Grand Challenge: Computational Neurophenomics for understanding people's behavior

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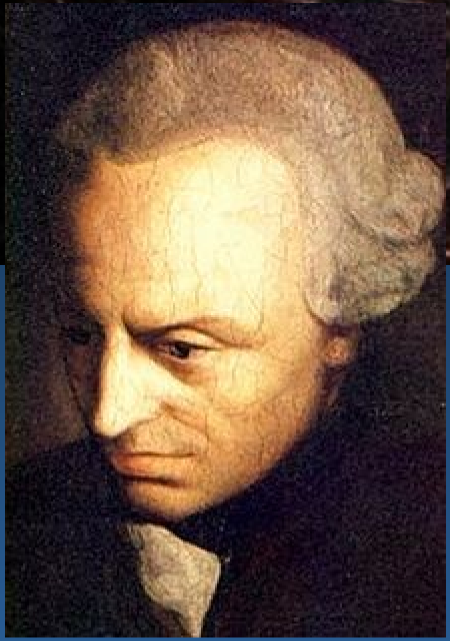
Google: W. Duch

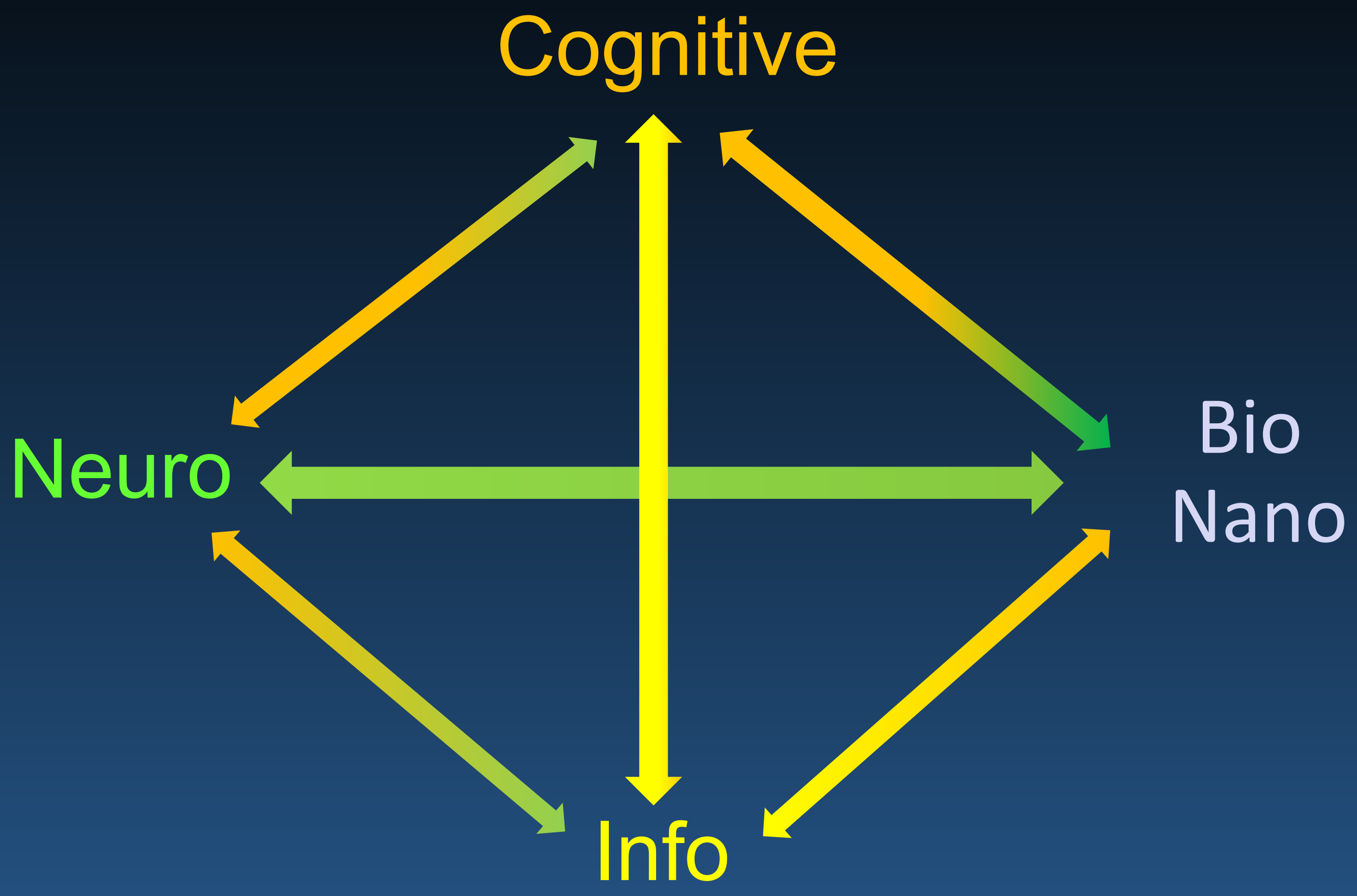
CAMK, Warszawa, 1. 07.15



Immanuel Kant

22 April 1724 – 12 February 1804)

21 Century Technologies



Center of Modern Interdisciplinary Technologies

Why am I interested in this?

Bio + Neuro + Cog Sci + Physics =

Neurocognitive lab.

5 units with many projects requiring experimental work.

Main theme: maximizing human potential.
Pushing the limits of brain plasticity and understanding brain-mind relations, with a lot of help from computational intelligence!
Funding: national/EU grants.

Our toys


personal genome machine


Treatment Coil
Prefrontal Cortex
Stimulated Area
Magnetic Field
NEUROSTAR

DI NCU Projects:NCI

Neurocognitive Informatics: understanding complex cognition
=> creating algorithms that work in similar way.

- Computational creativity, insight, intuition, imagery.
- Imagery agnosia, especially imagery amusia.
- Neurocognitive approach to language, word games.
- Medical information retrieval, analysis, visualization.
- Comprehensive theory of autism, ADHD, phenomics.
- Visualization of high-D trajectories, EEG signals, neurofeedback.
- Brain stem models & consciousness in artificial systems.
- Geometric theory of brain-mind processes.
- Infants: observation, guided development.
- Neural determinism, free will & social consequences.

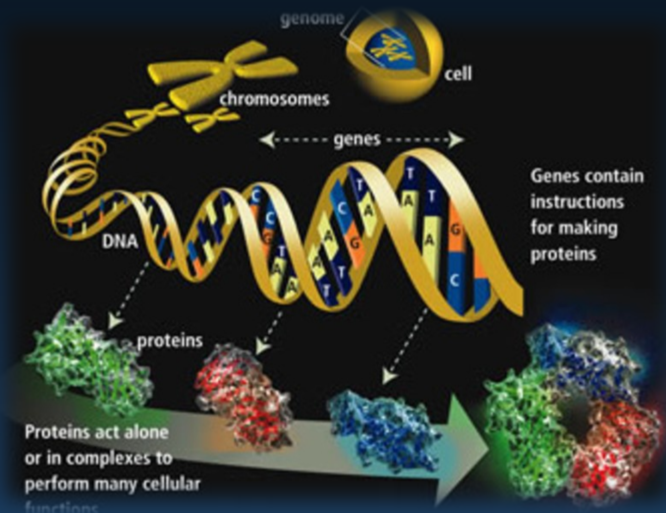
DI NCU Projects: CI

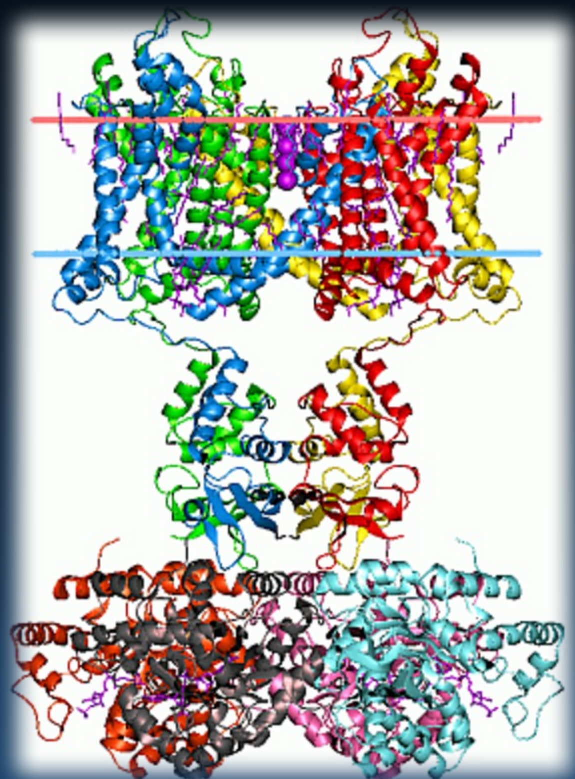
Google W. Duch => List of projects, talks, papers

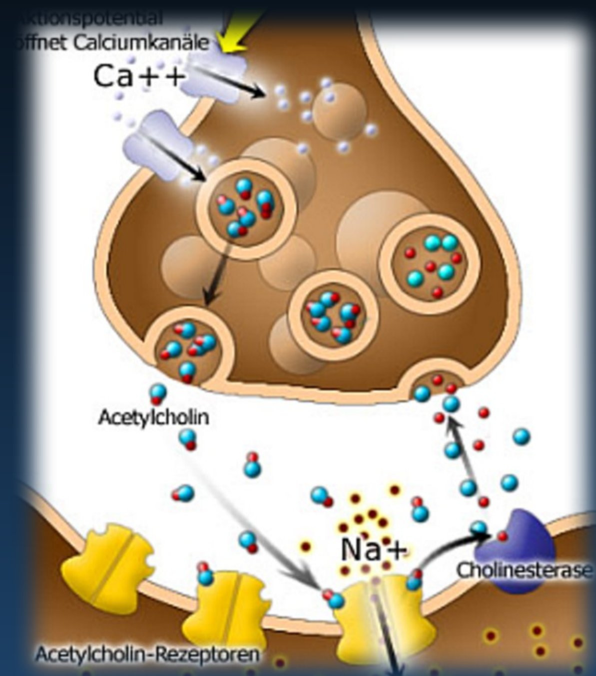
Computational intelligence (CI), main themes:

- Foundations of computational intelligence: transformation based learning, k-separability, learning hard boole’an problems.
- Novel learning: projection pursuit networks, QPC (Quality of Projected Clusters), search-based neural training, transfer learning or learning from others (ULM), aRPM, SFM ...
- Understanding of data: prototype-based rules, visualization.
- Similarity based framework for metalearning, heterogeneous systems, new transfer functions for neural networks.
- Feature selection, extraction, creation of enhanced spaces.
- General meta-learning, or learning how to learn, deep learning.

From Genes to Neurons

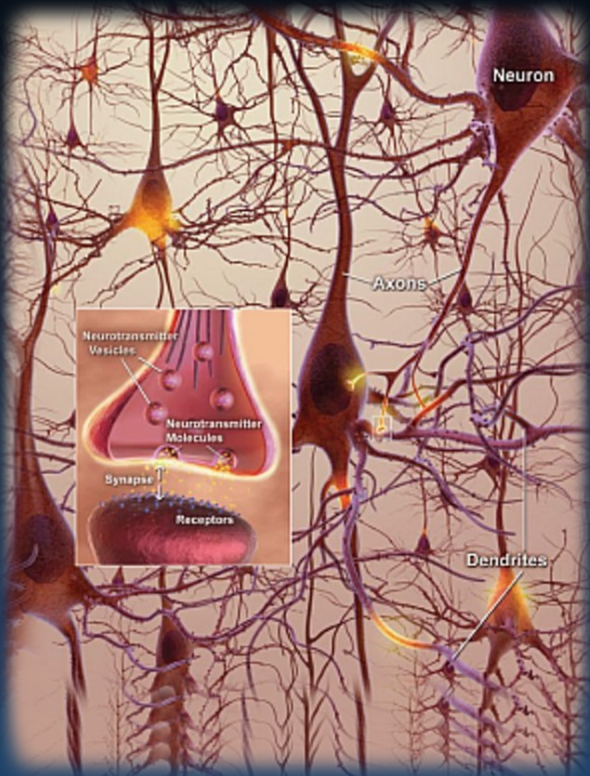


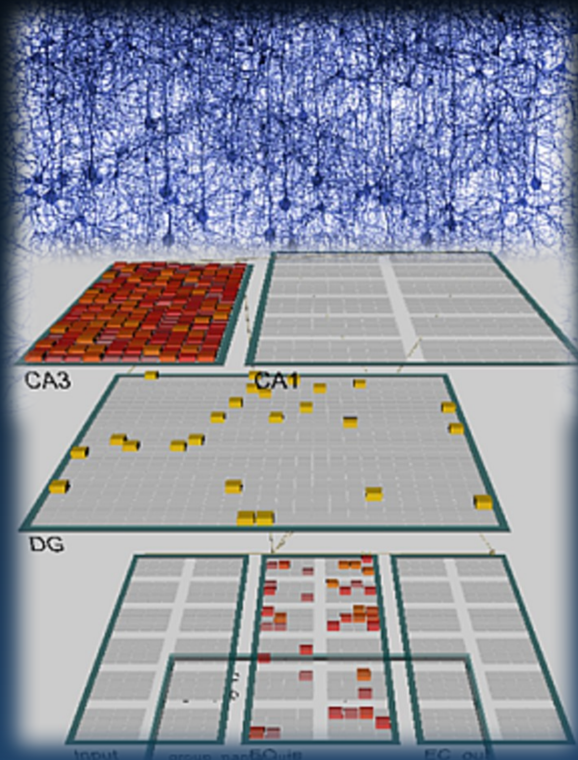


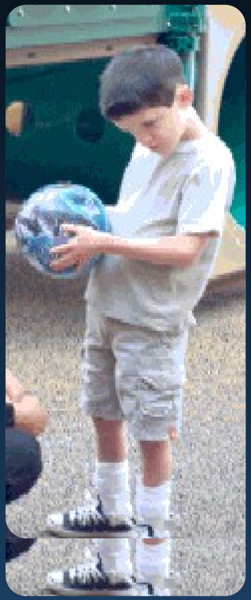


Genes => Proteins => receptors, ion channels, synapses
=> neuron properties, networks, neurodynamics
=> cognitive phenotypes, abnormal behavior, syndromes.

From Neurons to Behavior







Genes => Proteins => receptors, ion channels, synapses
=> neuron properties, networks
=> neurodynamics => cognitive phenotypes, abnormal behavior!

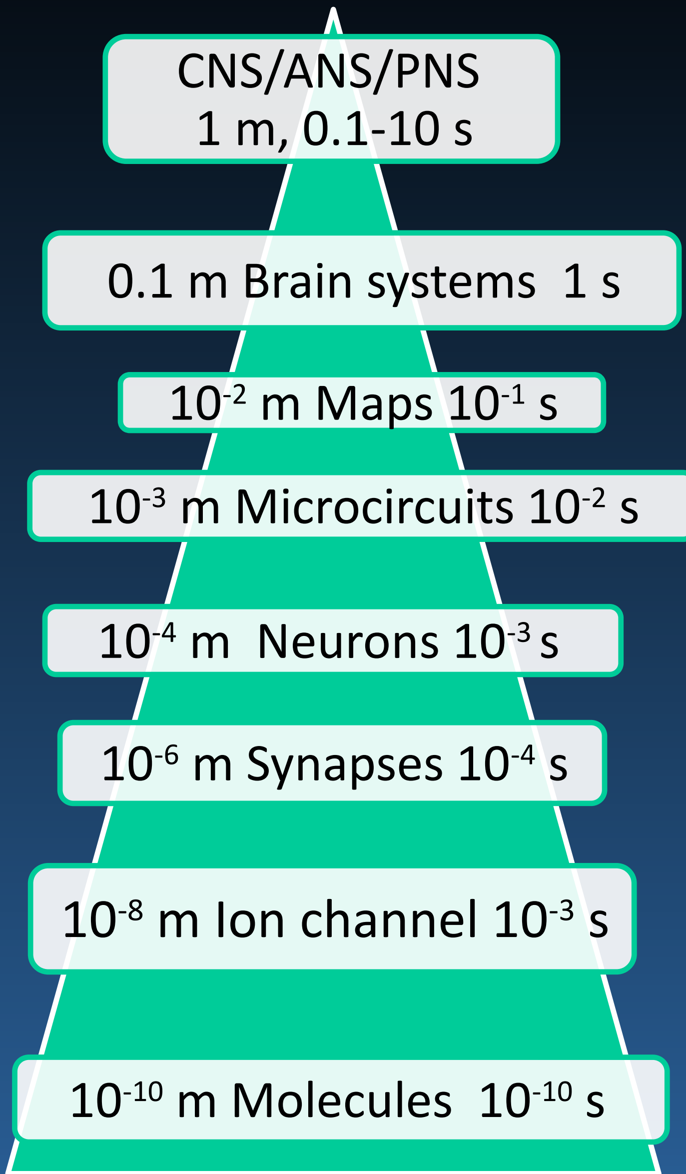
Space/time scales

Spatiotemporal resolution:

- spatial scale: 10 orders of magnitude, from 10^{-10} m to 1 m.
- temporal scale: 10 or more orders of magnitude, from 10^{-10} s to 1 s.

Architecture:

- hierarchical and modular
- ordered in large scale, chaotic in small;
- specific projections: interacting regions wired to each other;
- diffused: regions interact through hormones and neurotransmitters;
- functional:
  subnetworks dedicated to specific tasks.



Phenomics

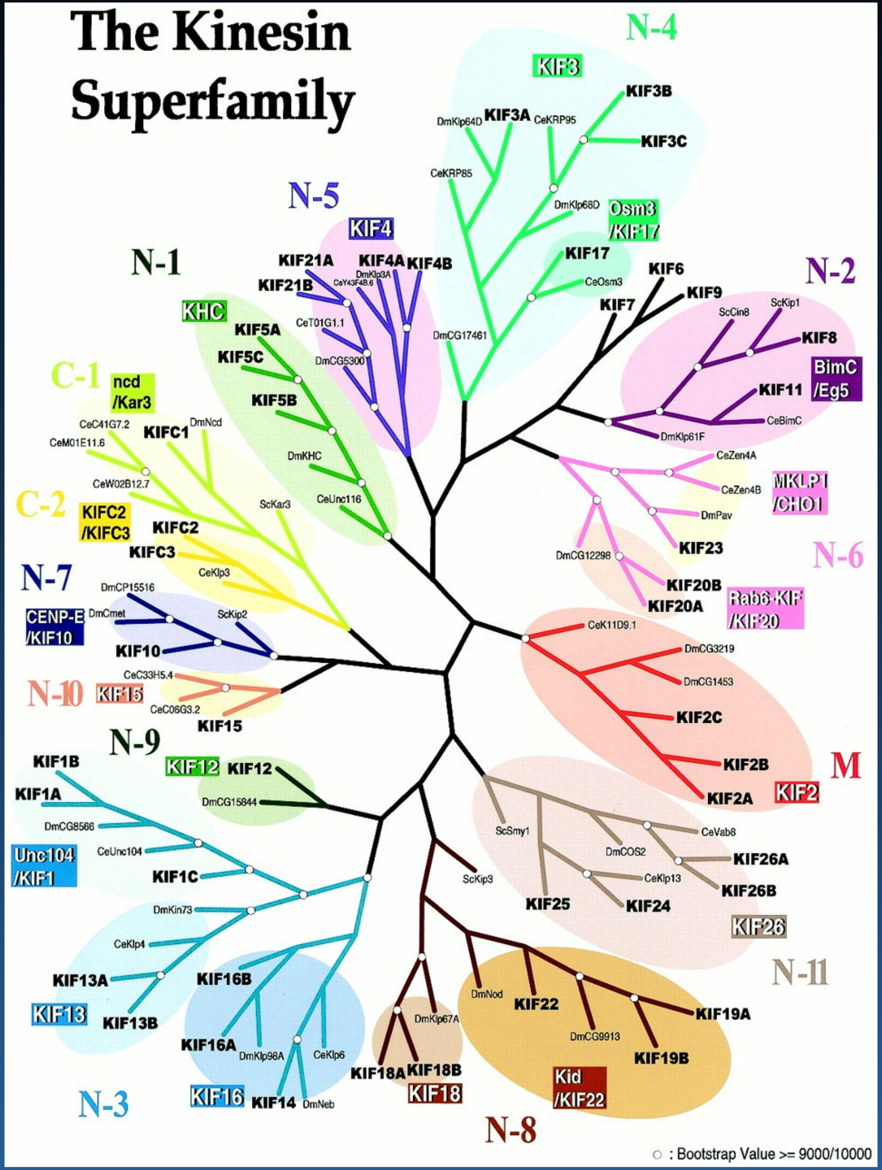
Phenomics is the branch of science concerned
with identification and description of measurable
physical, biochemical and psychological traits of organisms.
Genom, proteom, interactom, exposome, virusom , connectom …
omics.org has a list of over 400 various …*omics* !

Human Genome Project, since 1990.
Human Epigenome Project, since 2003.
Human Connectome Project, since 2009.
Developing Human Connectome Project, UK 2013 + many others.

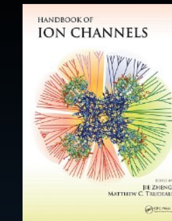
Behavior, personality, cognitive abilities <= phenotypes at all levels.
Still many white spots on maps of various phenomes.

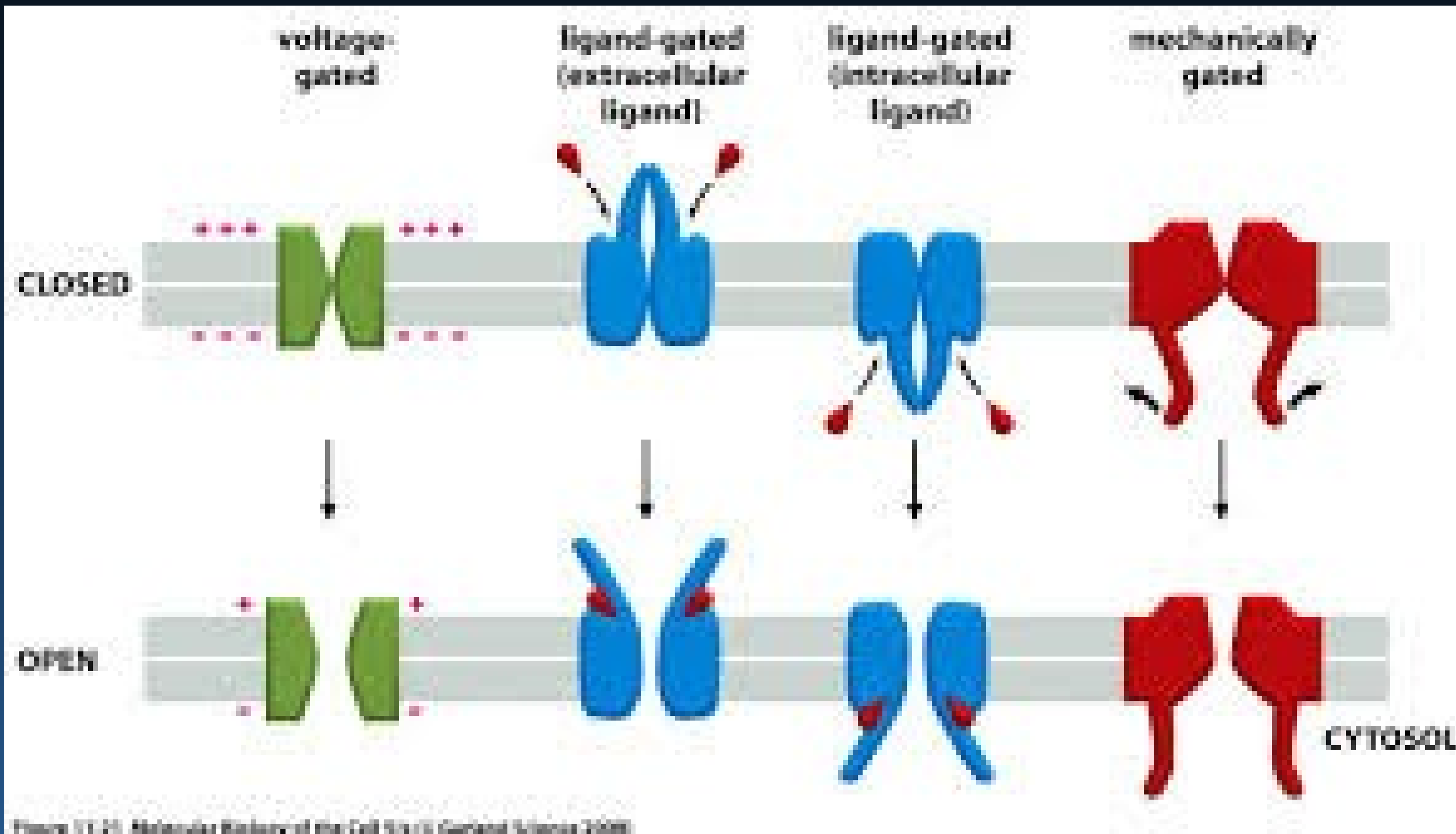
Can neurocognitive phenomics be developed to understand general behavior of people? Where should we start?

Protein families

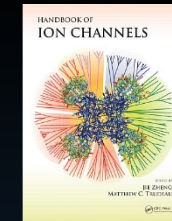


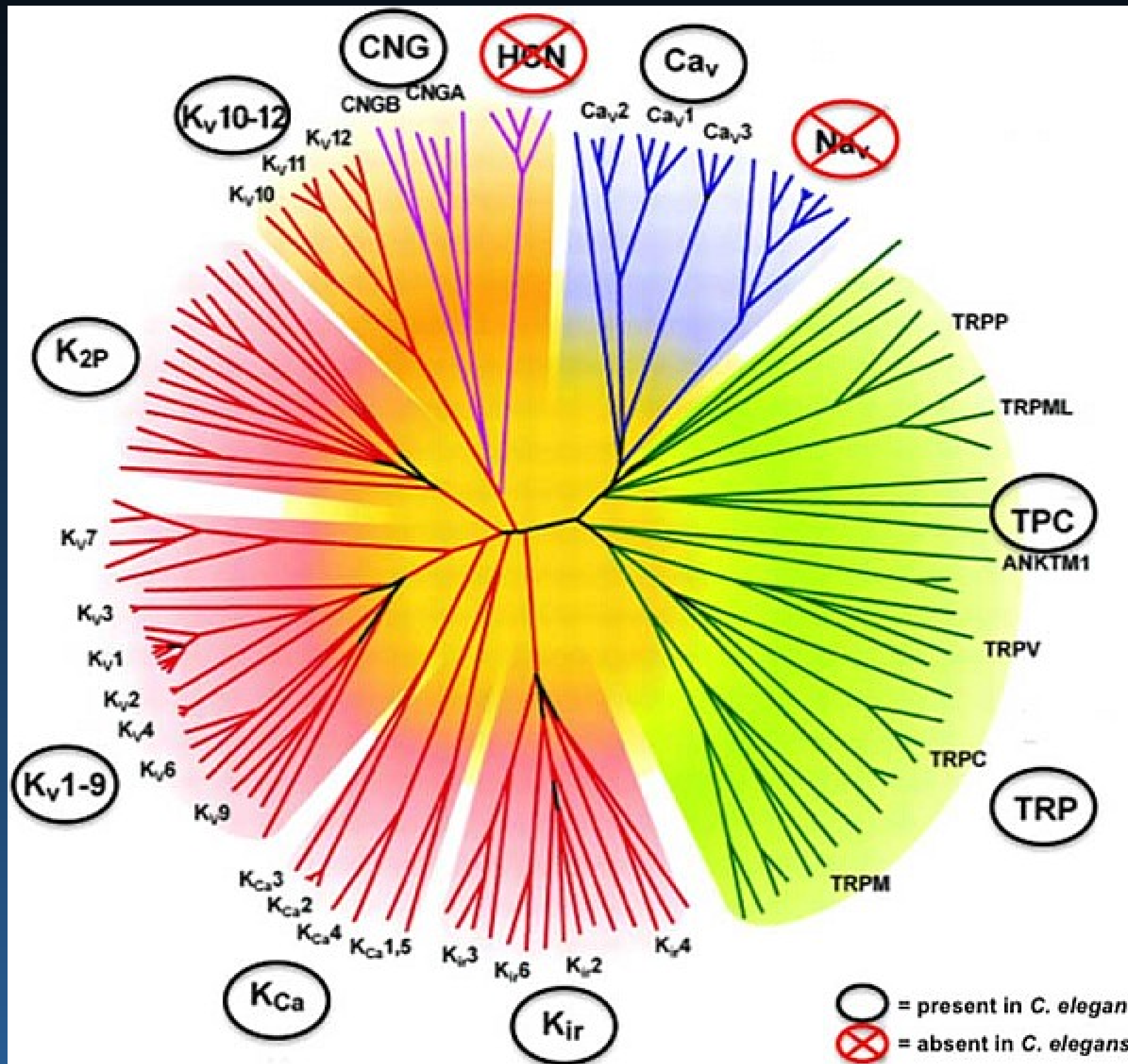
Ion channels



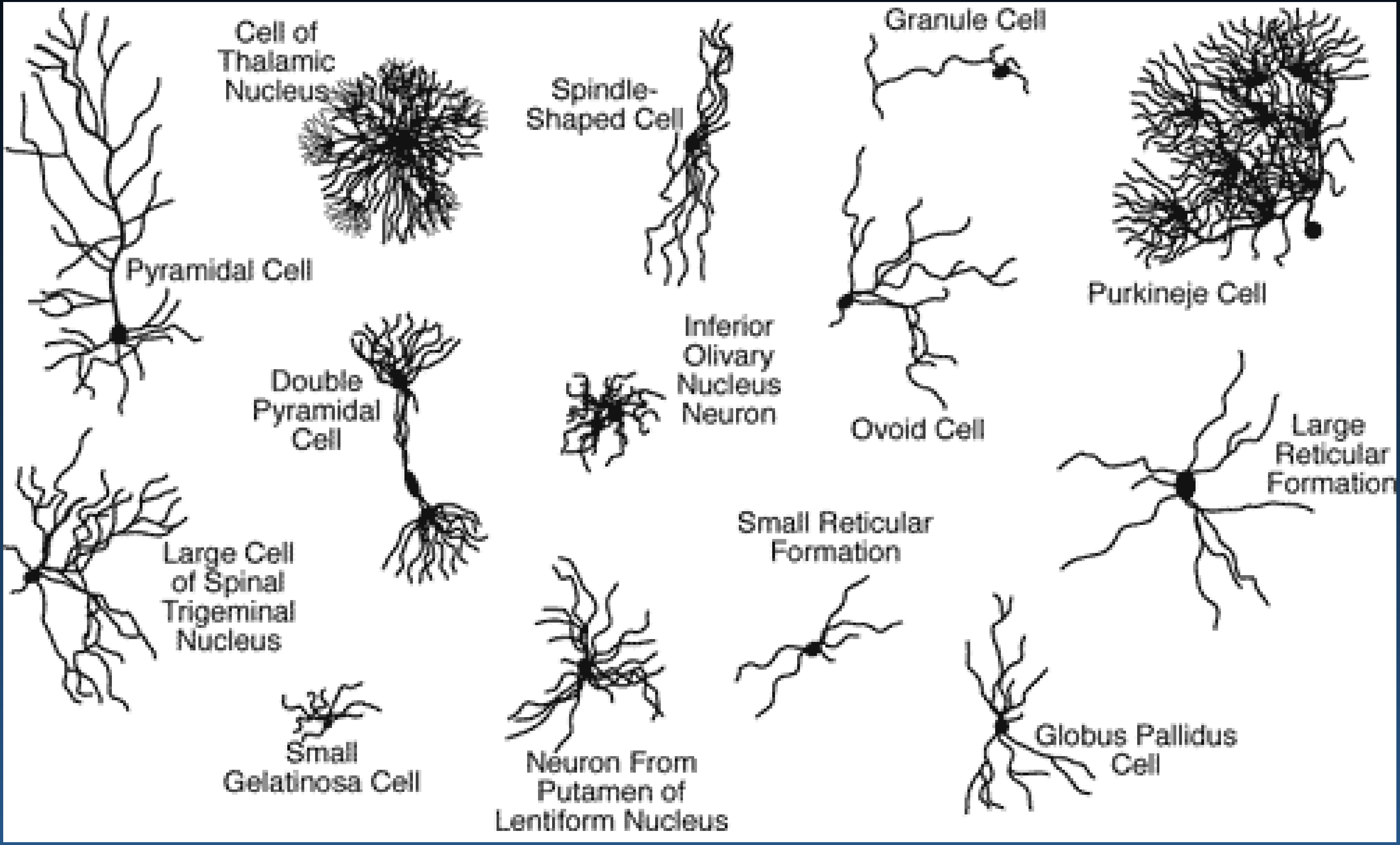


Voltage-gated ion channels

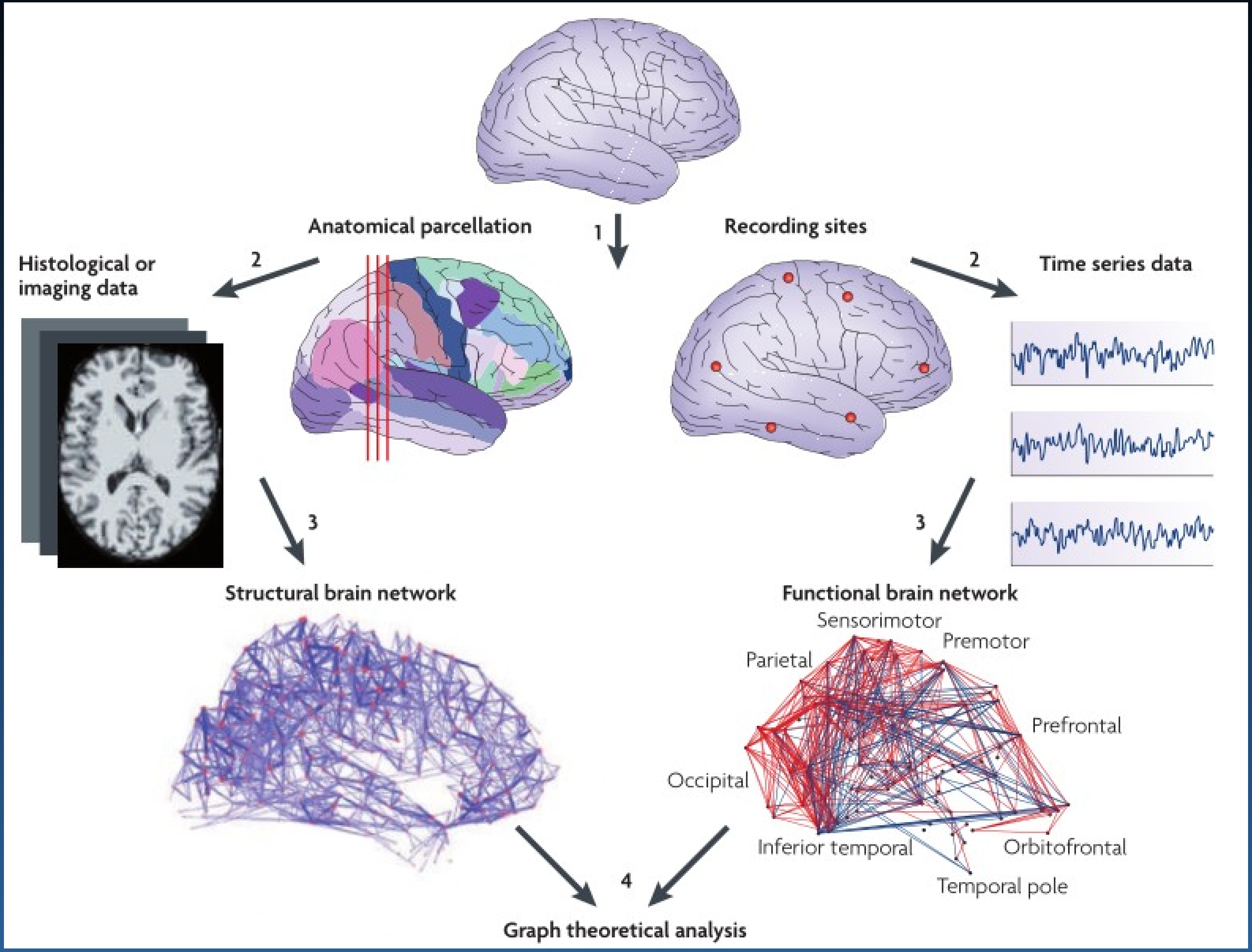




Neurons


Cell of Thalamic Nucleus
Spindle-Shaped Cell
Granule Cell
Purkineje Cell
Pyramidal Cell
Inferior Olivary Nucleus Neuron
Double Pyramidal Cell
Ovoid Cell
Large Reticular Formation
Small Reticular Formation
Large Cell of Spinal Trigeminal Nucleus
Small Gelatinosa Cell
Neuron From Putamen of Lentiform Nucleus
Globus Pallidus Cell

Structure and function

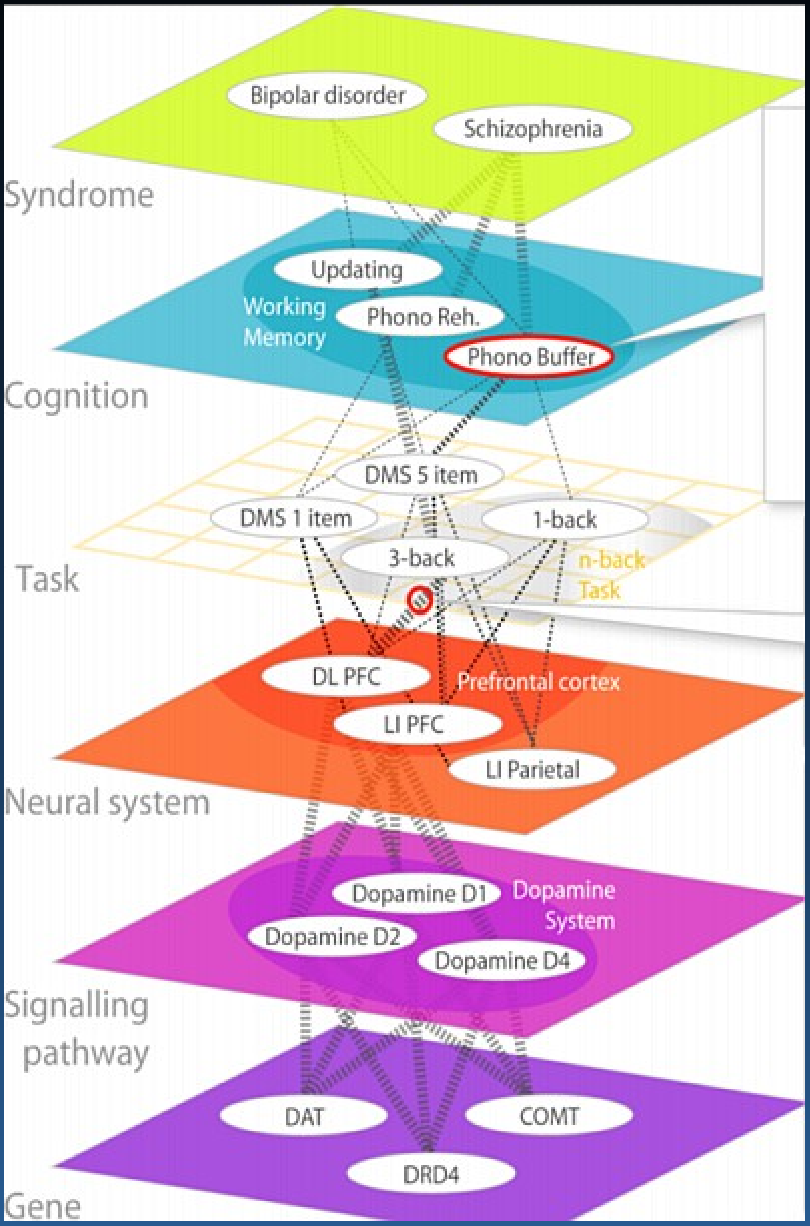


Neuropsychiatric Phenomics in 6 Levels

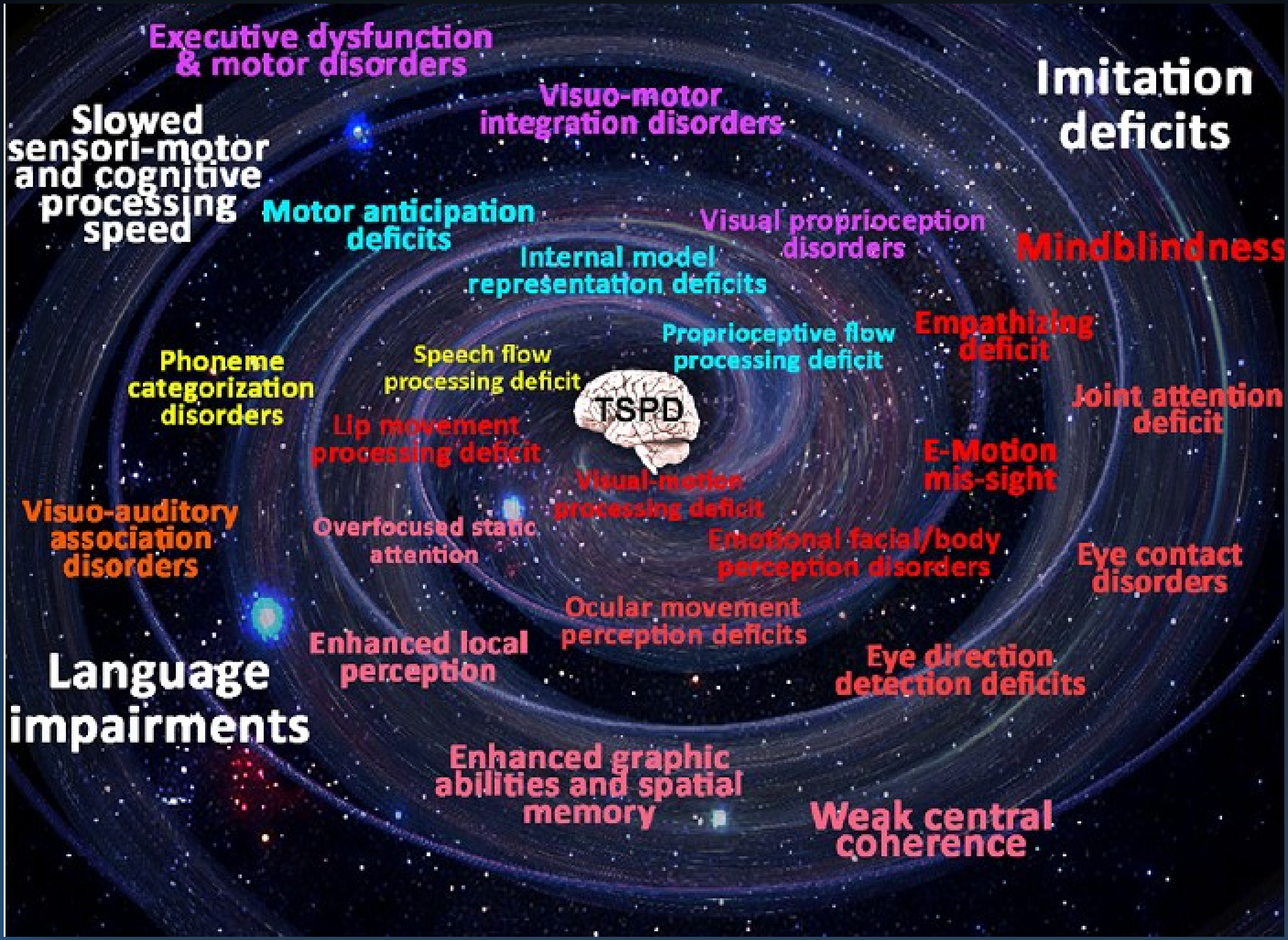
According to
The Consortium for Neuropsychiatric Phenomics (CNP)
http://www.phenomics.ucla.edu

From genes to molecules to neurons to networks to large systems => tasks, cognitive subsystems and syndromes.

Neurons and networks are right in the middle of this hierarchy.

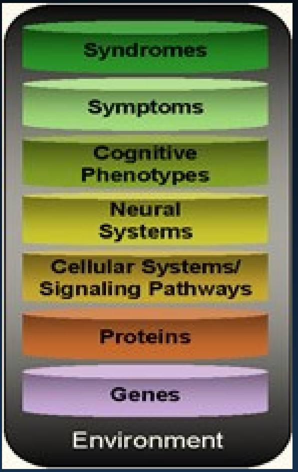


Temporo-spatial processing disorders



B. Gepner, F. Feron, Autism: A world changing too fast for a mis-wired brain? Neuroscience and Biobehavioral Reviews (2009).

Neurophenomics Research Strategy



The Consortium for Neuropsychiatric Phenomics (2008):
bridge all levels, one at a time, from environment to syndromes.

Our strategy: identify biophysical parameters of neurons required for normal neural network functions and leading to abnormal cognitive phenotypes, symptoms and syndromes.

- Start from simple neurons and networks, increase complexity.
- Create models of cognitive function that may reflect some of the symptoms of the disease, for example problems with attention.
- Test and calibrate the stability of these models in a normal mode.
- Determine model parameter ranges that lead to similar symptoms.
- Relate these parameters to the biophysical properties of neurons.

Result: mental events at the network level are described in the language of neurodynamics and related to low-level neural properties.
Example: relation of ASD/ADHD symptoms to neural accommodation.

Neurocognitive Phenomics

Phenotypes may be described at many levels. Ex. from top down: learning styles - education, psychiatry & psychology,

neurophysiology, connectomes, microcircuits, neural networks,

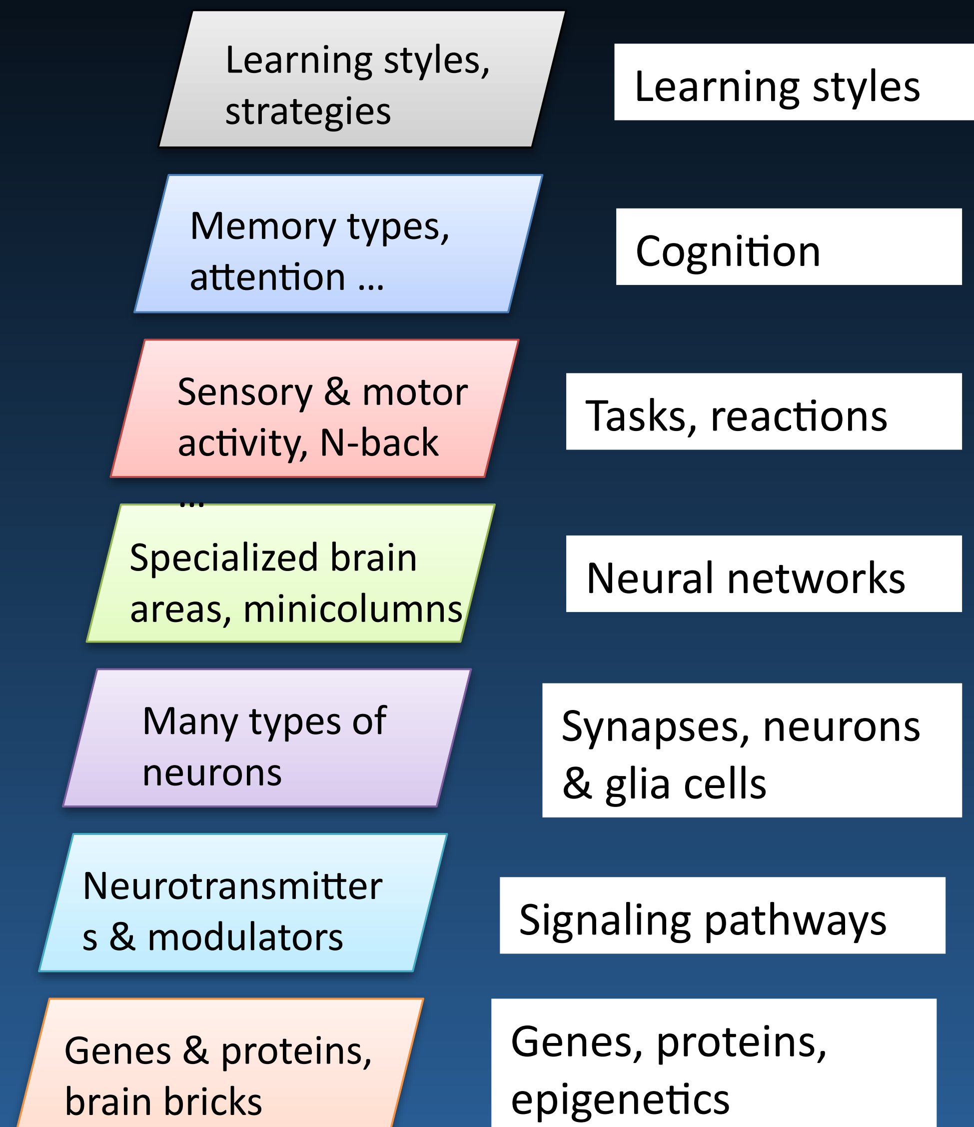
Neurobiology - organs, tissues, cells,

biophysics, biochemistry & bioinformatics.

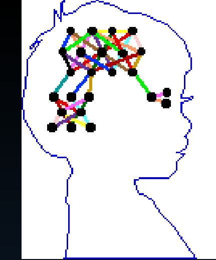
Neurocognitive phenomics is even greater challenge than neuropsychiatric phenomics.

Effects are more subtle but this is the only way to understand fully human/animal behavior.

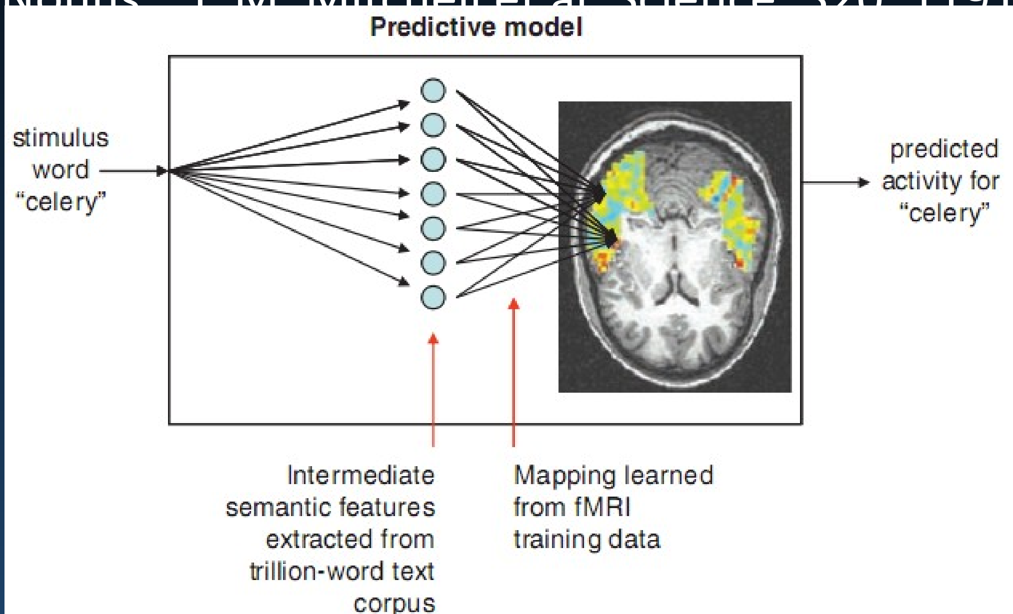
Data driven science!

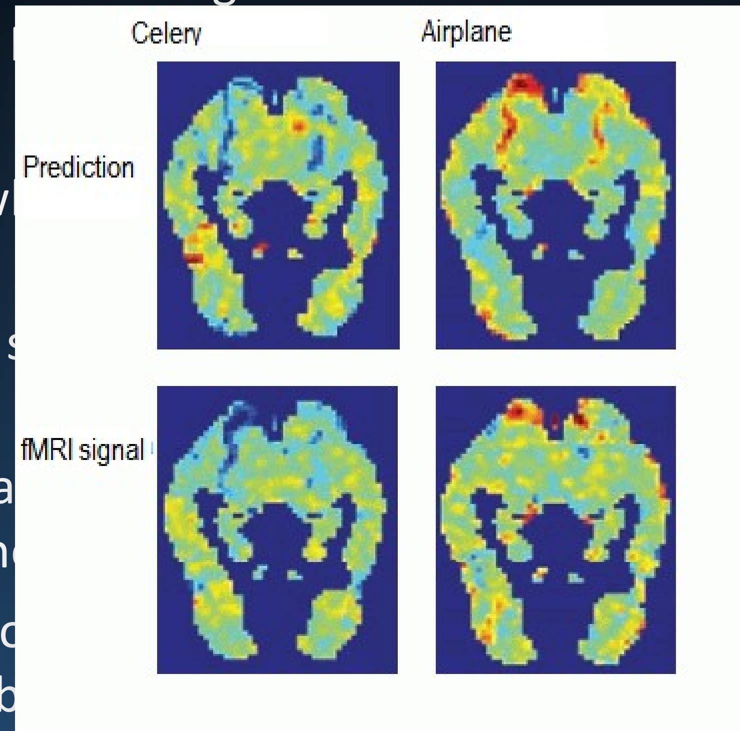


Private thoughts?



Predicting Human Brain Activity Associated with the Meanings of Nouns," T. M. Mitchell et al, Science, 320, 1191,



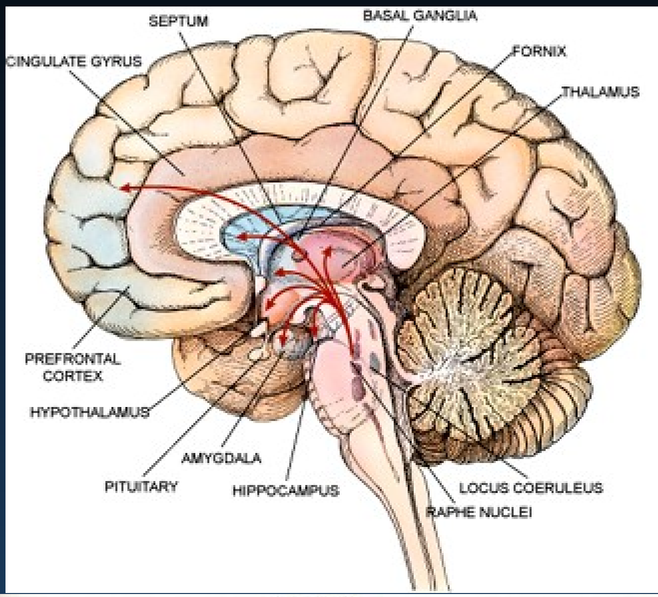


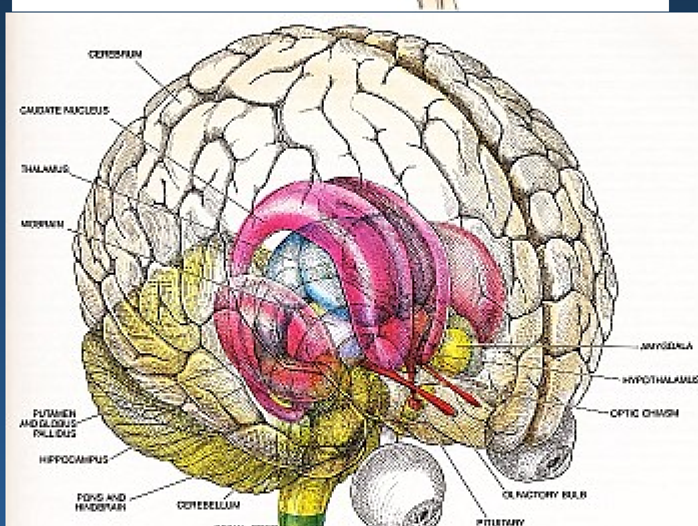
-
-
-
- activity for over 100 nouns for which fMRI has b

Overlaps between activation of the brain for different words may serve as expansion coefficients for word-activation basis set.

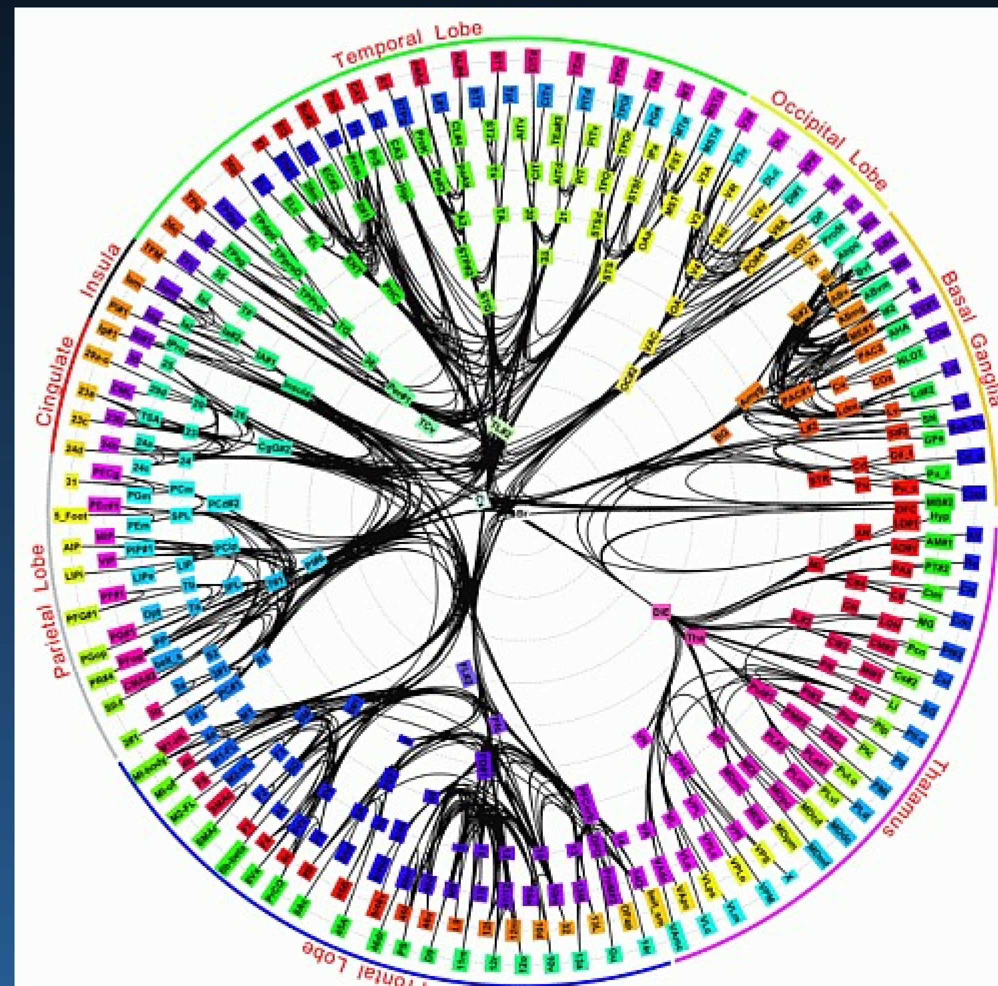
In future: I may know what you'll think before you will know it yourself! Intentions may be known seconds before they become conscious!

Modules: core brain

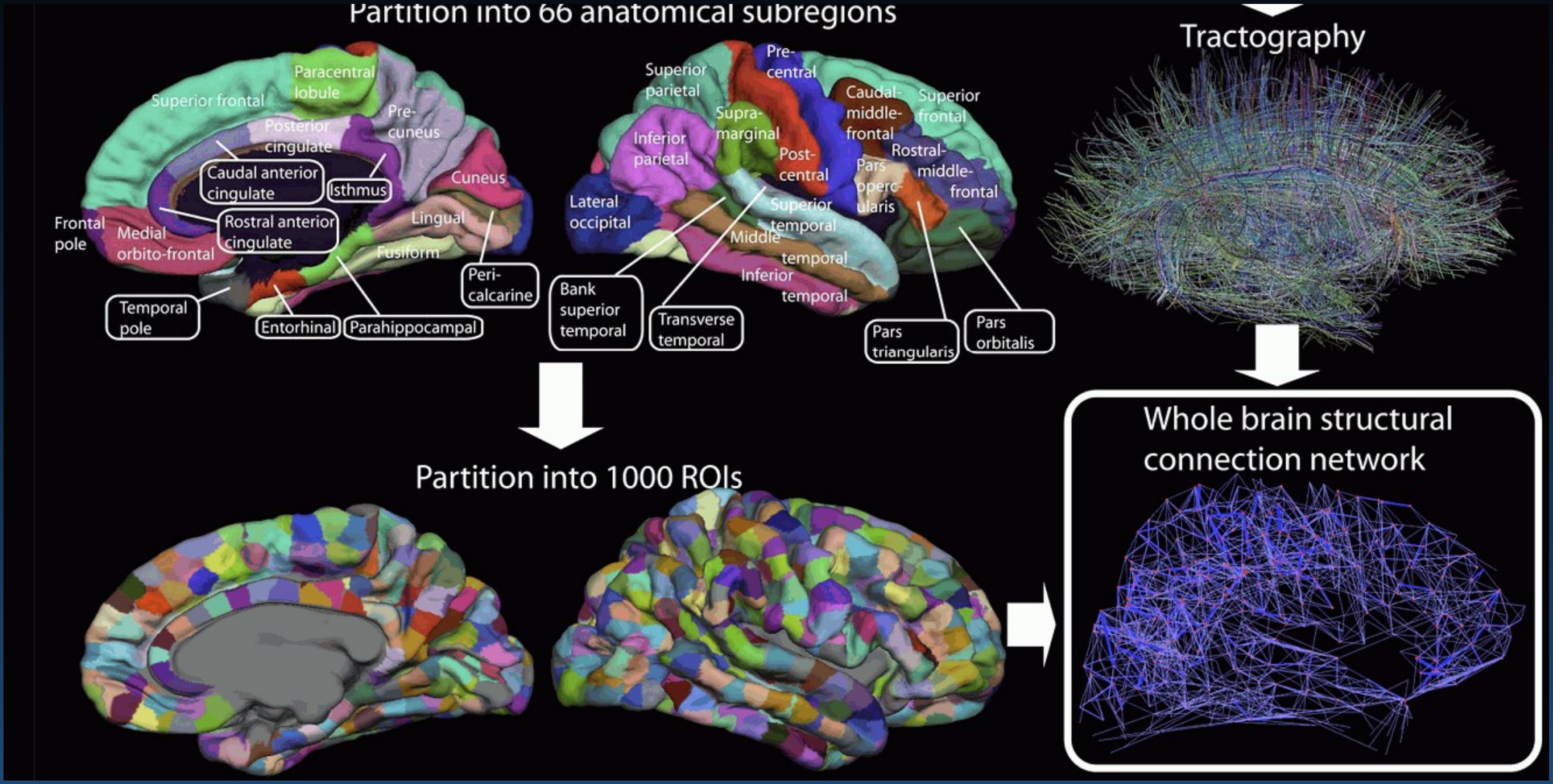




Connectivity of 383 regions in macaque brain; Modha & Singh, PNAS 2010.



Connectome Project



Brain-based representations of concepts based on distribution of activity over 1000 ROIs should be possible.

Nicole Speer et al.

Reading Stories Activates Neural Representations of Visual and Motor Experiences.

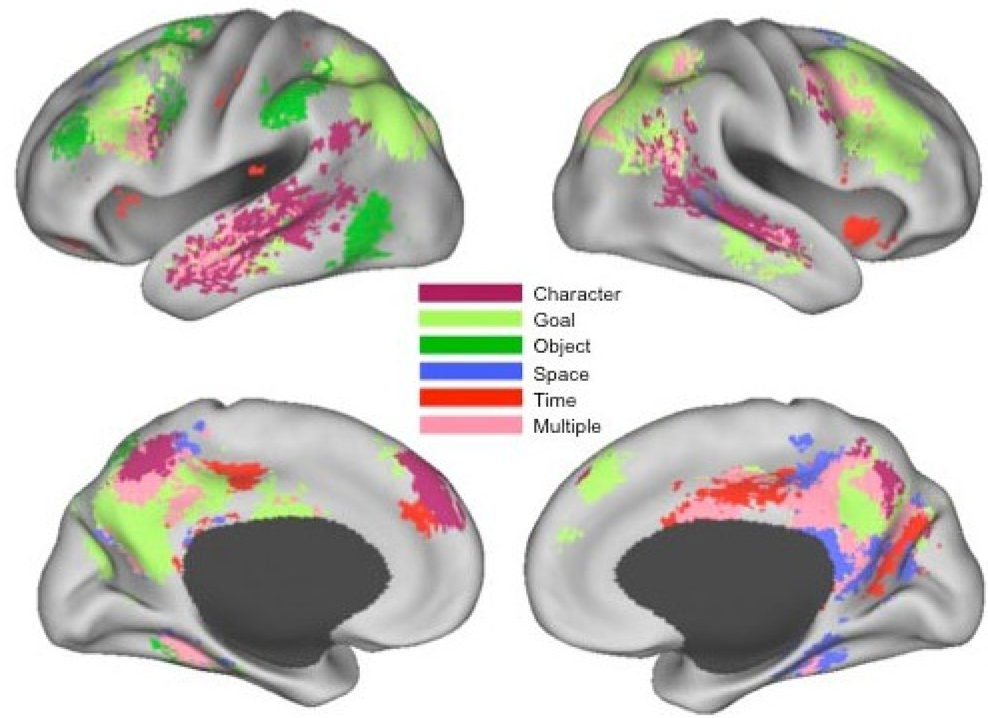
Psychological Science 2009; 20(8): 989–999.

Meaning: always slightly different, depending on the context, but still may be clusterized into relatively samll number of distinct meanings.

A

Clause	Cause	Character	Goal	Object	Space	Time
...[Mrs. Birch] went through the front door into the kitchen.	●				●	
Mr. Birch came in	●	●			●	
and, after a friendly greeting,	●					●
chatted with her for a minute or so.	●					●
Mrs. Birch needed to awaken Raymond.		●				
Mrs. Birch stepped into Raymond's bedroom,			●		●	
pulled a light cord hanging from the center of the room,				●		
and turned to the bed.						
Mrs. Birch said with pleasant casualness,						
"Raymond, wake up."						
With a little more urgency in her voice she spoke again:						
Son, are you going to school today?						
Raymond didn't respond immediately.		●				●
He screwed up his face			●			
And whimpered a little.						

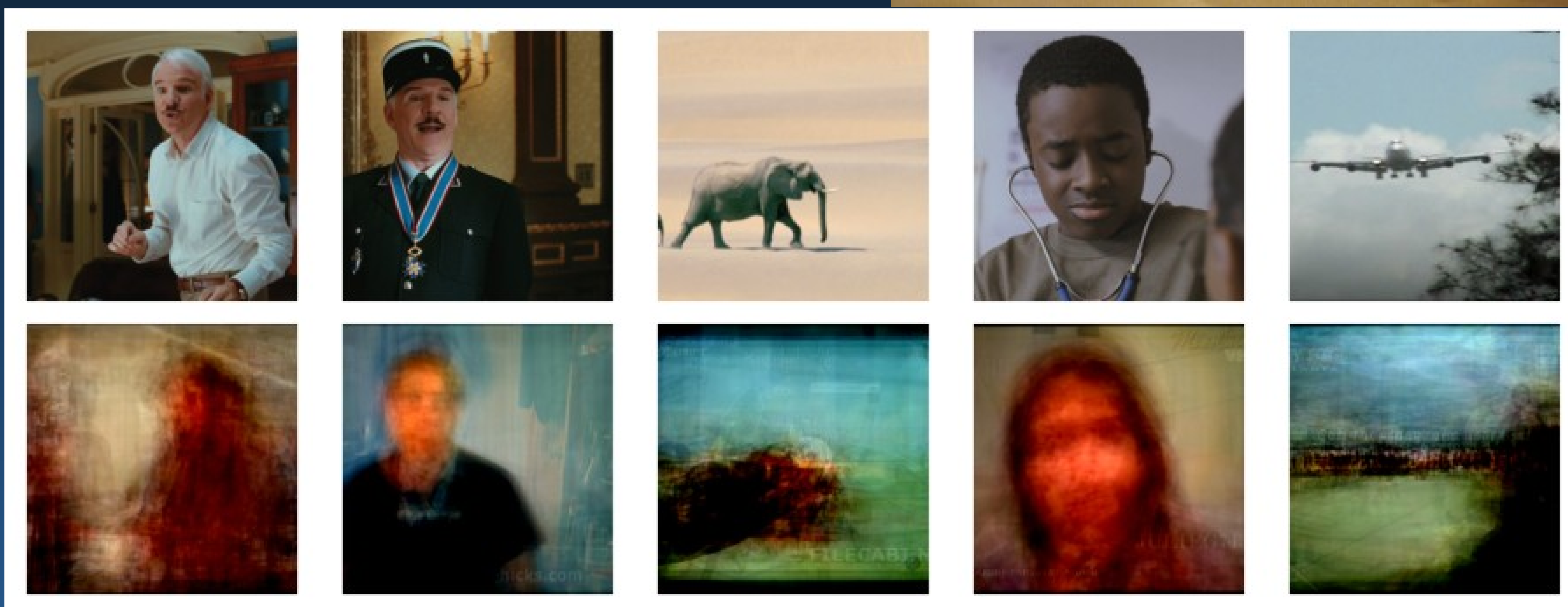
B



Looking inside

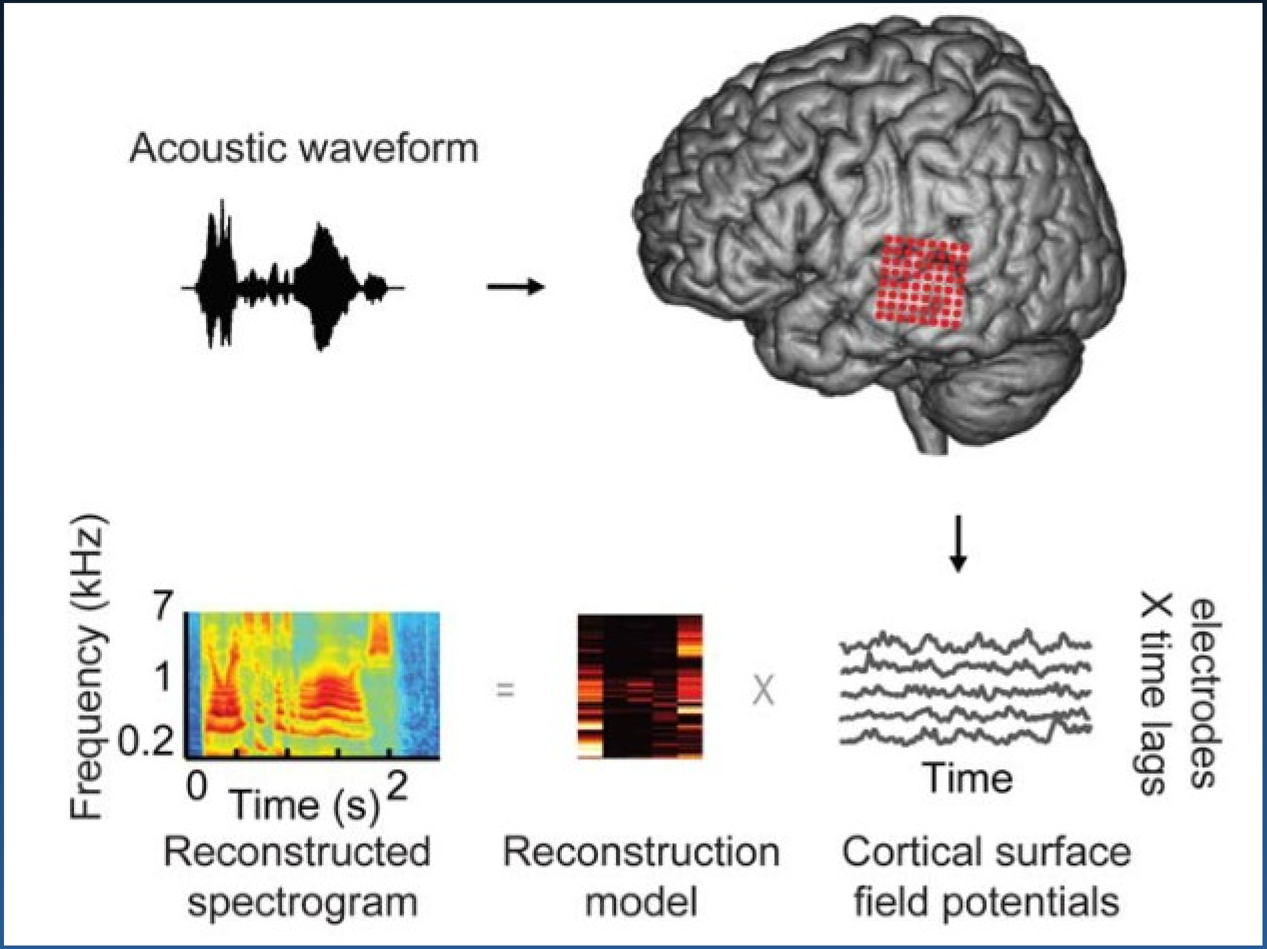
Scanner fMRI 4 Tesla

S. Nishimoto et al. Current Biology 21, 1641-1646, 2011

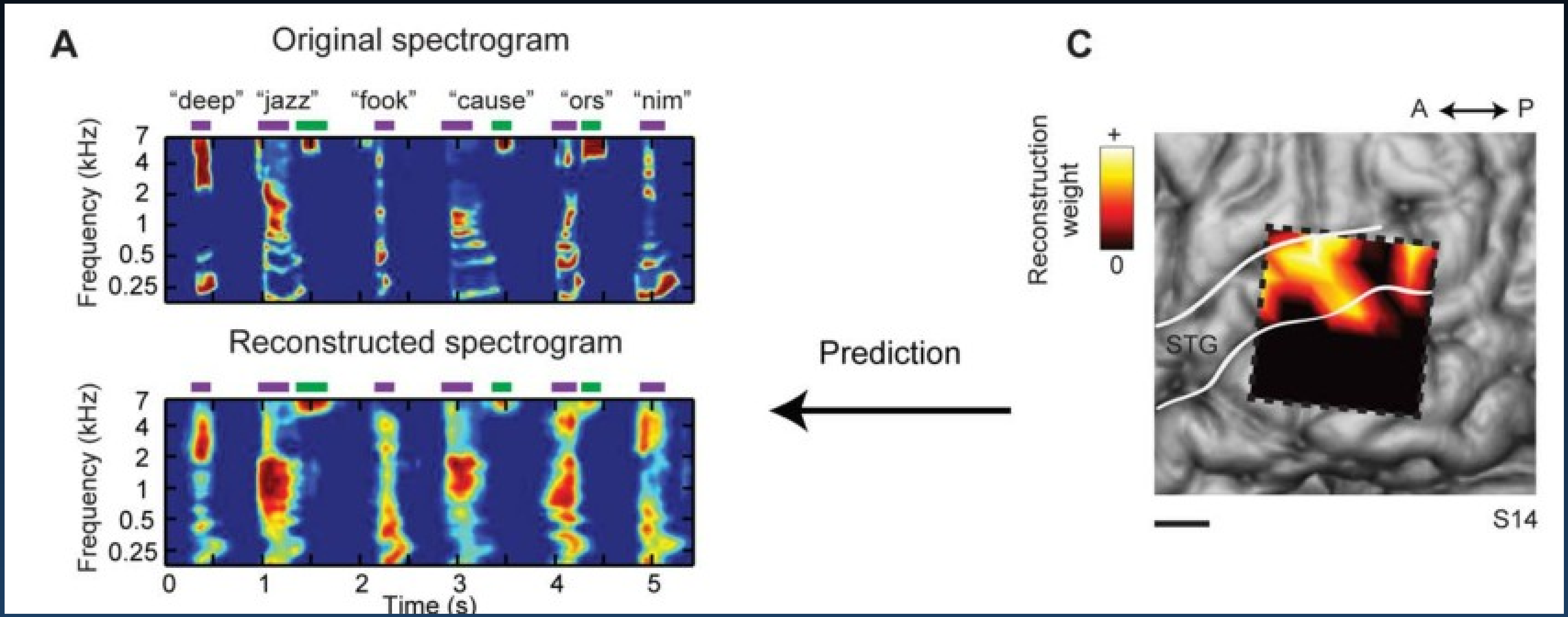


Hearing your thoughts

Spectrogram-based reconstruction of the same speech segment, linearly decoded from a set of electrodes.

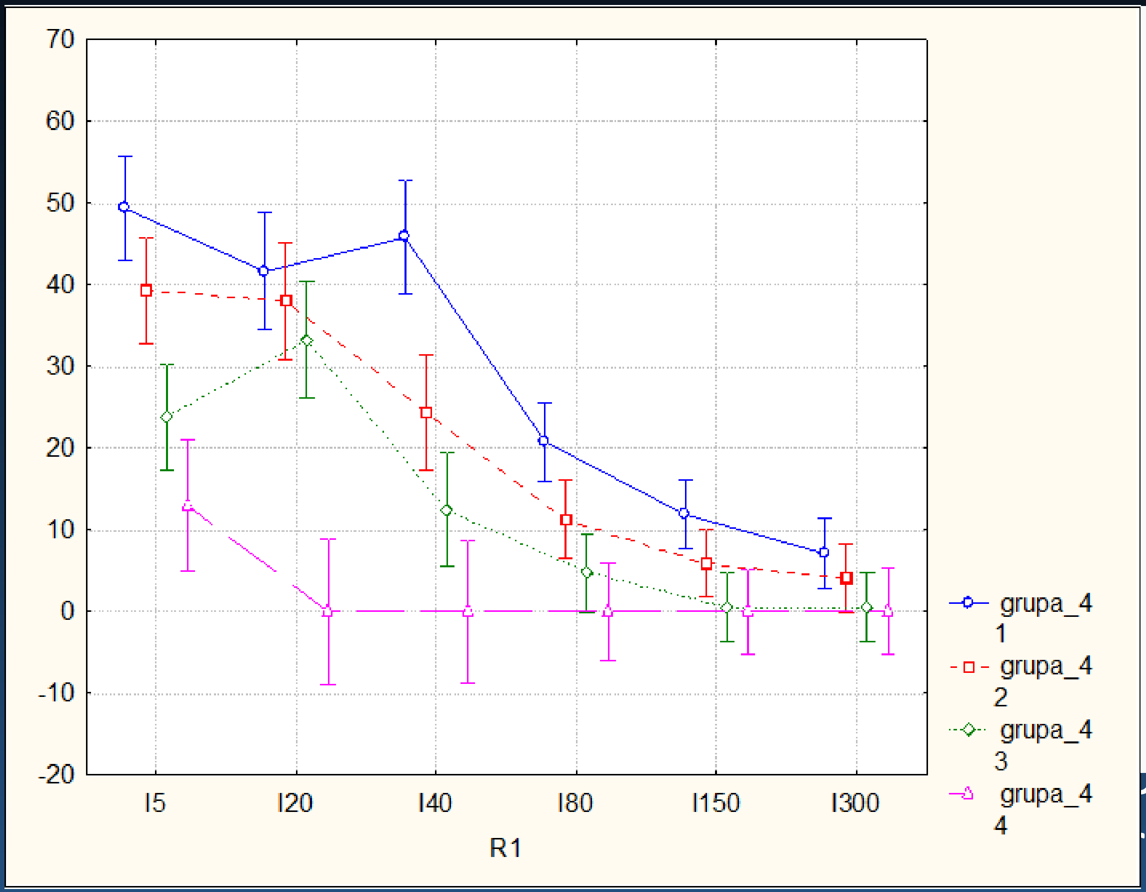


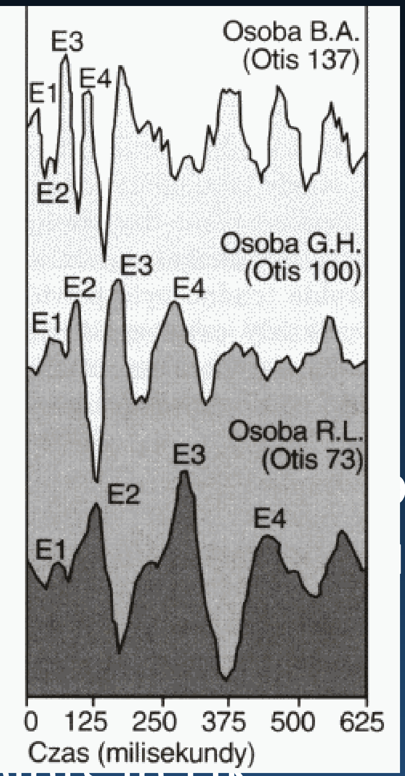
Thought: time, frequency, place, energy

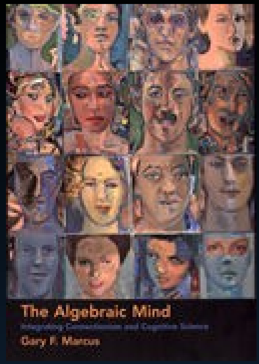


Pasley et al. Reconstructing Speech from Human Auditory Cortex
PLOS Biology 2012

Abstract thinking







very
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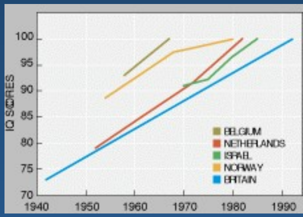
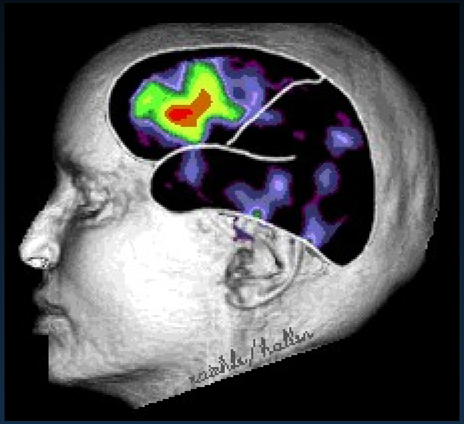
ints in UK.
brains?



Geometric model of mind



Objective ⇔ Subjective.

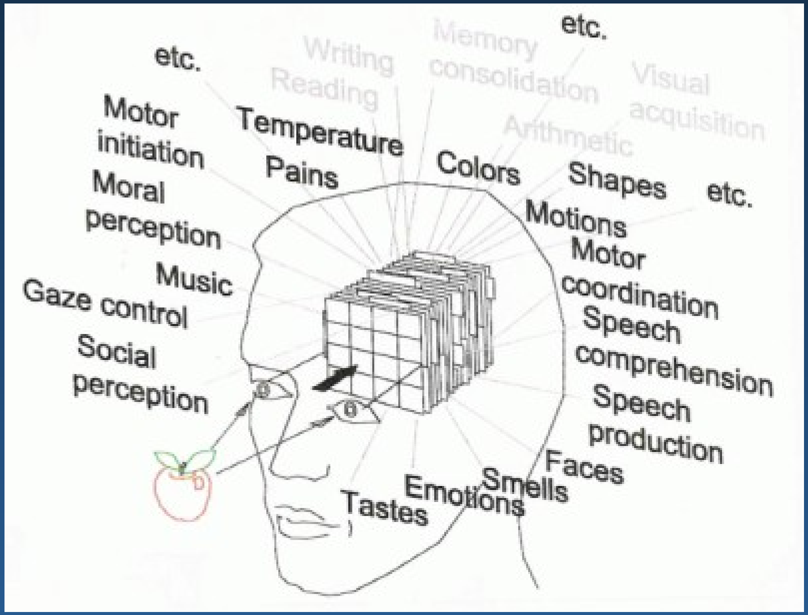
Brain ⇔ Mind.

Neurodynamics describes state of the brain activation measured using EEG, MEG, NIRS-OT, PET, fMRI or other techniques.

How to represent mind state?

In the space based on dimensions that have subjective interpretation: intentions, emotions, qualia.

Mind state and brain state trajectory should then be linked together by transformations (BCI).



Computational Models

Models at various level of detail.

- Minimal model includes neurons with 3 types of ion channels.

Models of attention:

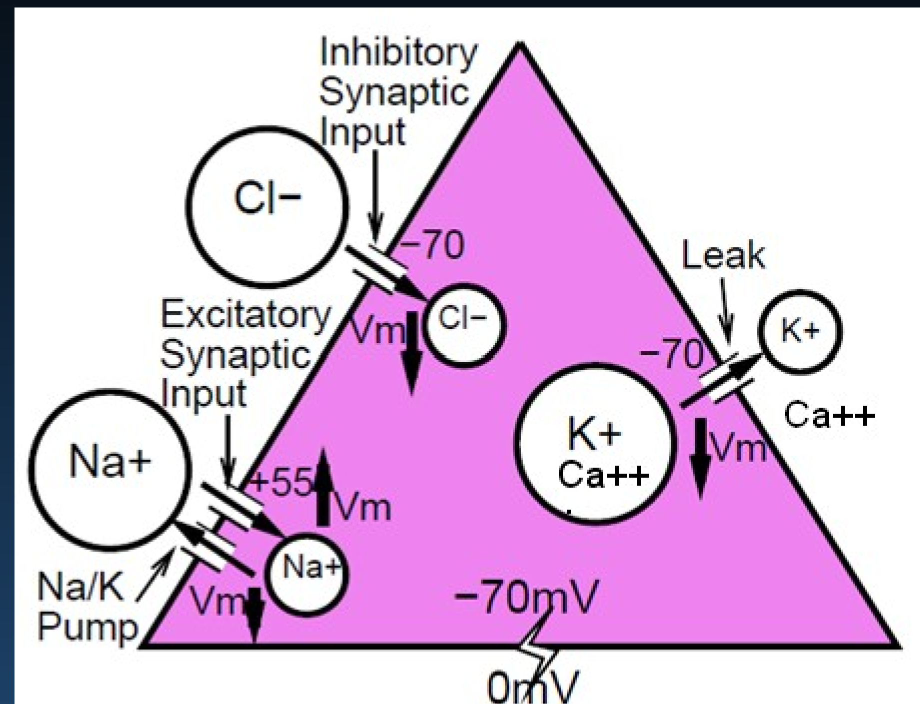
- Posner spatial attention;
- attention shift between visual objects.

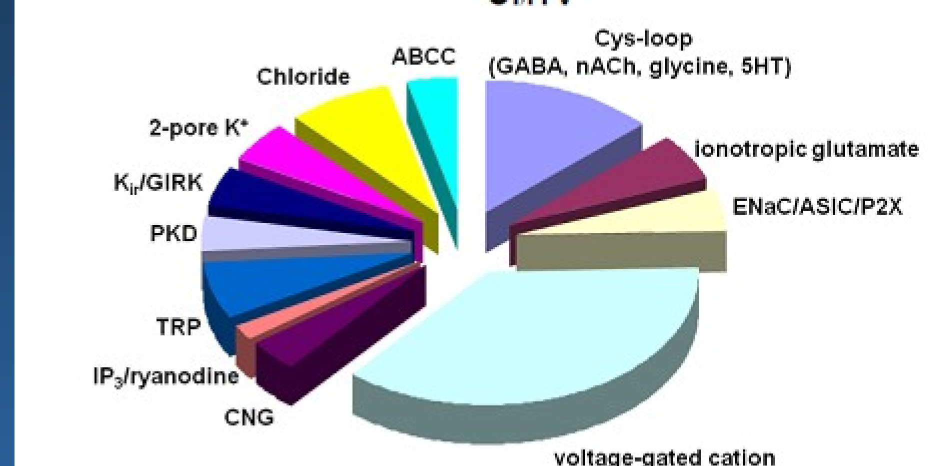
Models of word associations:

- sequence of spontaneous thoughts.

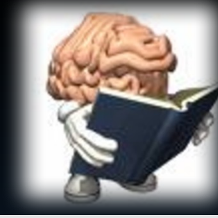
Models of motor control.

Critical: control of the increase in intracellular calcium, which builds up slowly as a function of activation.
Initial focus on the leak channels, 2-pore K^+, looking for genes/proteins.



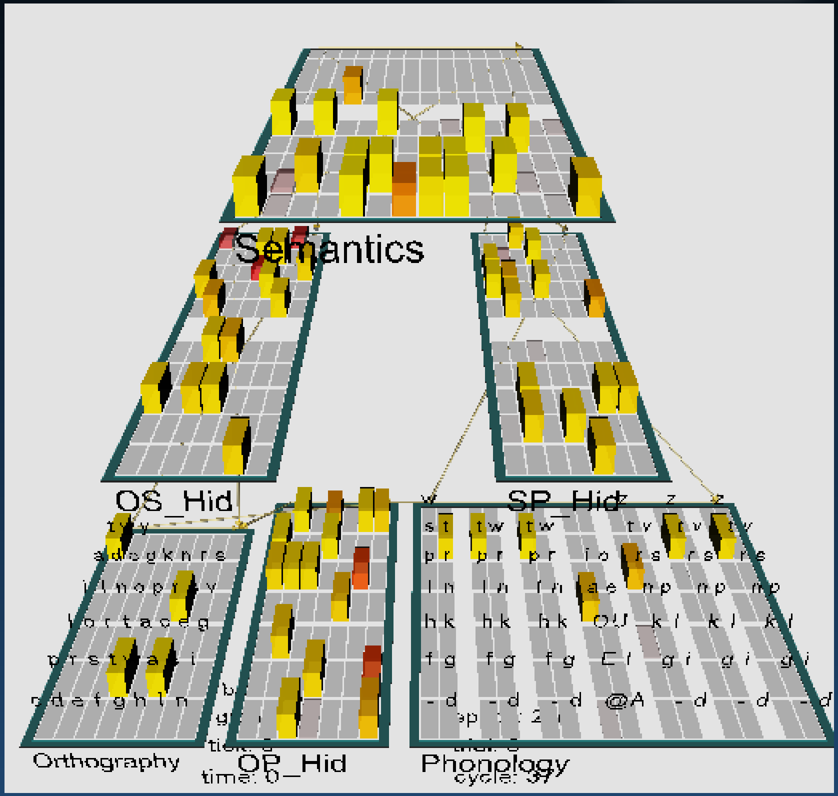


Model of reading & dyslexia



Emergent neural simulator:

Aisa, B., Mingus, B., and O'Reilly, R. The emergent neural modeling system. Neural Networks,
21, 1045-1212, 2008.



3-layer model of reading:

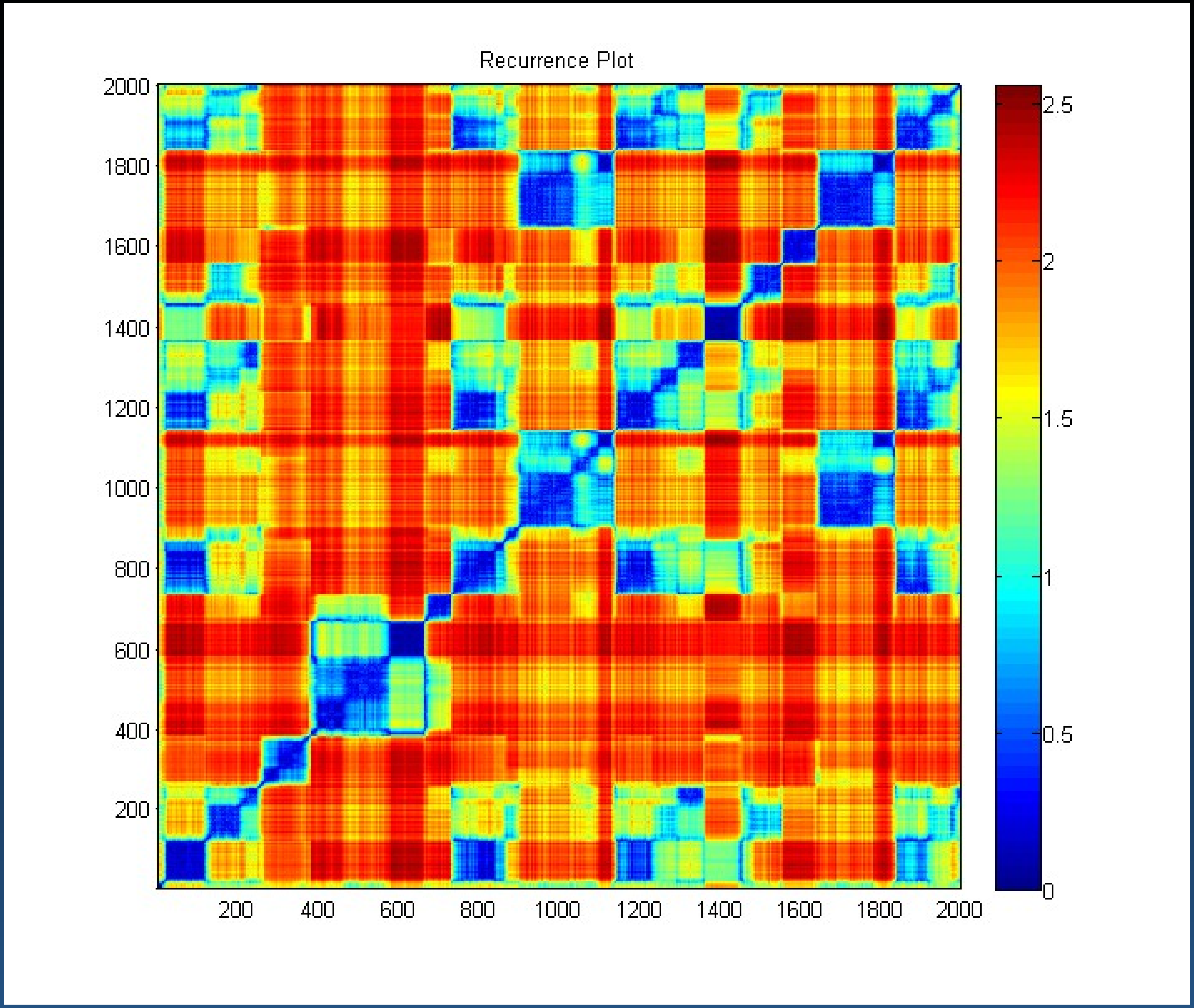
orthography, phonology, semantics, or distribution of activity over 140 microfeatures of concepts.

Hidden layers in between.

Learning: mapping one of the 3 layers to the other two.

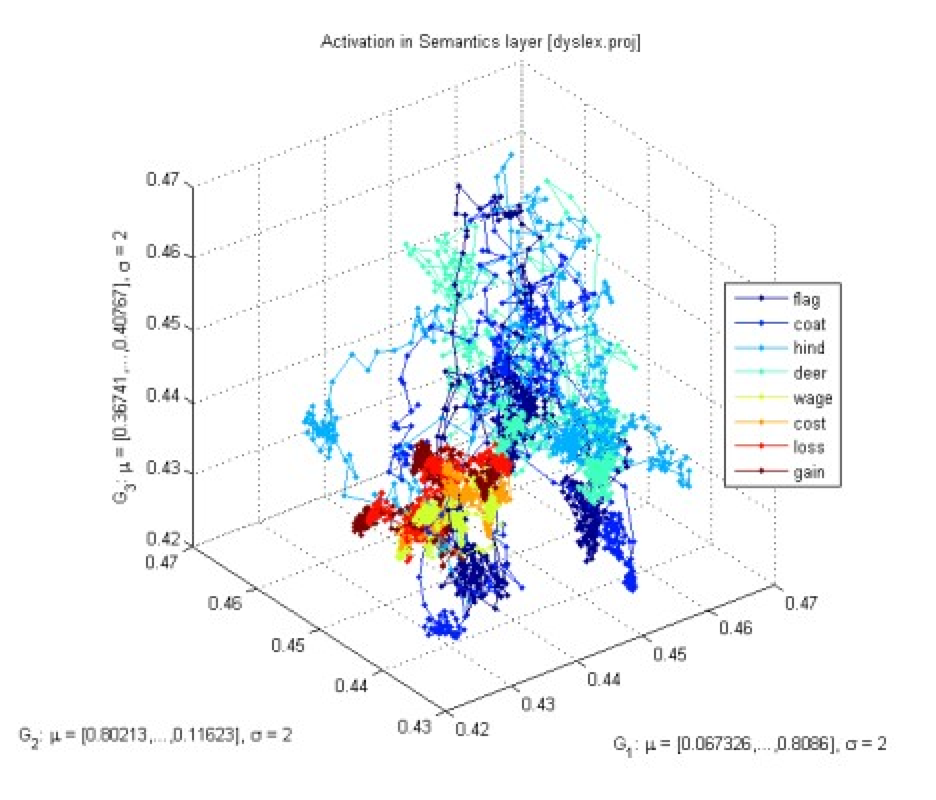
Fluctuations around final configuration = attractors representing concepts.

How to see properties of their basins, their relations?



„Gain": trajectory of semantic activations quickly changes to new prototype synchronized activity, periodically returns.

Attrac



Attention results from:

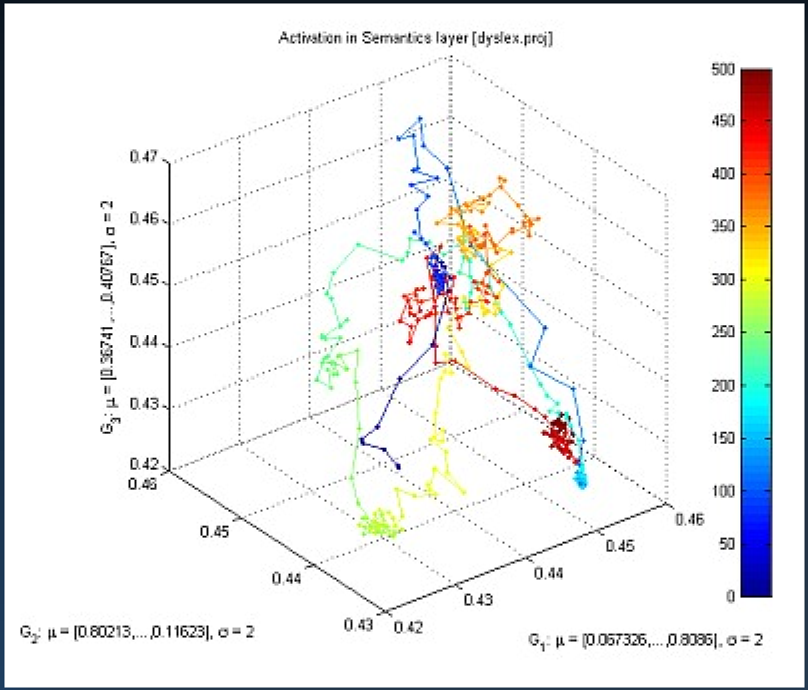
- inhibitory competition,
- bidirectional interactive processing,
- multiple constraint satisfaction.

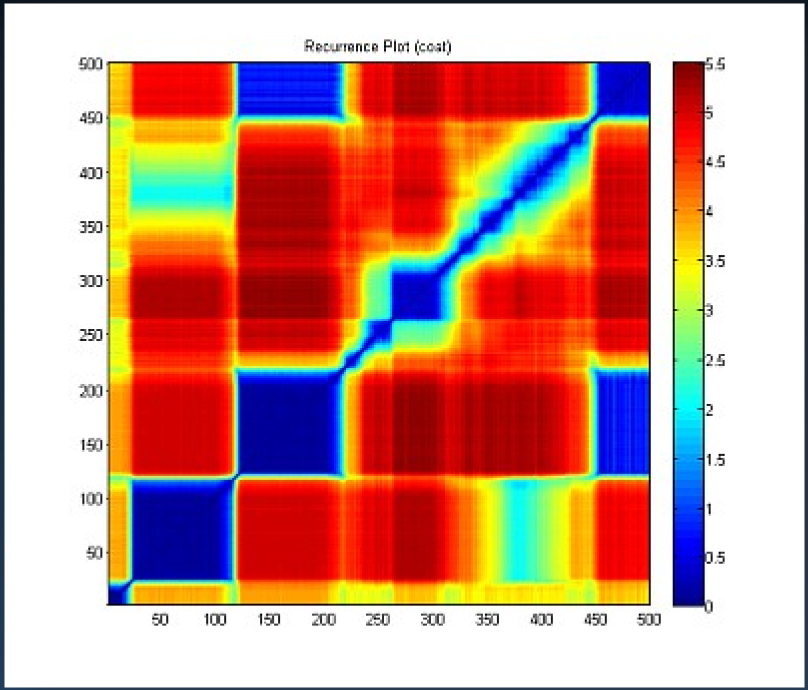
Basins of attractors: input activations {LG

- Normal case: relatively large, easy associations, moving from one basin of attraction to another, exploring the activation space.
- Without accommodation (voltage-dependent K^+ channels): deep, narrow basins, hard to move out of the basin, associations are weak.

Accommodation: basins of attractors shrink and vanish because neurons desynchronize due to the fatigue; this allows other neurons to synchronize, leading to quite unrelated concepts (thoughts).

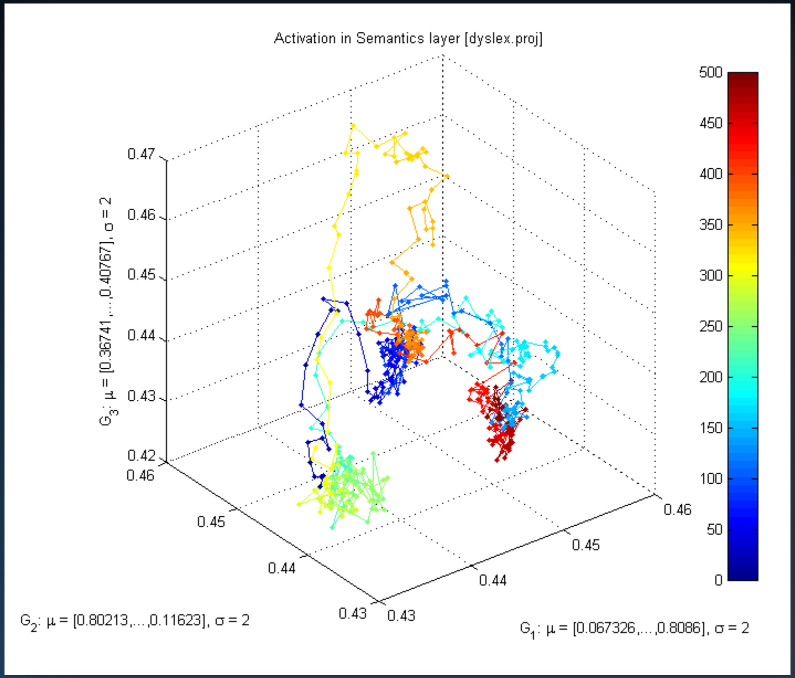
Fast transitions

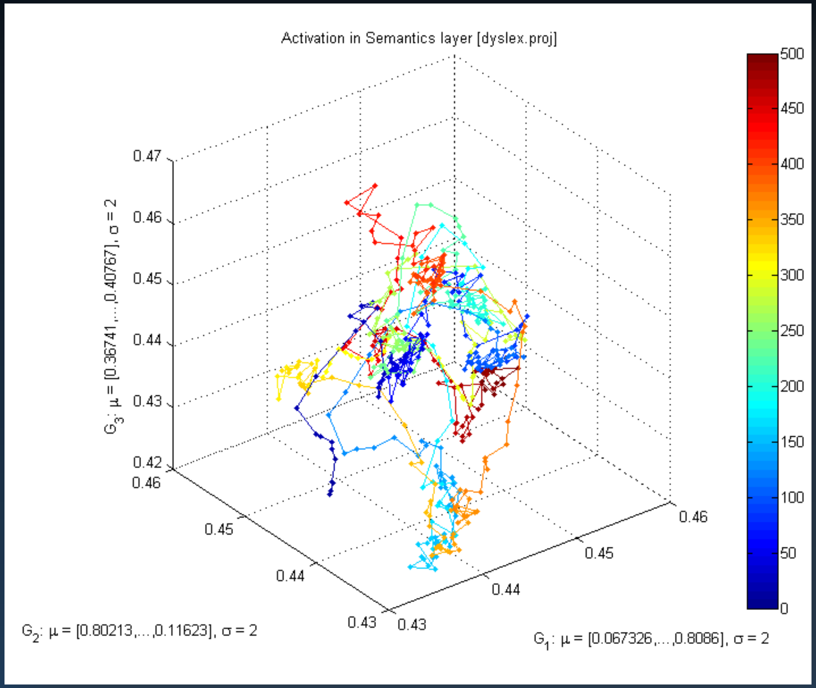




Attention is focused only for a brief time and than moved to the next attractor basin, some basins are visited for such a short time that no action may follow, no chance for other neuronal groups to synchronize. This corresponds to the feeling of confusion, not being conscious of fleeting thoughts.

Normal-ADHD



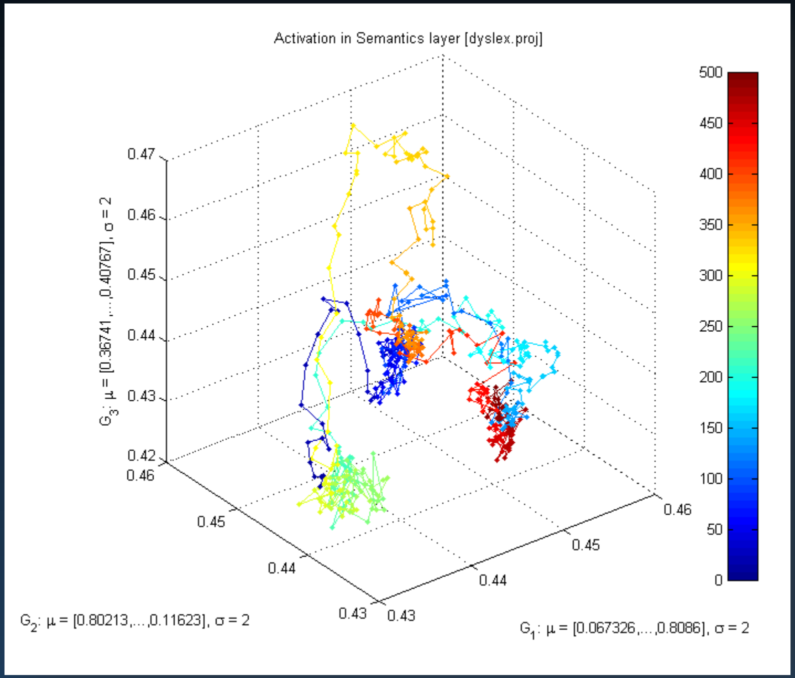


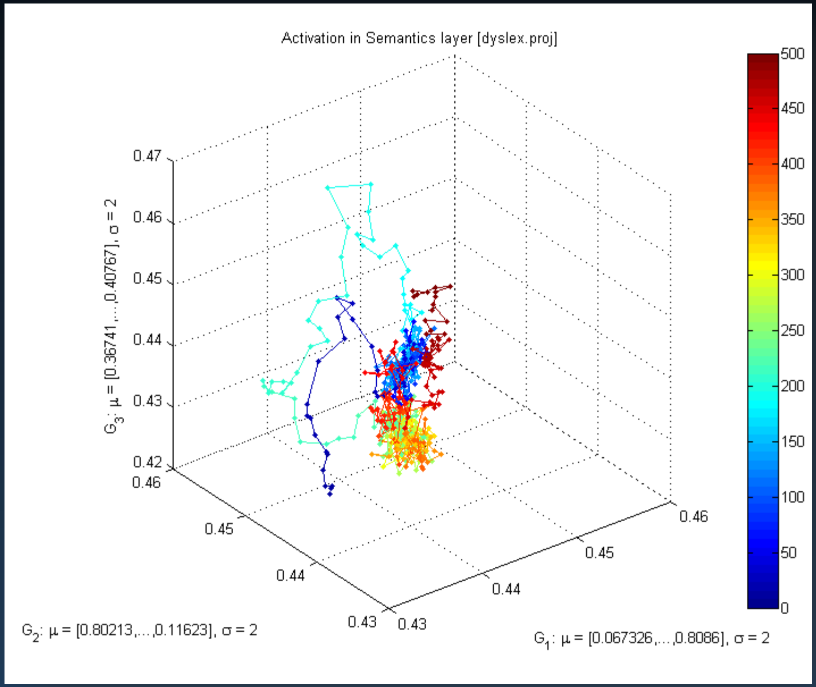
All plots for the flag word, different values of b_inc_dt parameter in the accommodation mechanism, b_inc_dt = 0.01 & b_inc_dt = 0.02

b_inc_dt = time constant for increases in intracellular calcium which builds up slowly as a function of activation.

http://kdobosz.wikidot.com/dyslexia-accommodation-parameters

Normal-Autism



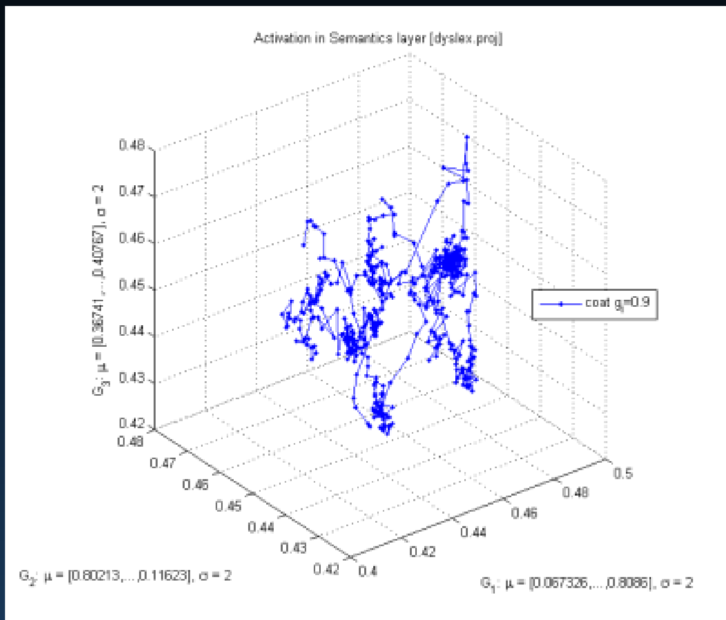


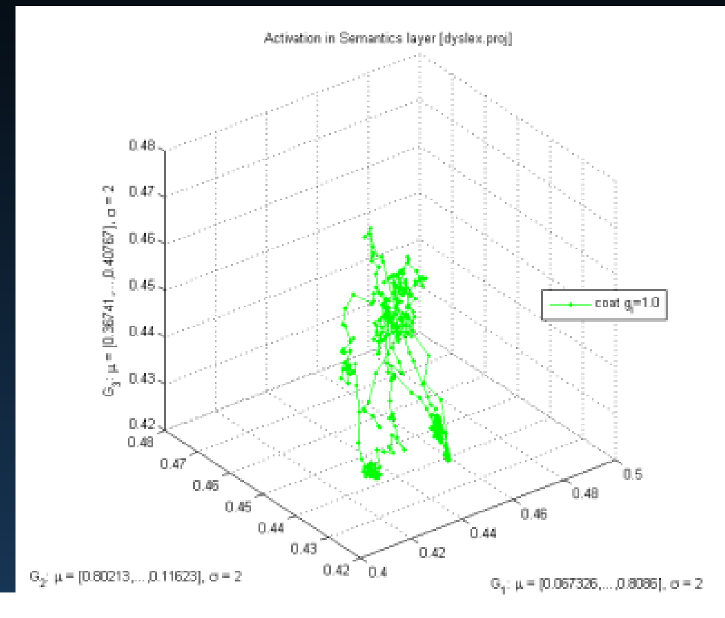
All plots for the flag word, different values of b_inc_dt parameter in the accommodation mechanism. b_inc_dt = 0.01 & b_inc_dt = 0.005

b_inc_dt = time constant for increases in intracellular calcium which builds up slowly as a function of activation.

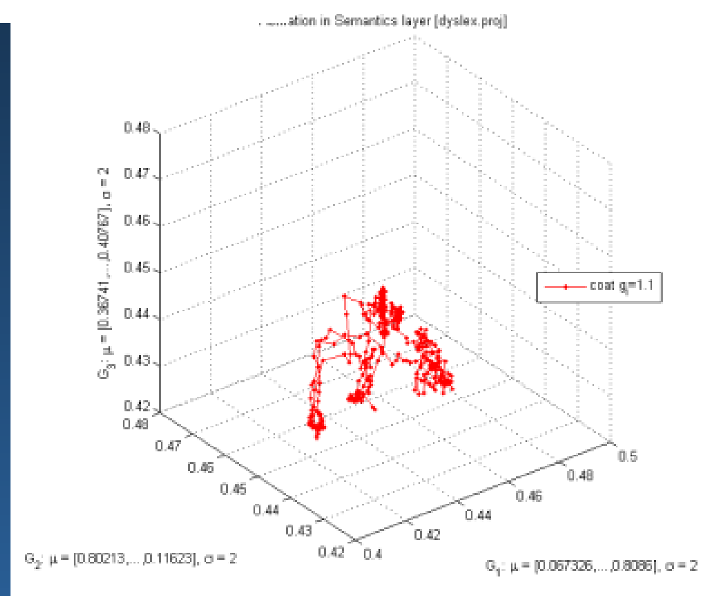
http://kdobosz.wikidot.com/dyslexia-accommodation-parameters

Inhibition



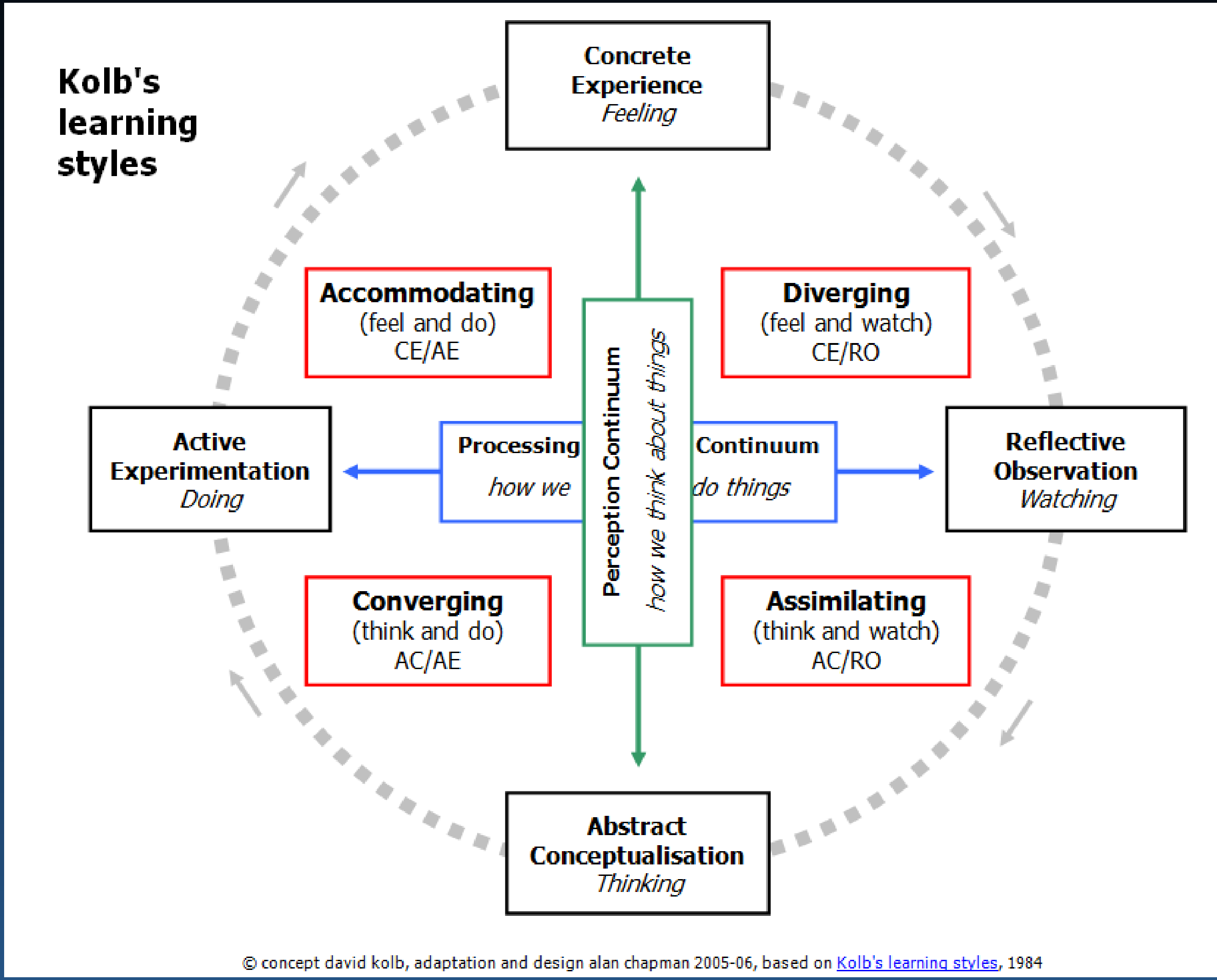


Increasing g_i from 0.9 to 1.1 reduces the attractor basin sizes and simplifies trajectories.

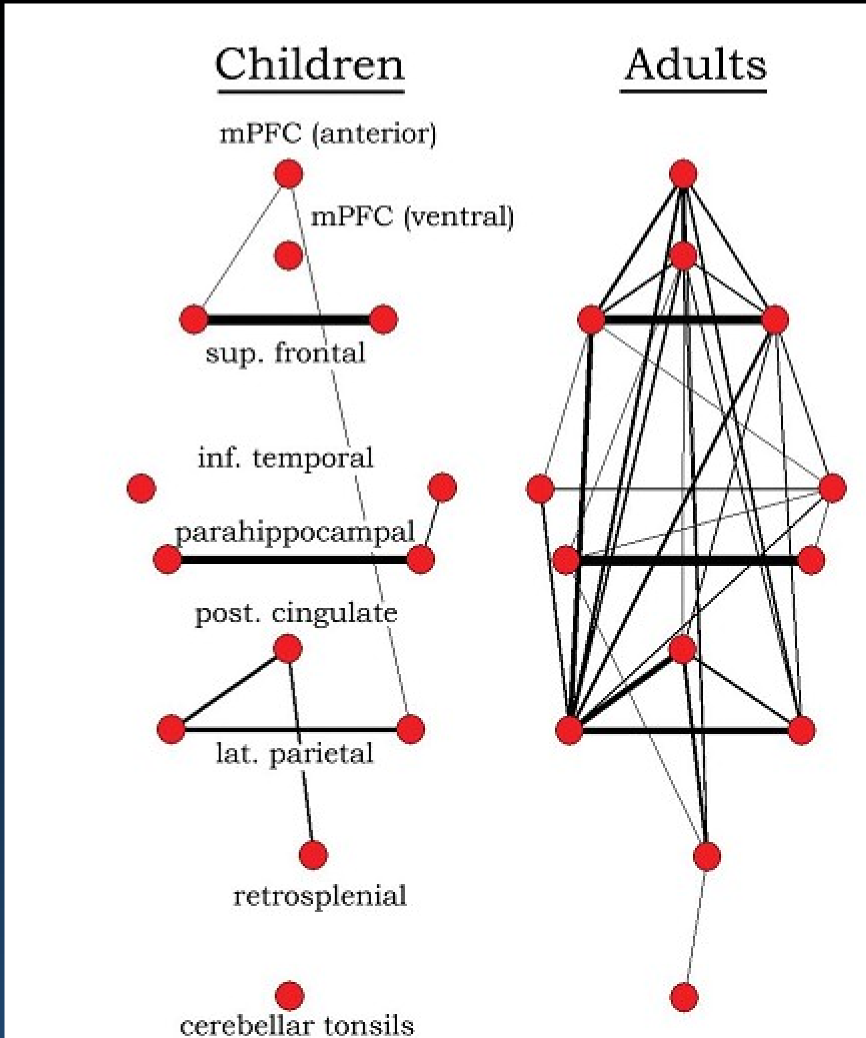


Strong inhibition, empty head …

Learning styles



David Kolb, *Experiential learning: Experience as the source of learning and development* (1984), and *Learning Styles Inventory*.



earning styles

and in the first years of life.

t is very difficult and depends on low-level
vays) processes, but may be influenced by

cesses S⇔S.

nd synchronization, frontal⇔parietal
weak functional connections prefrontal

n differ depending on whether the brain is

a large-scale brain network (cingulate cortex, mPFC, lateral PC), shows low activity for goal-related actions; strong activity in social and emotional processing, mindwandering, daydreaming.

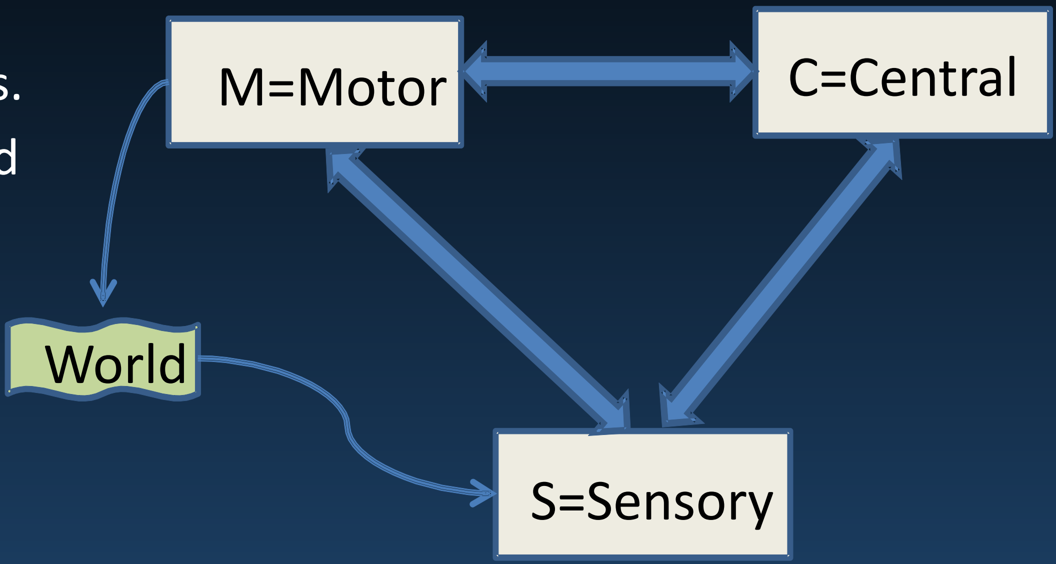
Connectome and learning styles

Simple connectome models may help to connect and improve learning classification of the styles.

S, Sensory level, occipital, STS, and somatosensory cortex;

C, central associative level, abstract concepts that have no sensory components,

mostly parietal, temporal and prefrontal lobes.



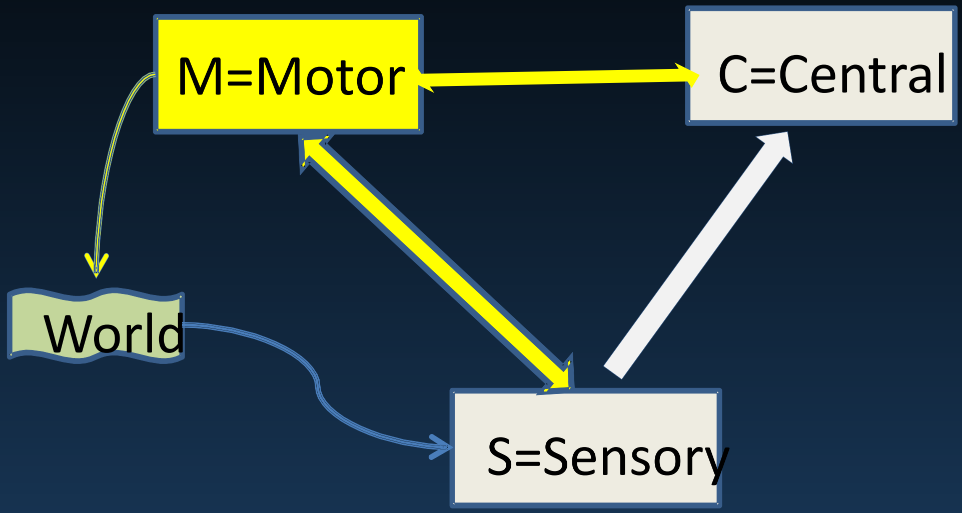
M, motor cortex, motor imagery & physical action.
Frontal cortex, basal ganglia.

Even without emotion and reward system predominance of activity within or between these areas explains many learning phenomena.

Learning styles D1

Kolb passive-active dimension, observation – experimentation: motor-central processes M⇔C, sensory-motor processes M⇔S.

Autistic people: processes at the motor level M⇔M, leads to repetitive movements, echolalia.



The *Learning Styles Inventory* is a tool to determine learning style. The tool divides people into 4 types of learners:

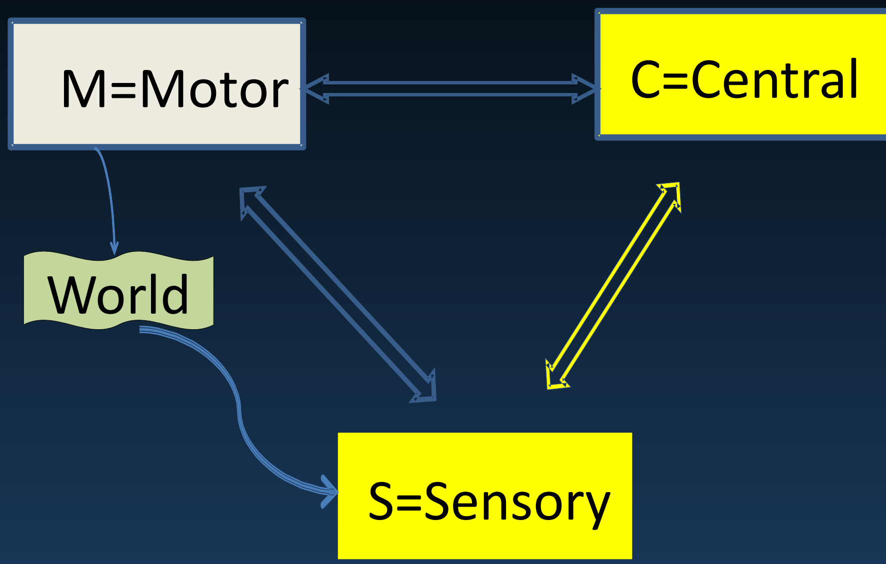
- divergers (concrete, reflective),
- assimilators (abstract, reflective),
- convergers (abstract, active),
- accommodators (concrete, active).

Learning styles D2

Kolb perception-abstraction:
coupling within sensory S⇔S areas, vs.
coupling within central C⇔C areas.

Strong C=>S leads to vivid imagery dominated by sensory experience.

Autism: vivid detailed imagery, no generalization.

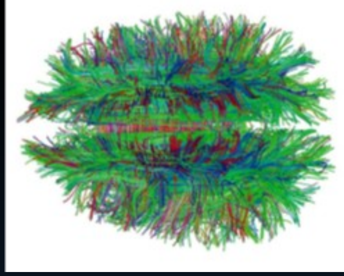


Attention = synchronization of neurons, limited to S, perception S⇔S strongly binds attention => no chance for normal development.

Asperger syndrome strong C=>S activates sensory cortices preventing understanding of metaphoric language.

If central C⇔C processes dominate, no vivid imagery but efficient abstract thinking is expected - mathematicians, logicians, theoretical physicist, theologians and philosophers ideas.

4 styles and more



Assimilators think and watch: prone to abstract thinking, reflective observation, inductive reasoning due to strong connections S=>C and within C⇔C, weak connections from S=>M and C=>M.

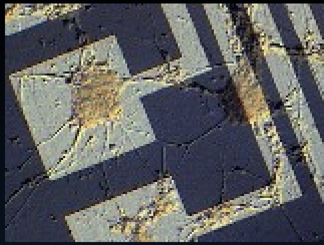
Convergers combine abstract conceptualization, active experimentation, using deductive reasoning in problem solving.
Strong C⇔C and C=>M flow of activity.

Divergers focus on concrete experience S⇔S, strong C⇔S connections and C⇔C activity facilitating reflective observation, strong imagery, novel ideas but weak motor activity.

Accommodators have balanced sensory, motor and central processes and thus combine concrete experience with active experimentation supported by central processes S⇔C⇔M.

The idea of learning styles is criticized because there was no theoretical framework behind it, but objective tests of the learning styles may be based on brain activity.

The Great Artificial Brain Race



BLUE BRAIN, HBP: École Polytechnique Fédérale de Lausanne, in Switzerland, use an IBM supercomputer to simulate minicolumn.

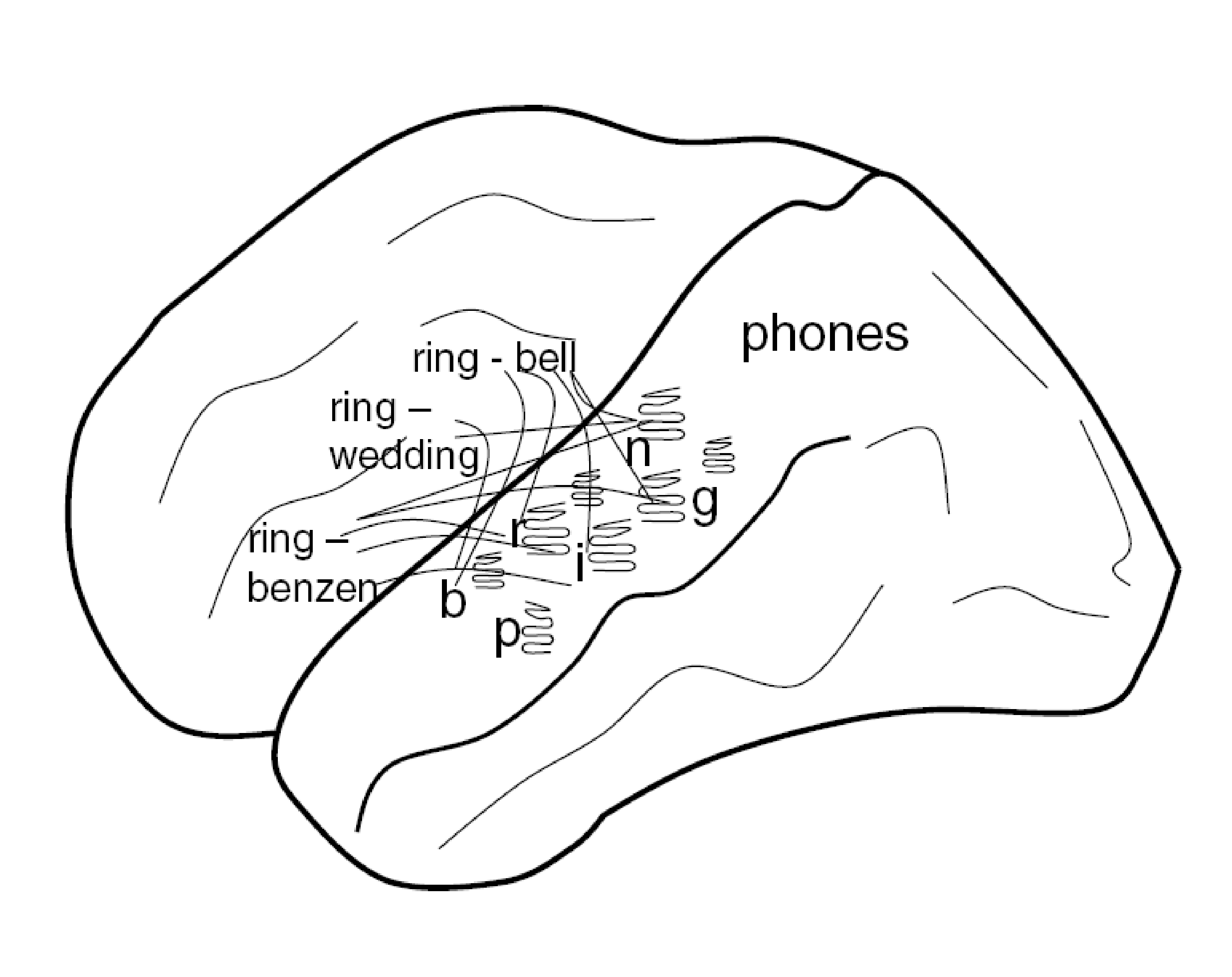
C2: 2009 IBM Almaden built a cortical simulator on Dawn, a Blue Gene/P supercomputer at Lawrence Livermore National Lab. C2 simulator re-creates 10^9 neurons connected by 10^{13} synapses, small mammal brain.

NEUROGRID: Stanford (K. Boahen), developing chip for ~ 10^6 neurons and ~ 10^{10} synapses, aiming at artificial retinas for the blind.

IFAT 4G: Johns Hopkins Uni (R.Etienne-Cummings) Integrate and Fire Array Transceiver, over 60K neurons with 120M connections, visual cortex model.

Brain Corporation: San Diego (E. Izhakievich), neuromorphic vision.

BRAINSCALES: EU neuromorphic chip project, FACETS, Fast Analog Computing with Emergent Transient States, now BrainScaleS, complex neuron model ~16K synaptic inputs/neuron, integrated closed loop network-of-networks mimicking a distributed hierarchy of sensory, decision and motor cortical areas, linking perception to action.



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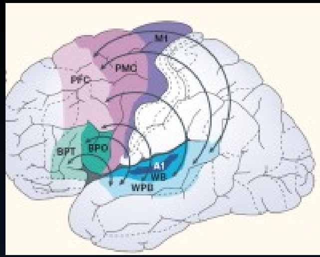


atures of products;
dictionary.

new words are being
y cortex.

ation of phonemes will
ns; context + inhibition in
rds.

ltering (competition)

Imagination: chains of phonemes activate both word and non-word representations, depending on the strength of the synaptic connections. **Filtering**: based on associations, emotions, phonological/semantic density.

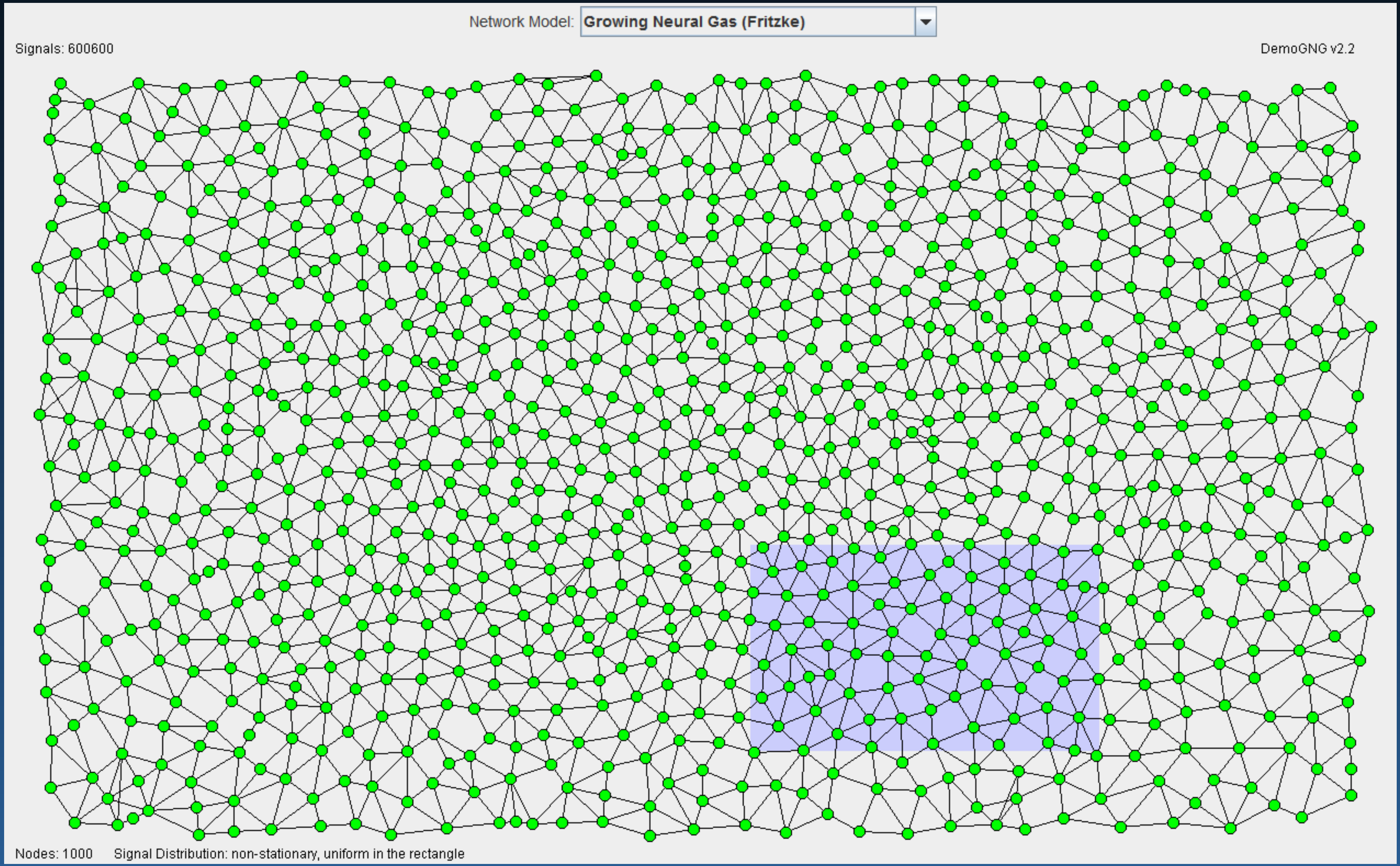
discoverity = {disc, disco, discover, verity} (discovery, creativity, verity)
digventure ={dig, digital, venture, adventure} new!
Server: http://www.braingene.yoyo.pl

Conspiracy in the brain

- Emotional situations => neurotransmitters => neuroplasticity => fast learning, must be important.
- Fast learning => high probability of wrong interpretation.
- Traumatic experiences, hopelessness, decrease brain plasticity and leave only strongest association.
- Conspiracy theories form around associations with frozen brain activities, that become strong attractors channeling thoughts.
- Simple associations save brain energy and rational arguments cannot change them.
- This explanation becomes so obviously obvious …

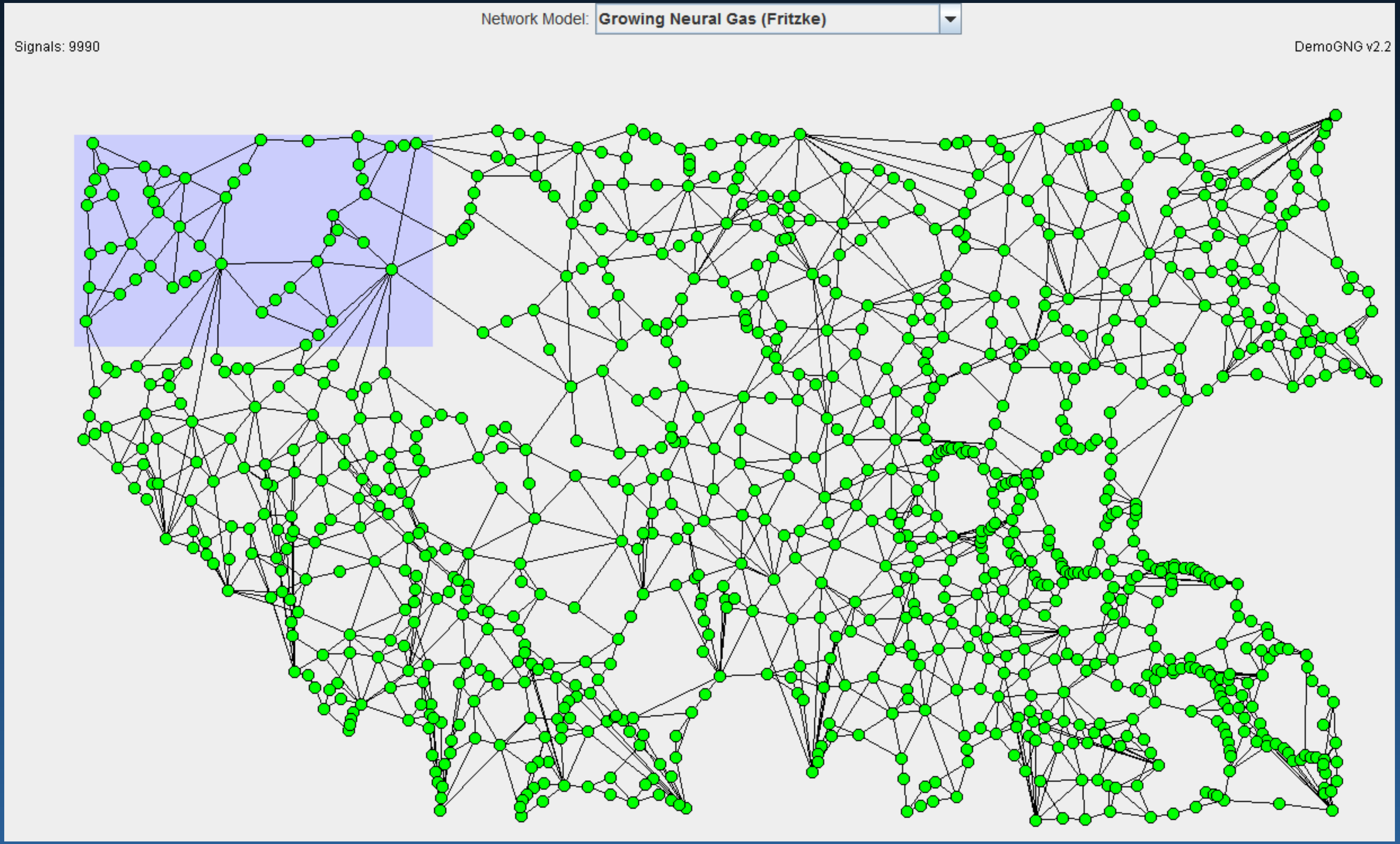
Internalization of environment

Episodes are remembered and serve as reference points, if observations are unbiased they reflect reality.



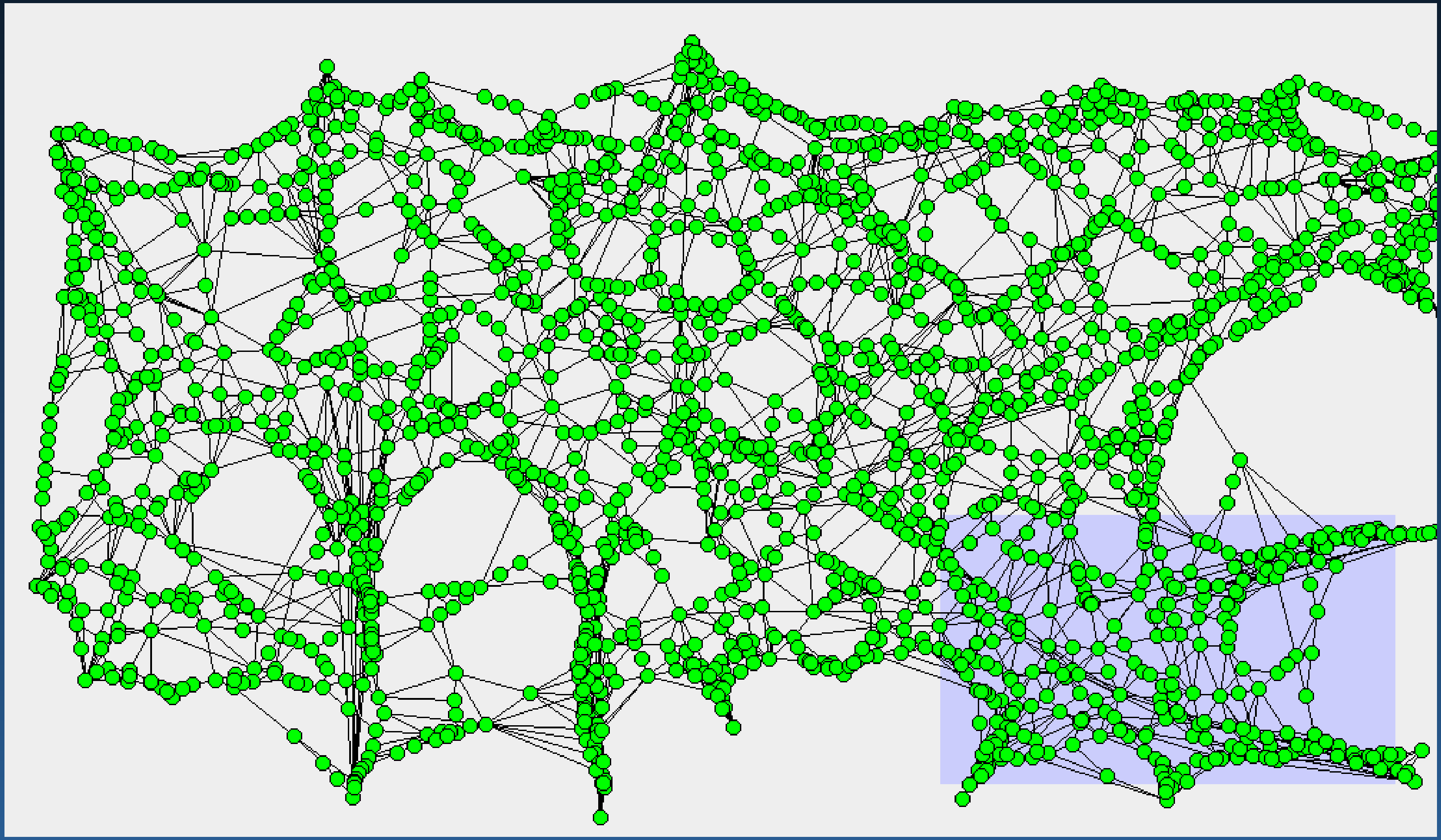
Extreme plasticity

Brain plasticity (learning) is increased if long, Slow strong emotions are involved. Followed by depressive mood it leads to severe distortions, false associations, simplistic understanding.



Conspiracy views

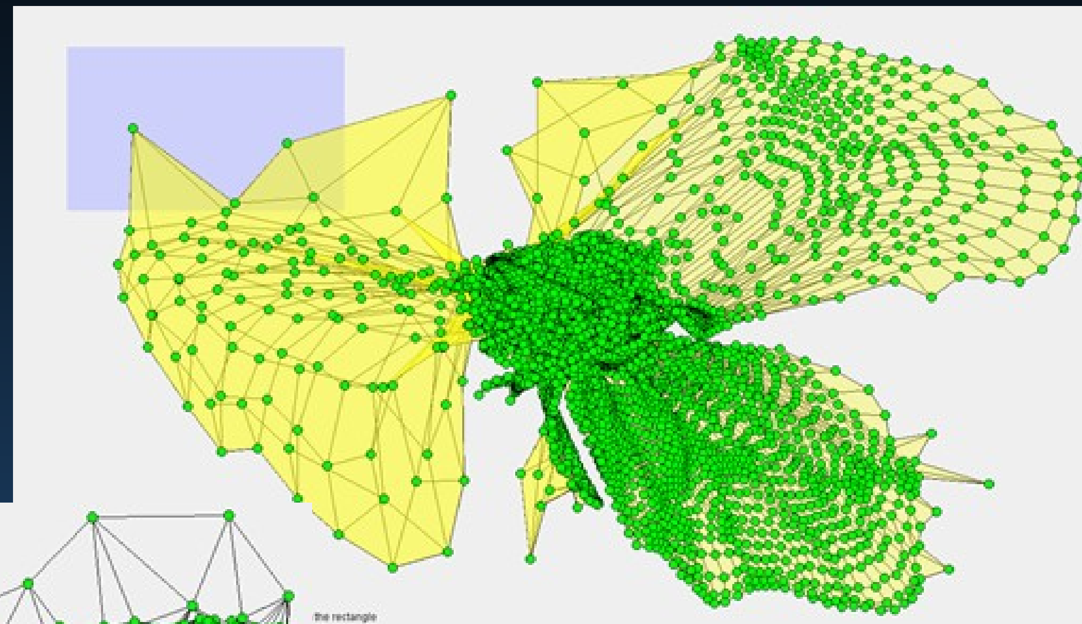
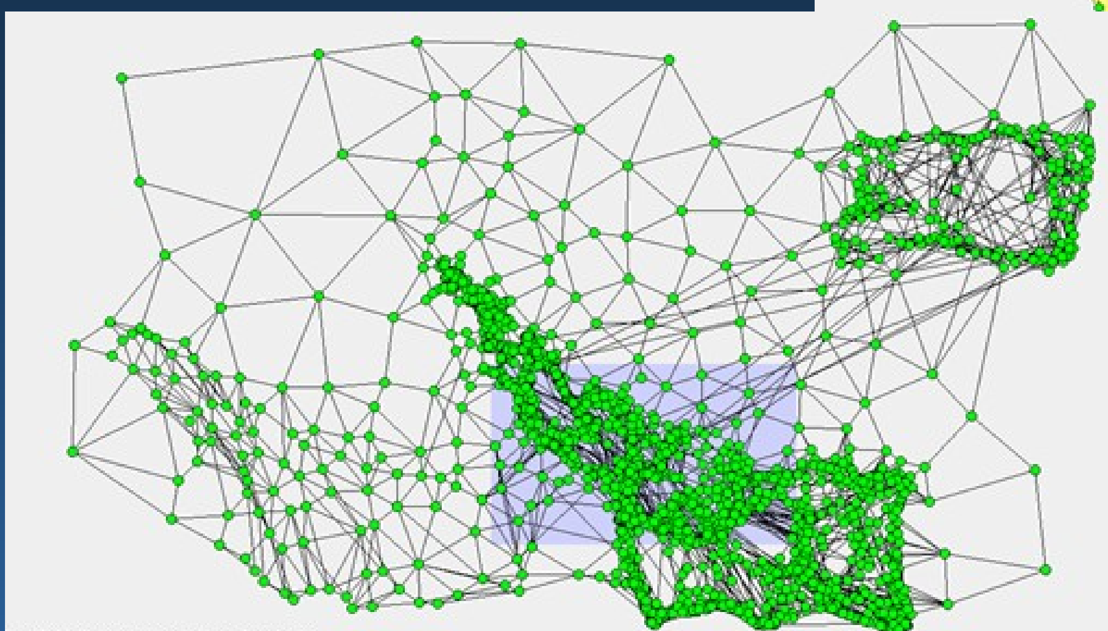
Illuminati, masons, Jews, UFOs, or twisted view of the world leaves big holes and admits simple explanations that save mental energy, creating „sinks” that attract many unrelated episodes.



Memoids …

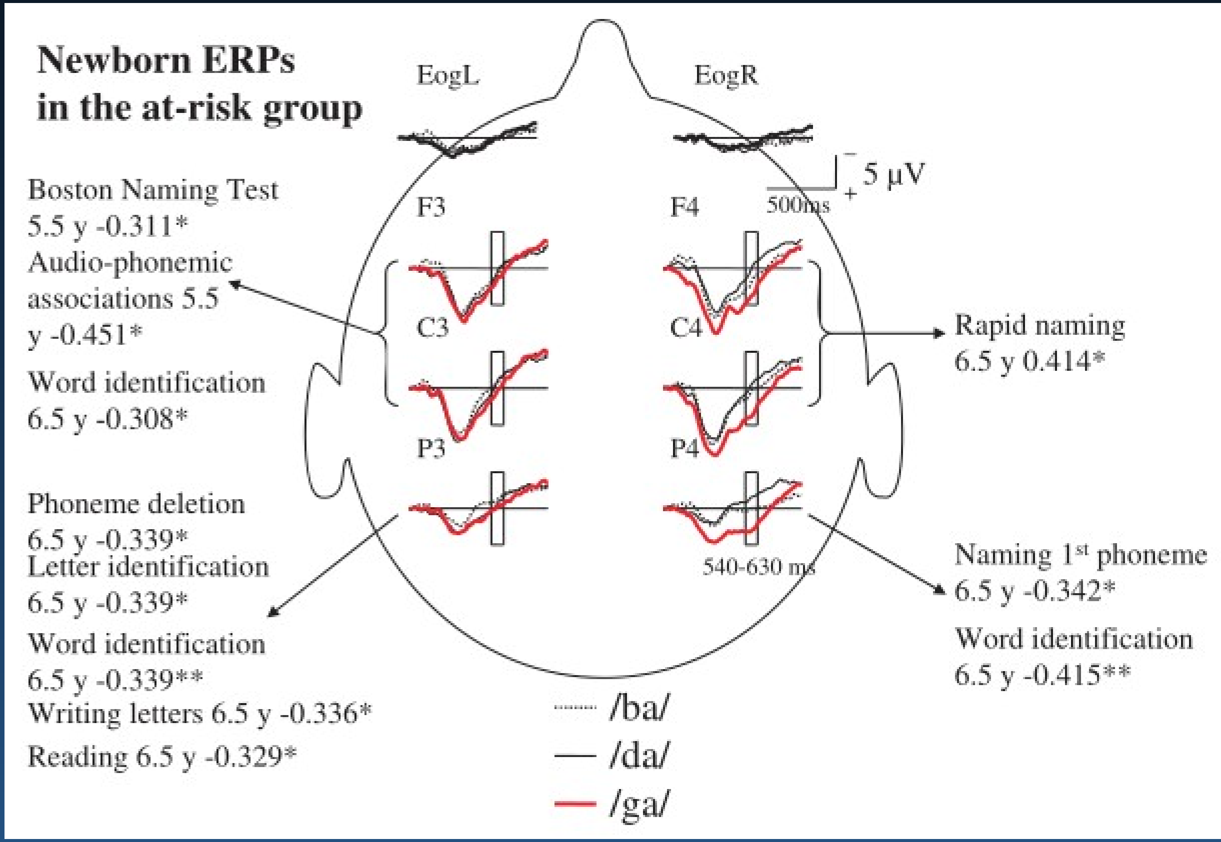
Totally distorted world view, mind changed into a memplex …

Ready for sacrifice.

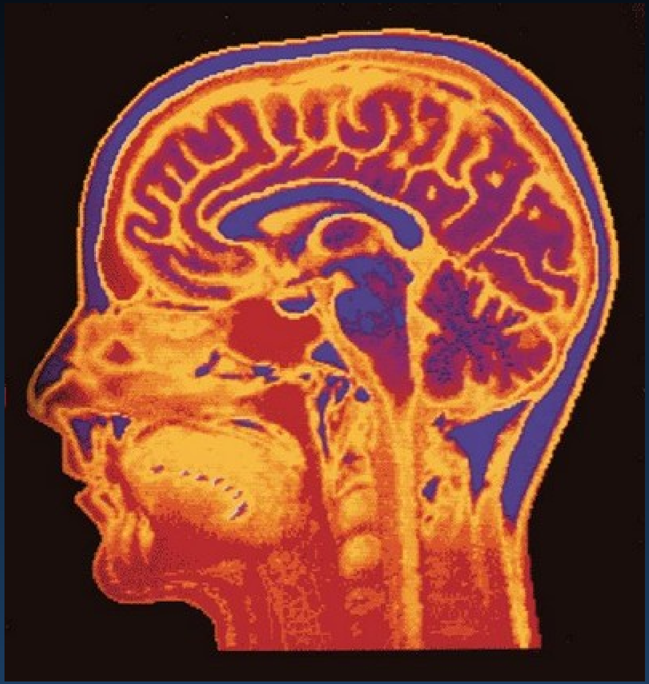
Infants, syllables

Brains of newborns react to ba/ga/da syllables in the 3–5 day of life in a way that allows for prediction of problems with learning to read years later.



Understanding by creating brains

- "Here, we aim to understand the brain to the extent that we can make humanoid robots solve tasks typically solved by the human brain by essentially the same principles. I postulate that this 'Understanding the Brain by Creating the Brain' approach is the only way to fully understand neural mechanisms in a rigorous sense."



- M. Kawato, From 'Understanding the Brain by Creating the Brain' towards manipulative neuroscience.
  Phil. Trans. R. Soc. B 27 June 2008 vol. 363 no. 1500, pp. 2201-2214
- Humanoid robot may be used for exploring and examining neuroscience theories about human brain.
- Engineering goal: build artificial devices at the brain level of competence.

Few Initiatives

IEEE Computational Intelligence Society Task Force (J. Mandziuk & W. Duch), **Towards Human-like Intelligence.**

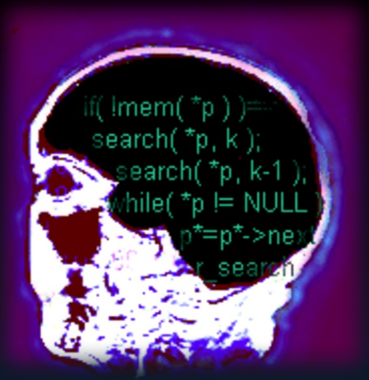
World Congress of Computational Intelligence 2014 Special Session: Towards Human-like Intelligence (A-H Tan, J. Mandziuk, W .Duch)

Brain-Mind Institute School (25.06-3.08.2012), International Conference on Brain-Mind (ICBM) and Brain-Mind Magazine (Juyang Weng, Michigan SU).

AGI: conference, Journal of Artificial General Intelligence comments on Cognitive Architectures and Autonomy: A Comparative Review (special issue, eds. Tan A-H, Franklin S, Duch W).

BICA: Annual International Conf. on Biologically Inspired Cognitive Architectures, 3rd Annual Meeting of the BICA Society, Palermo, Italy, 31.10- 3.11.2012

Neurocognitive informatics



Use inspirations from the brain, derive practical algorithms!

My own attempts - see my webpage, Google: W. Duch

1. Mind as a shadow of neurodynamics: geometrical model of mind processes, psychological spaces providing inner perspective as an approximation to neurodynamics.

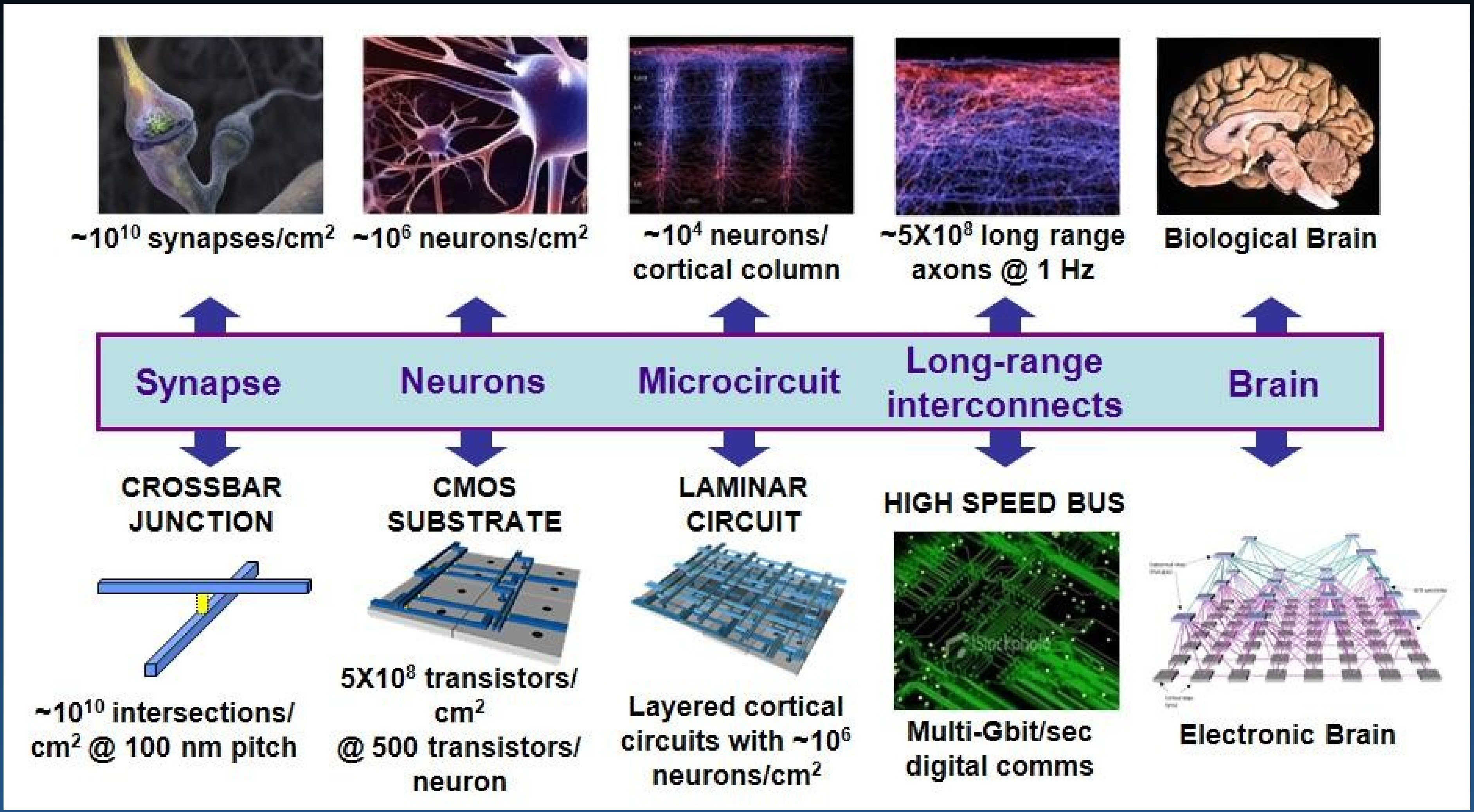
2. Intuition: learning from partial observations, solving problems without explicit reasoning (and combinatorial complexity) in an intuitive way.

3. Neurocognitive linguistics: how to find neural pathways in the brain.

4. Creativity in limited domains + word games, good fields for testing.

Duch W, Intuition, Insight, Imagination and Creativity,
IEEE Computational Intelligence Magazine 2(3), August 2007, pp. 40-52

From brains to machines



Source: DARPA Synapse project

EU FP7 FET Flagships

Initially 26 projects, reduced to 6 candidates for
FET (Future Emerging Technologies)
Flagships Projects, each planned for 10 year, 1 billion €.

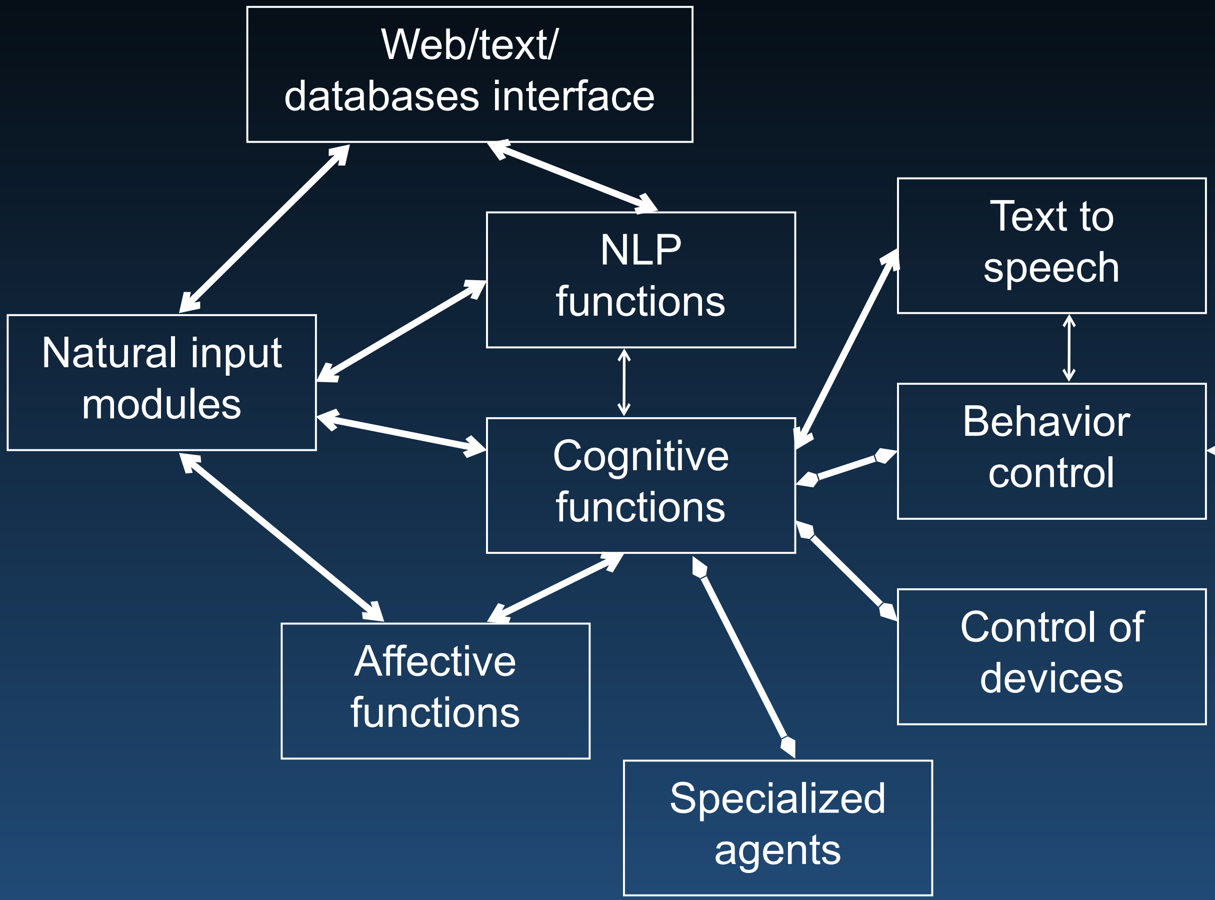
2 winning projects announced in 2012.

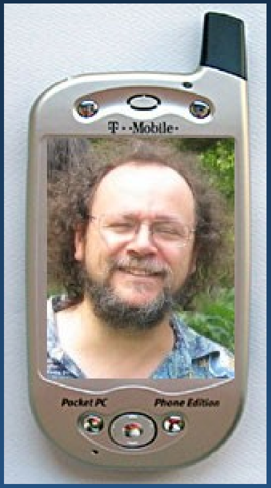
- HBP-PS: *The Human Brain Project*, understanding the way the human brain works. Could be the key to enabling a whole range of brain related or inspired developments in ICT, as well as having transformational implications for neuroscience and medicine.
  "Mind and brain" project submitted by our group lost to HBP.

  Integrate all we know about the brain in one computational model.

- Graphene-CA: Graphene Science and technology for ICT and beyond, electronics, spintronics, photonics, plasmonics …

DREAM top-level architecture





DREAM project is focused on perception (visual, auditory, text inputs), cognitive functions (reasoning based on perceptions), natural language communication in well defined contexts, real time control of the simulated/physical head.

Conclusions

Grand challenges

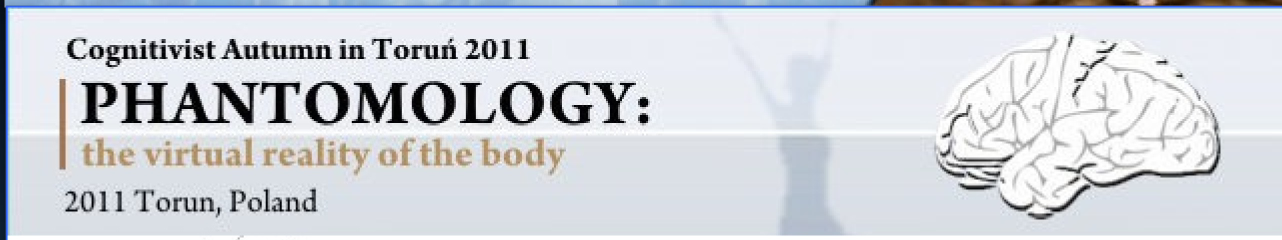
are facing phenomics

at every level!

Is there a shorter route
to understand human behavior?

I do not think so …

Duch W, *Brains and Education: Towards Neurocognitive Phenomics*.



Recent conferences: Neuromania, Neurohistory of art, Homo communicativus, Trends in interdisciplinary studies, http://www.kognitywistyka.umk.pl