman's original conception of a single general factor.

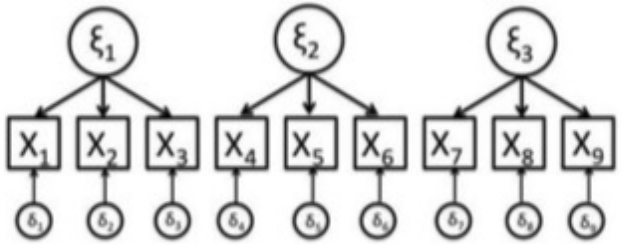


Figure 2. A model depicting Thurstone's original (but later revised) conception of orthogonal group factors.

Both models capture important aspects of intellectual functioning but also neglect others. Sperman's model captures the positive manifold but does not account for the result that some tests are more highly correlated than others. Thurstone's model does not capture the overall correlation between specific abilities.

Kovacs, K., & Conway, A. R. A. (2016). Process Overlap Theory: A unified account of the general factor of intelligence. ***Psychological Inquiry, 27***(3), 151–177. http://doi.org/10.1080/1047840X.2016.1153946

Markon, K. E. (2019). Bifactor and Hierarchical Models: Specification, Inference, and Interpretation. ***Annual Review of Clinical Psychology, 15***(1), 51–69. http://doi.org/10.1146/annurev-clinpsy-050718-095522

The Psychometric Approach to Intelligence

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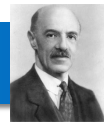

Intelligence as the product of specific faculties

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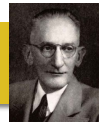
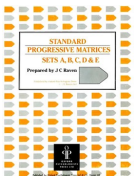


Scales

Stanford-Binet

Army Alpha



Raven

Wechsler

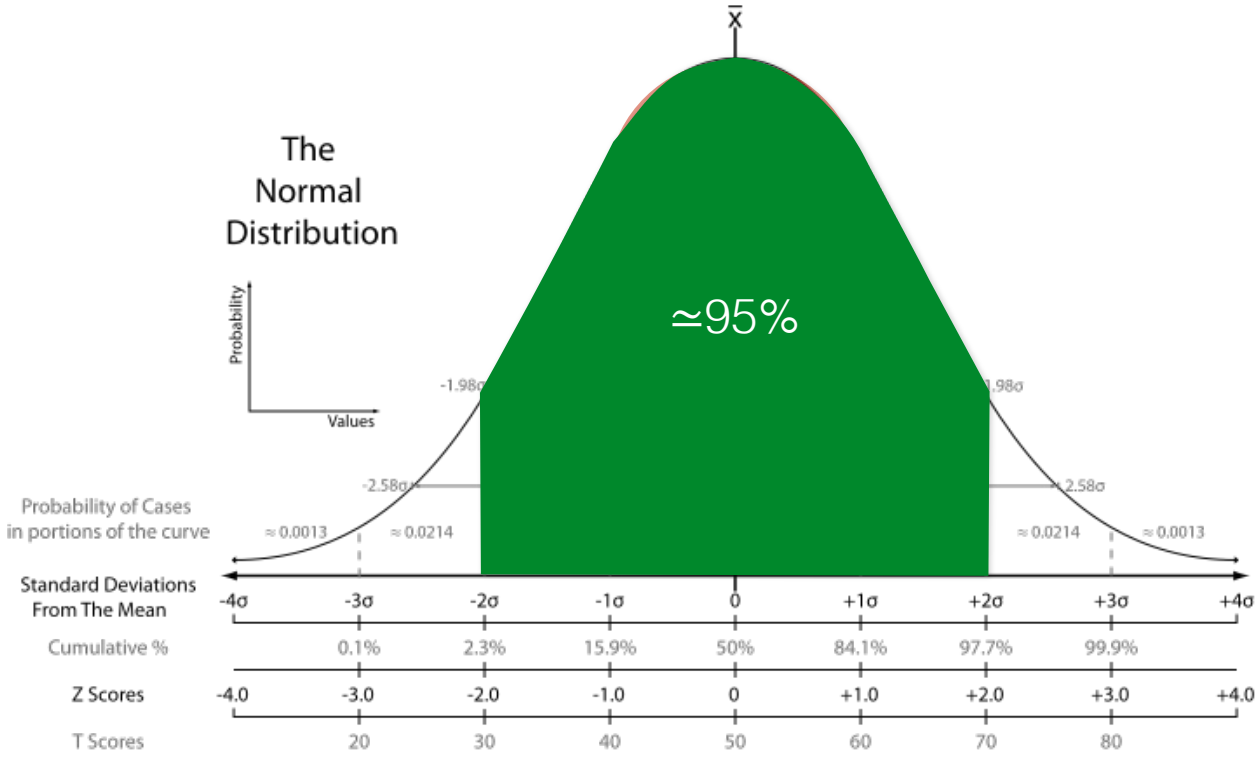
....

1900 1925 1950 1975 2000

The Psychometric Approach to Intelligence

Intelligence (as IQ) is a relative statement

"without variation in mental abilities there would be no latent variables—the last survivor of a meteor collision with Earth would still have cognitive abilities and mental limitations but would not have *g*." (Kovacs & Conway, 2016, p. 153)



The distribution of test results is standardized as having a mean of 100 and a standard deviation of 15. Consequently, about 2/3 of the population have an IQ between 85 and 115. The larger the distance from 100, the fewer individuals can be found with a given IQ.

http://de.wikipedia.org/wiki/Intelligenzquotient

$$IQ = 100 + 15 \times \frac{\text{Raw score - Mean}}{\text{Standard Deviation}}$$

The Psychometric Approach to Intelligence

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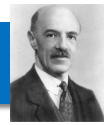

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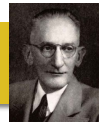
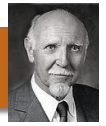


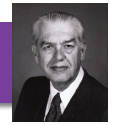
Synthesis: Cattell-Horn-Carroll Model

Raymond B. Cattell (1905-1998)



John L. Horn (1928-2006)

John B. Carroll (1916-2003)



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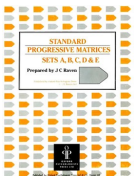

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The Psychometric Approach to Intelligence

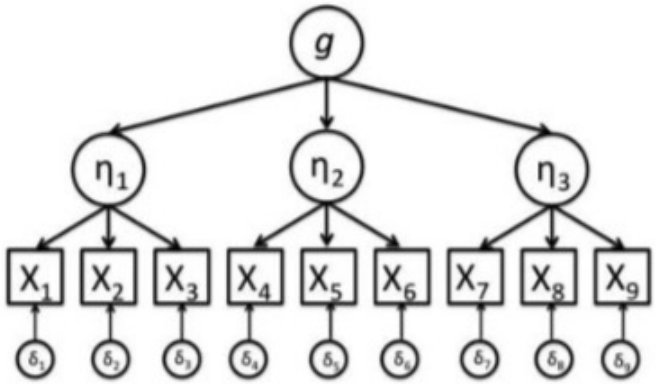


Figure 4. A hierarchical model of cognitive abilities.

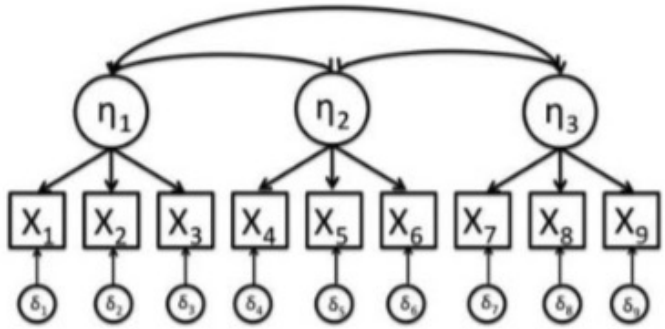


Figure 5. An oblique model of cognitive abilities.

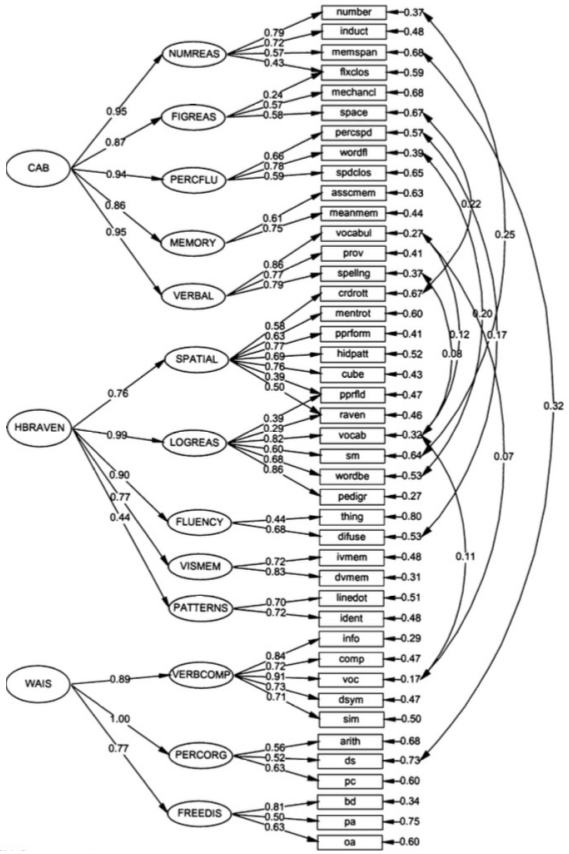
although these models are structurally different, their fits (and predictions) are equivalent, making it difficult to obtain a definitive answer to the structure of mental functions!

Kovacs, K., & Conway, A. R. A. (2016). Process Overlap Theory: A Unified Account of the General Factor of Intelligence. ***Psychological Inquiry, 27***(3), 151–177. http://doi.org/10.1080/1047840X.2016.1153946

Markon, K. E. (2019). Bifactor and Hierarchical Models: Specification, Inference, and Interpretation. ***Annual Review of Clinical Psychology, 15***(1), 51–69. http://doi.org/10.1146/annurev-clinpsy-050718-095522

The Psychometric Approach to Intelligence

Convergent validity



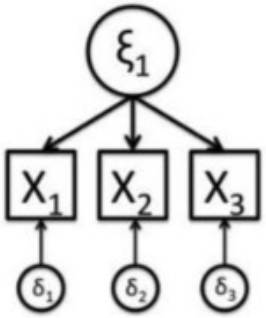
"We addressed the extent to which this prediction was true using three mental ability batteries administered to a heterogeneous sample of 436 adults. Though the particular tasks used in the batteries reflected varying conceptions of the range of human intellectual performance, the g factors identified by the batteries were completely correlated (correlations were **.99**, **.99**, and **1.00**). This provides further evidence for the existence of a higher-level g factor and suggests that its measurement is not dependent on the use of specific mental ability tasks."

Johnson W, Bouchard TJ, Krueger RF, McGue M, Gottesman II. (2004). Just one g: Consistent results from three test batteries. Intelligence, 32, 95–107

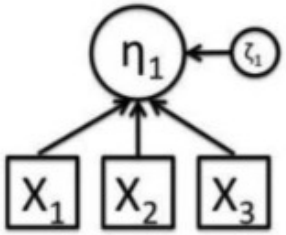
Johnson, W., Nijenhuis, J. T., & Bouchard, T. J., Jr. (2008). Still just 1 g: Consistent results from five test batteries. Intelligence, 36(1), 81–95.

The Psychometric Approach to Intelligence

reflective



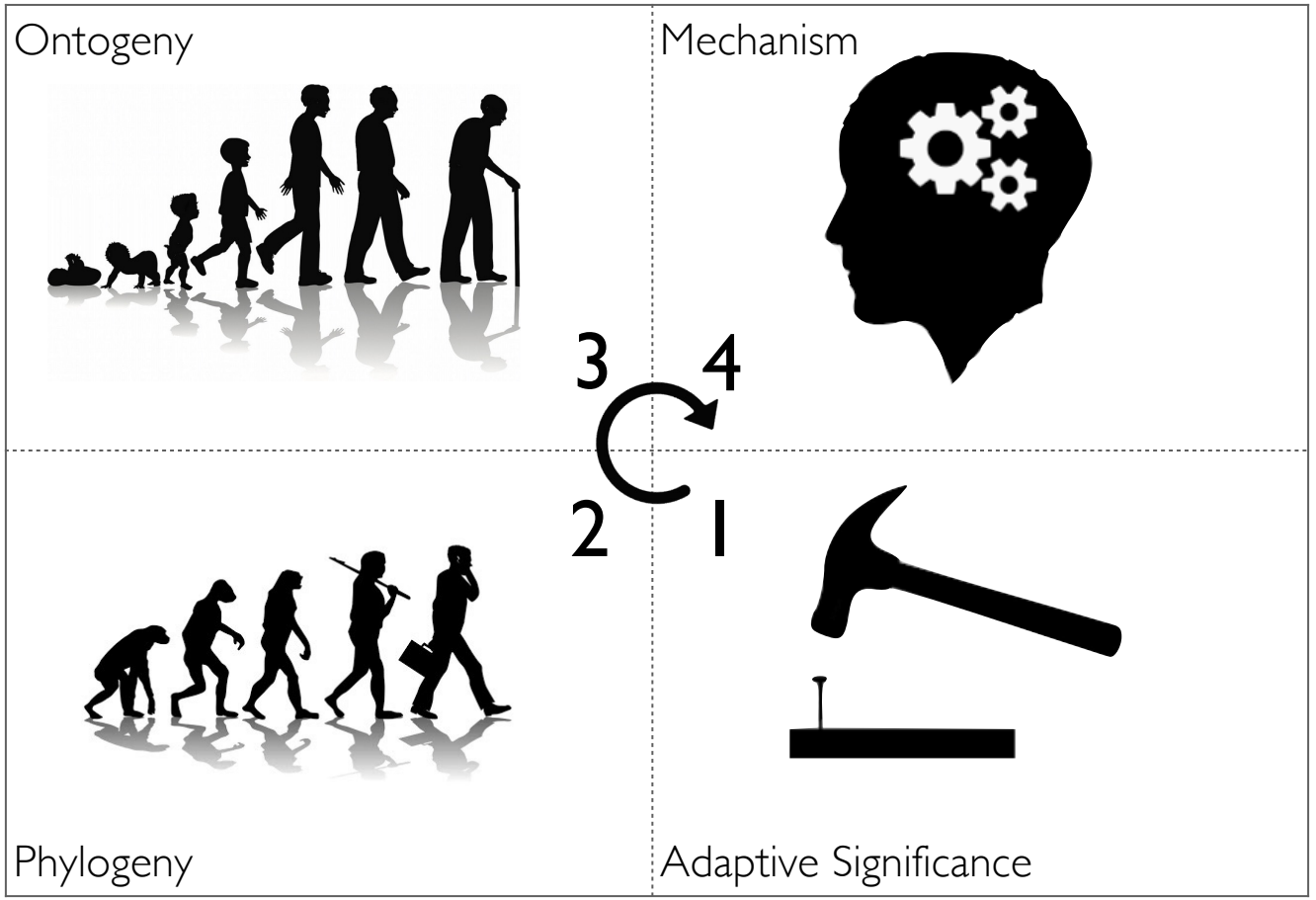
formative



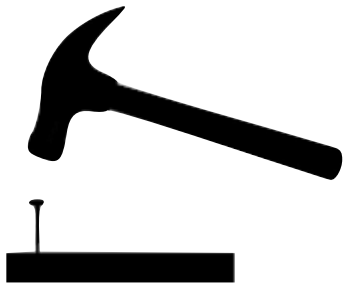
the two models are formally equivalent but conceptually distinct; **g** is a central psychological construct (and statistical device) developed to account for the empirical findings of a positive manifold; yet, it is still controversial whether to think of it as cause (reflective model) or consequence (formative model) of how the mind works…

Kovacs, K., & Conway, A. R. A. (2016). Process Overlap Theory: A Unified Account of the General Factor of Intelligence. ***Psychological Inquiry, 27***(3), 151–177. http://doi.org/10.1080/1047840X.2016.1153946

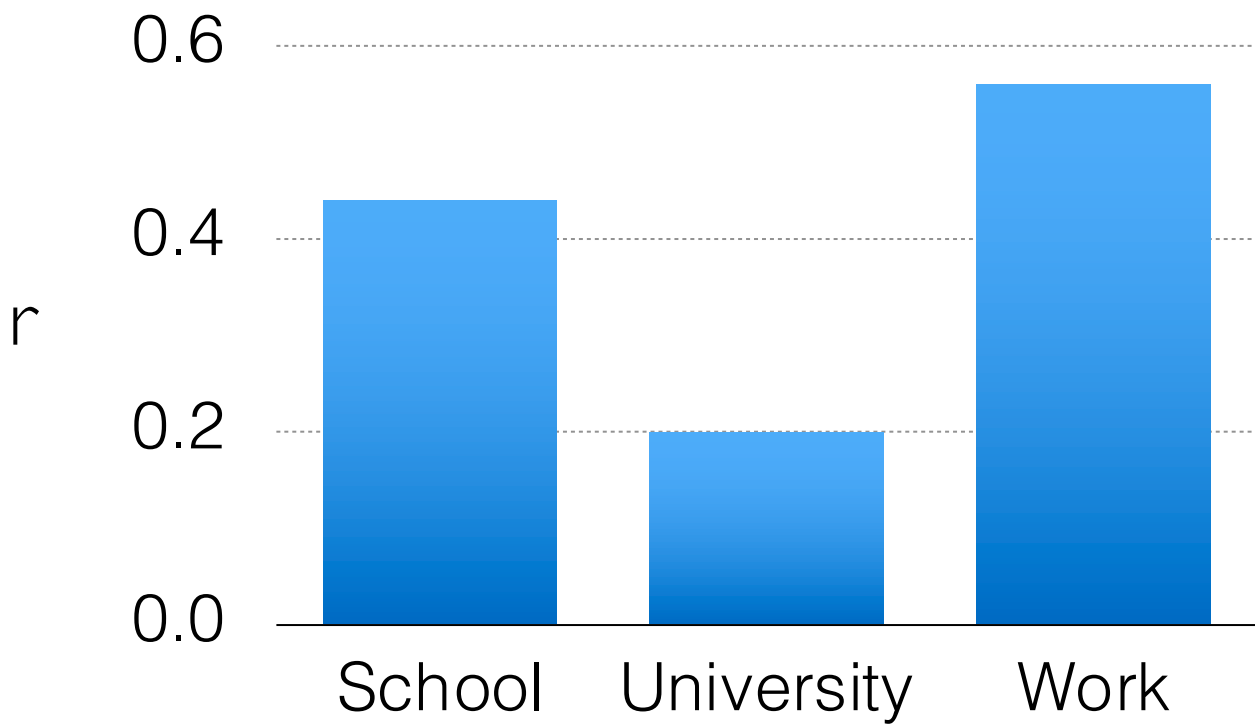
Intelligence



Intelligence

Ontogeny	Mechanism
Phylogeny	 Adaptive Significance

Intelligence is a Predictor of Academic and Work Performance



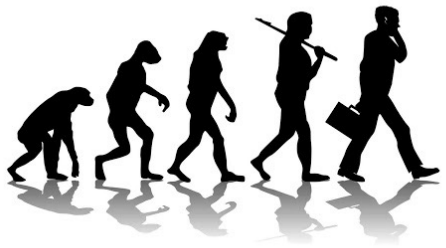
Roth, B., Becker, N., Romeyke, S., Schäfer, S., Domnick, F., & Spinath, F. M. (2015). Intelligence and school grades: A meta-analysis. ***Intelligence***, ***53***(C), 118–137.

Richardson, M., Abraham, C. & Bond, R. (2012). Psychological correlates of university students' academic performance: A systematic review and meta-analysis. ***Psychological Bulletin, 138***, 353-387.

Schmidt, F. L., & Hunter, J. E. (1998). The validity and utility of selection methods in personnel psychology: Practical and theoretical implications of 85 years of research findings. ***Psychological Bulletin. 124***, 262-274.

The link between intelligence and job performance is not without controversy. For a recent overview see DOI: 10.26775/OP.2023.02.12

Intelligence

Ontogeny	Mechanism
 Phylogeny	Adaptive Significance

Evidence for *g* in non-human animals is weak

Species	Number of Studies	Tasks	*N*	Support for *g*
Primates	4	8-15	22-106	2/4 (50%)
Rodents	12	4-8	22-241	11/12 (92%)
Dogs	1	6	68	1/1 (100%)
Birds	4	4-6	11-22	2/4 (50%)

In comparison to the overwhelming evidence for *g* in humans, the non-human animal literature is less clear about its existence, albeit current summaries suggest a positive manifold (see table above). However, the existence of a positive manifold does not allow us to conclude equivalence of *g* between species – tasks are fundamentally different AND a positive manifold requires a mechanistic explanation…

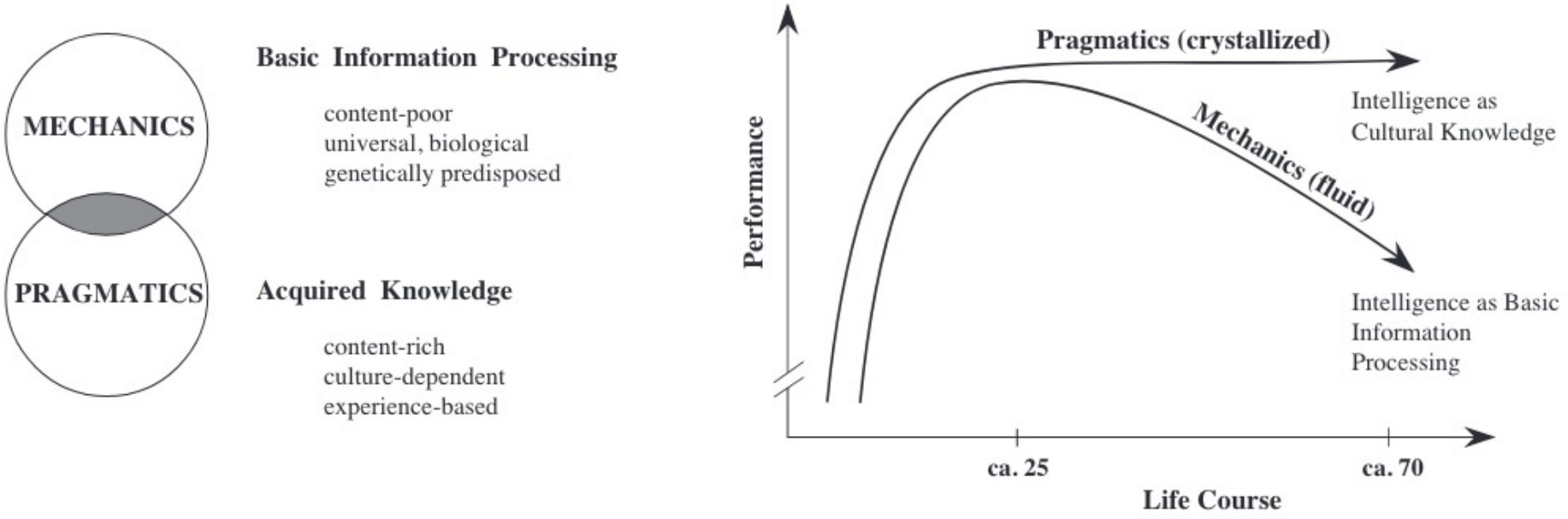
Shaw, R. C., & Schmelz, M. (2017). Cognitive test batteries in animal cognition research: Evaluating the past, present and future of comparative psychometrics. Animal Cognition, 20(6), 1003–1018. https://doi.org/10.1007/s10071-017-1135-1

Burkart, J. M., Schubiger, M. N., & Van Schaik, C. P. (2017). The evolution of general intelligence. *Behavioral and Brain Sciences*, *40*, e195. https://doi.org/10.1017/S0140525X16000959

Intelligence

Ontogeny 	Mechanism
Phylogeny	Adaptive Significance

Evidence for different components of *g*



The figure underscores the principles of **multidimensionality** and **multidirectionality** in intellectual development across the human lifespan. It distinguishes between two components, mechanics and pragmatics of cognition, and shows mechanics peaking and declining earlier in life, whereas pragmatics peak later and decline more gradually, highlighting the interplay between biological and cultural factors in cognitive development.

Baltes, P. B., Staudinger, U. M., & Lindenberger, U. (1999). Lifespan Psychology: Theory and Application to Intellectual Functioning. Annual Review of Psychology, 50(1), 471–507. https://doi.org/10.1146/annurev.psych.50.1.471

Intelligence

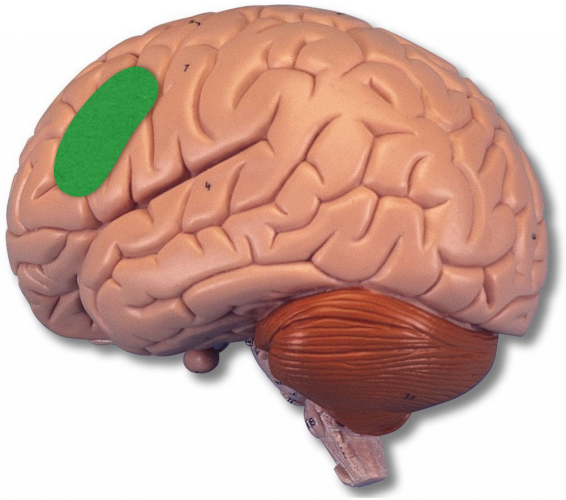
Ontogeny	Mechanism 
Phylogeny	Adaptive Significance

Neural Theories of Intelligence

Table I. Summary of Cognitive Neuroscience Theories of Human Intelligence

	Functional localization			System-wide topology and dynamics		
	Primary region	Primary network	Multiple networks	Small-world topology	Network flexibility	Network dynamics
Lateral PFC Theory [103]	✓	x	x	x	x	x
P-FIT Theory [75]	x	✓	x	x	x	x
MD Theory [82]	x	✓	x	x	x	x
Process Overlap Theory [83]	x	x	✓	x	x	x
Network Neuroscience Theory	x	x	✓	✓	✓	✓

Lateral PFC



"Early studies investigating the neurobiology of *g* implicated the lateral prefrontal cortex (PFC). motivating an influential theory based on the role of this region in cognitive control functions for intelligent behavior"

Barbey, A. K. (2018). Network Neuroscience Theory of Human Intelligence. ***Trends in Cognitive Sciences***, ***22***(1), 8–20. http://doi.org/10.1016/j.tics.2017.10.001

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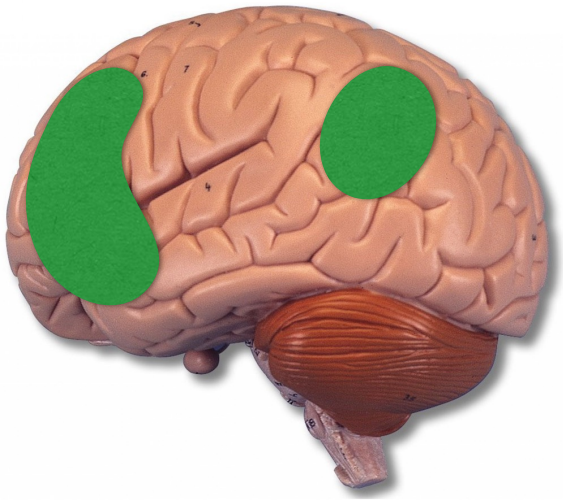
MD Theory [82]	x	✓	x	x	x	x
Process Overlap Theory [83]	x	x	✓	x	x	x
Network Neuroscience Theory	x	x	✓	✓	✓	✓

P-FIT/MD

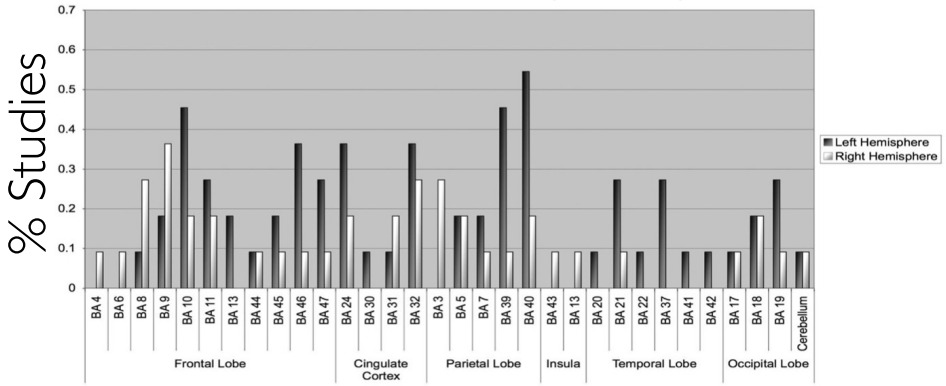


"The landmark Parietofrontal Integration Theory (P-FIT) appeals to the frontoparietal network to explain individual differences in intelligence, proposing that g reflects the capacity of this network to evaluate and test hypotheses for problem-solving. A central feature of the P-FIT model is an emphasis on the integration of knowledge between frontal and parietal cortex, afforded by white-matter fiber tracks that enable efficient communication among regions. Evidence to support the role of the frontoparietal network role in a broad range of problem-solving tasks later motivated the Multiple-Demand (MD) Theory, which proposes that this network underlies attentional control mechanisms for goal-directed problem-solving"

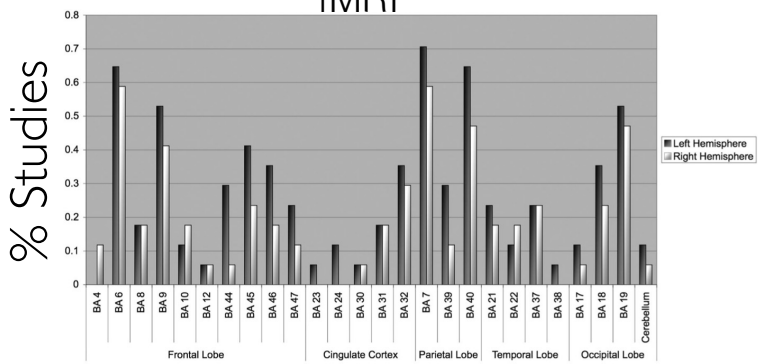
Barbey, A. K. (2018). Network Neuroscience Theory of Human Intelligence. ***Trends in Cognitive Sciences***, ***22***(1), 8–20. http://doi.org/10.1016/j.tics.2017.10.001

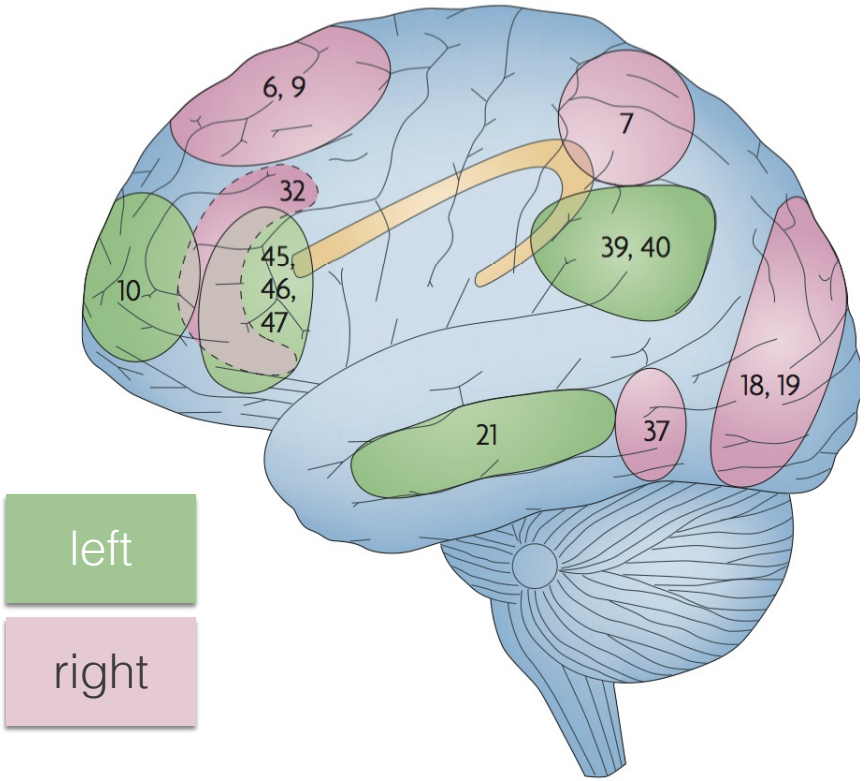
Parieto-Frontal Integration Theory of Intelligence

DTI (diffusion tensor imaging);
VBM (Voxel-based Morphometry)



fMRI





The loci of intelligence differences: Based on a review of all the structural and functional neuroimaging literature that was available, Jung and Haier proposed the parieto-frontal integration theory of intelligence (P-FIT), which is a very general description of how intelligence is distributed in the brain. The figure shows Brodmann Areas (BAs) involved in intelligence, as well as the arcuate fasciculus (shown in yellow) as a promising candidate for a white matter tract that connects the involved brain regions. BAs shown in green indicate predominantly left-hemispheric correlations and BAs shown in pink indicate predominantly right-hemispheric correlations with intelligence.

Deary, I. J., Penke, L. & Johnson, W. (2010). The neuroscience of human intelligence differences. ***Nature Reviews Neuroscience, 11***, 201-211.

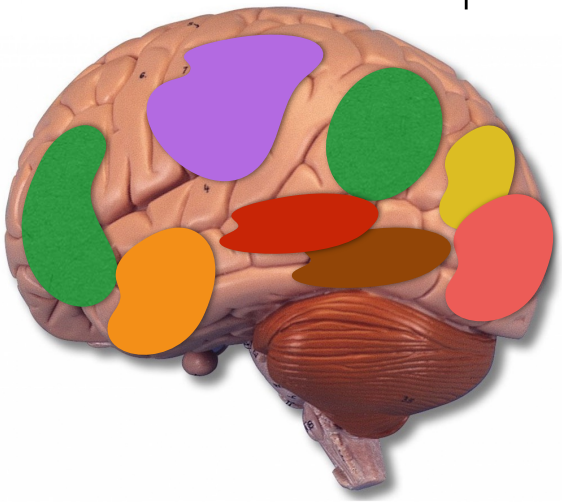
Jung, R. E. & Haier, R. J. (2007). The Parieto-Frontal Integration Theory (P-FIT) of intelligence: Converging neuroimaging evidence. ***Behavioral and Brain Sciences, 30***, 135–154.

Neural Theories of Intelligence

Table I. Summary of Cognitive Neuroscience Theories of Human Intelligence

	Functional localization			System-wide topology and dynamics		
	Primary region	Primary network	Multiple networks	Small-world topology	Network flexibility	Network dynamics
Lateral PFC Theory [103]	✔	x	x	x	x	x
P-FIT Theory [75]	x	✔	x	x	x	x
MD Theory [82]	x	✔	x	x	x	x
Process Overlap Theory [83]	x	x	✔	x	x	x
Network Neuroscience Theory	x	x	✔	✔	✔	✔

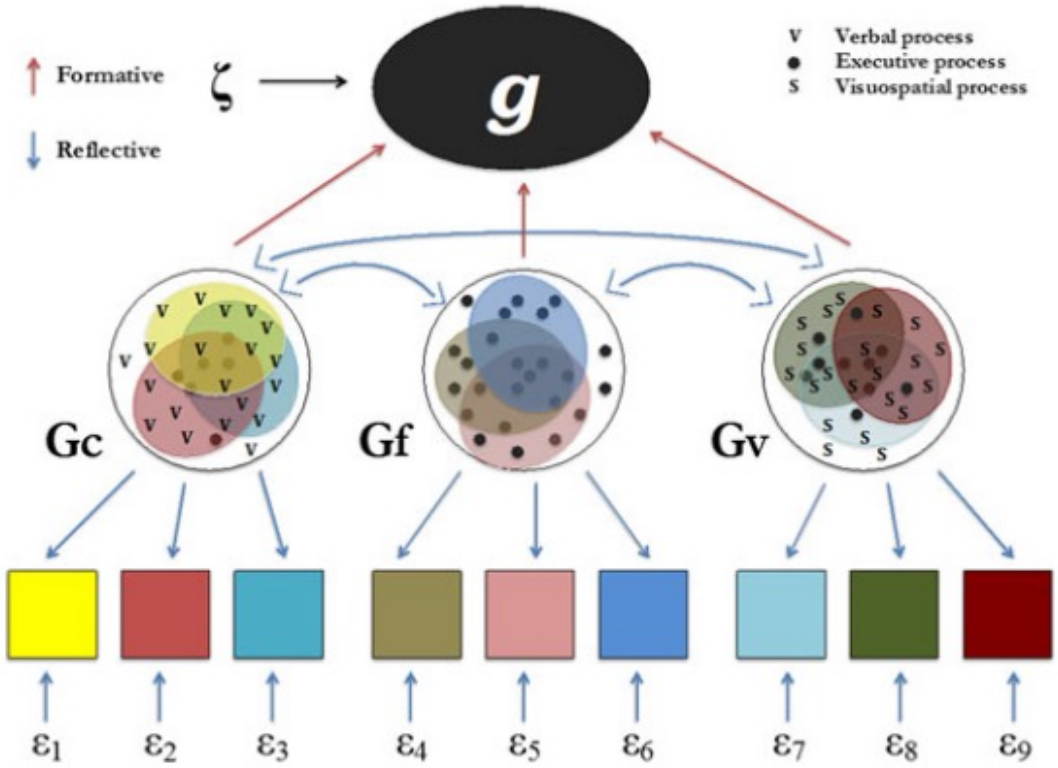
Process Overlap



"Finally, the Process Overlap Theory represents a recent network approach that accounts for individual differences in *g* by appealing to the spatial overlap among specific brain networks, reflecting the shared cognitive processes underlying *g*. Thus, contemporary theories suggest that individual differences in *g* originate from functionally localized processes within specific brain regions or networks"

Barbey, A. K. (2018). Network Neuroscience Theory of Human Intelligence. ***Trends in Cognitive Sciences***, ***22***(1), 8–20. http://doi.org/10.1016/j.tics.2017.10.001

Neural Theories of Intelligence



"process overlap theory translates to a hybrid structural model: part formative, part reflective. As a reflective causal model it corresponds to the oblique model, but it can also accommodate g as a formative latent variable—the common consequence, rather than the common cause, of the correlation between group factors. (…) Because process overlap is probably not the only source of the all-positive correlations, this model also accommodates other sources of the general factor, which can range from white matter tract integrity to mutualism, and so on."

"

Kovacs, K., & Conway, A. R. A. (2016). Process Overlap Theory: A Unified Account of the General Factor of Intelligence. ***Psychological Inquiry, 27***(3), 151–177. http://doi.org/10.1080/1047840X.2016.1153946

Neural Theories of Intelligence

Table I. Summary of Cognitive Neuroscience Theories of Human Intelligence

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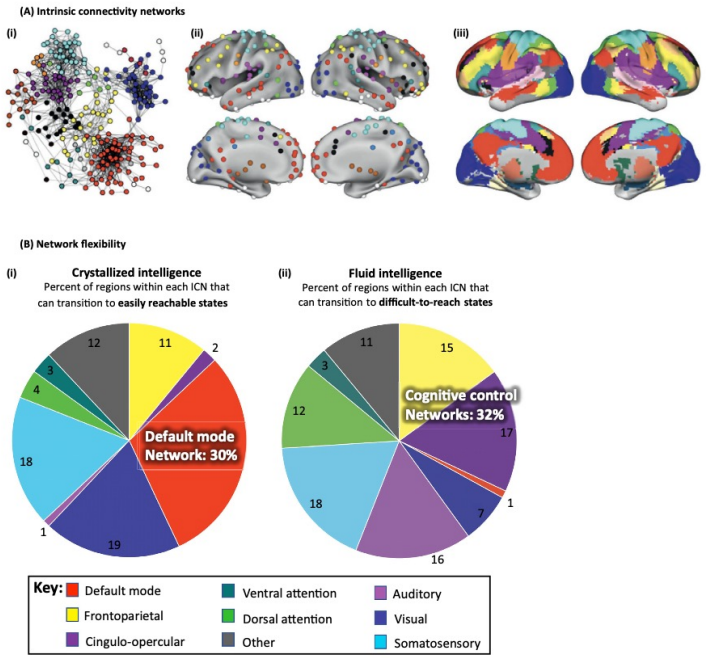
P-FIT Theory [75]	x	✔	x	x	x	x
MD Theory [82]	x	✔	x	x	x	x
Process Overlap Theory [83]	x	x	✔	x	x	x
Network Neuroscience Theory	x	x	✔	✔	✔	✔

Network Neuroscience (NNT)



"NNT adopts a new perspective, proposing that g originates from individual differences in the system-wide topology and dynamics of the human brain. According to this approach, the small-world topology of brain networks enables the rapid reconfiguration of their modular community structure, creating globally coordinated mental representations of a desired goal-state and the sequence of operations required to achieve it. The capacity to flexibly transition between network states therefore provides the foundation for individual differences in g, engaging (i) easy-to-reach network states to construct mental representations for crystallized intelligence based on prior knowledge and experience, and accessing (ii) difficult-to-reach network states to construct mental representations for fluid intelligence based on cognitive control functions that guide adaptive reasoning and problem-solving."

Barbey, A. K. (2018). Network Neuroscience Theory of Human Intelligence. ***Trends in Cognitive Sciences***, ***22***(1), 8–20. http://doi.org/10.1016/j.tics.2017.10.001

Summary

- **Intelligence:** consensual yet perhaps unsatisfying definition as “ability to reason, plan, solve problems”; evolutionary principles may be helpful to understand organizational principles of human psychology – including the idea of modularity of mind (i.e., the idea that a cognitive system is composed of somewhat independent, specialized modules); comparison to a *differential* (relative; non-mechanistic) perspective on intellectual function that focuses on the statistical modeling of inter-individual differences

- **Adaptive significance:** intelligence (IQ) matters because it has criterion/predictive validity concerning important life outcomes (e.g., health, academic and work performance) and can be used as criterion for interventions (e.g., educational interventions)

- **Comparative approaches:** some but mixed evidence for a positive manifold in non-human animals, difficult comparability to humans and limited mechanistic understanding of higher-order abilities due to substantive and methodological limitations

- **Neural basis of intelligence:** different models emphasize primary regions (frontal cortex), primary networks (parieto-frontal network), or coordination of networks potentially distributed across the brain (process overlap theory, network theory)

- ***g***: central (statistical) construct to account for positive manifold; controversial status as cause or consequence of specific cognitive/neural mechanisms (reflective vs. formative models of intelligence, with modern theories integrating both) - one can think of **cognitive psychology** as the discipline working out a ***mechanistic*** explanation for *g…*