Cognitive Computational Modelling of Human Brain

Principles and Organization

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CIBIT
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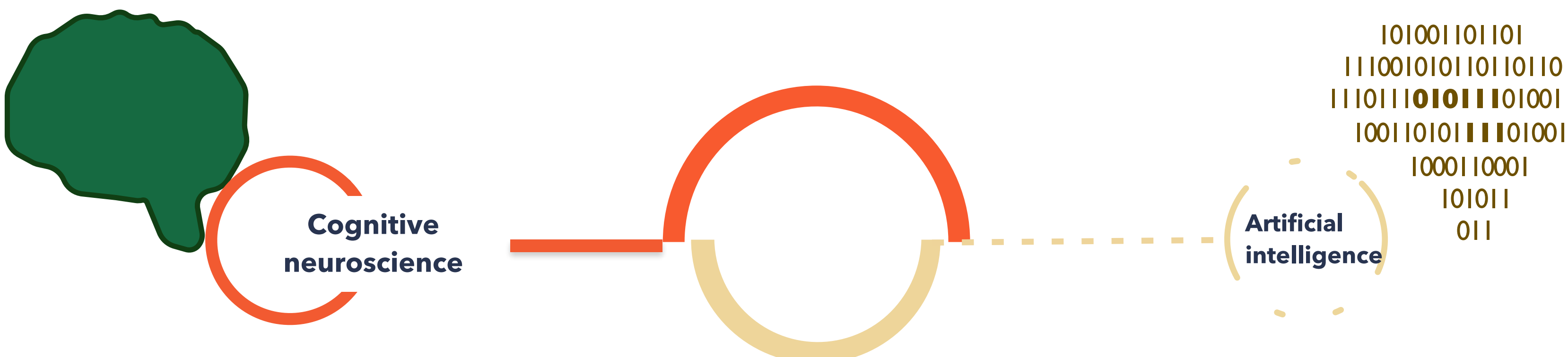
Discussion topics

- Biology, Mathematics, Logic (and artificial intelligence)
- Functional **segregation** and **integration**
- **Networks** and **graph** representation
  - Basis for connectivity studies
  - Connectivity and network analysis
    - **Network characterization**
- Decoding the brain
- Controllability from an engineering perspective

The relationship between cognitive science and artificial intelligence

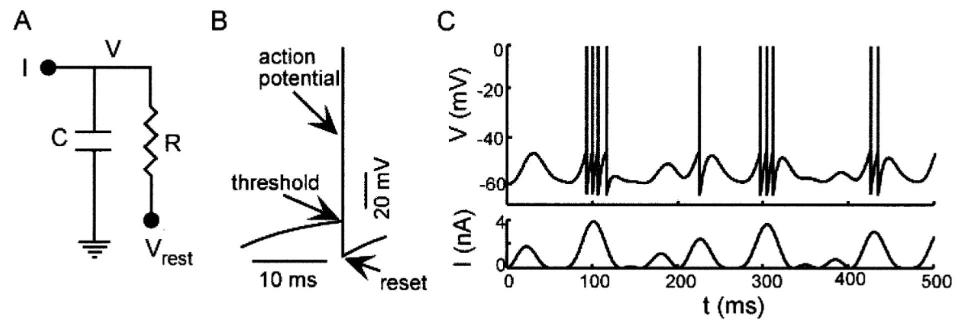


"One of the goals of the cybernetics movement was to find common elements in the functioning of animals and machines."

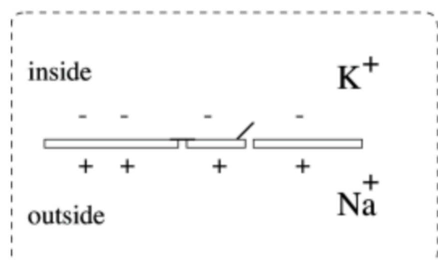
Abraham, T. H. (2002). (Physio)logical circuits: The intellectual origins of the McCulloch-Pitts neural networks. J. Hist. Behav. Sci. 38, 3–25. doi:10.1002/jhbs.1094.

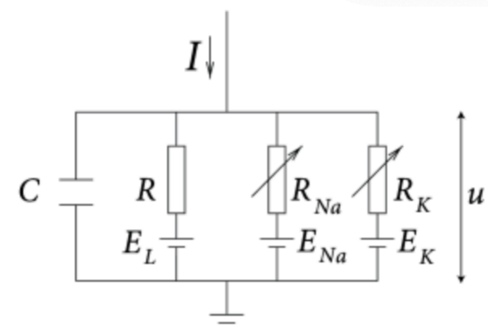
An historical view - neuron model

1907 Lapicque's model



1952 A. L. Hodgkin and A. F. Huxley





An historical view

Attempted to create an alphabet of human thought, each letter of which represented a concept and could be combined and manipulated according to a set of logical rules to compute all knowledge
Gottfried Leibniz

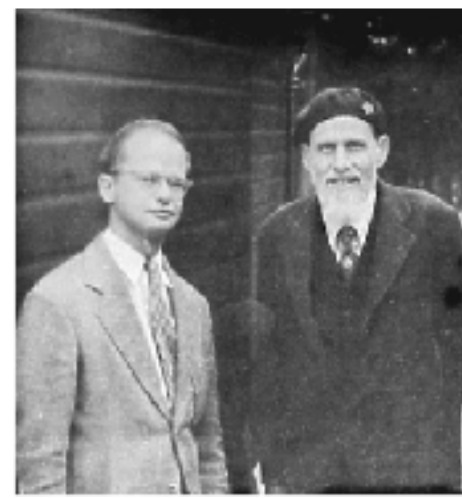
17th century

1910-1913

“Principia Mathematica”
Bertrand Russell, Alfred Whitehead

1943

“A logical calculus of the ideas immanent in nervous activity”
Warren McCulloch
Walter Pitts



McCulloch (right) and Pitts (left) in 1949, source: www.semanticscholar.com

The relationship between cognitive science and artificial intelligence

- The radical story written by McCulloch-Pitts (neurons perform logical calculus) was the first to adapt the principles of computation to mind-body connection
- These notions would support the idea that neural networks can form formal logical systems
- A network can carry out endless computations
    - Basis of the human thought

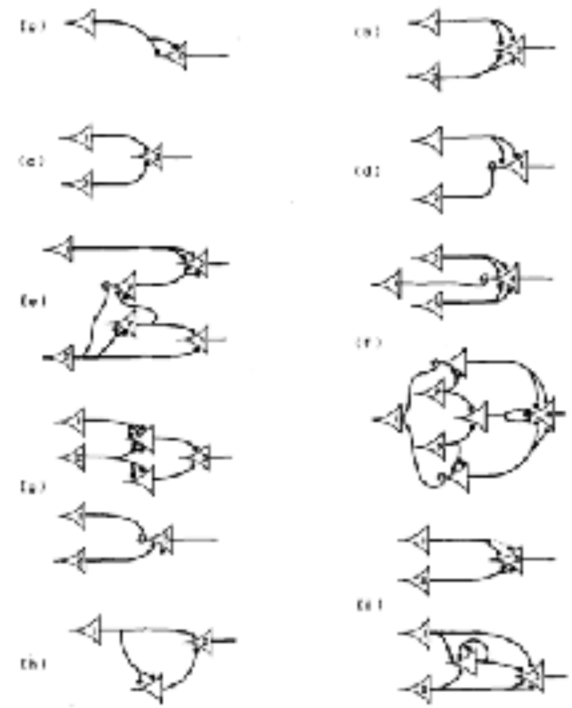


Figure 1. The neuron c_i is always marked with the numeral i upon the body of the cell, and the corresponding action is denoted by "N" with i subscript, as in the text:

(a) $N_2(t) . \equiv . N_1(t-1)$;
(b) $N_3(t) . \equiv . N_1(t-1) \vee N_2(t-1)$;
(c) $N_3(t) . \equiv . N_1(t-1) . N_2(t-1)$;
(d) $N_3(t) . \equiv . N_1(t-1) . \sim N_2(t-1)$;
(e) $N_3(t) : \equiv : N_1(t-1) . \vee . N_2(t-3) . \sim N_2(t-2)$;
$N_4(t) . \equiv . N_2(t-2) . N_2(t-1)$;
(f) $N_4(t) : \equiv : \sim N_1(t-1) . N_2(t-1) \vee N_3(t-1) . \vee . N_1(t-1)$.
$N_2(t-1) . N_3(t-1)$

Abraham, T. H. (2002). (Physio)logical circuits: The intellectual origins of the Mcculloch-Pitts neural networks. J. Hist. Behav. Sci. 38, 3–25. doi:10.1002/jhbs.1094.

Computational models guiding cognitive neuroscience


Electronic 'Brain' Teaches Itself

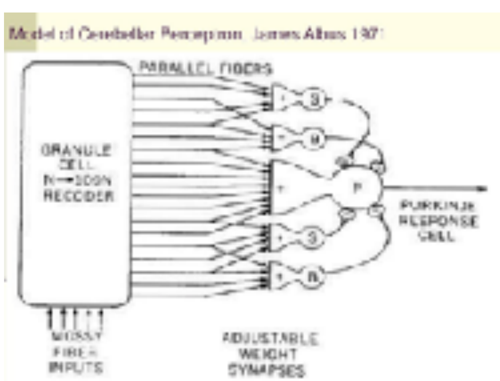
Self-Reproduction

1958

"Electronic brain teaches itself"
Perceptron, Frank Rosenblatt

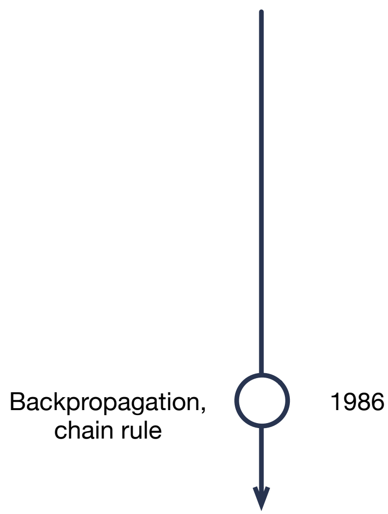
Function emerges from a network (distributed across its neurons and connections between them)

Perceptron at work, the cerebellum model (James Albus).



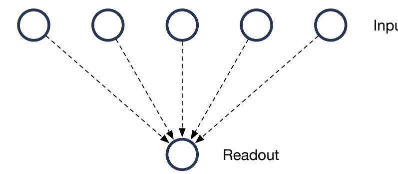
1971

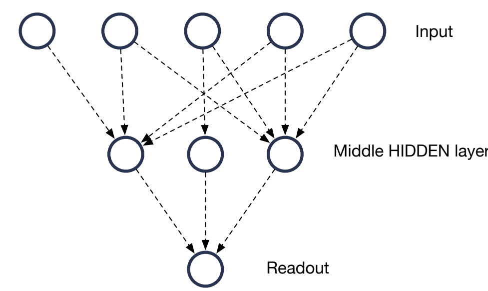
Cognitive neuroscience guiding computational intelligence



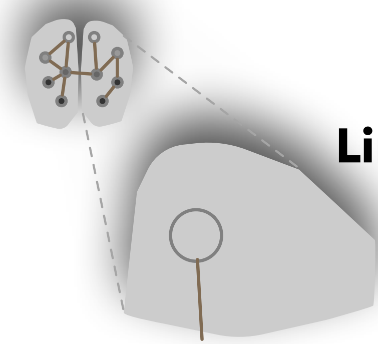
- Intelligence and learning needs more than one layer
  - Generalization capability, memory etc.
  - Hidden layers
    - An additional layer would allow some generalization

But how about *learning*? *Backpropagation*





An historical view on the neural correlates of function - a clinical perspective (localizationism).



Link between **brain trauma, damage** and **function impairment.**

1861 — Tan tan
By Paul Broca
Non-fluent aphasic patient

1868 — Phineas Gage
By John Harlow
Frontal lobe and related behaviours

...

1957 — H.M
By W. Scoville
Bilateral medial temporal lobe removal and anterograde memory

Phineas Gage, Louis Victor Leborgne ("tan tan"), Henry Molaison (H.M.)

Thiebaut De Schotten, M., Dell'Acqua, F., Ratiu, P., Leslie, A., Howells, H., Cabanis, E., et al. (2015). Cereb. Cortex 25, 4812–4827. doi:10.1093/cercor/bhv173.

An historical view on the neural correlates of function and dysfunction - **Disconnexion** in animals and man (Geschwind, N. (1965))

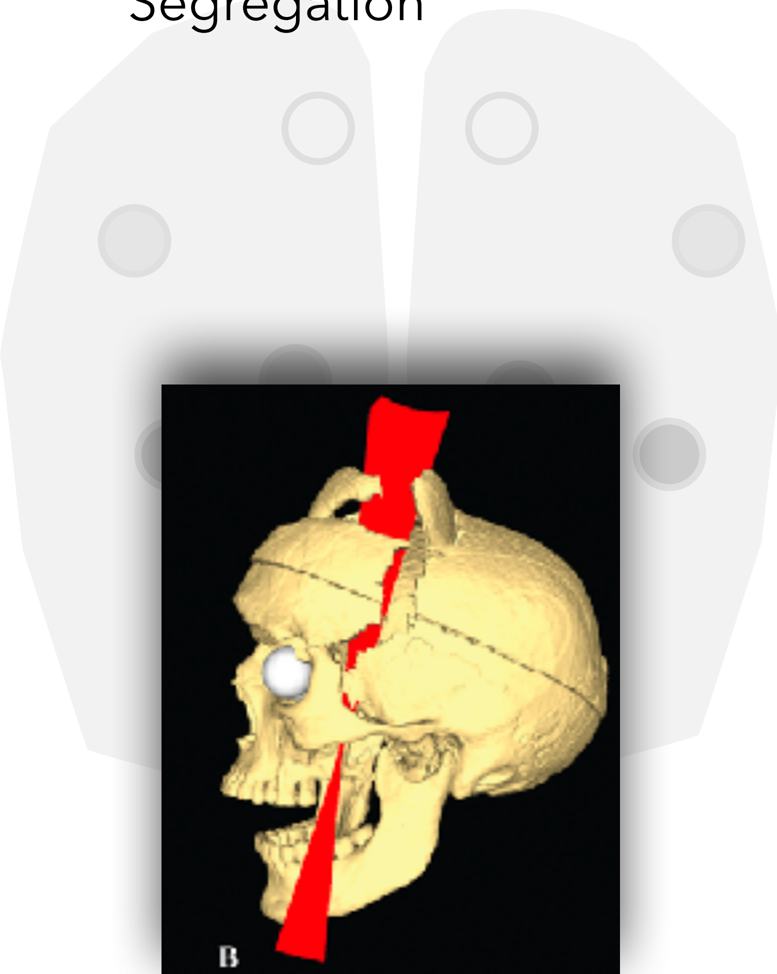
III. *Disconnexion Syndromes in Man*
The anatomical basis of language
Pure word-blindness without agraphia
Pure word-deafness
Lesions of Wernicke's area
Tactile aphasia

An interest in the connexions between different parts of the speech region and between the speech region and the remainder of the brain dated back to almost the earliest of the classical writings. Wernicke (1874) had already predicted the existence of a particular aphasic syndrome resulting from disconnexion of the sensory speech zone from the motor speech area by a single lesion in the left hemisphere. Subsequent developments showed him correct in principle although probably at least partially incorrect in his assumption as to the location of the pathway between these regions. These earliest studies concentrated on lesions of white matter

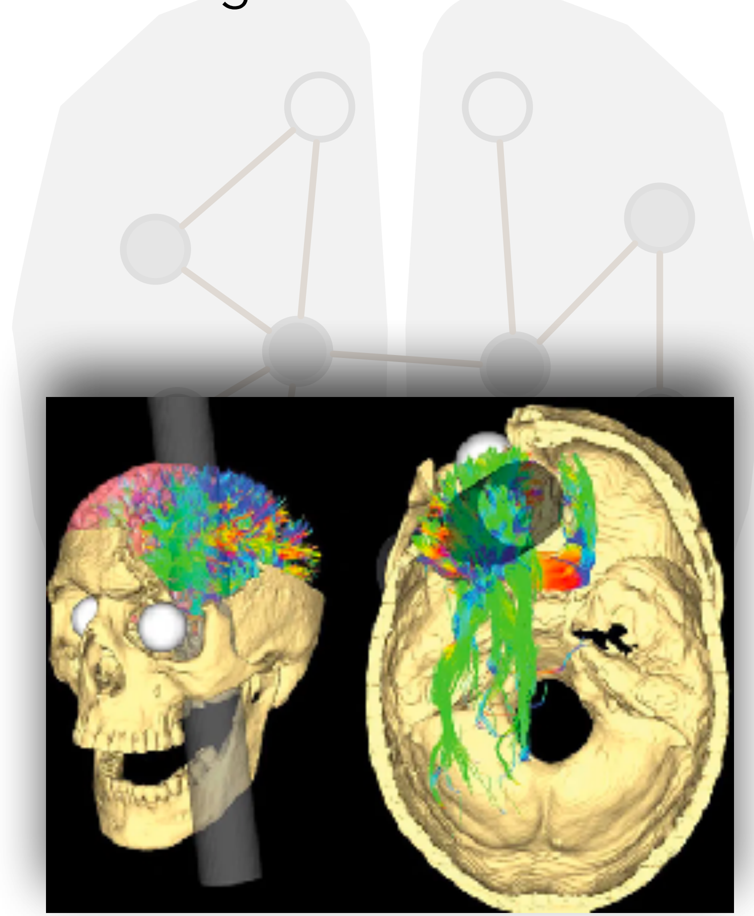
Geschwind, N. (1965). Disconnexion syndromes in animals and man: Part I. Brain 88, 237–394. doi:10.1007/s11065-010-9131-0.

Fundamental principals of organization

Segregation



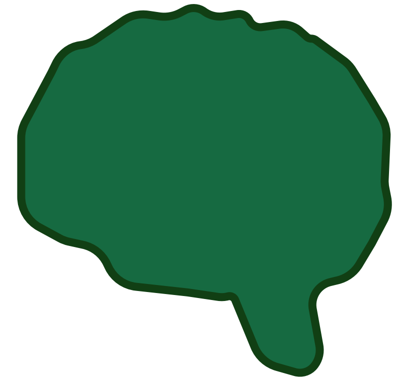
Integration



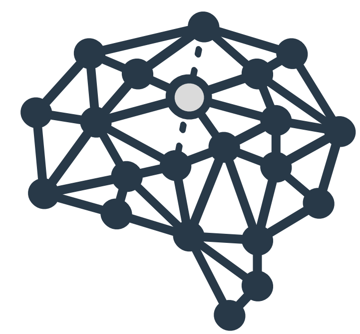
van Horn, J. D., et al.(2012). Mapping connectivity damage in the case of phineas gage. PLoS ONE, 7(5). https://doi.org/10.1371/journal.pone.0037454

From a "segregation" viewpoint toward,

"In the past decade functional neuroimaging has been (…) successful in establishing **functional segregation** as a principal of organization (…). **Functional segregation** is inferred by the presence of activation foci in change score or statistical parametric maps."
Friston (1994)

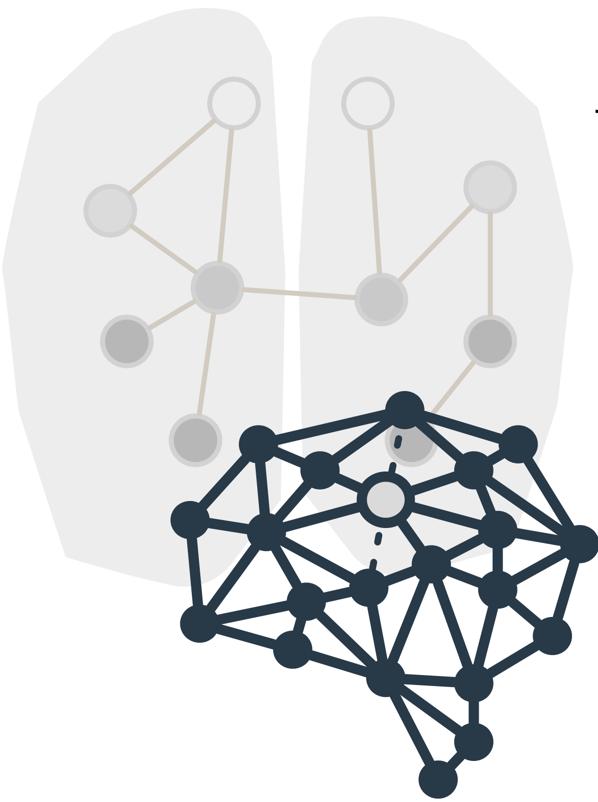


"A notion of cortical function has prevailed in which **different parts specialize in performing particular processing** of the sensory input".
Zamora-López et al. (2011)



Friston, K. J. (1994). Functional and effective connectivity: A synthesis. Human Brain Mapping, 2, 56–78
Zamora-López, G., Zhou, C., & Kurths, J. (2011). Exploring brain function from anatomical connectivity. Frontiers in Neuroscience, 5, 1–11

To an integrated view of the brain.



"Newer approaches have addressed the **integration of functionally specialized areas** through characterizing neurophysiological activations in terms of **distributed changes.**"

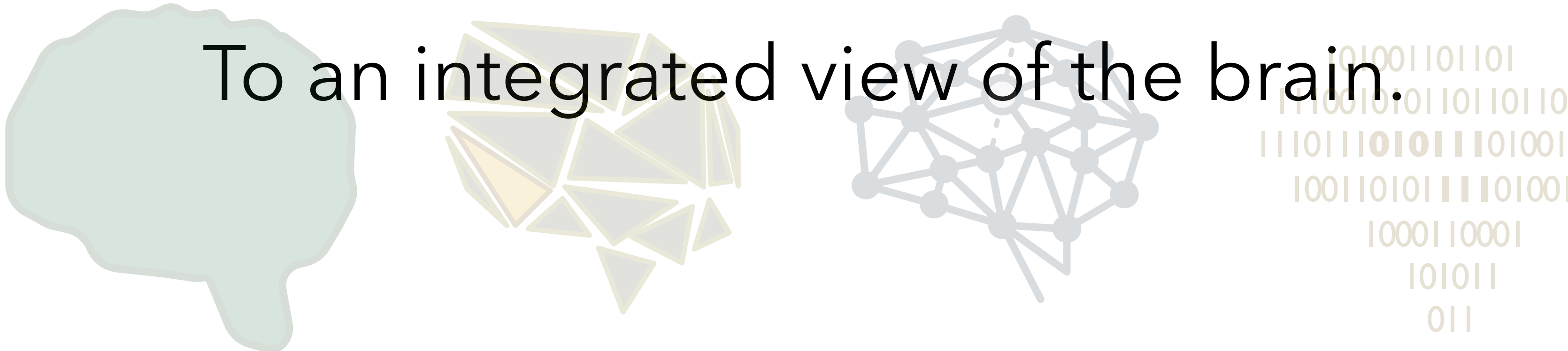
Friston (1994)

"This proposal ***rejects*** **a single anatomical site** for the integration of memory and motor processes and a single store for the meaning of entities of events."

Damasio (1989)

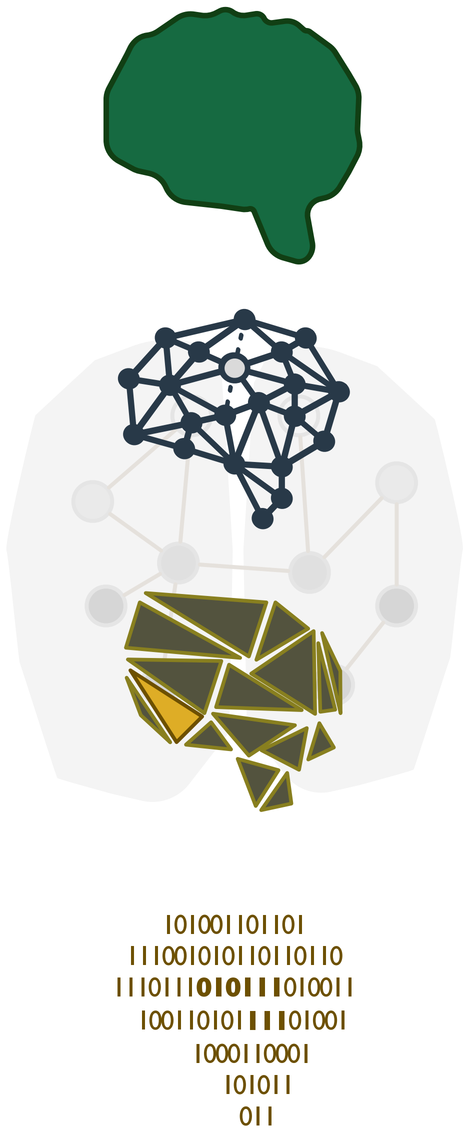
Friston, K. J. (1994). Functional and effective connectivity: A synthesis. Human Brain Mapping, 2, 56–78
Damasio, A. (1989). Time-locked multiregional retroactivation: a systems-level proposal for the neural substrates of recall and recognition. Cognition, 33(1–2), 25–62.

To an integrated view of the brain.



The brain is a **giant interconnected**, **feed-forward** and **feed-back** recurrent **network**

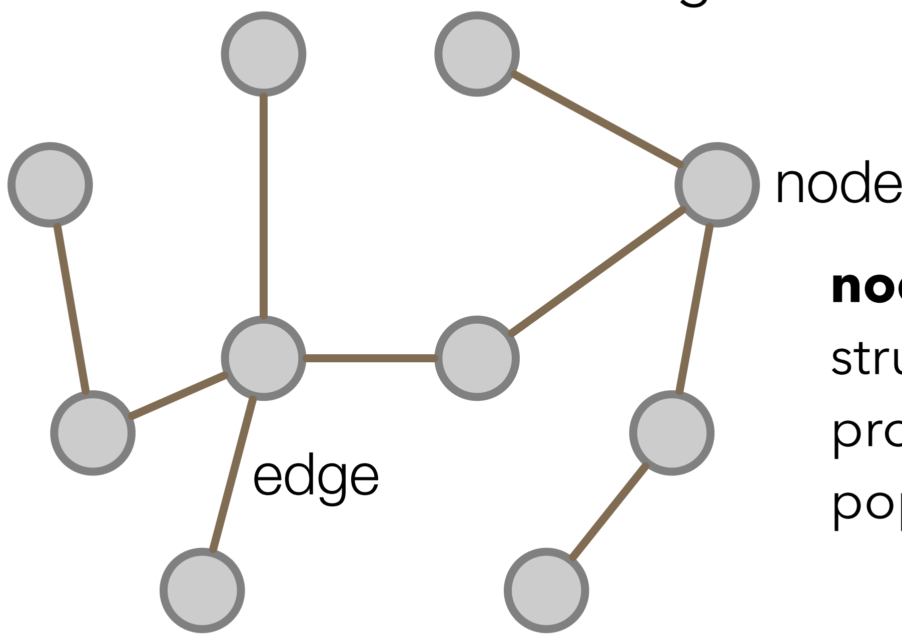
These systems, also known as **Non-linear dynamical systems**, **cannot be predicted looking at specific components of the systems** - they have emergent properties from the whole, connected components- consciousness or thought is the most relevant in humans.



Network Neuroscience

Modeling networks as graphs

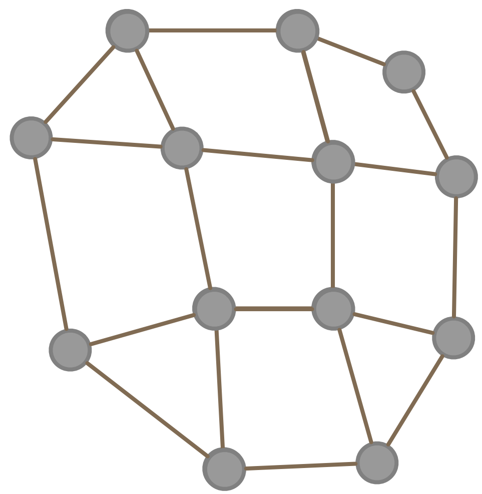
Networks can be modeled as graph of nodes connected by edges



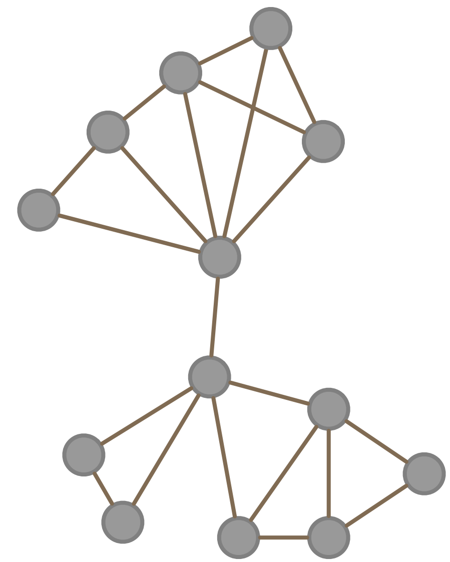
nodes. Represent basic units - structural, functional, processing units (e.g. neuron or population of neurons)

edges. Represent the interactions between units or nodes (structural or functional connection between units)

Graph theory - Exploring ***network structure***

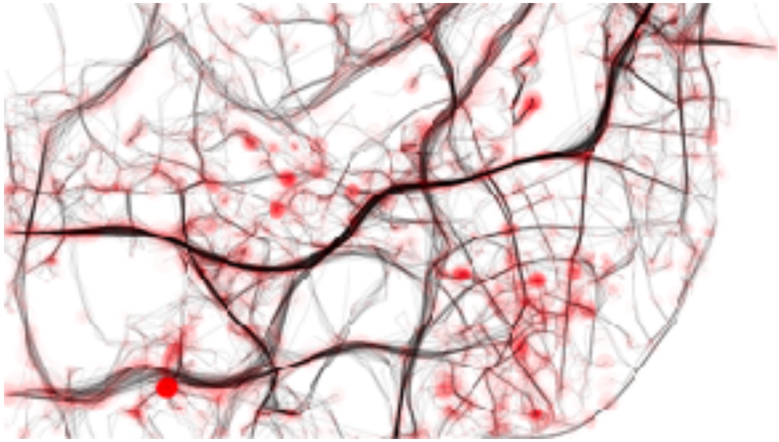


most nodes are connected with 3/4 other nodes

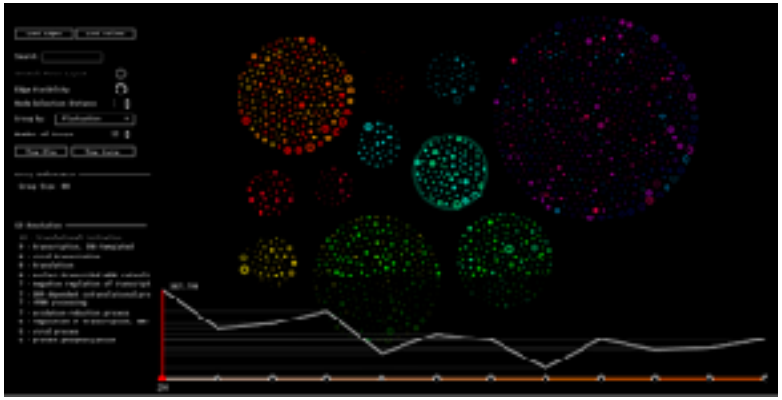


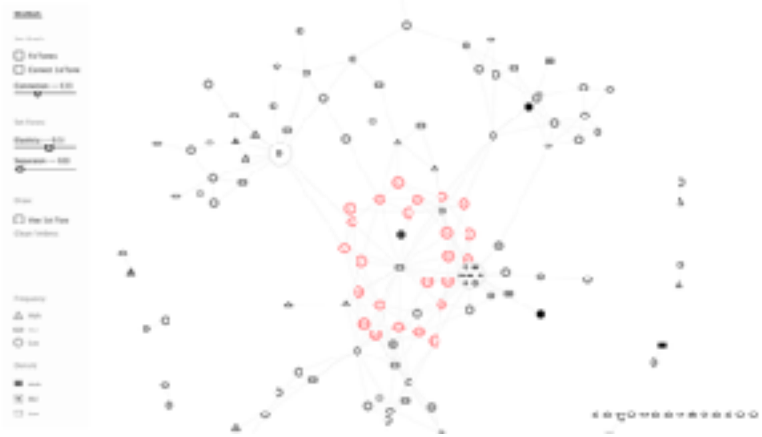
Some nodes connect different ‘modules’

Graphs as generic models for characterization of networks



https://cdv.dei.uc.pt/lisbons-blood-vessels/

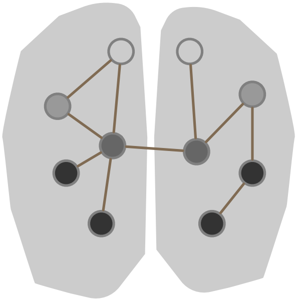




Connectome

Structural description of the **network elements and connections** forming the human brain

Sporns et al. (2005)



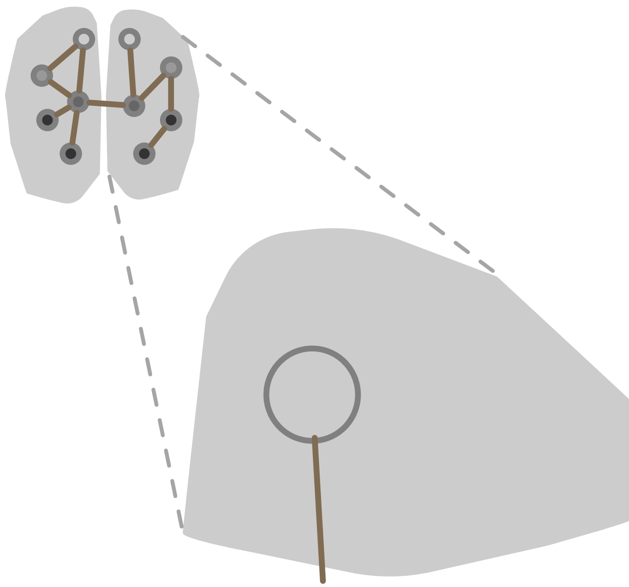
…forms the structure for the…

"understanding of how human cognitive function emerges from neuronal structure and dynamics."

Connectivity and network neuroscience

Sporns, O., Tononi, G., & Kötter, R. (2005). The human connectome: A structural description of the human brain. PLoS Computational Biology, 1(4), 0245–0251.

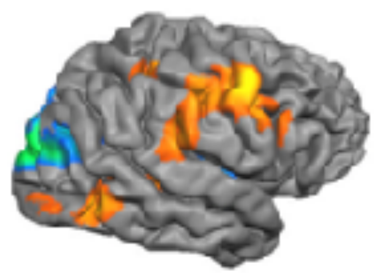
Defining network **nodes**



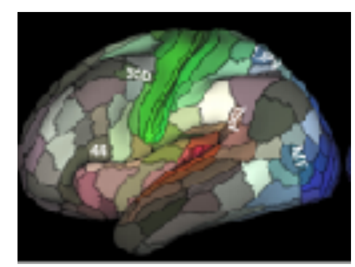
Spatially constrained, **intrinsically homogeneous** and **extrinsically distinct**

(e.g. functional, statistical, anatomical/cytoarchitecture arguments, multi-modal)

Brodmann areas - citoarchitecture



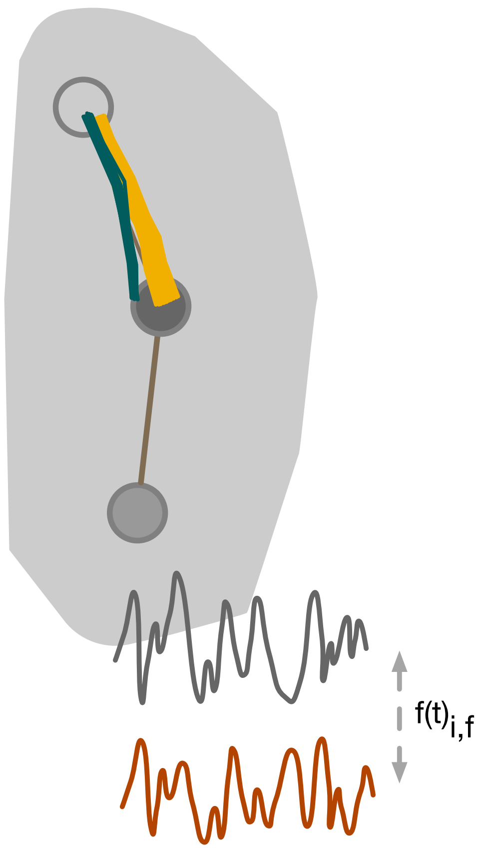
Functional-Probabilistic



Multi-modal (Glasser et al., 2016)

Sporns, O., Tononi, G., & Kötter, R. (2005). The human connectome: A structural description of the human brain. PLoS Computational Biology, 1(4), 0245–0251.

Exploring network **edges** meaning



Friston, K. J. (1994). Functional and effective connectivity: A synthesis. Human Brain Mapping, 2, 56–78

Structural connectivity

Described by physical connections between regions

- directionality cannot be resolved via data analysis (e.g. Diffusion-Weighted Imaging - DWI)

Functional connectivity

Statistical dependence between neurophysiological signals

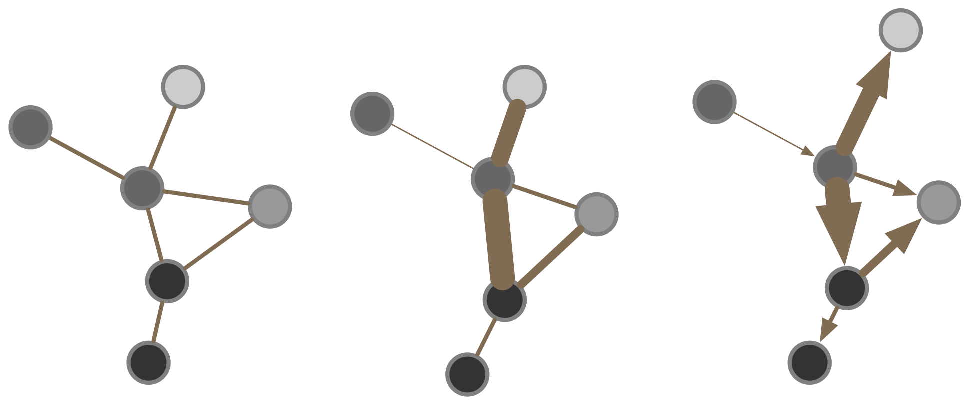
- can be directed or undirected

Effective connectivity

Influence that one node exerts over another (model-based fitting of signals)

- *causal* interaction (e.g. dynamic causal modeling)

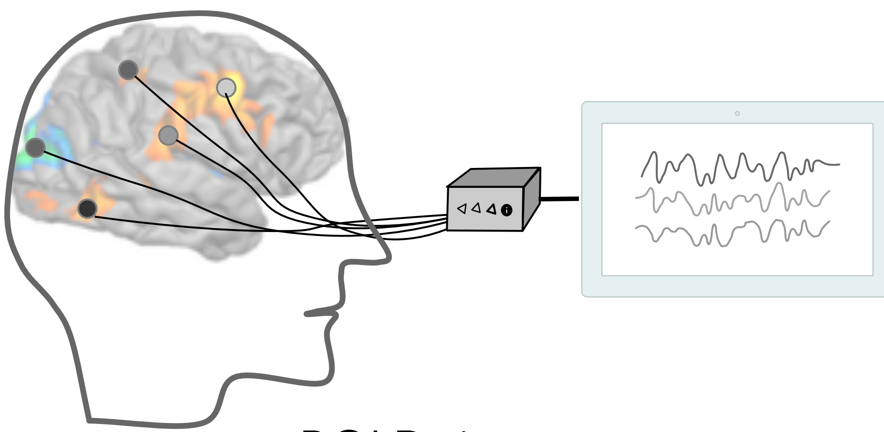
Exploring network **edges** meaning



Weights	Binary	Weighted	Weighted
Direction	Undirected	Undirected	Directed

Functional connectivity

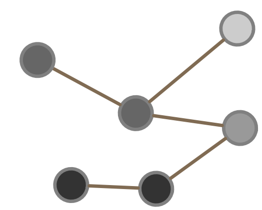
Statistical dependence between neurophysiological signals



e.g. BOLD time course of voxels, EEG traces per electrode

Compute some **measure of (pair-wise) coupling:**

Correlation
Partial correlation
Mutual Information,
Etc



We can have different types of tasks:

- **Resting state**
- **Dynamic**
- **Task** (block design)

Directed functional connectivity as measured by **Granger** causality

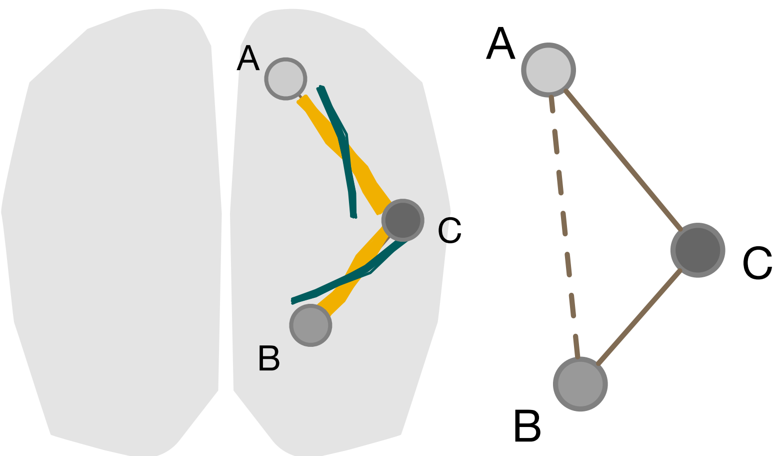
Granger Causality (Granger, 1969) is based on Vector Auto-regression model to calculate **causality** based on e.g. Time Series data BOLD activity derived from different ROIs

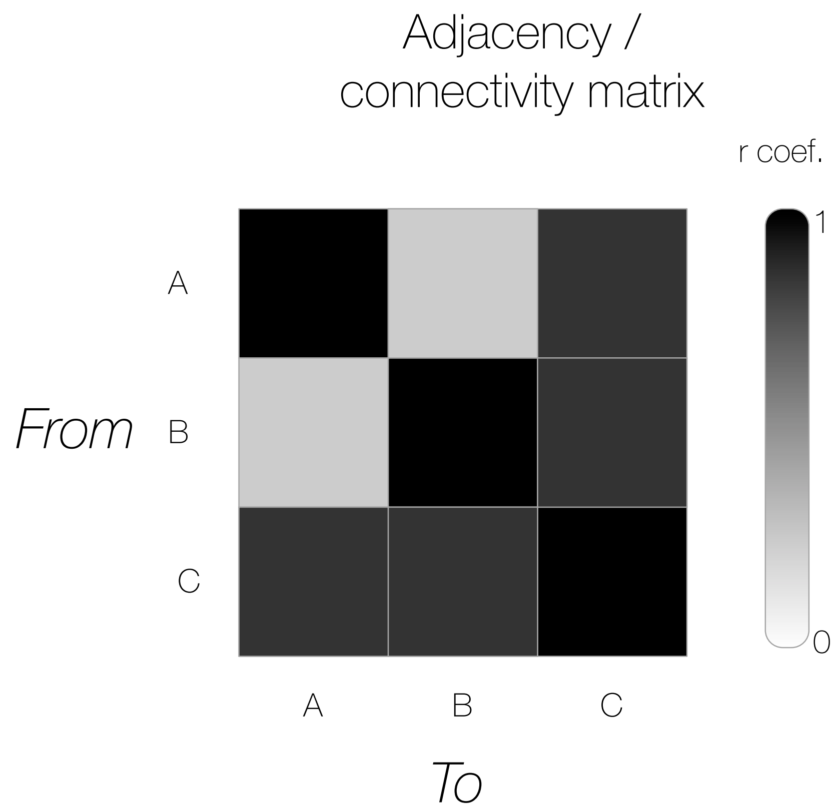
$$X_1(t) = \sum_{i=1}^{p} A_{11i} X_1(t-i) + \sum_{j=1}^{p} A_{12j} X_2(t-j) + \epsilon_1(t)$$

$$X_2(t) = \sum_{j=1}^{p} A_{21j} X_1(t-j) + \sum_{i=1}^{p} A_{22i} X_2(t-i) + \epsilon_2(t)$$

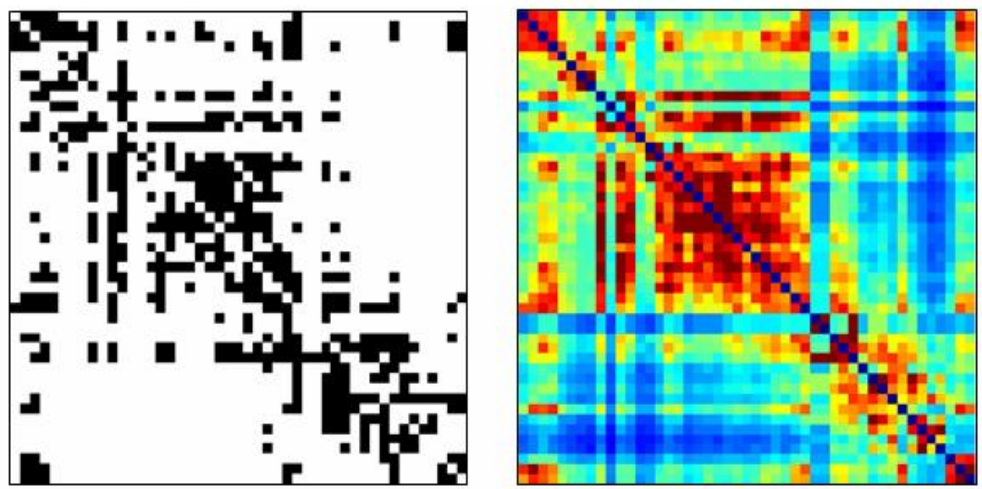
"If past values of X1 and X2 can predict future value of X2 better than past values of X2 alone, then **X1 *granger cause* X2**"

Graphical representation of Functional connectivity - graph or connectivity matrix



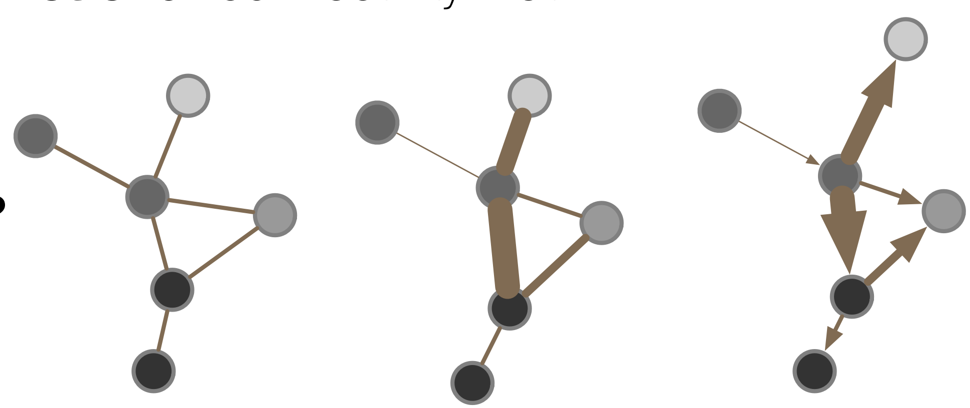


Graph with "few more" nodes

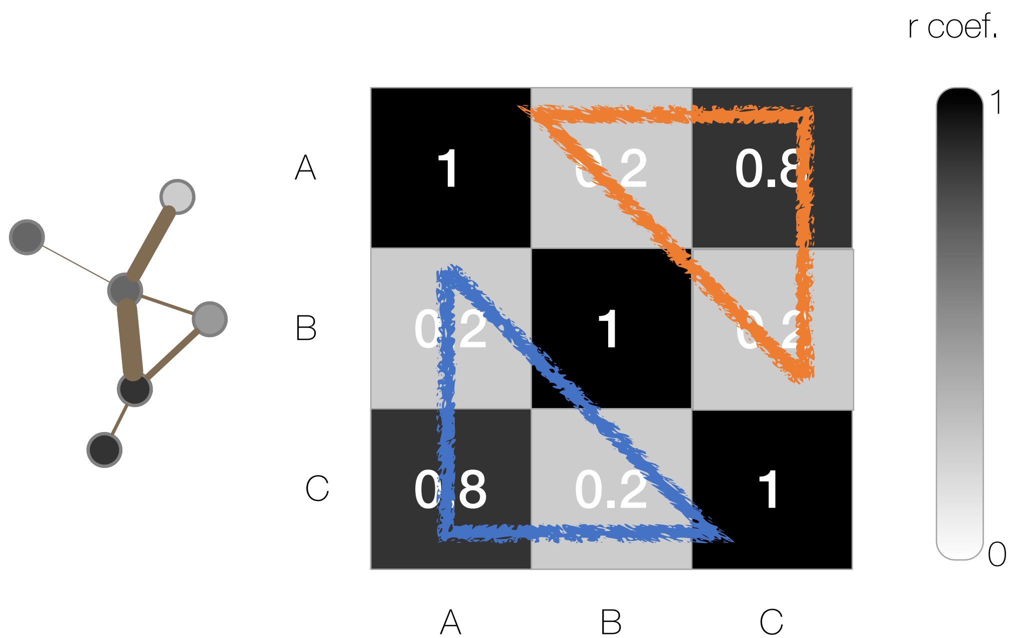


structural vs. ***functional*** connectivity matrix

Q. Graph characteristics?
Which one?

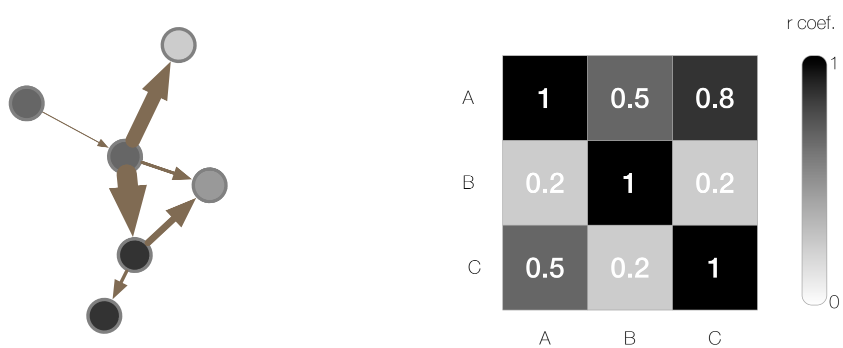


Functional connectivity as a graph - directed vs. undirected network



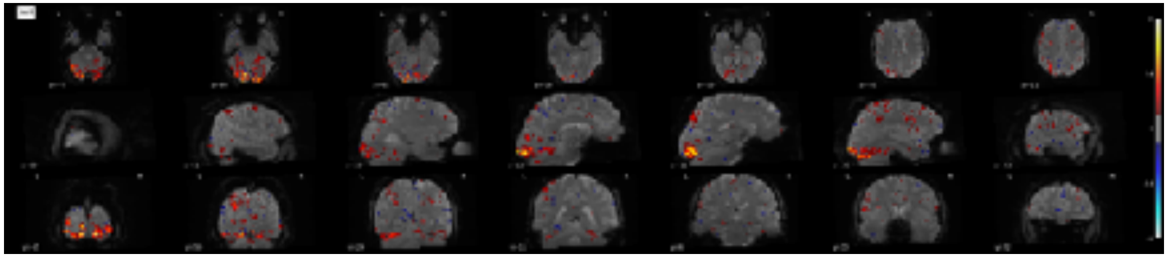
The upper triangle of the matrix is located above the diagonal

In an **undirected** network, **the upper and lower triangles are identical** - the matrix is **symmetric**
Aij=Aji

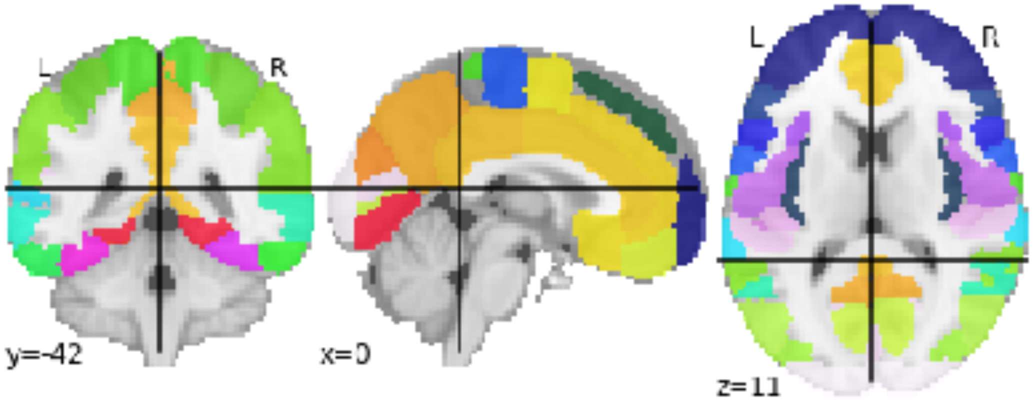


In a directed network, the upper and lower triangles may not be equal - the matrix is asymmetric

Functional connectivity as a **connectivity matrix - an example**

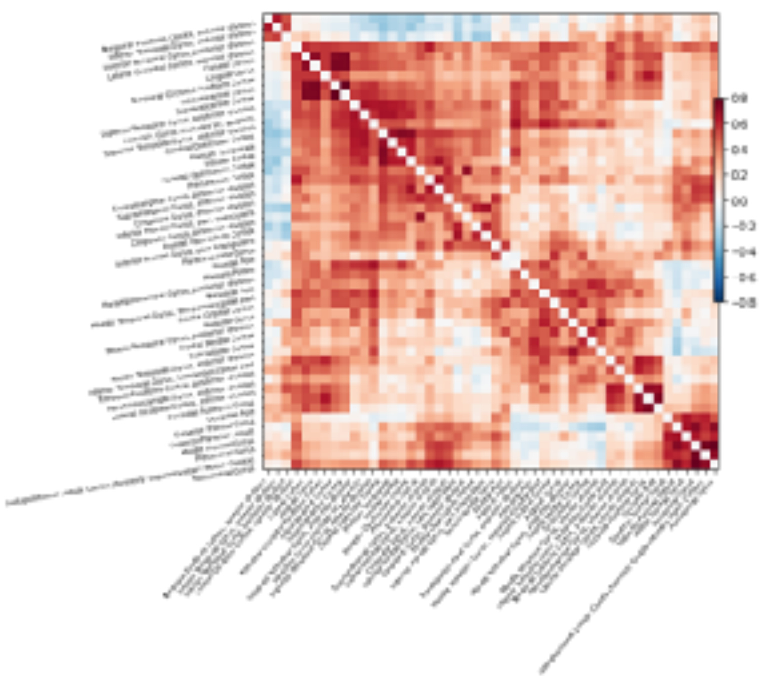


Identify nodes - e.g. functional/ Anatomical masks

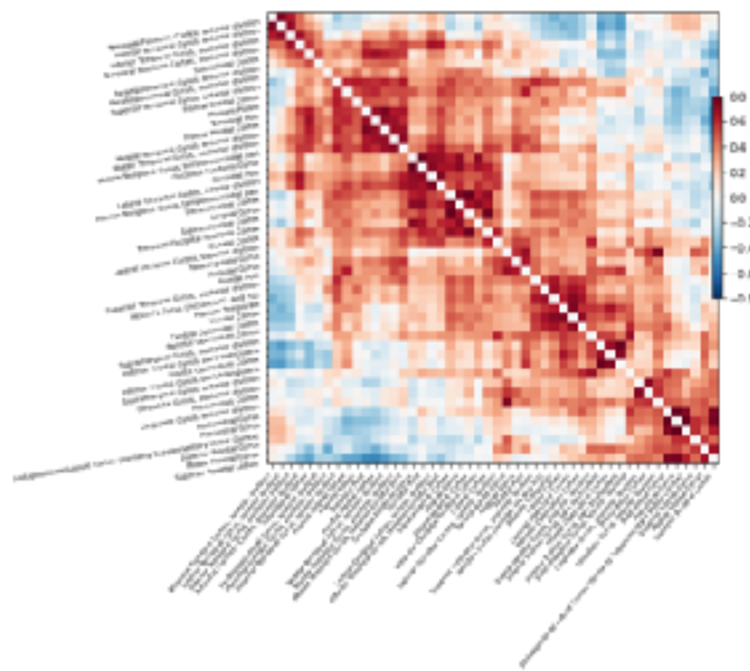


Functional connectivity as a **connectivity matrix - an example**

Rest

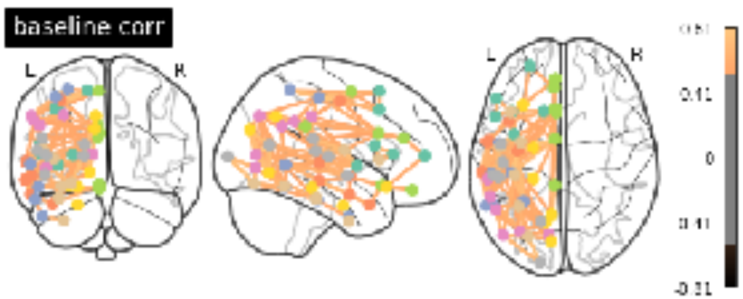


Phonologic task

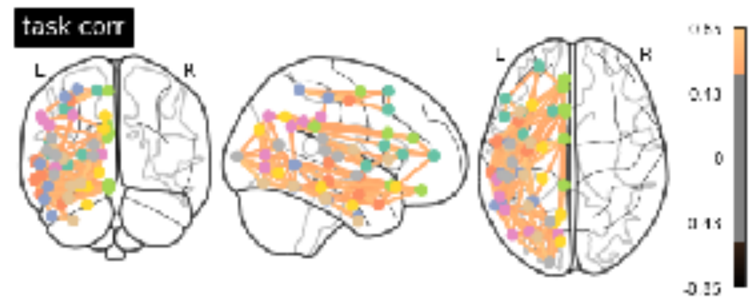


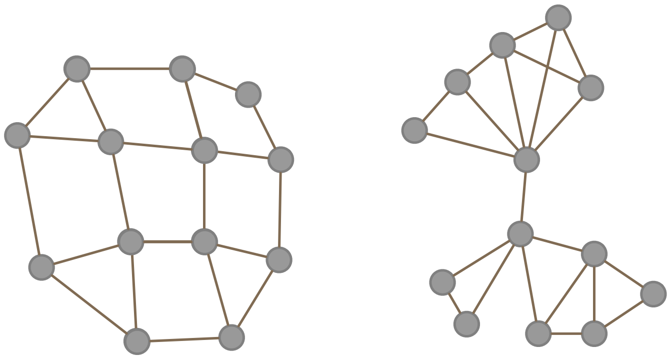
Functional connectivity as a **graph** - **an example**

Rest



Phonologic task





Network analysis - basic concepts and examples

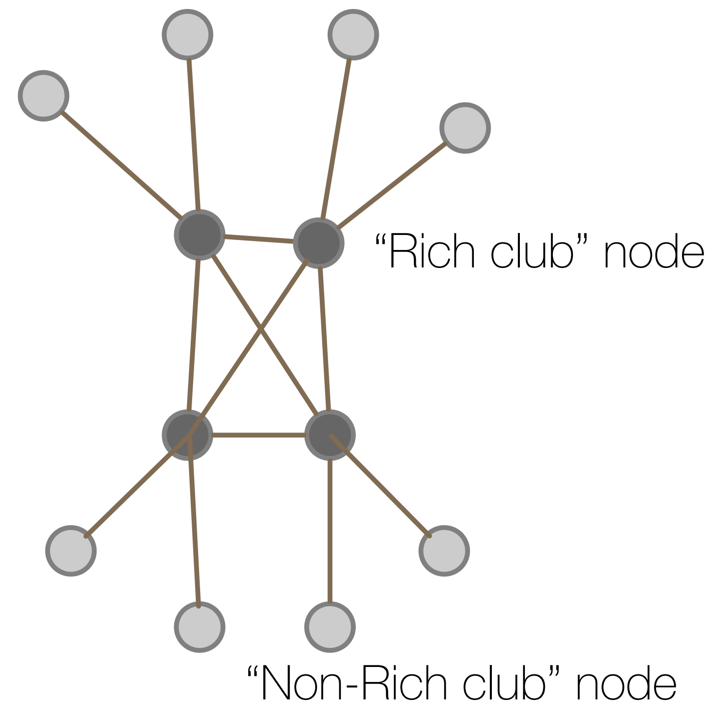
Common measures of interest in **Network Analysis**

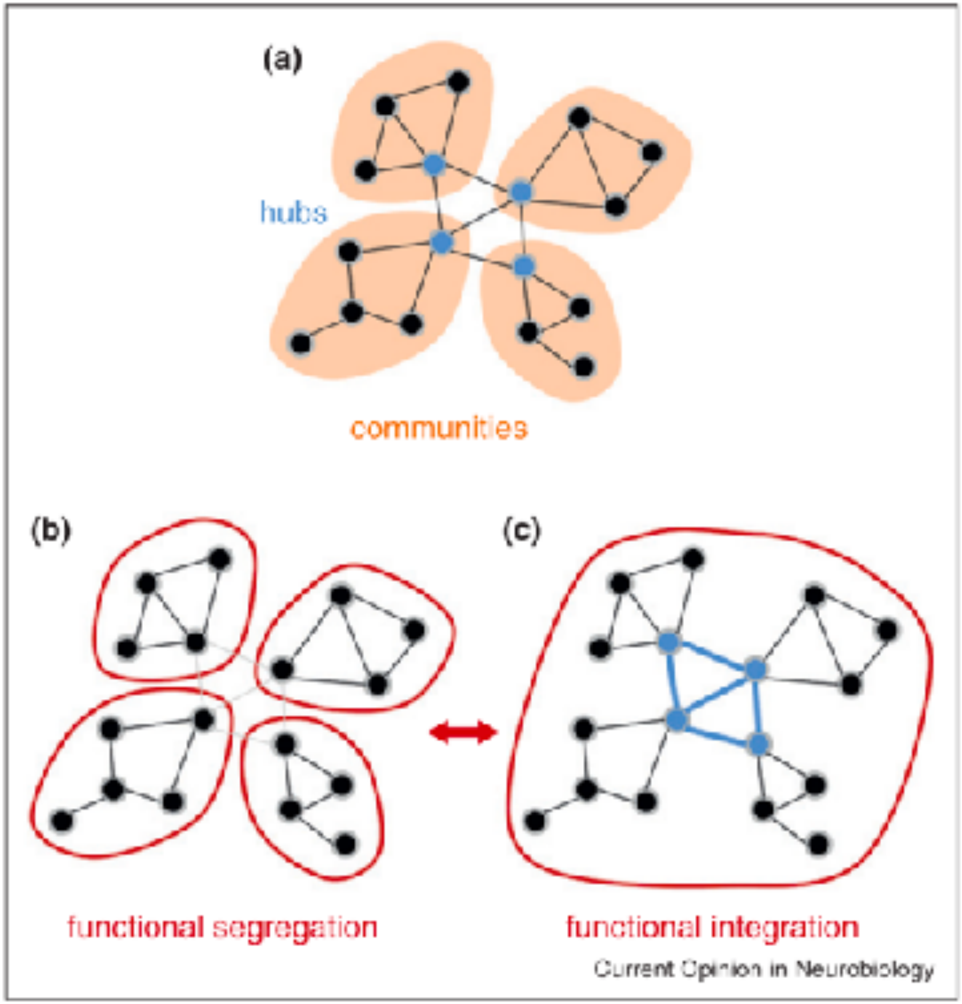
Bassett, D. S., Zurn, P., and Gold, J. I. (2018). On the nature and use of models in network neuroscience. Nat. Rev. Neurosci. 19, 566–578. doi:10.1038/s41583-018-0038-8.

Characterize the connections per node - local vs. global properties of a network

One simple, yet important, local statistic of a node is **centrality**—how influential a node is in the context of the broader network

e.g. "**Rich Club**" coefficient
- Network's *hub* (high-degree node) **are on average more interconnected** than lower-lower-degree nodes.



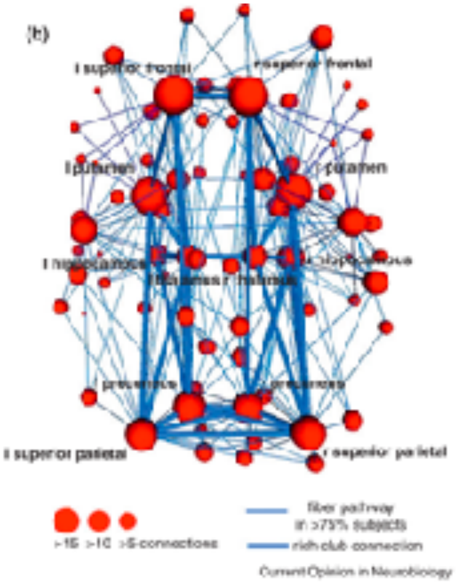


(b) Functional segregation indicated by **strong functional coupling within communities (red)** with little or no functional coupling across communities.

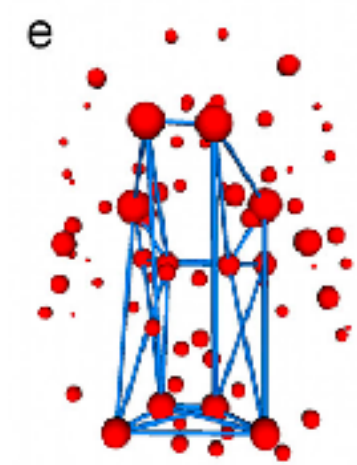
(c) **Functional integration indicated by globally strong functional coupling, including strong information flow across network hubs** and their mutual interconnections **(blue)**.

Sporns, O. (2013). Network attributes for segregation and integration in the human brain. Current Opinion in Neurobiology, 23(2), 162–171. https://doi.org/10.1016/j.conb.2012.11.015

Connectome



"Almost all regions the brain have at least one link directly to the rich club."



"These **12 hubs** have twice the connections of other brain regions"
"Best connected of all is the precuneus."
(Van den Heuvel, 2011)

Sporns, O. (2013). Network attributes for segregation and integration in the human brain. Current Opinion in Neurobiology, 23(2), 162–171. https://doi.org/10.1016/j.conb.2012.11.015
van den Heuvel, M. P., & Sporns, O. (2011). Rich-Club Organization of the Human Connectome. Journal of Neuroscience, 31(44), 15775–15786.

NETWORK NEUROSCIENCE

REVIEW

Graph theory approaches to functional network organization in brain disorders: A critique for a brave new small-world

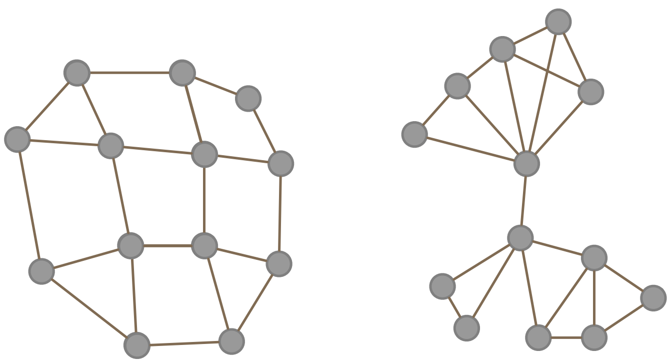
Michael N. Hallquist[1,2] and Frank G. Hillary[1,2,3]

[1]Department of Psychology, Pennsylvania State University, University Park, PA, USA
[2]Social Life and Engineering Sciences Imaging Center, University Park, PA, USA
[3]Department of Neurology, Hershey Medical Center, Hershey, PA, USA

Table 1. Clinical disorders represented in the review of 106 clinical network neuroscience studies

Clinical phenotype	*n* (frequency)
Alzheimer's disease/MCI	19 (17.9%)
Epilepsy/seizure disorder	13 (12.3%)
Depression/affective	12 (11.3%)
Schizophrenia	11 (10.4%)
Alcohol/substance abuse	7 (6.6%)
Parkinson's disease/subcortical	6 (5.7%)
Traumatic brain injury	6 (5.7%)
Anxiety disorders	5 (4.7%)
ADHD	5 (4.7%)
Stroke	4 (2.8%)
Cancer	3 (2.8%)
Multiple sclerosis	2 (1.9%)
Autism spectrum disorder	2 (1.9%)
Disorders of consciousness	2 (1.9%)
Somatization disorder	2 (1.9%)
Dual Diagnosis	2 (1.9%)
Other neurological disorder	3 (2.8%)
Other psychiatric disorder	2 (1.9%)

Note. ADHD = attention deficit hyperactivity disorder; MCI = mild cognitive impairment.



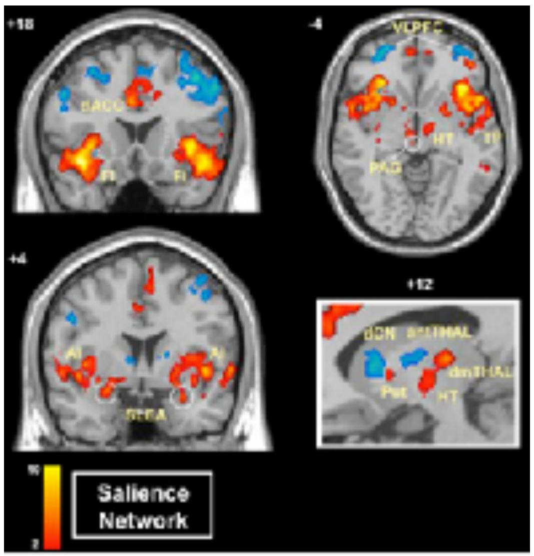
Network analysis - biological inspiration

Default mode network

The *Cognitive Atlas* currently defines the **DMN as "an organized spontaneous network of neural activity that is modulated during attention-demanding cognition",** which is characterized by "**spontaneous BOLD signal fluctuations** which tend to **inversely correlate with** fluctuations in **other networks**,…".

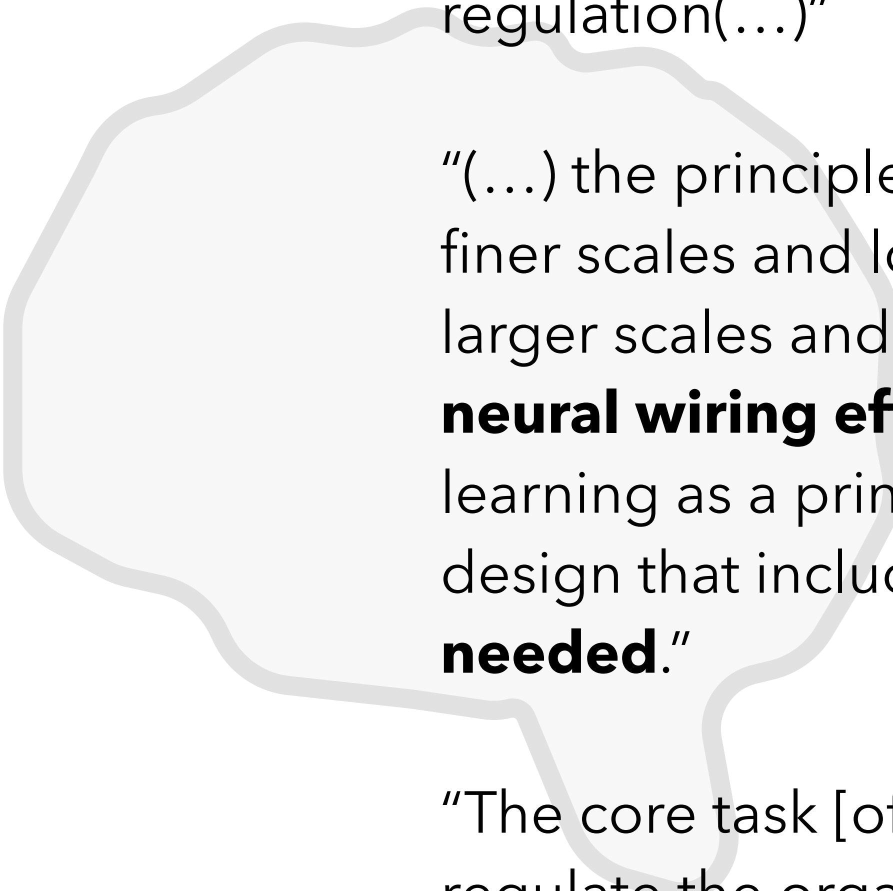
Raichle, M. E. (2015). The Brain's Default Mode Network. Annual Review of Neuroscience, 38(1), 433–447. https://doi.org/10.1146/annurev-neuro-071013-014030

Saliency network



"**AI** and **ACC form the core of a Saliency Network** that f**acilitates the detection of important environmental stimuli**. (…) what makes the SN special is that it **triggers a cascade of cognitive control signals** that have a major impact on how such **a stimulus is subsequently processed**."

Menon, V., and Uddin, L. Q. (2010). Saliency, switching, attention and control: a network model of insula function. Brain Struct. Funct. 214, 655–667. doi:doi:10.1007/s00429-010-0262-0.



“Advantages of anticipatory regulation(…)”

“(…) the principles of neural design at finer scales and lower levels apply at larger scales and higher levels; describe **neural wiring efficiency**; and discuss learning as a principle of biological design that includes “save **only what is needed**.”

“The core task [of the brain] … is to regulate the organism’s internal milieu”

Sterling P., Laughling S (2015). Principles of neural design

Allostasis

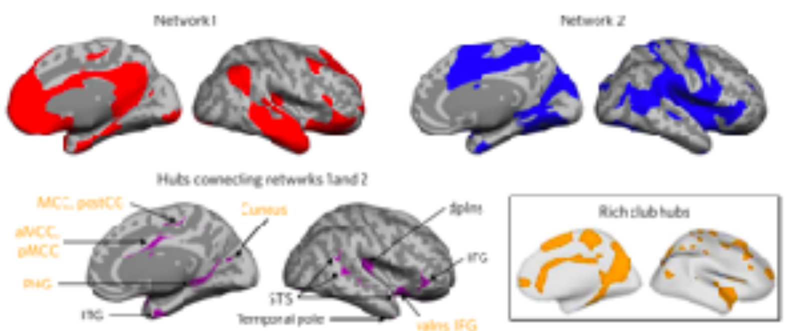
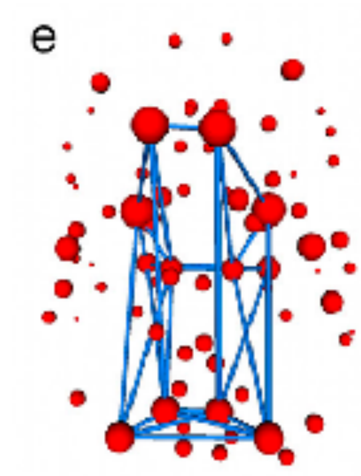
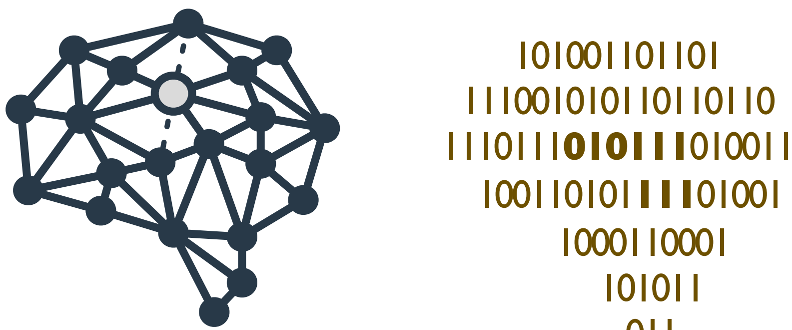


Figure 3 | The unified allostatic-interoceptive system is composed of two large-scale intrinsic networks that share several hubs. Networks of the unified allostatic-interoceptive system are shown in red and blue, and hubs are shown in purple; for coordinates, see Supplementary Table 4. Hubs belonging to the 'rich club' are shown in yellow. Rich club hubs figure adapted with permission from ref., Society for Neuroscience. All maps result from the sample of 280 participants binarized at $P < 10^{-5}$ uncorrected from a one-sample two-tailed t-test. These results were replicated in a second sample, $N = 270$ participants, indicating that they are reliable and cannot be attributed to random error (Supplementary Fig. 2). IFG, inferior frontal gyrus; ITG, inferior temporal gyrus; PHG, parahippocampal gyrus; pMCC, posterior midcingulate cortex; postCG, postcentral gyrus; STS, superior temporal sulcus.



"These **12 hubs** have twice the connections of other brain regions"
"Best connected of all is the precuneus."
(Van den Heuvel, 2011)

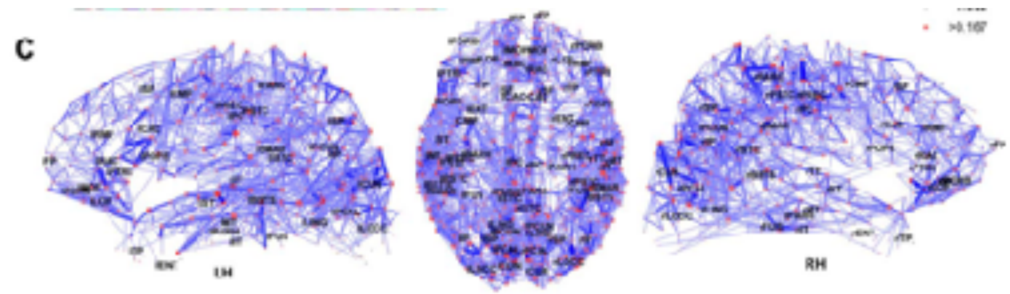
Kleckner, I. R., Zhang, J., Touroutoglou, A., Chanes, L., Xia, C., Simmons, W. K., et al. (2017). Evidence for a large-scale brain system supporting allostasis and interoception in humans. Nat. Hum. Behav. 1. doi:10.1038/s41562-017-0069.

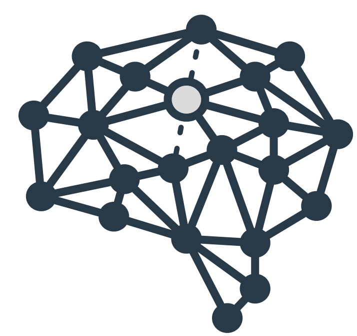


From a network structure to cognitive and clinical neuroscience

Neural representations

- Biological structure,
- Conceptual model, i.e. a network architecture
- Basis for concept, procedures representations?



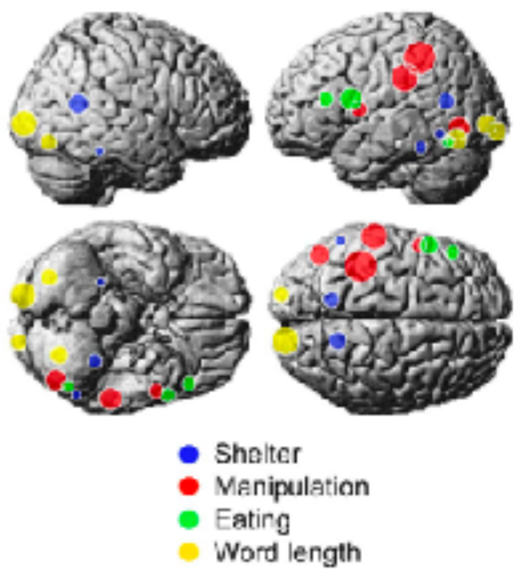


Hagmann, P., Cammoun, L., Gigandet, X., Meuli, R., Honey, C. J., Van Wedeen, J., et al. (2008). Mapping the structural core of human cerebral cortex. *PLoS Biol.* 6, 1479–1493. doi:10.1371/journal.pbio.0060159.

Neurosemantic theory

Table 1. 60 stimulus words grouped into 12 semantic categories.

Category	Exemplar 1	Exemplar 2	Exemplar 3	Exemplar 4	Exemplar 5
body parts	leg	arm	eye	foot	hand
furniture	chair	table	bed	desk	dresser
vehicles	car	airplane	train	truck	bicycle
animals	horse	dog	bear	cow	cat
kitchen utensils	glass	knife	bottle	cup	spoon
tools	chisel	hammer	screwdriver	pliers	saw
buildings	apartment	barn	house	church	igloo
building parts	window	door	chimney	closet	arch
clothing	coat	dress	shirt	skirt	pants
insects	fly	ant	bee	butterfly	beetle
vegetables	lettuce	tomato	carrot	corn	celery
man-made objects	refrigerator	key	telephone	watch	bell



"biologically-driven semantic dimensions underlying the neural representation of concrete nouns"

"From this analysis emerge *(16 locations)* three main semantic factors underpinning the neural representation of nouns naming physical objects, which we label manipulation, shelter, and eating."

Just, M. A., Cherkassky, V. L., Aryal, S., and Mitchell, T. M. (2010). A neurosemantic theory of concrete noun representation based on the underlying brain codes. PLoS One 5. doi:10.1371/journal.pone.0008622.

Neurosemantic theory as clinical biomarker

Table 2. Stimulus concepts

Suicide	Positive	Negative
apathy	bliss	boredom
death	carefree	criticism
desperate	comfort	cruelty
distressed	excellent	evil
fatal	good	gloom
funeral	innocent	guilty
hopeless	kindness	inferior
lifeless	praise	terrible
overdose	superior	trouble
suicide	vitality	worried

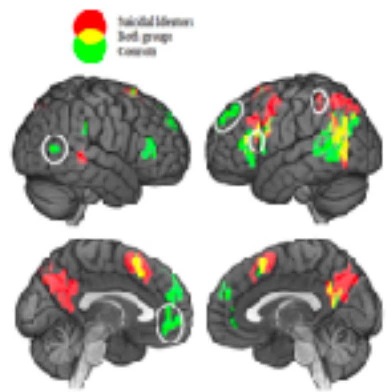


Figure 1. Clusters of stable voxels of the suicidal ideator group and the control group. White ellipses indicate the 5 discriminating locations.

Just, M. A., Pan, L., Cherkassky, V. L., McMakin, D. L., Cha, C., Nock, M. K., et al. (2017). Machine learning of neural representations of suicide and emotion concepts identifies suicidal youth. Nat. Hum. Behav. 1, 911–919. doi:10.1038/s41562-017-0234-y.

Journal of Affective Disorders 212 (2017) 78–85

Contents lists available at ScienceDirect

Journal of Affective Disorders

journal homepage: www.elsevier.com/locate/jad

Research paper

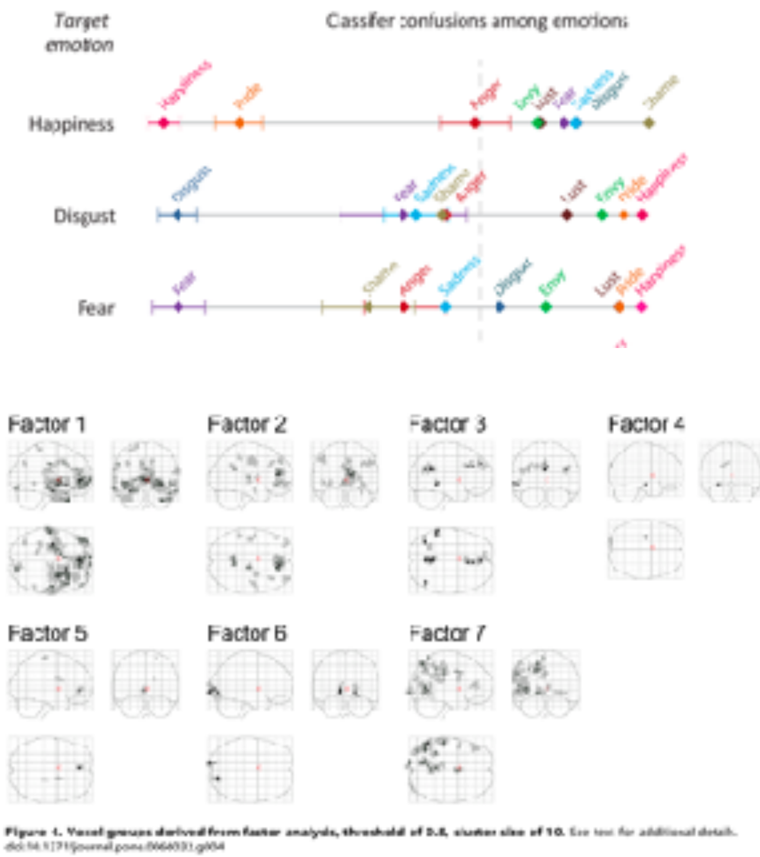
Alterations of functional connectivity and intrinsic activity within the cingulate cortex of suicidal ideators

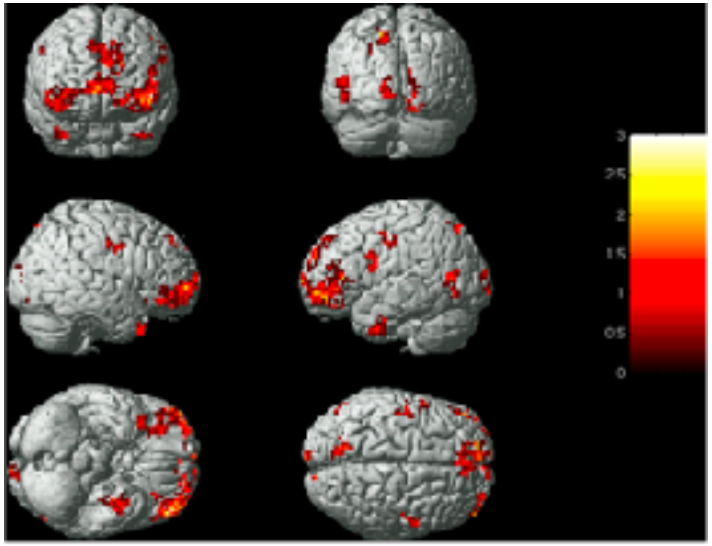
Henry W. Chase[a,*], Anna Maria Segreti[a], Timothy A. Keller[b], Vladimir L. Cherkassky[b], Marcel A. Just[b], Lisa A. Pan[a], David A. Brent[a]

[a] Department of Psychiatry, University of Pittsburgh School of Medicine, Pittsburgh, PA, United States
[b] Department of Psychology, Carnegie Mellon University, Pittsburgh, PA, United States

- Suicidal ideators (though disorder)
  - Controls showed **greater coupling between the dACC and dPCC, compared to the dACC and ventral PCC**
    - **Reversed in the suicidal ideators**
- The **structural integrity of the cingulum** bundle (**DTI**) also **explained variation** in the functional connectivity measures
- Findings provide evidence of **abnormalities in the DMN underlying the tendency towards suicidal ideation**

Identifying Emotions on the Basis of Neural Activation

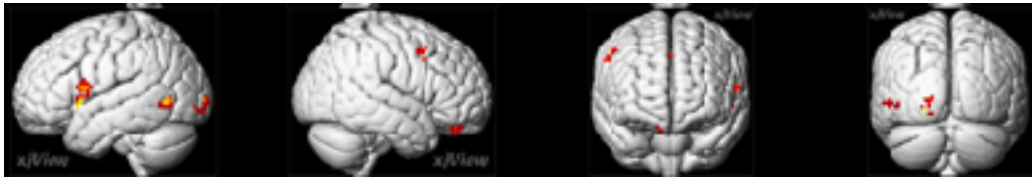




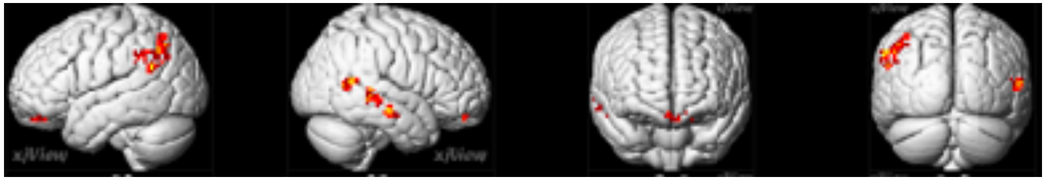
Kassam, K. S., Markey, A. R., Cherkassky, V. L., Loewenstein, G., and Just, M. A. (2013). Identifying Emotions on the Basis of Neural Activation. PLoS One 8. doi:10.1371/journal.pone.0066032.

Biomarker for autism?
best voxels identifying facial expression

Control group



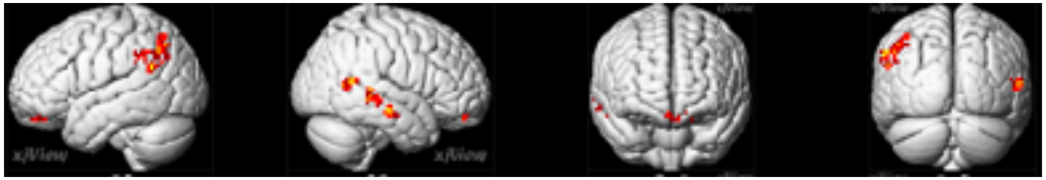
ASD group



Direito et al., in progress

After neurofeedback training

ASD group **before**

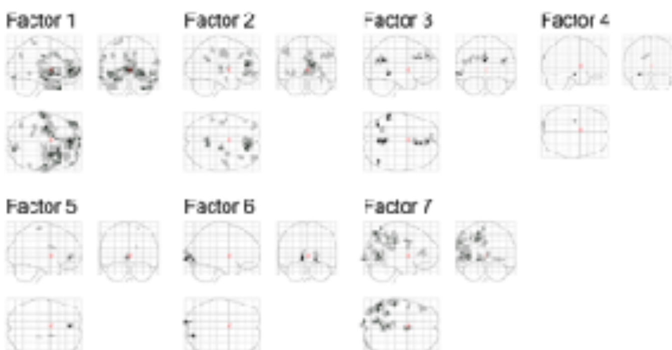


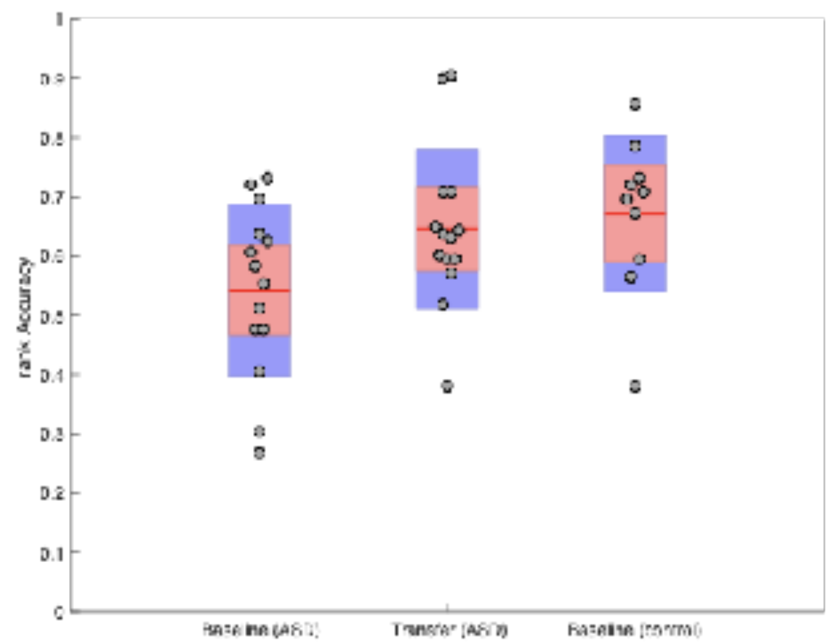
ASD group **after**

Direito et al., in progress

Comparing results using emotions factors

Classification results using factor associated with the concepts valence and social

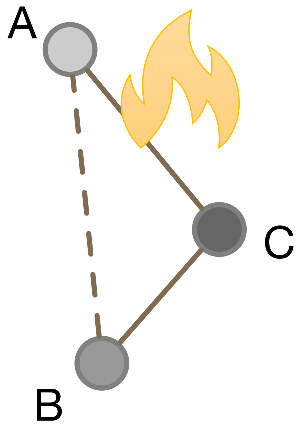




Direito et al., in progress

Semantic maps

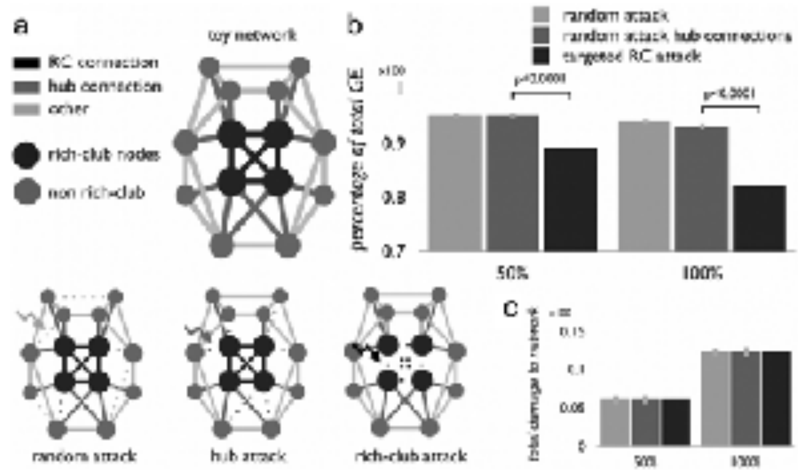
http://gallantlab.org/huth2016/



Targeting connectivity markers in novel interventions - basic concepts and examples

"Attacking" the network and controllability

Differential outcome based on the edge/node "under attack"



nature COMMUNICATIONS

ARTICLE

Received 7 Apr 2015 | Accepted 19 Aug 2015 | Published 1 Oct 2015 DOI: 10.1038/ncomms9414 OPEN

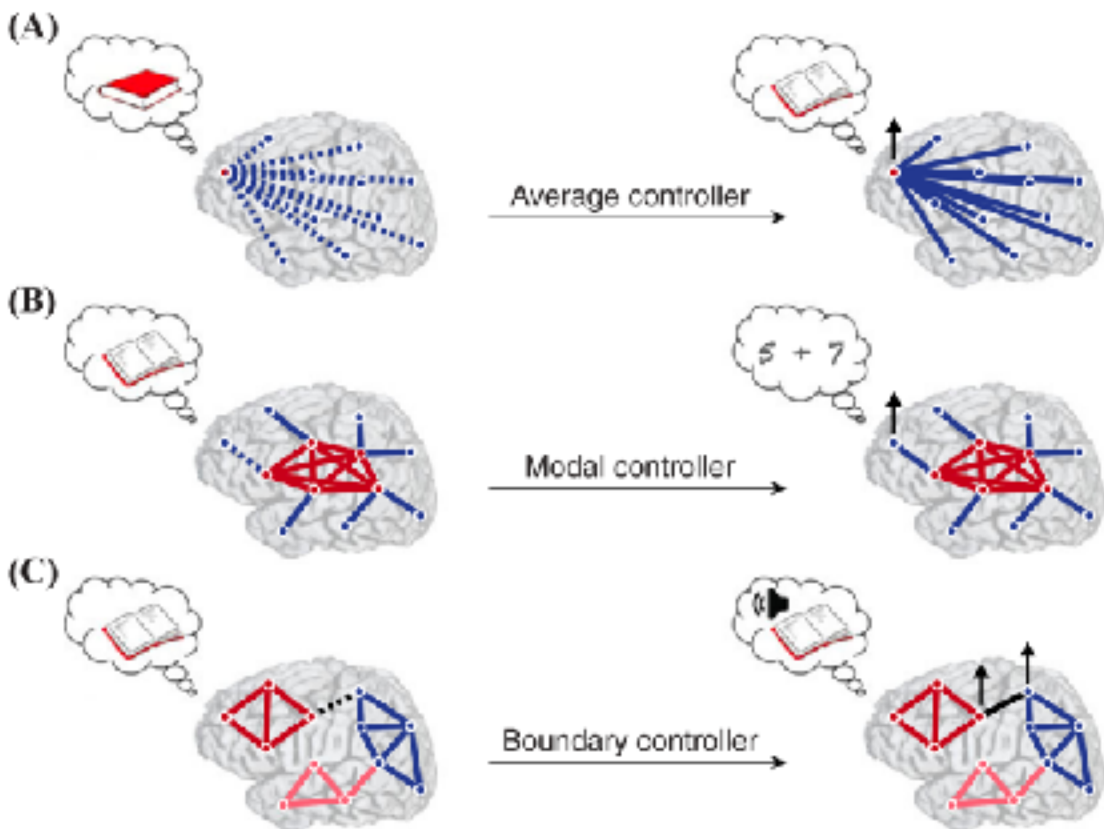
Controllability of structural brain networks

Shi Gu[1,2], Fabio Pasqualetti[3], Matthew Cieslak[4], Qawi K. Telesford[2,5], Alfred B. Yu[5], Ari E. Kahn[2], John D. Medaglia[2], Jean M. Vettel[4,5], Michael B. Miller[4], Scott T. Grafton[4] & Danielle S. Bassett[2,5]

First studies on the controllability
- characterization of the nodes/ edges in terms of the stability of the system
- *intervention target?*

var
Gu

How to define a target?



Bassett, D. S., & Khambhati, A. N. (2017). A network engineering perspective on probing and perturbing cognition with neurofeedback. Annals of the New York Academy of Sciences, 1396, 126–143. https://doi.org/10.1111/nyas.13338

rt-fMRI Neurofeedback as an interventional tool

OXFORD

International Journal of Neuropsychopharmacology (2017) 20(10): 769–781

doi:10.1093/ijnp/pyx059
Advance Access Publication: July 17, 2017
Review

REVIEW

Resting-State Functional Connectivity-Based Biomarkers and Functional MRI-Based Neurofeedback for Psychiatric Disorders: A Challenge for Developing Theranostic Biomarkers

Takashi Yamada, MD, PhD; Ryu-ichiro Hashimoto, PhD; Noriaki Yahata, PhD; Naho Ichikawa, MA; Yujiro Yoshihara, MD, PhD; Yasumasa Okamoto, MD, PhD; Nobumasa Kato, MD, PhD; Hidehiko Takahashi, MD, PhD; Mitsuo Kawato, PhD

Study the relationship between **normalizing the biomarker** and **symptom changes** using fMRI-based neurofeedback

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Issue: *The Year in Cognitive Neuroscience*
REVIEW

A network engineering perspective on probing and perturbing cognition with neurofeedback

Danielle S. Bassett[1,2] and Ankit N. Khambhati[1]

The potential to use a perturbative approach like neurofeedback becomes particularly interesting when viewed in light of the emerging field of connectomics.
(…)
manipulating the activity in one area can have nontrivial effects on other areas.

Bassett, D. S., & Khambhati, A. N. (2017). A network engineering perspective on probing and perturbing cognition with neurofeedback. Annals of the New York Academy of Sciences, 1396, 126–143. https://doi.org/10.1111/nyas.13338

RESEARCH ARTICLE

WILEY

Stimulating neural plasticity with real-time fMRI neurofeedback in Huntington's disease: A proof of concept study

Marina Papoutsi[1] | Nikolaus Weiskopf[2,3] | Douglas Langbehn[4] | Ralf Reilmann[5,6] | Geraint Rees[3,7*] | Sarah J Tabrizi[1*]

[1]UCL Huntington's Disease Centre, Institute of Neurology, University College London, London, United Kingdom

[2]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

[3]Wellcome Trust Centre for Neuroimaging, Institute of Neurology, University College London, London, United Kingdom

[4]Carver College of Medicine, University of Iowa, Iowa City, Iowa

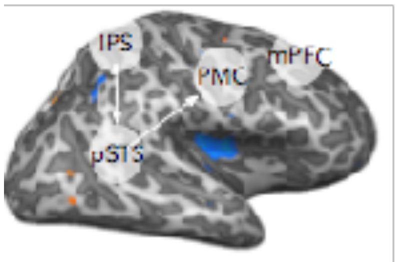
[5]George Huntington Institute and Department of Radiology, University of Muenster, Münster, Germany

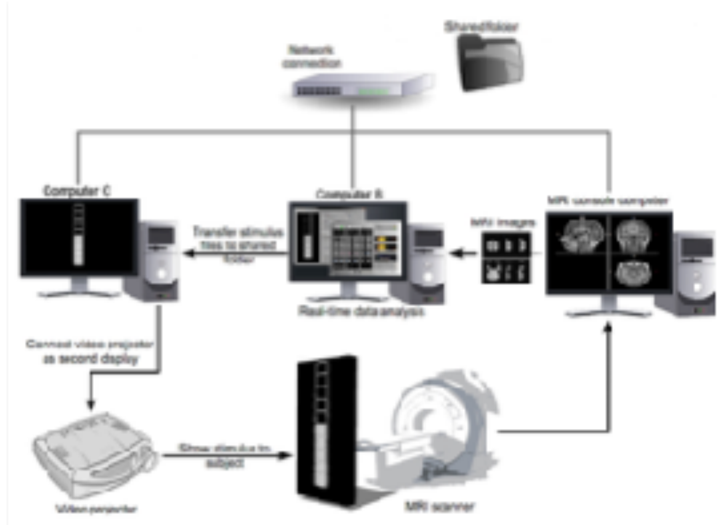
[6]Section for Neurodegeneration and Hertie Institute for Clinical Brain Research, University of Tuebingen, Tübingen, Germany

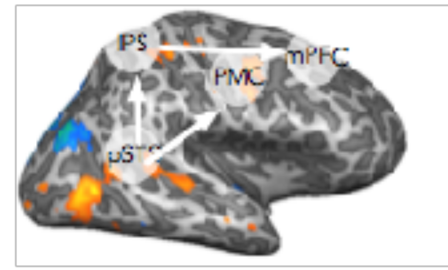
[7]Institute of Cognitive Neuroscience, University College London, London, United Kingdom

Preliminary evidence show **neuroplasticity** associated with neurofeedback training

- not only **target-region specific** but the whole network involved







pre-intervention evaluation

neurofeedback intervention

post-intervention evaluation

The network and connectivity analysis

João Pereira, Bruno Direito, Alexandre Sayal, Carlos Ferreira, and Miguel Castelo-Branco.Brain Connectivity.Nov 2019.662-672.http://doi.org/10.1089/brain.2019.0697

NeuroImage 62 (2012) 2232–2243

Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Review

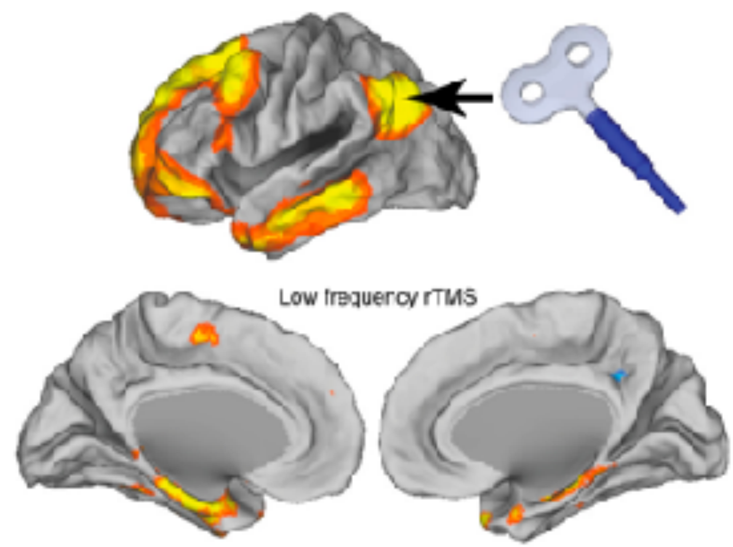
Measuring and manipulating brain connectivity with resting state functional connectivity magnetic resonance imaging (fcMRI) and transcranial magnetic stimulation (TMS)

Michael D. Fox [a,b,*], Mark A. Halko [b], Mark C. Eldaief [b,c], Alvaro Pascual-Leone [b,d]

[a] Partners Neurology Residency, Massachusetts General Hospital, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA
[b] Berenson-Allen Center for Noninvasive Brain Stimulation, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, MA, USA
[c] Division of Cognitive Neurology, Department of Neurology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, USA
[d] Institut Guttmann, Hospital de Neurorehabilitació, Institut Universitari adscrit a la Universitat Autònoma de Barcelona, Barcelona, Spain

"(…)TMS to modulate pathological network interactions identified with resting state fcMRI."

"Inhibitory TMS resulted in pronounced increases in functional connectivity between the stimulation site and the medial temporal lobe"

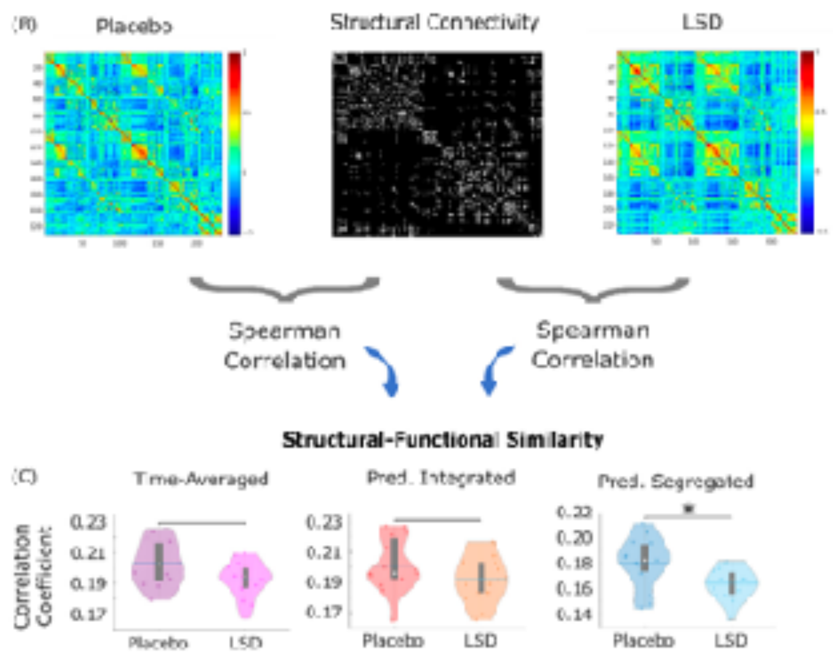


LSD alters dynamic integration and segregation in the human brain

Andrea I. Luppi[a,b,*], Robin L. Carhart-Harris[c], Leor Roseman[c], Ioannis Pappas[a,b,1], David K. Menon[a,d], Emmanuel A. Stamatakis[a]

[a] Division of Anaesthesia, School of Clinical Medicine, University of Cambridge, Cambridge CB2 0QQ, United Kingdom
[b] Department of Clinical Neurosciences, University of Cambridge, Cambridge CB2 0QQ, United Kingdom
[c] Center for Psychedelic Research, Department of Brain Science, Imperial College London, London W12 0NN, United Kingdom
[d] Wolfson Brain Imaging Centre, University of Cambridge, Cambridge CB2 0QQ, United Kingdom

"(…) the effects of LSD on brain function and subjective experience are non-uniform in time: **LSD makes globally segregated sub-states of dynamic functional connectivity more complex, and weakens the relationship between functional and anatomical connectivity"**




Questions?
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UNIVERSIDADE D COIMBRA
Bruno Direito
bruno.direito@uc.pt