

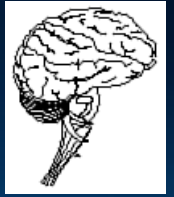
Neurodynamics, Neuroimaging & Brains



Włodzisław Duch

Neurocognitive Laboratory,
Center for Modern Interdisciplinary Technologies,
& Department of Informatics,
Nicolaus Copernicus University
Google: Wlodzislaw Duch

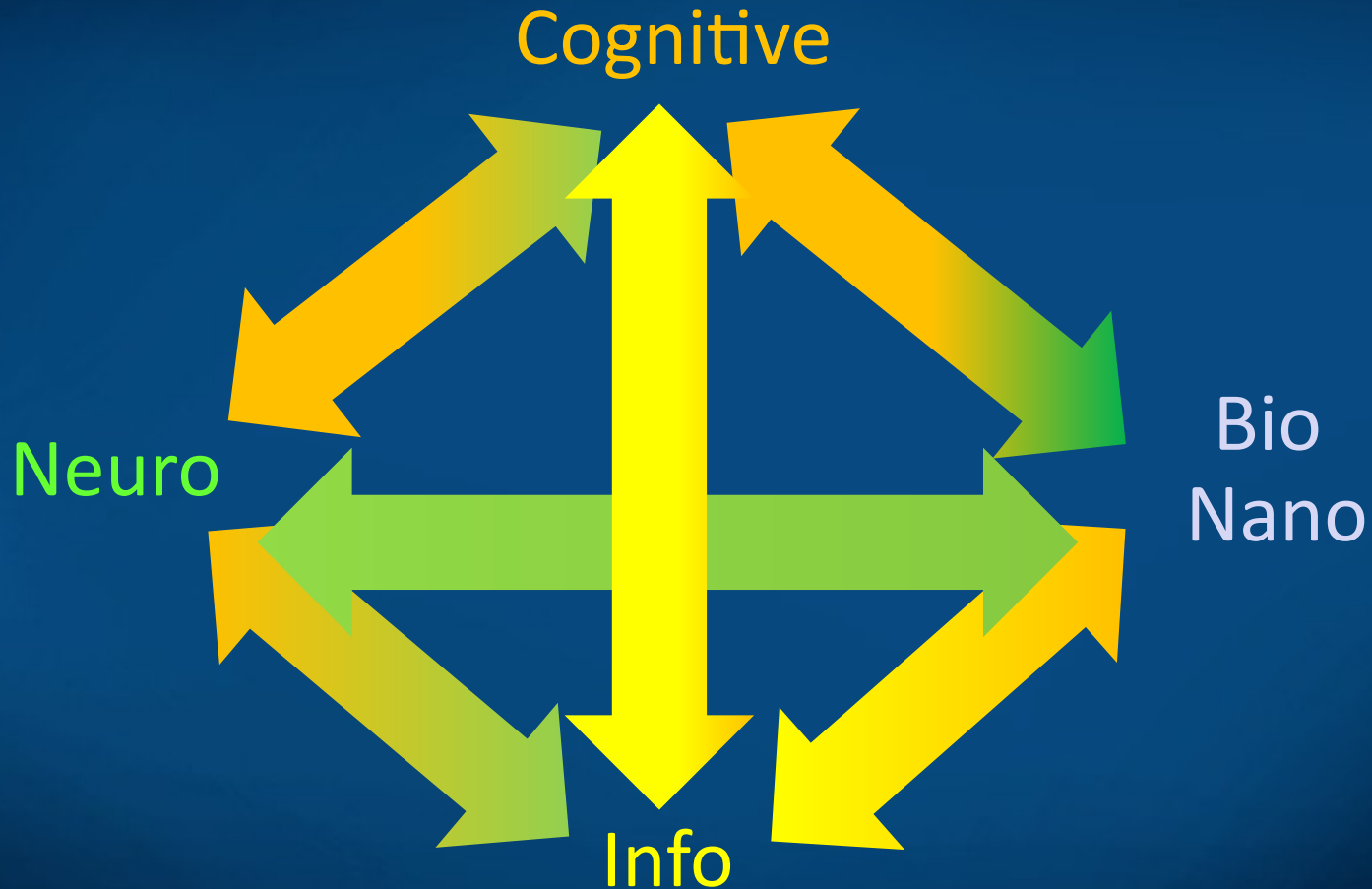
The story



Trying to address a few very important questions.

1. How can we understand mind-body relations?
Questions \Leftrightarrow Levels of description, neurocognitive phenomics.
2. Neuropsychiatry? Neurodynamics and ASD-ADHD, RDoC.
3. General behavior of people?
Associations, creativity, memory distortions, conspiracy theories, polarization of opinions, learning new domains.
4. How can we understand developmental processes?
Auditory perception, working memory, therapeutic games, dyscalculia, sensory imagery.
5. How to use neurodynamics, connectomics, neuroimaging, brain fingerprinting in practical applications.

Most important 21 century technologies



Ultimate technology: NeuroCognitive Informatics in Nano-hardware.

Studies in Computational Intelligence 63

Włodzisław Duch
Jacek Mańdziuk (Eds.)

Challenges for Computational Intelligence

 Springer

Studies in Computational Intelligence 358

Norbert Jankowski
Włodzisław Duch
Krzysztof Grąbczewski (Eds.)

Meta-Learning in Computational Intelligence

 Springer

Studies in Computational Intelligence 498

Krzysztof Grąbczewski

Meta-Learning in Decision Tree Induction

 Springer

Duch W, Mandziuk J (Eds.), *Challenges for Computational Intelligence*. Springer "Studies in Computational Intelligence" Series, Vol. 63, 2007.

Jankowski N, Duch W, Grąbczewski K, *Meta-learning in Computational Intelligence*. Springer 2011.

Center of Modern Interdisciplinary Technologies

Why am I
interested in this?

Bio + Neuro +
Cog Sci + Physics =>

NeuroCognitive Lab.

Other labs: molecular
biology, chemical
analytics, nanotech
and electronics.



Main theme: **maximizing human potential.**

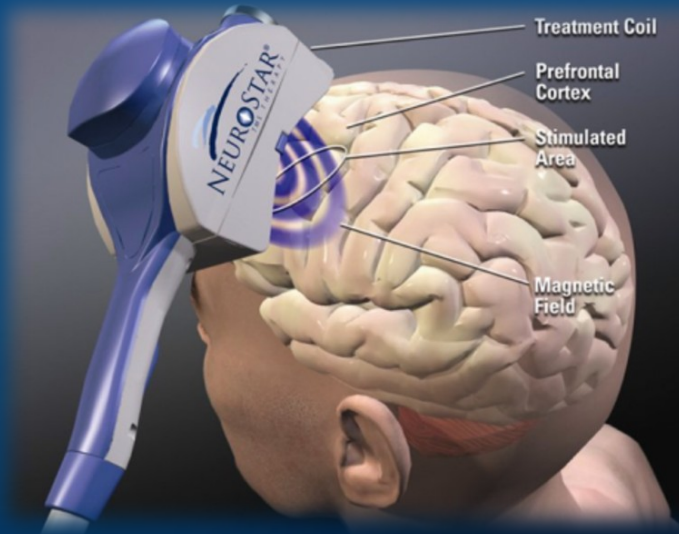
Goal: understanding brain-mind relations, with a lot of help from computational intelligence; pushing the limits of brain plasticity.

Big challenge! Funding: national/EU grants.

A group of neurofanatics



Our toys



Geometric model of mind

Objective \Leftrightarrow Subjective.

Brain \Leftrightarrow Mind.

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

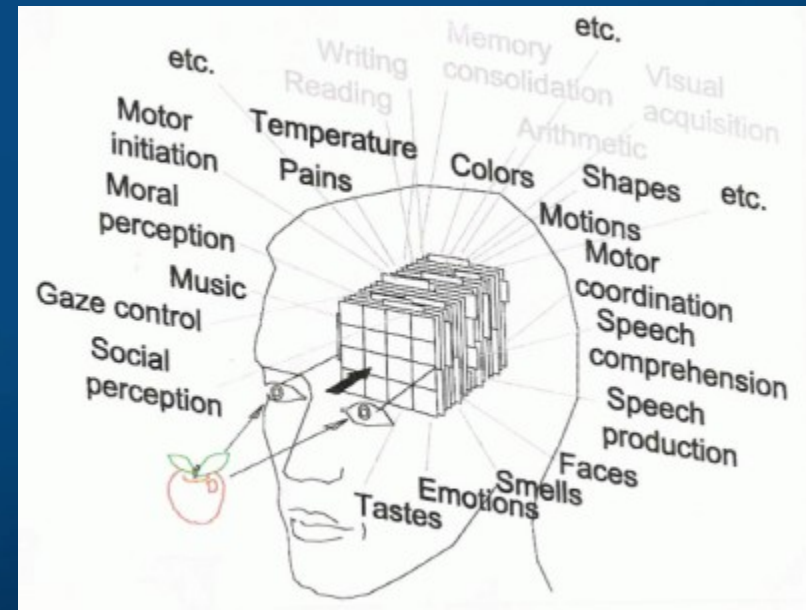
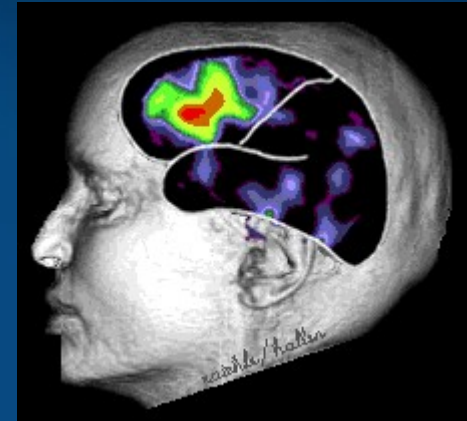
Mind states = $f(\text{Brain states})$

How to represent mind state?

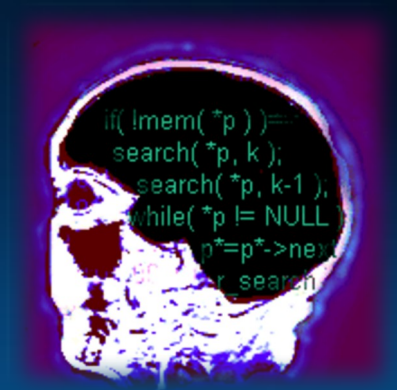
In the space based on dimensions that have subjective interpretation: intentions, emotions, qualia.

Mind state and brain state trajectory should then be linked together by some transformations. Intentions are uncovered by the **Brain-Computer Interfaces**.

Lack of neurophenomenology.



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), 2007, pp. 40-52

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.

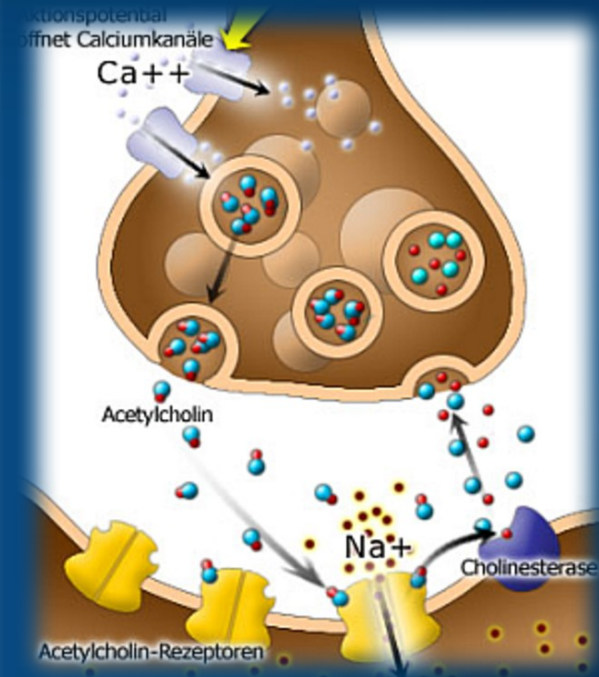
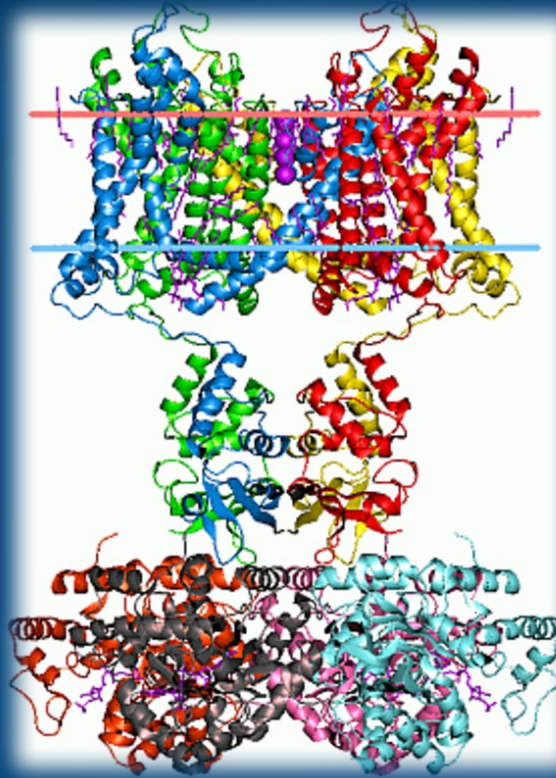
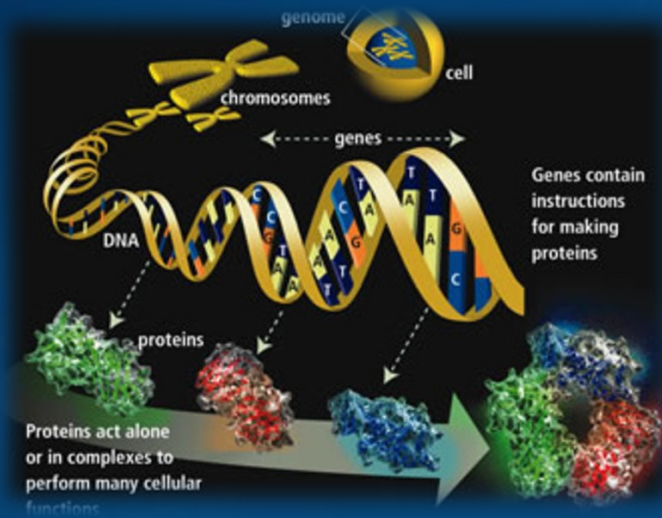
Developing Human Connectome Project, UK 2013 + many others.

Behavior, personality, cognitive abilities \leq 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?

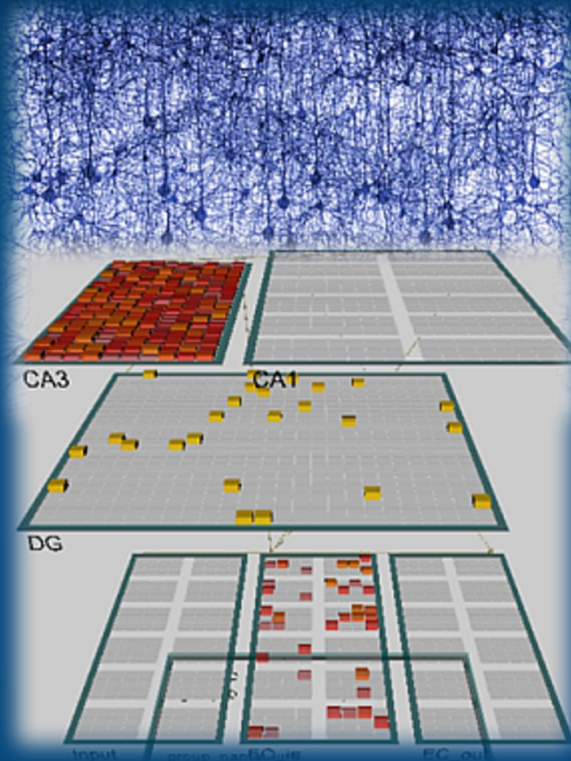
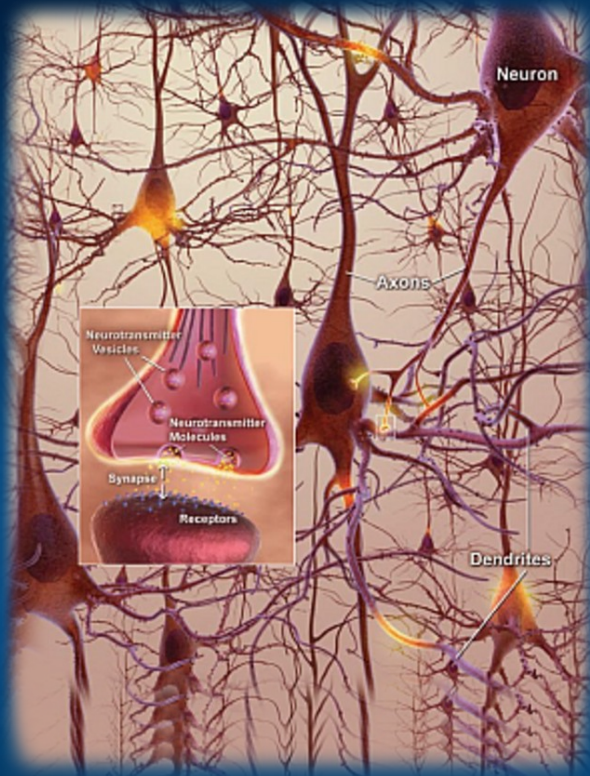


From Genes to Neurons



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

From Neurons to Behavior



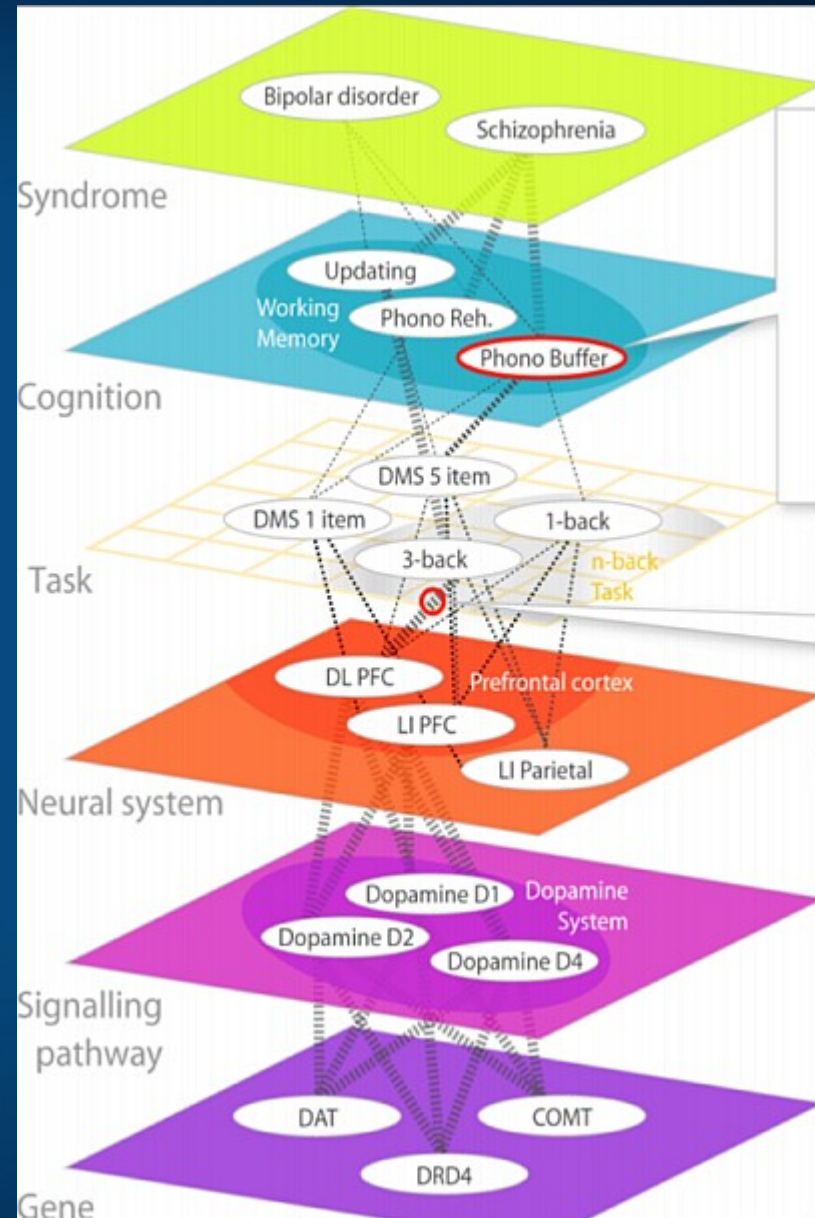
Genes => Proteins => receptors, ion channels, synapses
=> neuron properties, networks
=> **neurodynamics** => cognitive phenotypes, abnormal behavior!

Neuropsychiatric Phenomics in 6 Levels

Consortium for Neuropsychiatric Phenomics (CNP)/NIMH RoDC approach:

Research Domain Criteria (RoDC) analyzes 5 large brain systems – negative/positive valence systems, arousal, cognitive, affective systems – through interaction of Genes, Molecules, Cells, Circuits, Physiology, Behavior, Self-Report, and Research Paradigms.

From genes to cognitive subsystems and behavior, neurons and networks are **right in the middle** of this hierarchy.
=> **Neurodynamics is the key!**





RDoC Matrix for Negative Valence Systems

5 Psychological Constructs/Subconstructs:

Acute Threat ("Fear"); Potential Threat ("Anxiety"); Sustained Threat; Loss, Frustrative Nonreward

Each characterized by 8 aspects at different phenomic levels:

Genes	Molecules	Cells	Circuits	Physiology	Behavior	Self-Report	Paradigms
-------	-----------	-------	----------	------------	----------	-------------	-----------

Ex: Sustained Threat

Physiology: Dysregulated HPA axis | Error-related negativity

Behavior: Anhedonia/decreased appetitive behavior | Anxious Arousal

Attentional bias to threat | Avoidance | Decreased libido | Helplessness

behavior | Increased conflict detection | Increased perseverative behavior |

Memory retrieval deficits | Punishment sensitivity

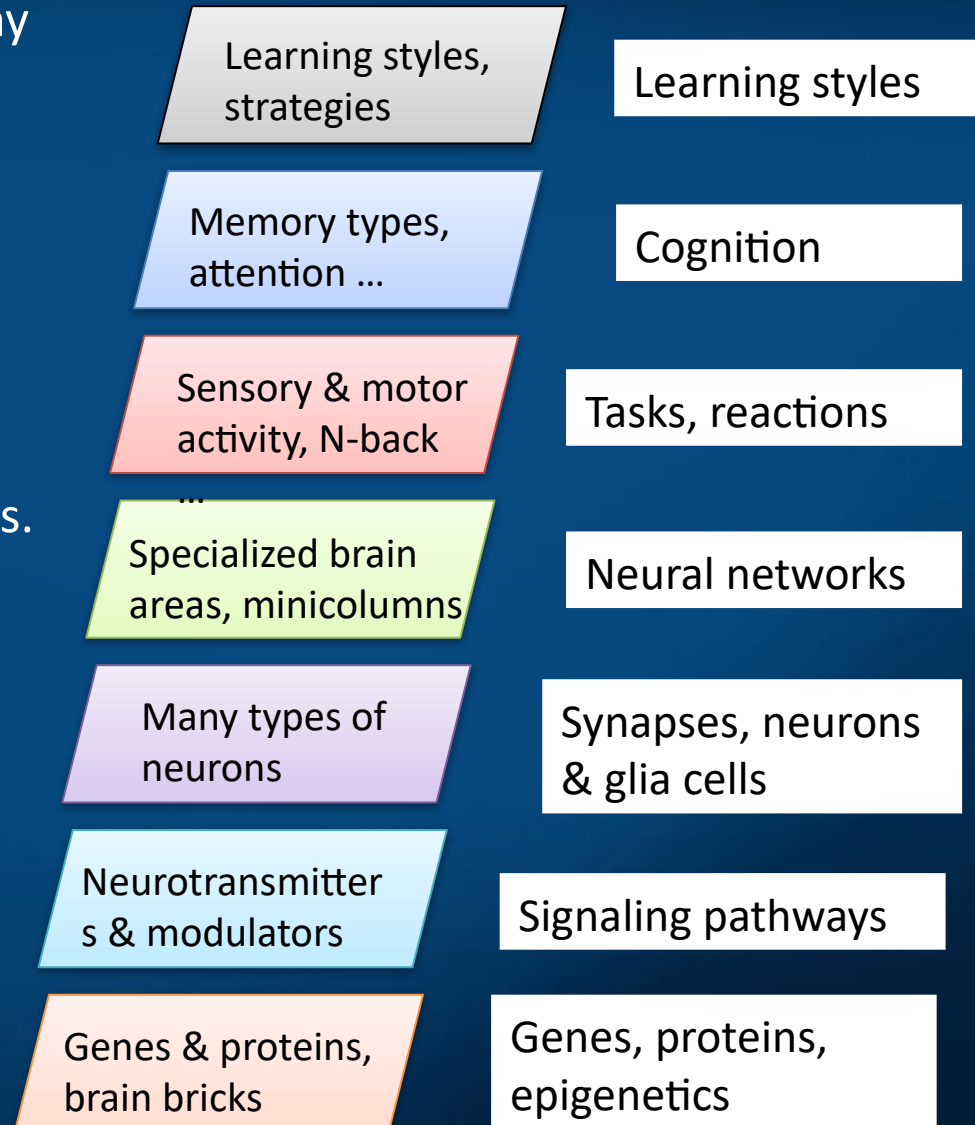
Neurocognitive Phenomics

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/chemistry & 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!



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.

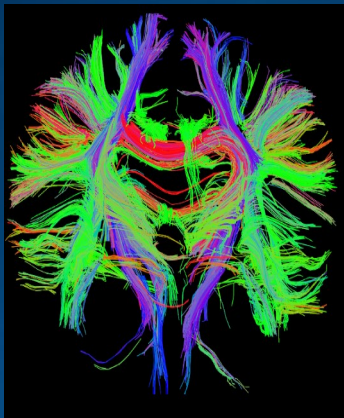
Result: mental events at the network level are described in the language of neurodynamics and related to low-level neural properties.

Example: relation of ASD/ADHD symptoms to neural accommodation.

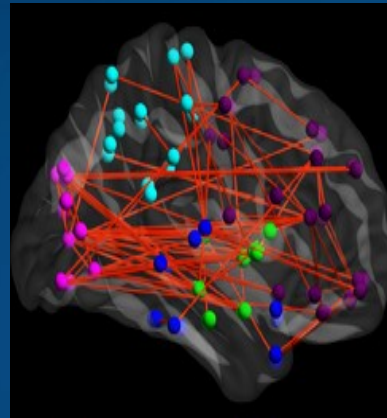


Human connectome and MRI/fMRI

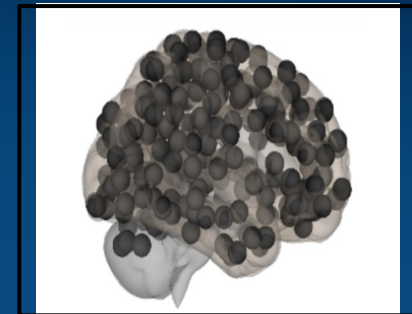
Structural connectivity



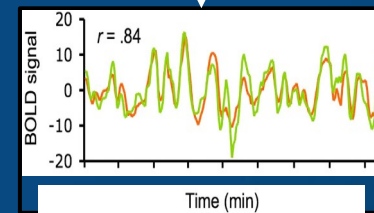
Functional connectivity



Node definition

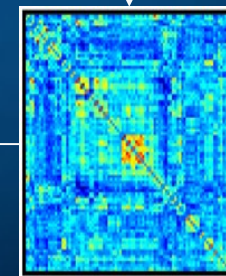


Signal extraction



Correlation calculation

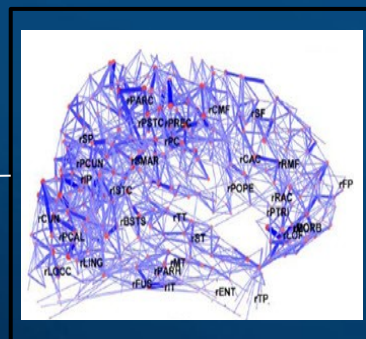
Correlation matrix



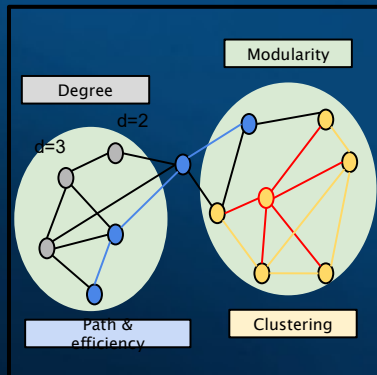
Binary matrix



Whole-brain graph



Graph theory



Genes=>Proteins

~ 5×10^{13} = 50T cells, 2m DNA/cell

~ 10^{14} m = 100 T km = 666 au!

~ 10^{15} = 1P synapses;

>1M new synapses/sec

~100G neuronów (10^{11})

>550.000 structures in Swiss-
proteome database

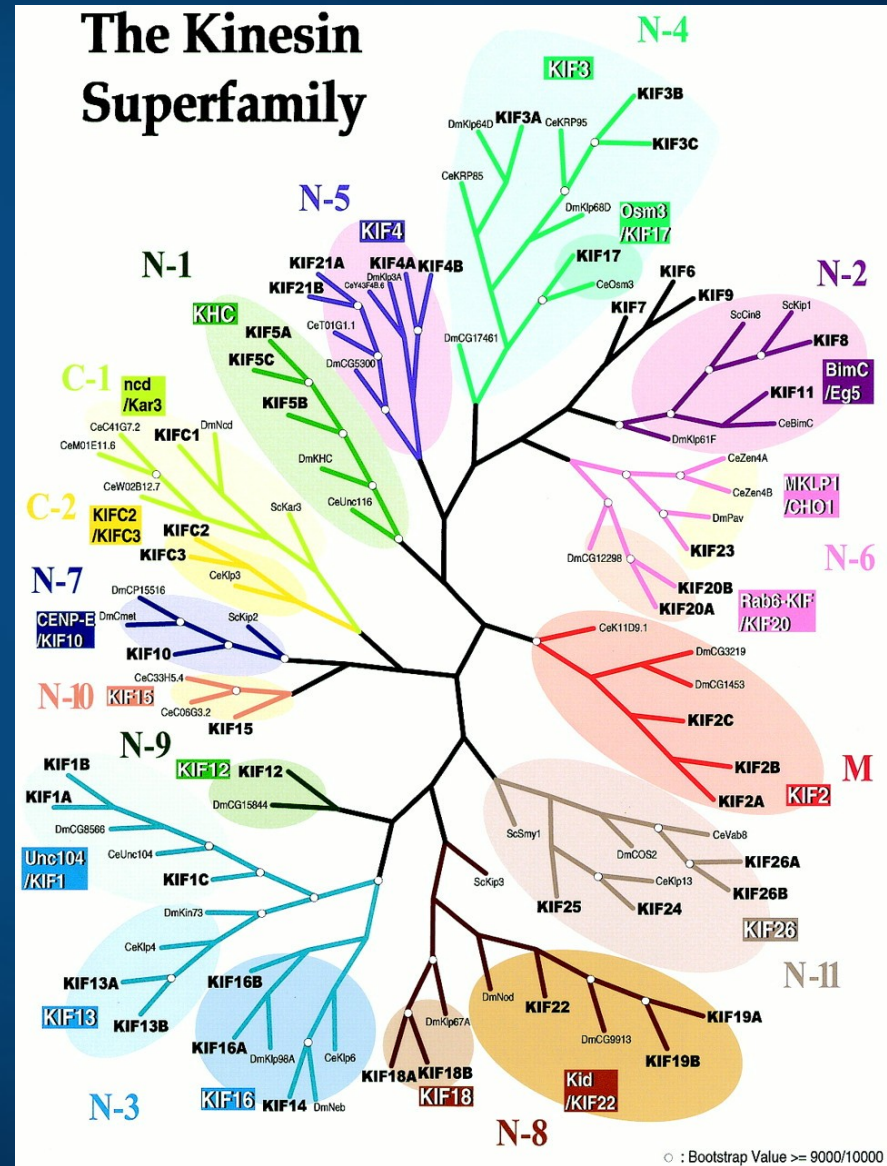
~60.000 protein families

~20.000 genes

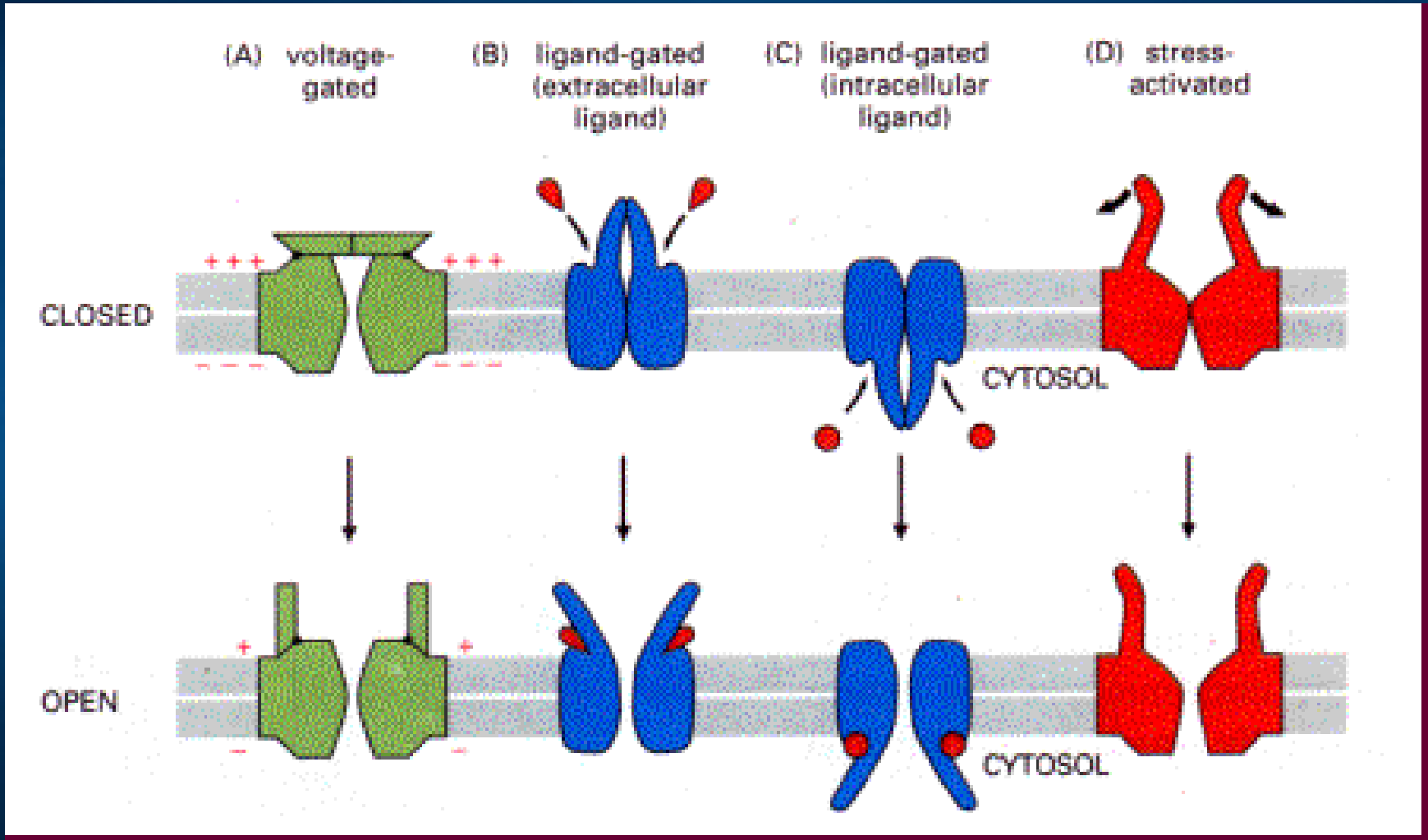
>100.000 proteins/cells

Organism is a process!

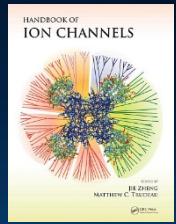
lifetime 4 days to >100 years.



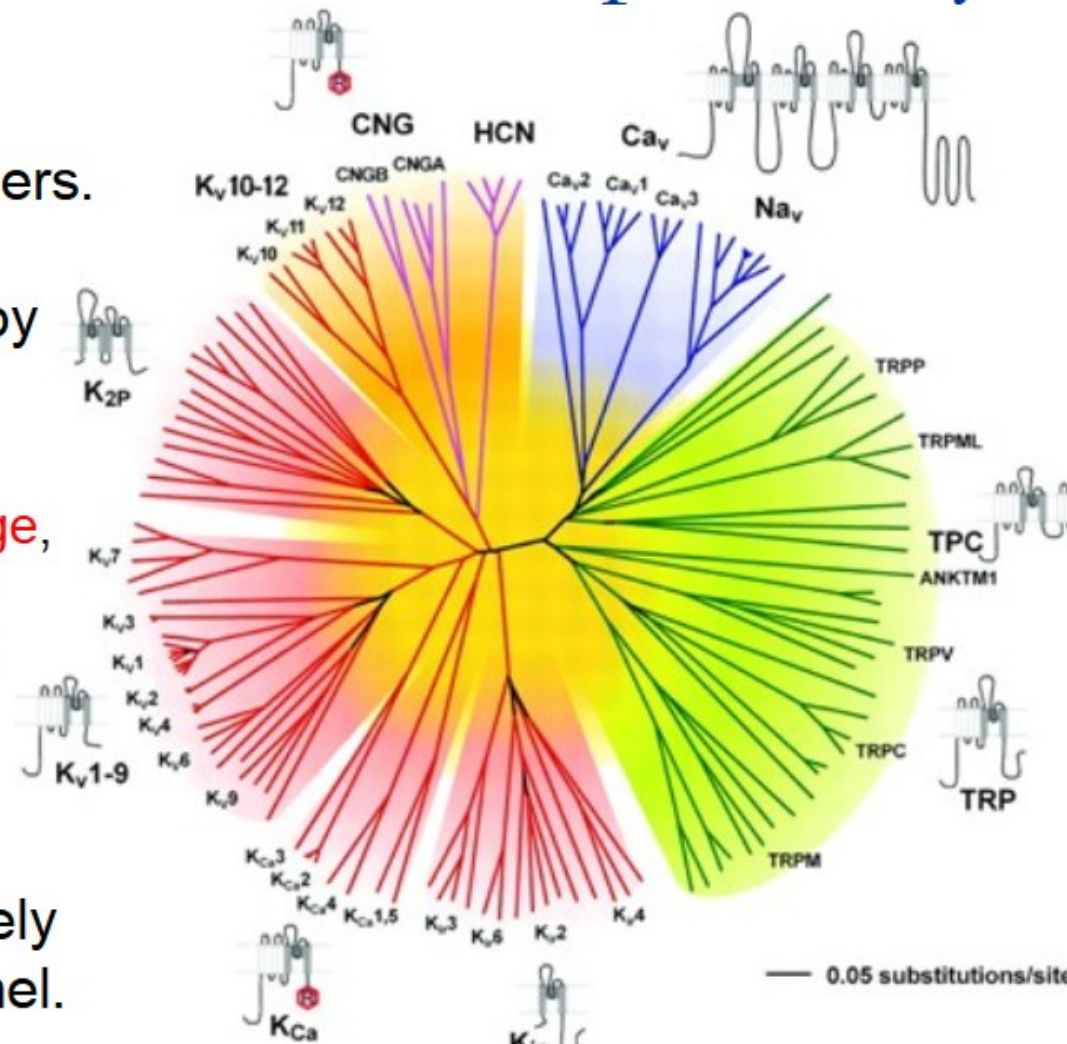
Ion channel types



Voltage-gated ion channels



- More than 140 members.
- Conductance varies by 100 fold.
- Variable gating: **voltage**, **2nd messengers**, **stimuli** (pH, heat, tension, etc.)
- $K_L \rightarrow Ca_v \rightarrow Na_v$
- Bacterial ancestor likely similar to KcsA channel.



Computational Models: Neurodynamics

Models at various level of detail.

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

Models of attention:

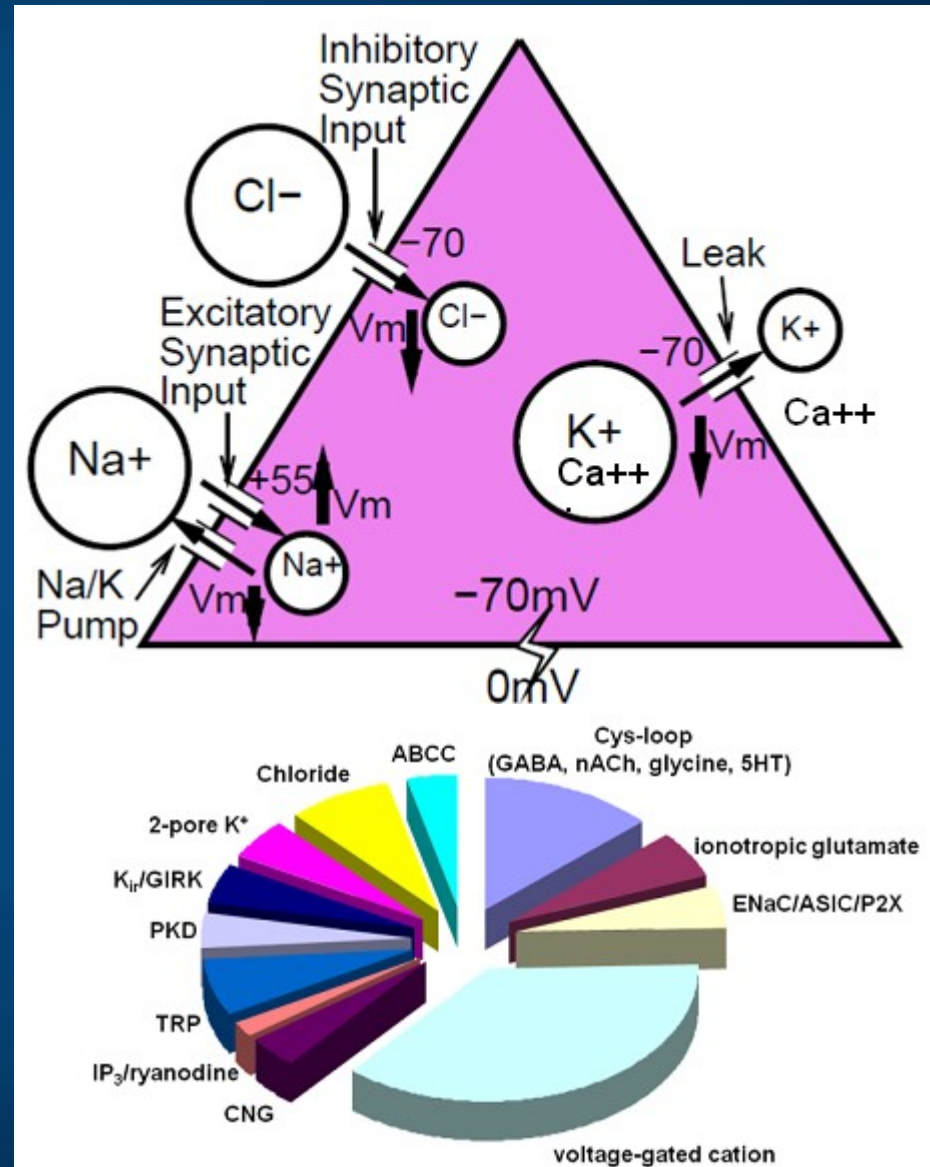
- Posner spatial attention;
- attention shift between visual objects.

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



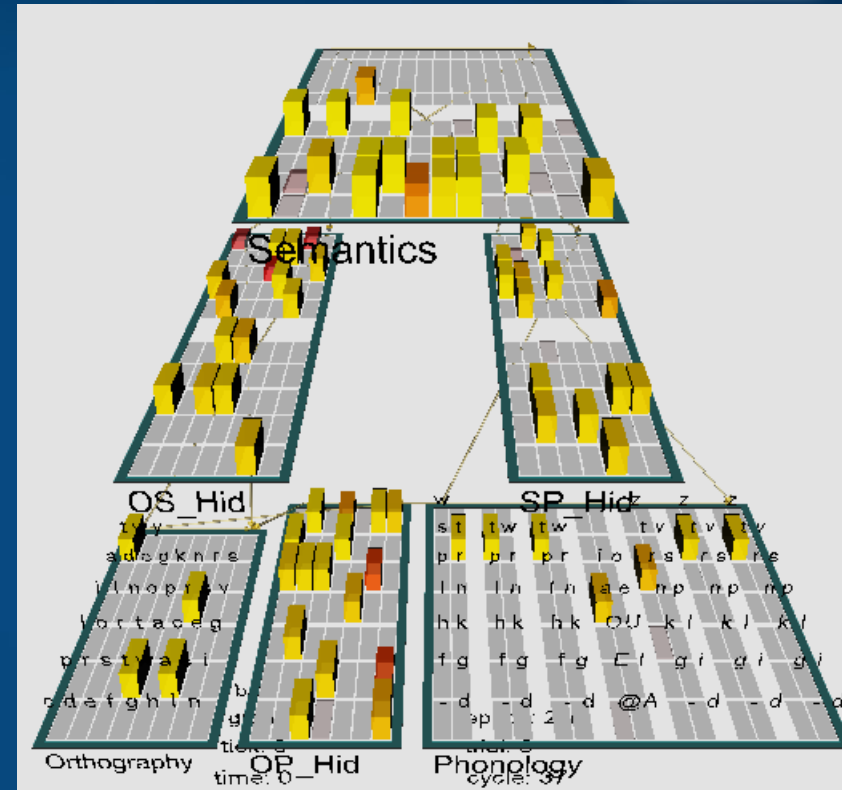
Emergent neural simulator:

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 defining concepts.

Hidden layers in between.

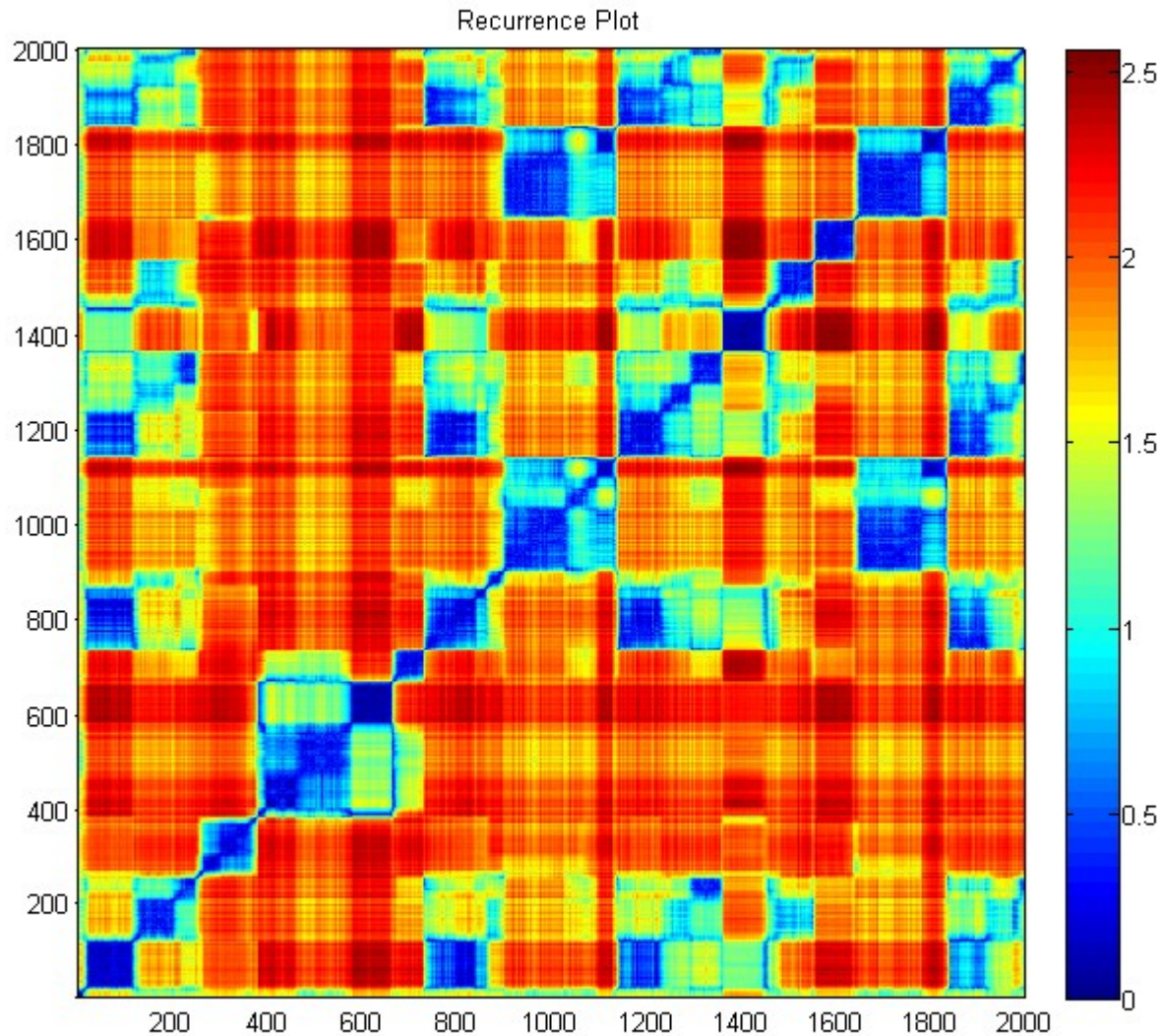


Learning: mapping one of the 3 layers to the other two.

Fluctuations around final configuration = attractors representing concepts.

How to see properties of their basins, their relations?

Model in **Genesis**: more detailed neuron description.



„Gain”: trajectory of semantic activations quickly changes to a new synchronized activity, periodically returns to the first basin of attraction.

Fuzzy Symbolic Dynamics (FSD)

Complementing information in RPs:

RP plots $S(t, t_0)$ values as a matrix; FSD

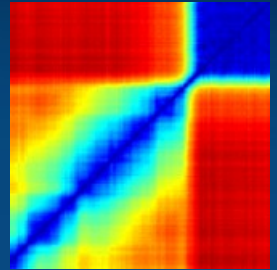
1. Standardize data.
2. Find cluster centers (e.g. by k-means algorithm): $\mu_1, \mu_2 \dots$
3. Use non-linear mapping to reduce dimensionality:

$$y_k(t; \mu_k, \Sigma_k) = \exp\left(-\left(\mathbf{x}(t) - \mu_k\right)^T \Sigma_k^{-1} \left(\mathbf{x}(t) - \mu_k\right)\right)$$

Localized membership functions $y_k(t; \mathcal{W})$:

sharp indicator functions \Rightarrow symbolic dynamics; $\mathbf{x}(t) \Rightarrow$ strings of symbols;
soft membership functions \Rightarrow fuzzy symbolic dynamics, dimensionality
reduction $Y(t) = (y_1(t; \mathcal{W}), y_2(t; \mathcal{W})) \Rightarrow$ visualization of high-dim data.

We may then see visualization of trajectory in some basin of attraction.
Such visualizations are simply referred to as “attractors”.



Fuzzy Symbolic Dynamics (FSD)

Complementing information in RPs:

RP plots $S(t, t_0)$ values as a matrix; FSD

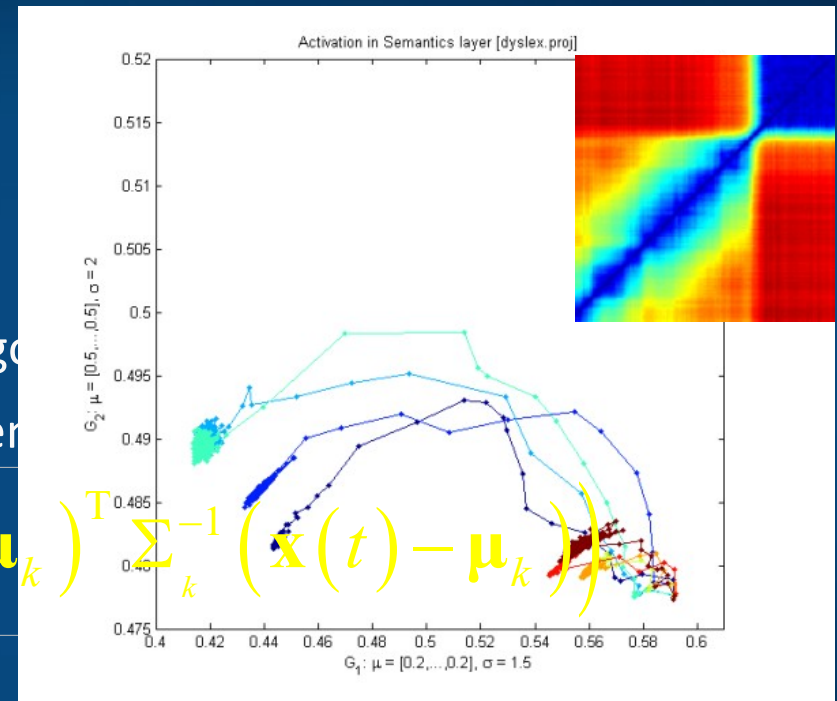
1. Standardize data.
2. Find cluster centers (e.g. by k-means algo)
3. Use non-linear mapping to reduce dimensionality

$$y_k(t; \boldsymbol{\mu}_k, \boldsymbol{\Sigma}_k) = \exp\left(-\left(\mathbf{x}(t) - \boldsymbol{\mu}_k\right)^T \boldsymbol{\Sigma}_k^{-1} \left(\mathbf{x}(t) - \boldsymbol{\mu}_k\right)\right)$$

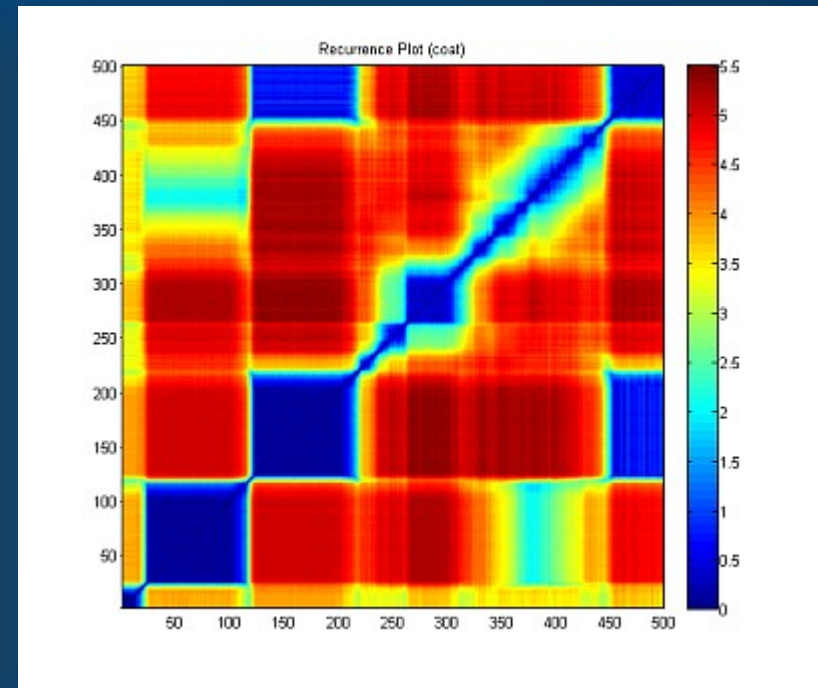
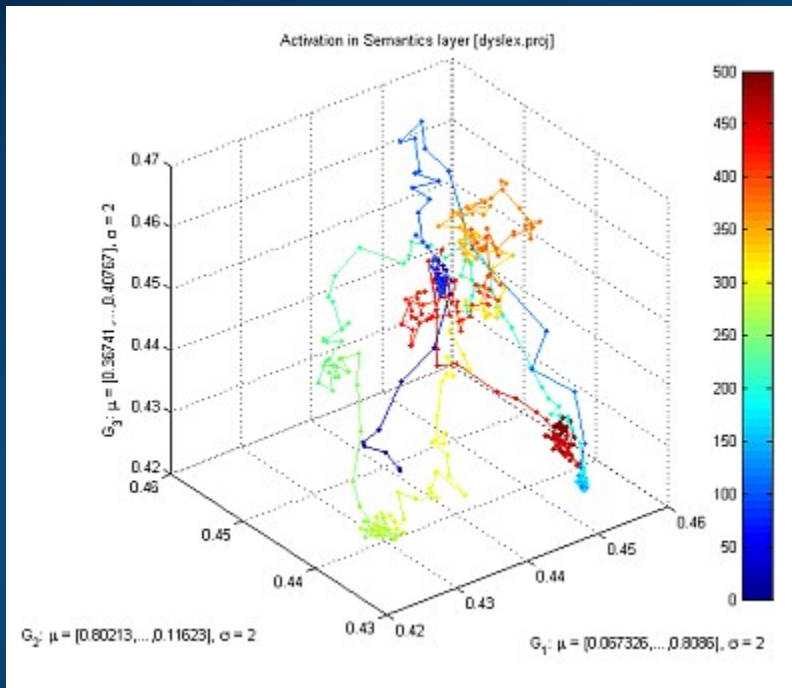
Localized membership functions $y_k(t; \mathcal{W})$:

sharp indicator functions => symbolic dynamics; $\mathbf{x}(t)$ => strings of symbols;
soft membership functions => fuzzy symbolic dynamics, dimensionality reduction
 $Y(t) = (y_1(t; \mathcal{W}), y_2(t; \mathcal{W}))$ => visualization of high-dim data.

We may then see visualization of trajectory in some basin of attraction.
Such visualizations are simply referred to as “attractors”.



Fast transitions



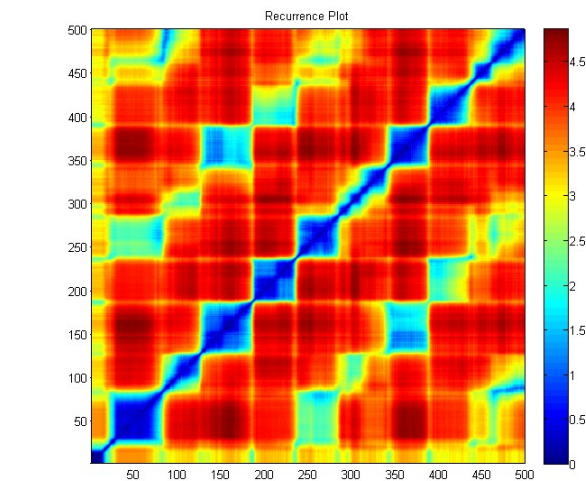
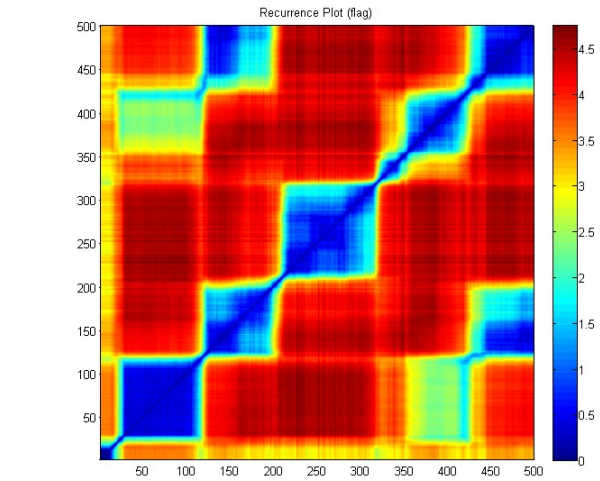
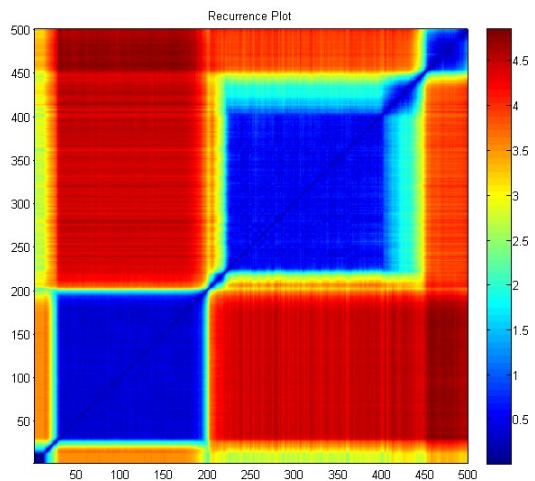
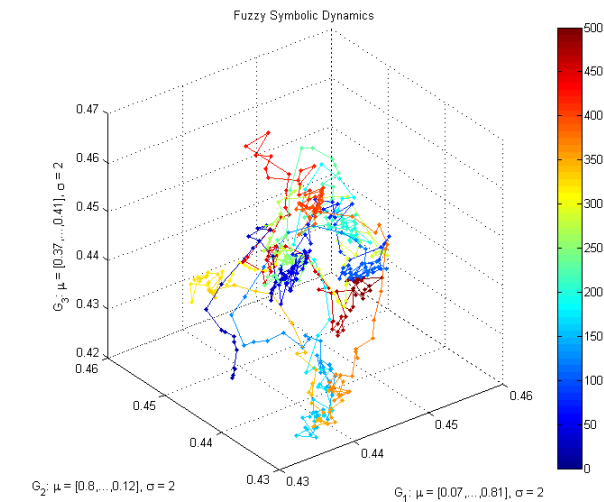
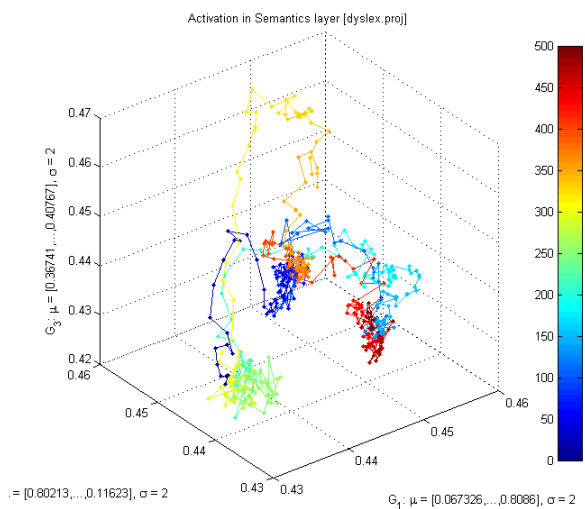
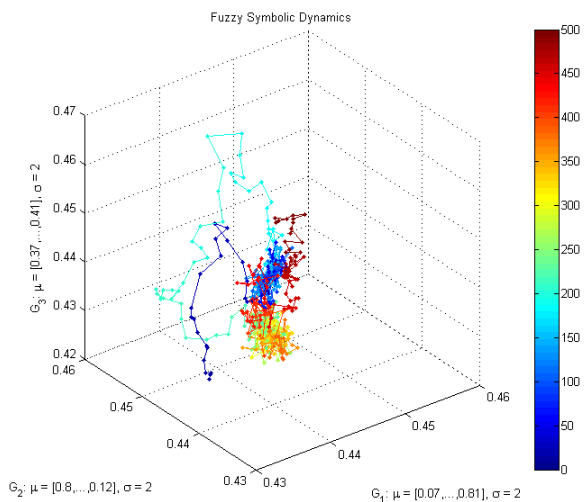
Attention is focused only for a brief time and then moved to the next attractor basin, some basins are visited for such a short time that no action may follow, no chance for other neuronal groups to synchronize. This corresponds to the feeling of confusion, not being conscious of fleeting thoughts.

Autism-Normal-ADHD

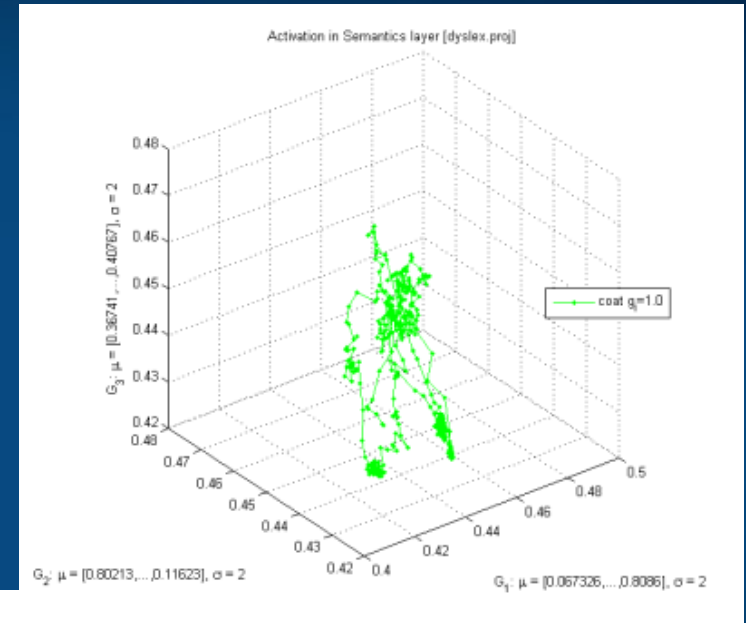
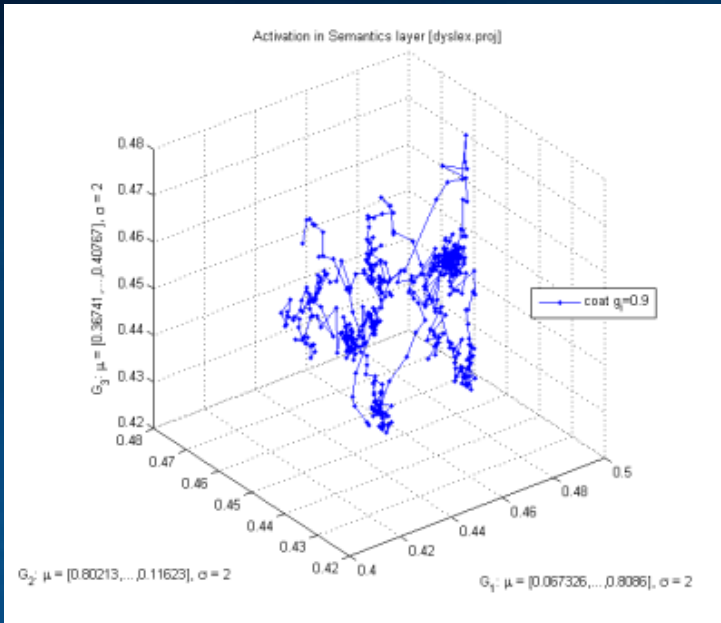
$b_inc_dt = 0.005$

$b_inc_dt = 0.01$

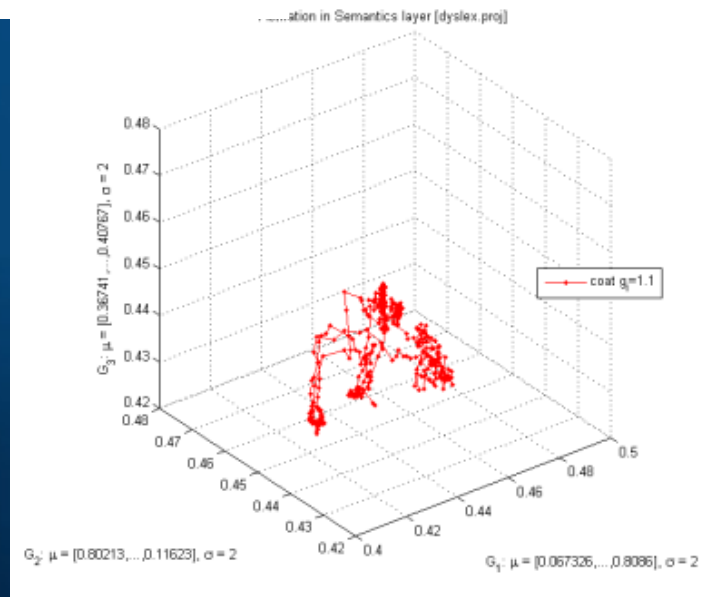
$b_inc_dt = 0.02$



Inhibition



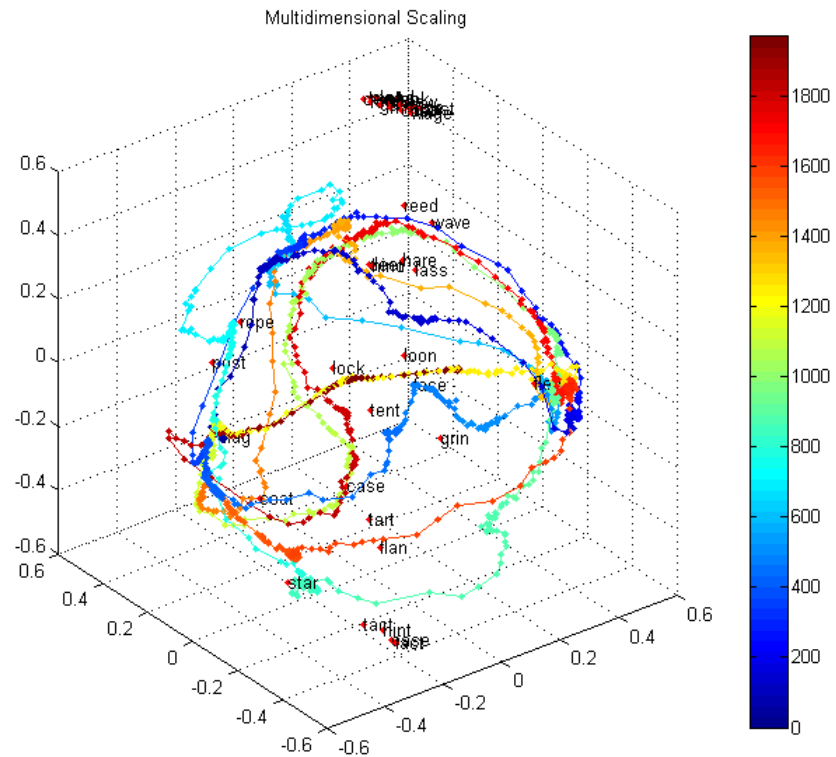
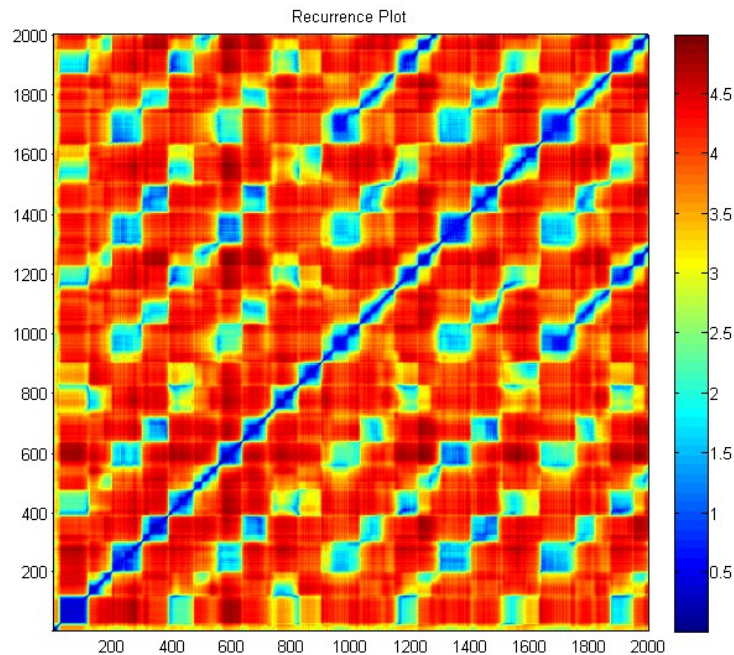
Increasing g_i from 0.9 to 1.1 reduces the attractor basin sizes and simplifies trajectories.



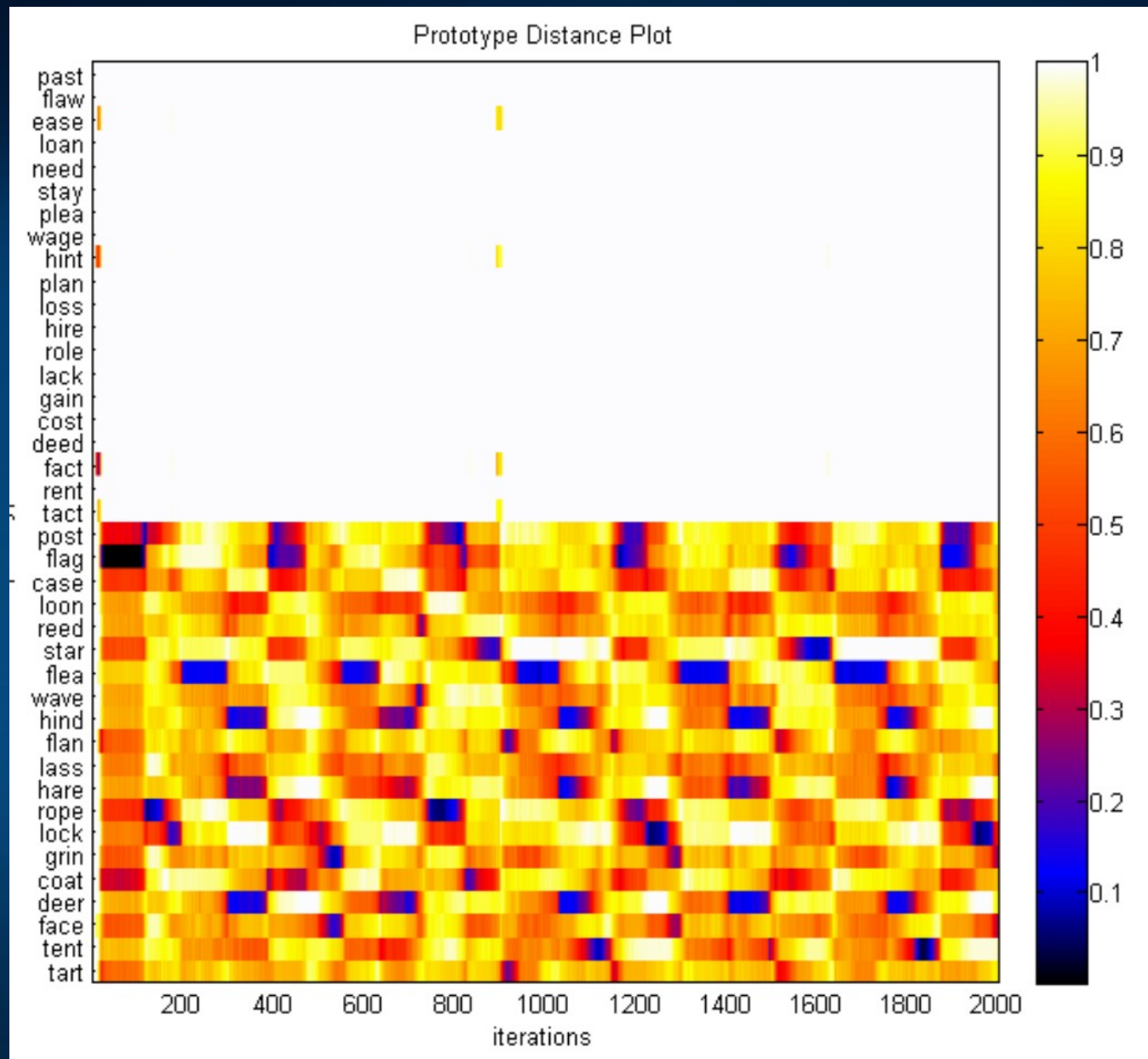
Strong inhibition,
empty head ...



Long trajectories



Recurrence plots and MDS visualization in 40-words microdomain, starting with the word “flag”.

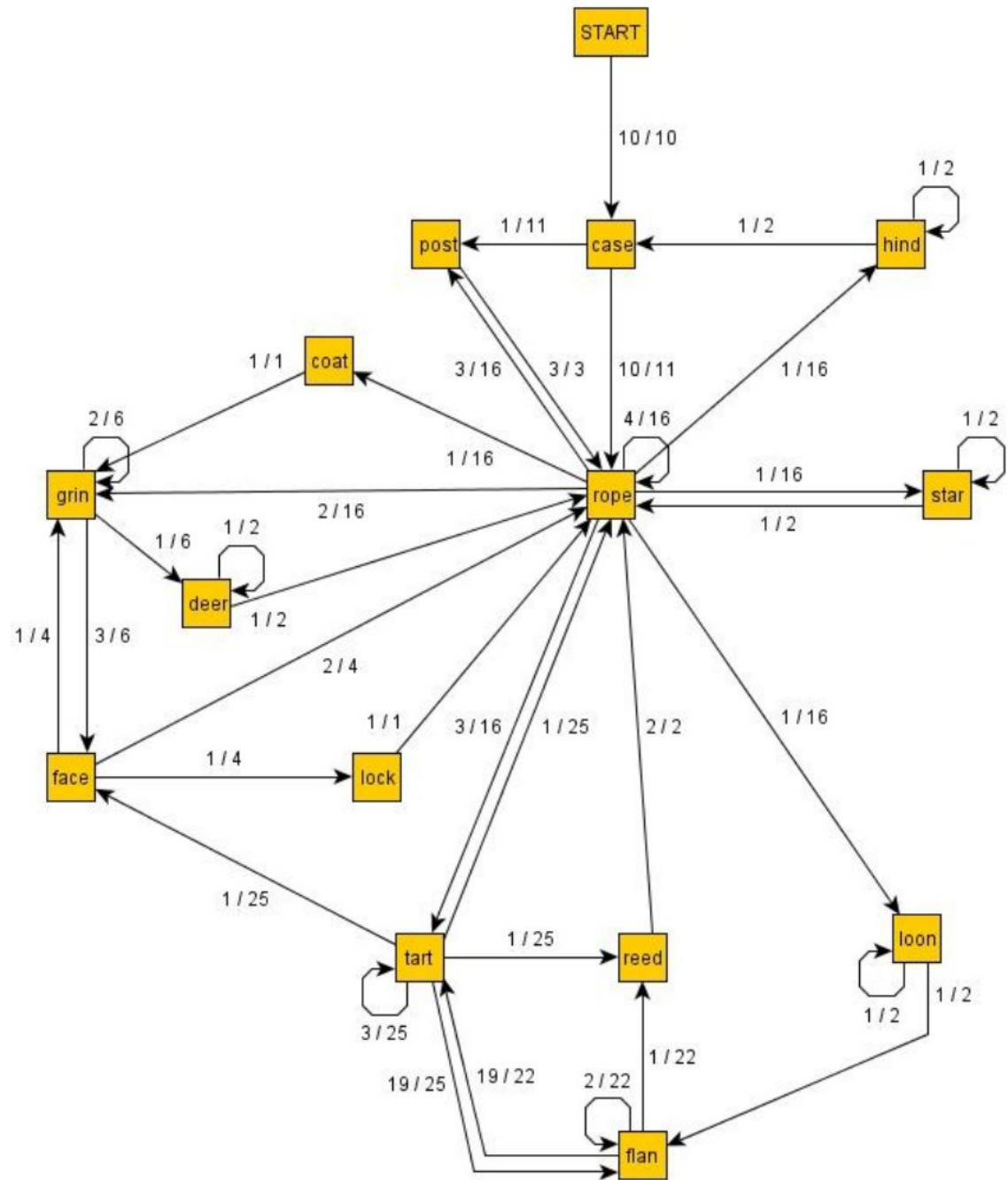


PDP for transitions starting from „flag”

Graph of transitions between attractors after 10 runs.

Why these particular transitions?

Connected attractors share some micro-features, some circuits (units) are deactivated, but visualization using RP or FSD does not show such details. The landscape of available attractors is also dynamic! Transition probabilities change, dimensions (features) are rescaled.



MDS word mapping

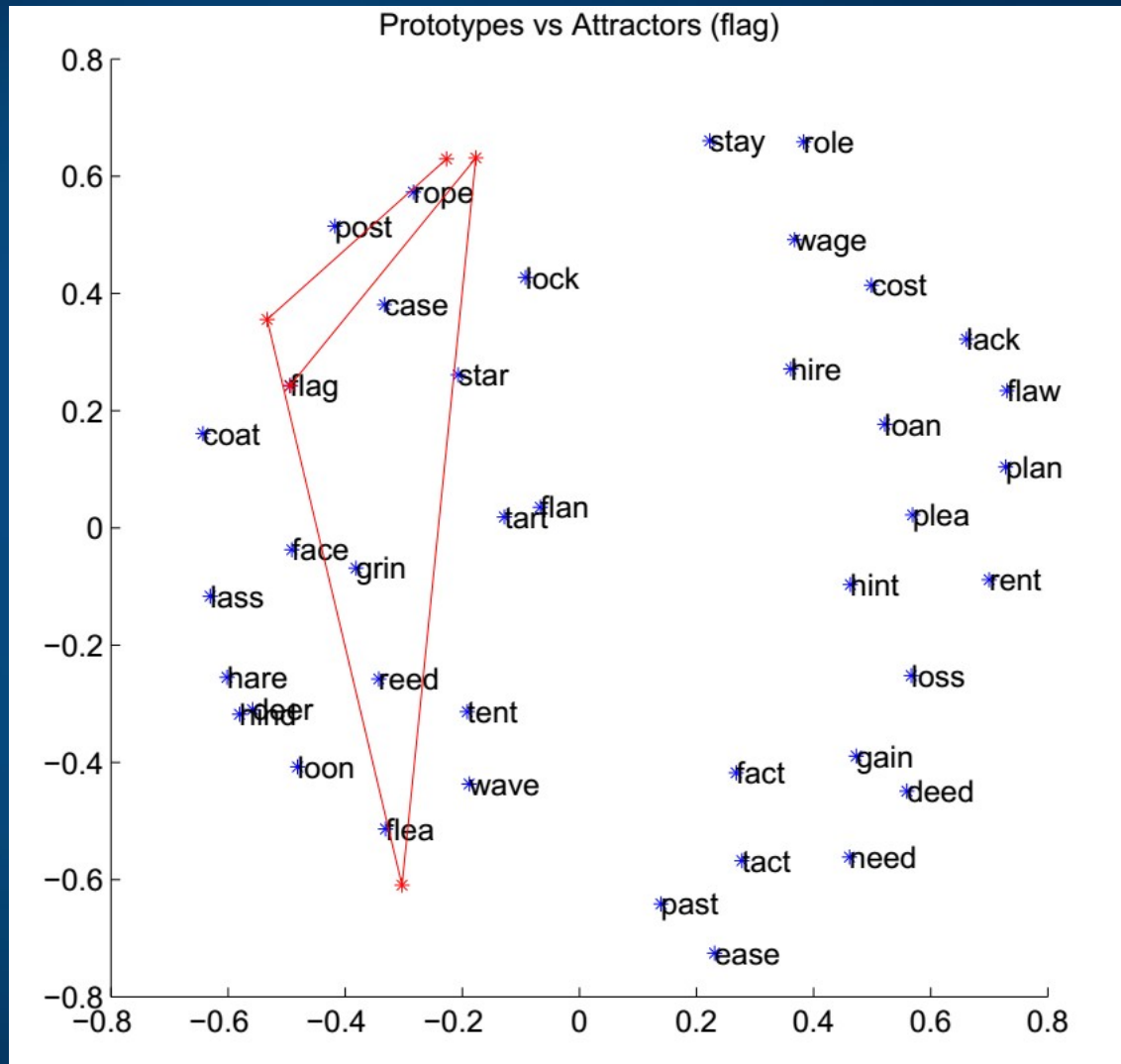
MDS representation of all 40 words, showing similarities of their 140 dimensional vectors.

Attractors are in some cases far from words.

Transition

Flag => rope => flea ...

Can we make semantic map of concepts in real brains? See trajectories of thought?



Brain modules and cognitive processes

Simple and more difficult tasks, requiring the whole-brain network reorganization.

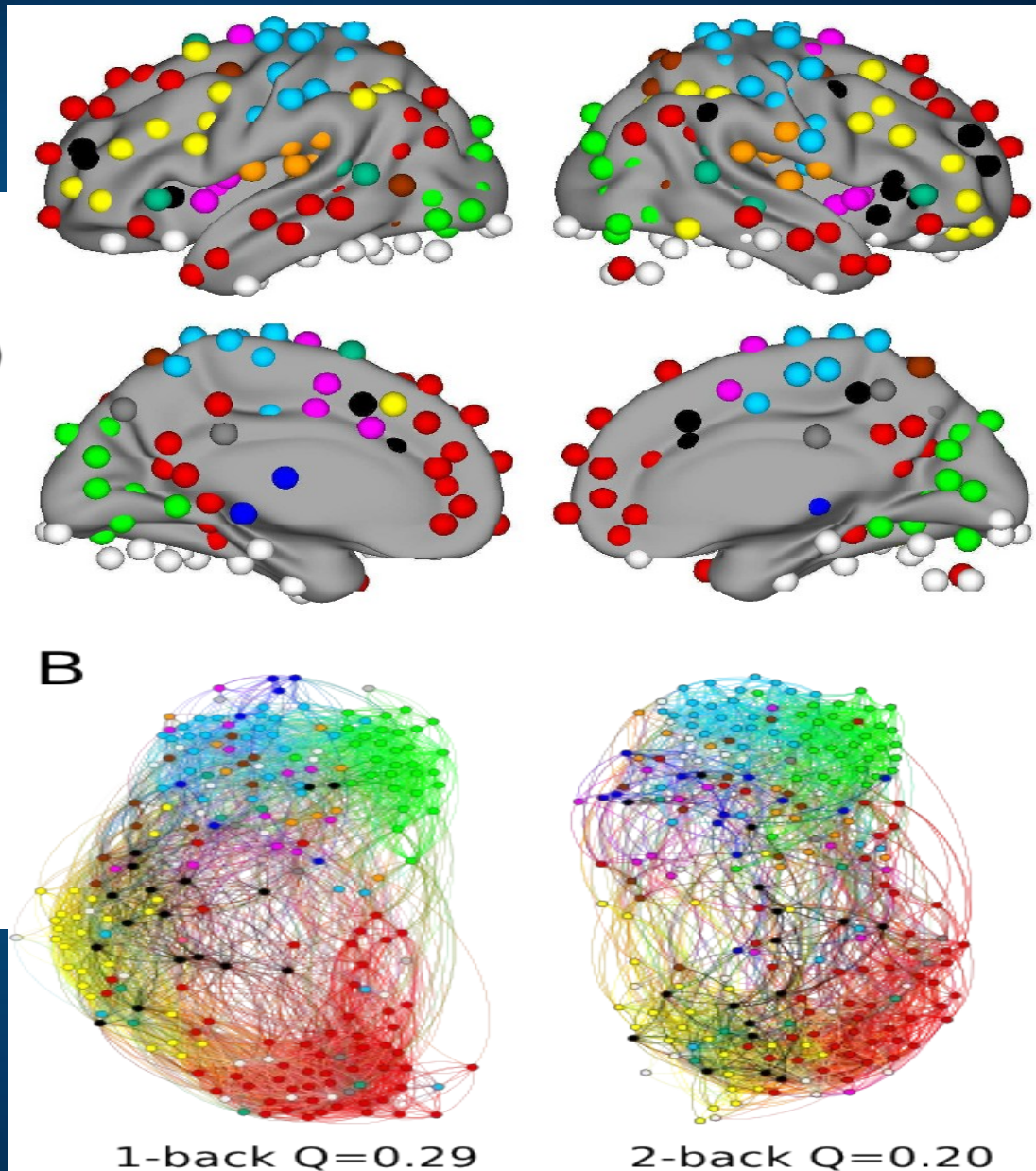
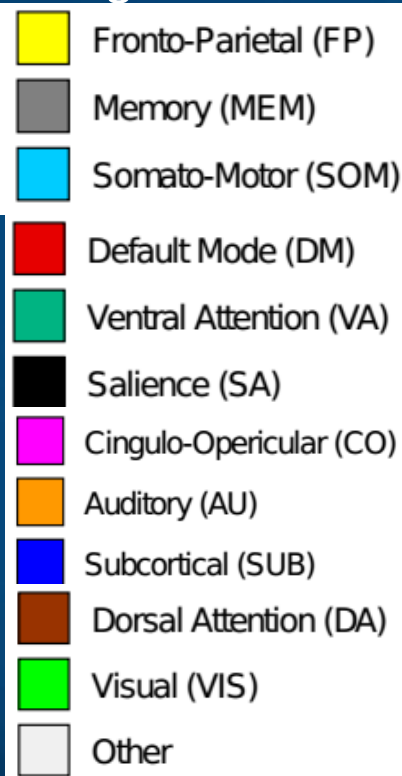
Left: 1-back

Right: 2-back

Average over 35 participants.

Left and midline sections.

K. Finc et al (HBM, in rev, with World Hearing Center, MPI for Human Development).



Brain modules and cognitive processes

Simple and more difficult tasks, requiring the whole-brain network reorganization.

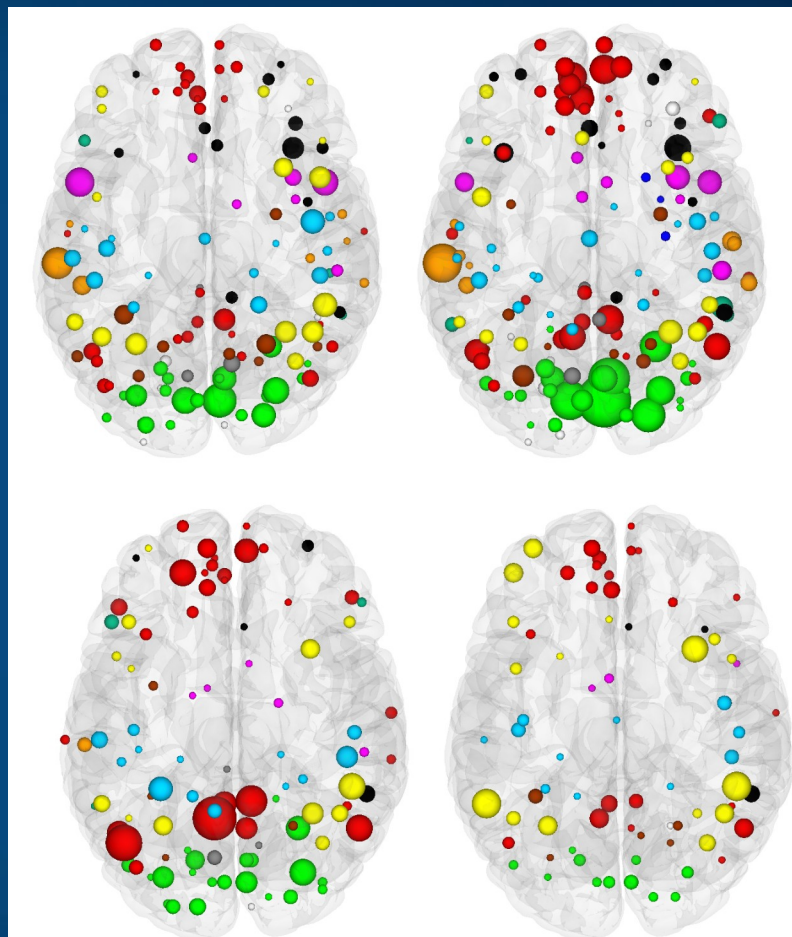
Left: 1-back Top: connector hubs

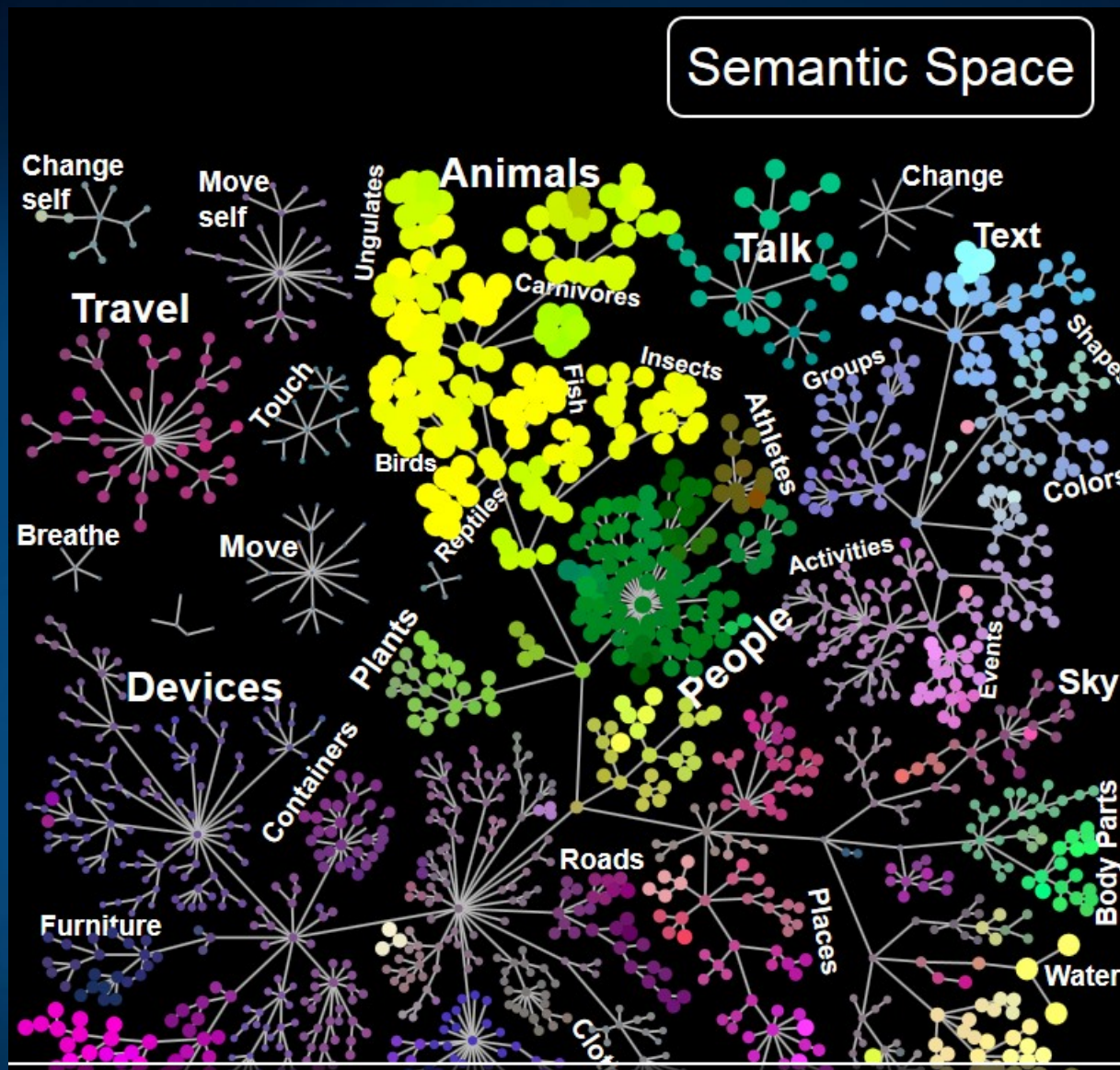
Right: 2-back Bottom: local hubs

Average over 35 *participants*.

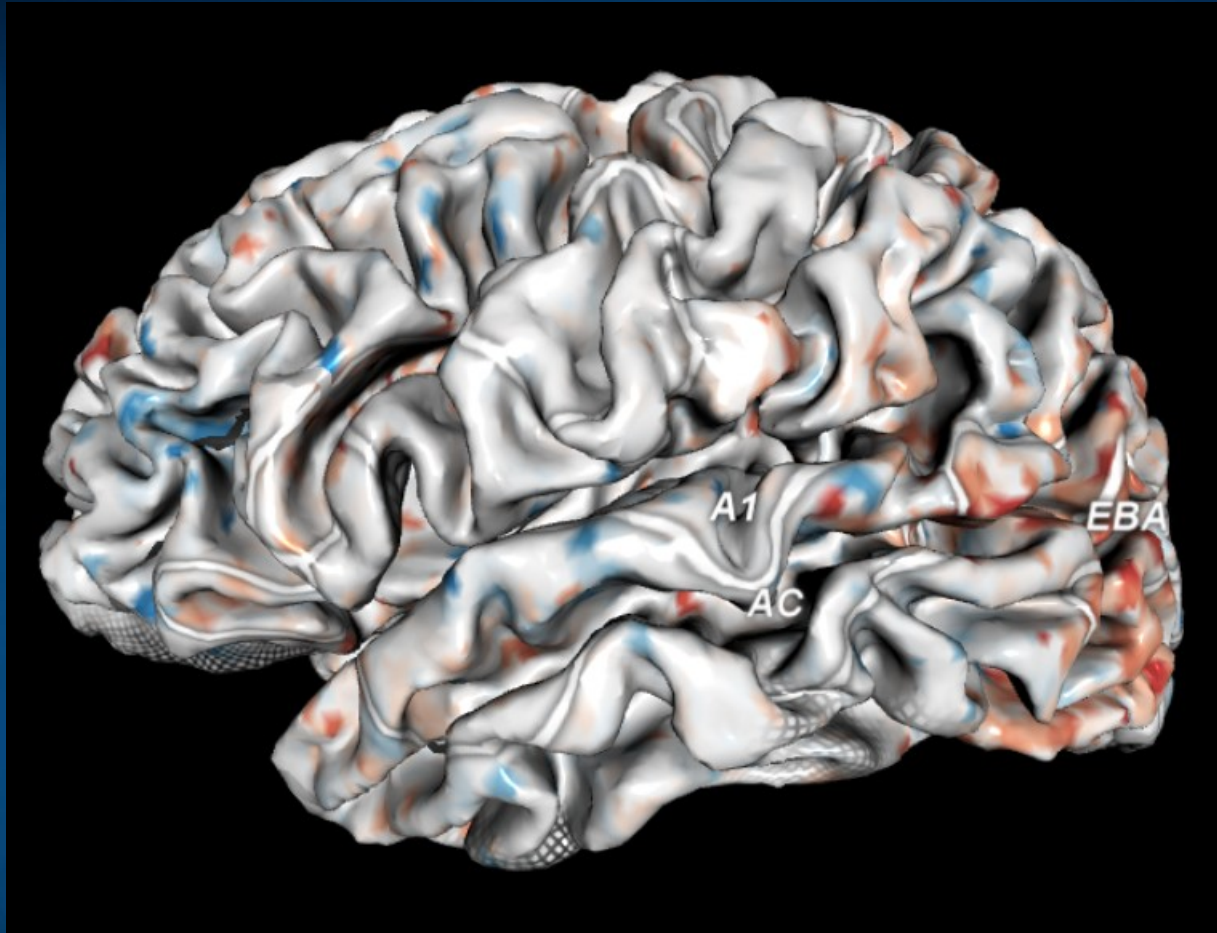
Dynamical change of the landscape of attractors? Less local, more global binding.

K. Finc et al (HBM, in rev).

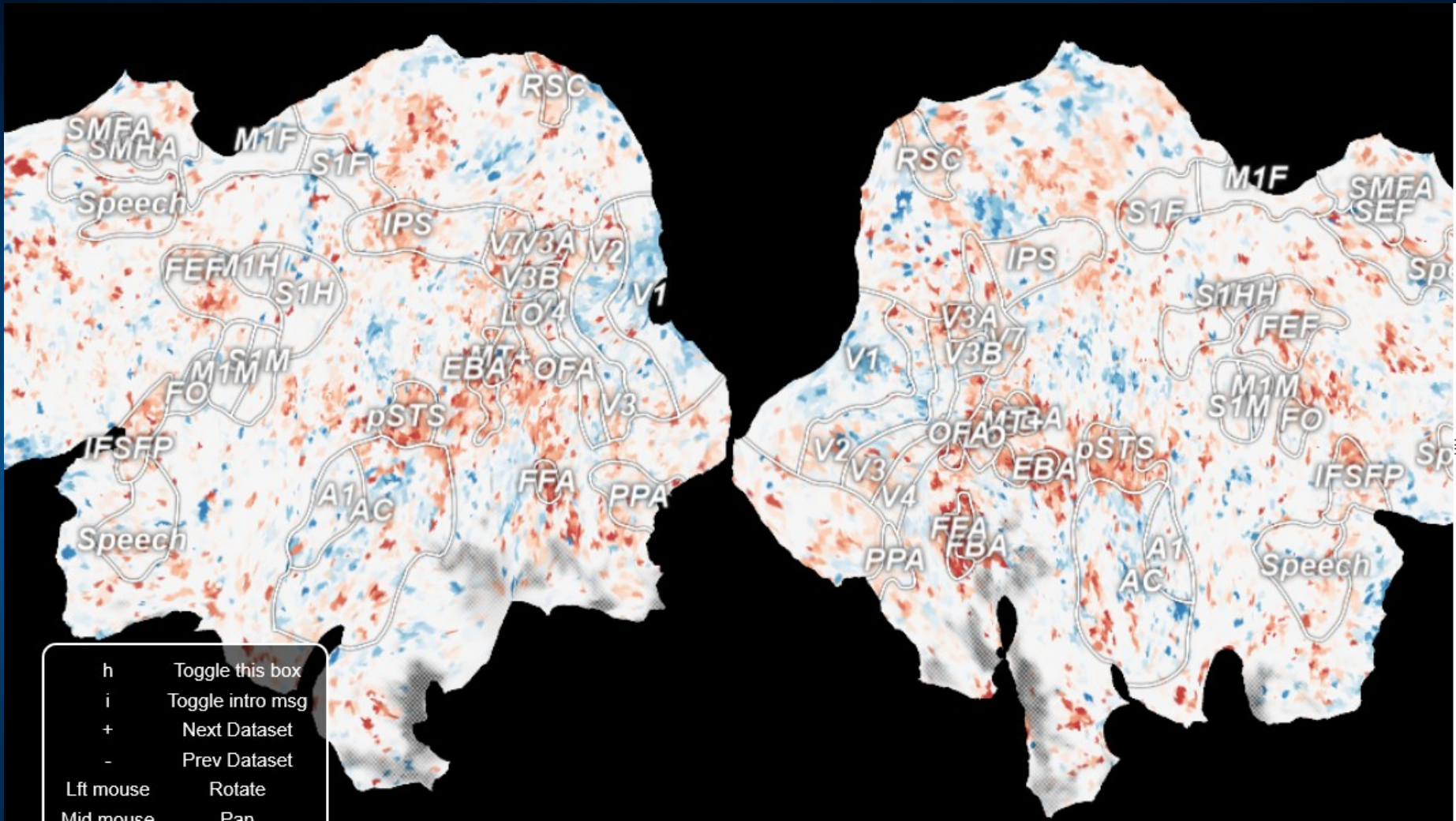




Activation of concepts in our minds leads to specific brain structure activity; each structure is involved in interpretation of many concepts (Gallant lab).



Activation of specific concept (mental state) leads to activation of specific brain areas and networks. Each such activation pattern contributes to semantic interpretation of many concepts through global brain activity.



This activation is sparse and may be better observed by looking at the flattened cortex: <http://gallantlab.org/brainviewer/huthetal2012/>

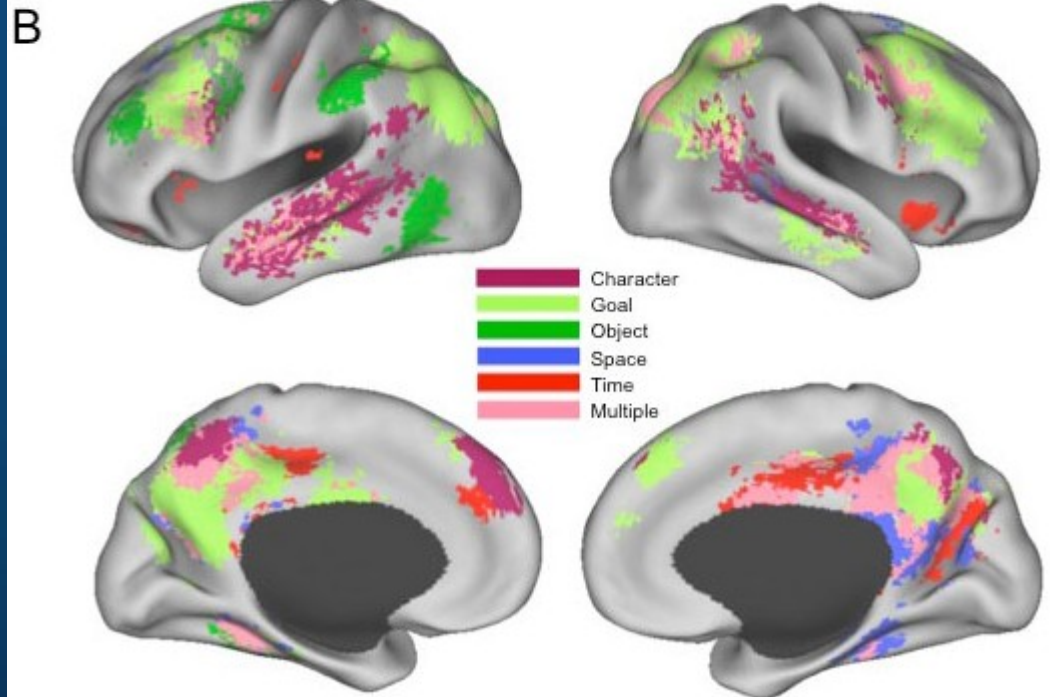
Nicole Speer et al.
 Reading Stories Activates
 Neural Representations of
 Visual and Motor
 Experiences.

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

Meaning: always slightly
 different, depending on the
 context, but still may be
 clusterized into relatively
 small 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.						

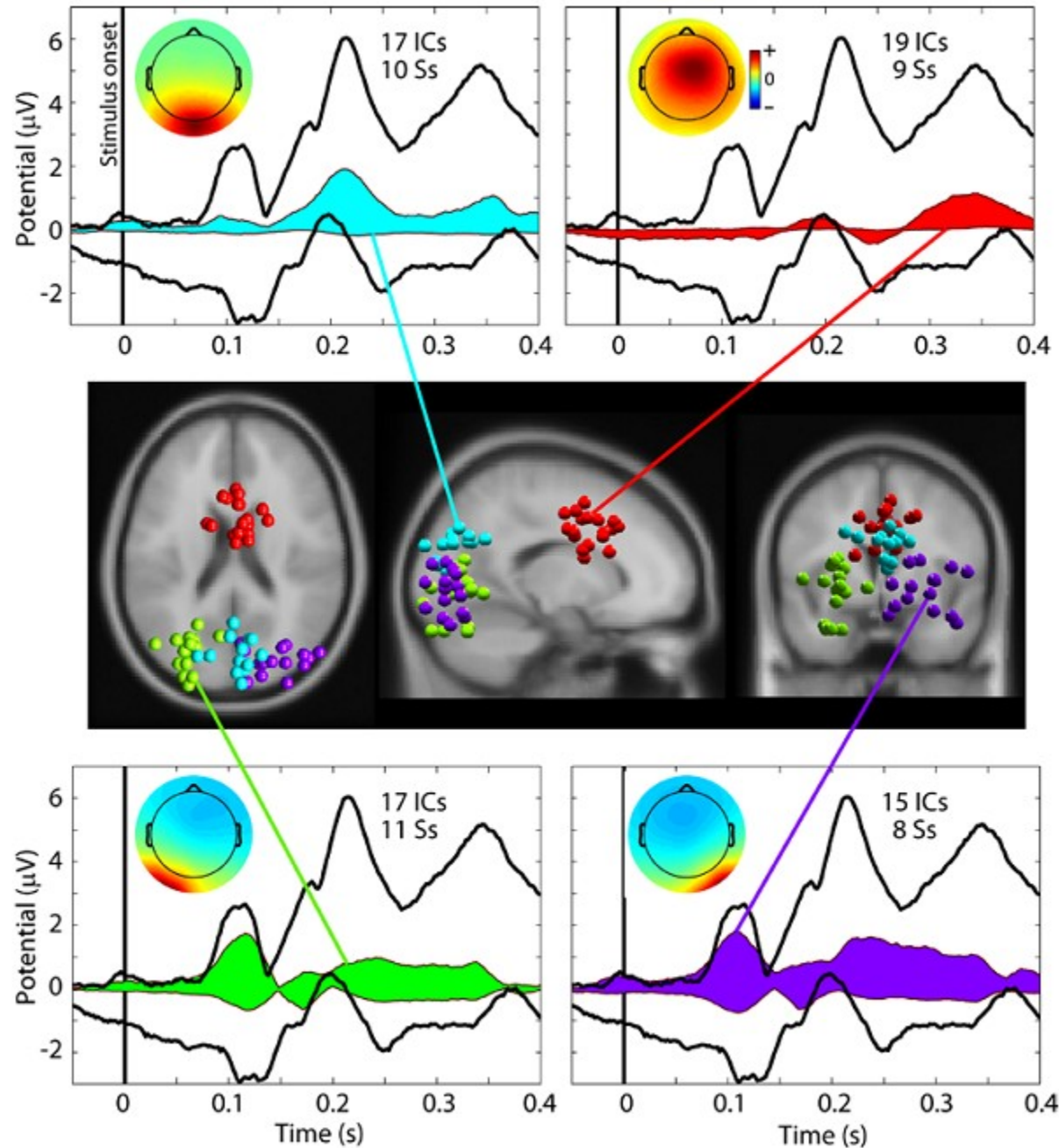


Source localization maps brain activity to attractor dynamics.

Problem: these sources pop up and vanish in different places.

Fig. from:
Makeig, Onton, 2009
ERP Features and
EEG Dynamics:
An ICA Perspective.

Brain fingerprinting:
discover in EEG specific
patterns for attractor
dynamics = subnetwork
activation.



Origin of the learning styles

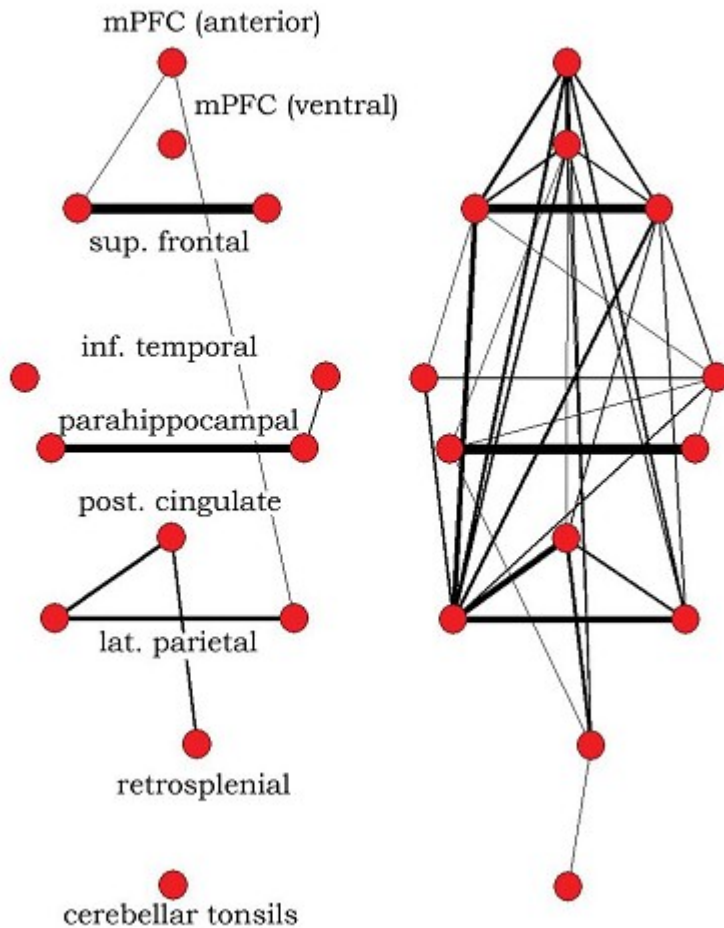
Connectomes develops before birth and in the first years of life.

Achieving harmonious development is very difficult and depends on low-level (genetic, epigenetic, signaling pathways) processes, but may be influenced by experience and learning.

- Excess of low-level (sensory) processes $S \leftrightarrow S$.
- Poor $C \leftrightarrow C$ neural connections and synchronization, frontal \leftrightarrow parietal necessary for abstract thinking, weak functional connections prefrontal lobe \leftrightarrow other areas.
- Patterns of activation in the brain differ depending on whether the brain is doing social or nonsocial tasks.
- “Default brain network” involves 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.

Children

Adults



Learning styles

and in the first years of life.

It is very difficult and depends on low-level (ways) processes, but may be influenced by

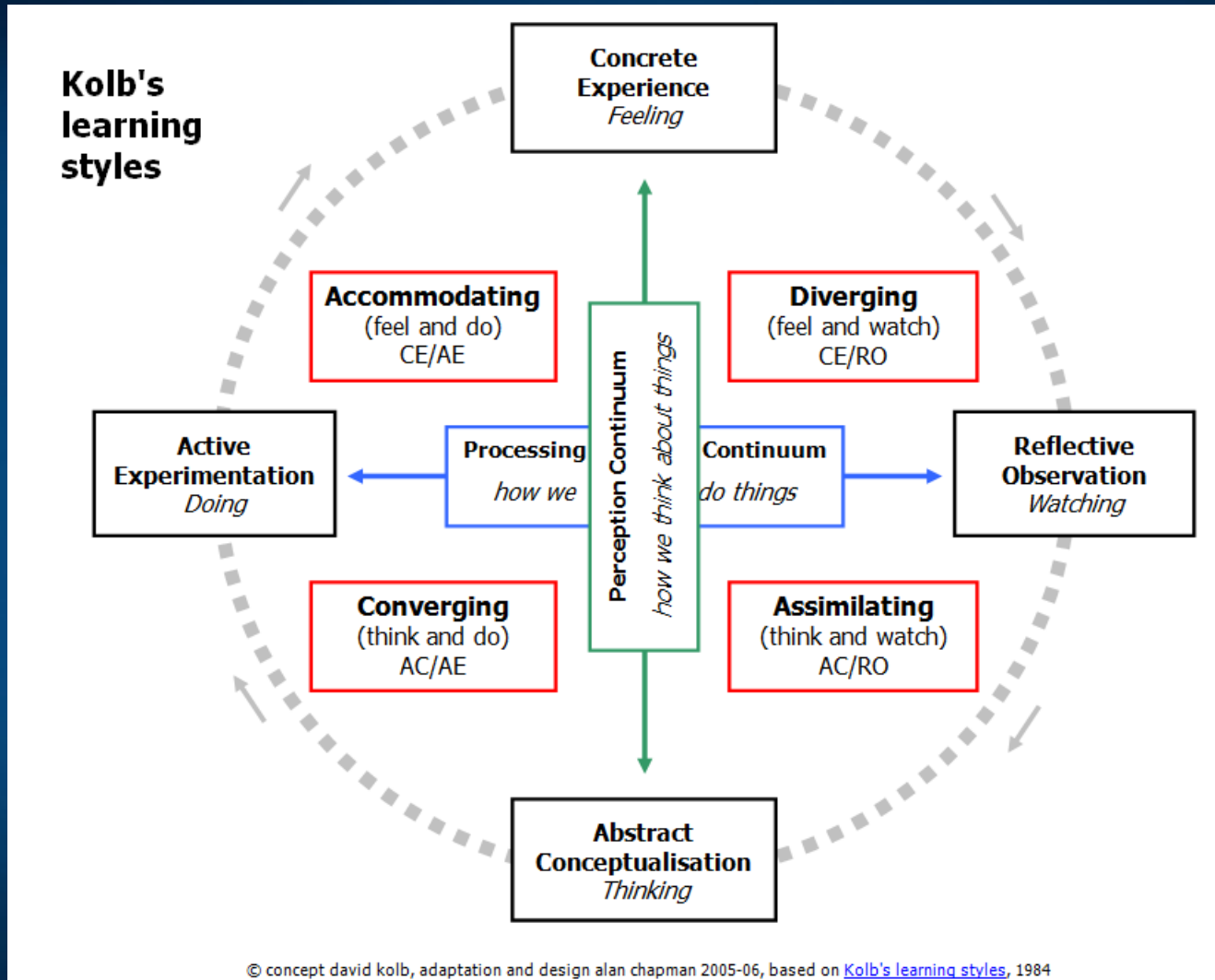
processes $S \leftrightarrow S$.

and synchronization, frontal \leftrightarrow parietal
weak functional connections prefrontal

can differ depending on whether the brain is

as 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.

Learning styles



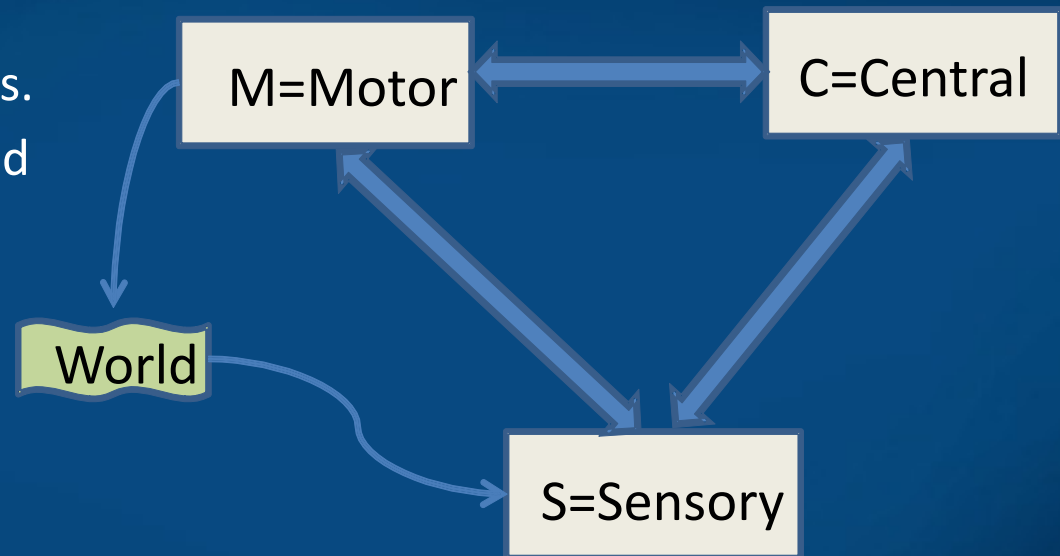
David Kolb, *Experiential learning: Experience as the source of learning and development* (1984), and *Learning Styles Inventory*.

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.



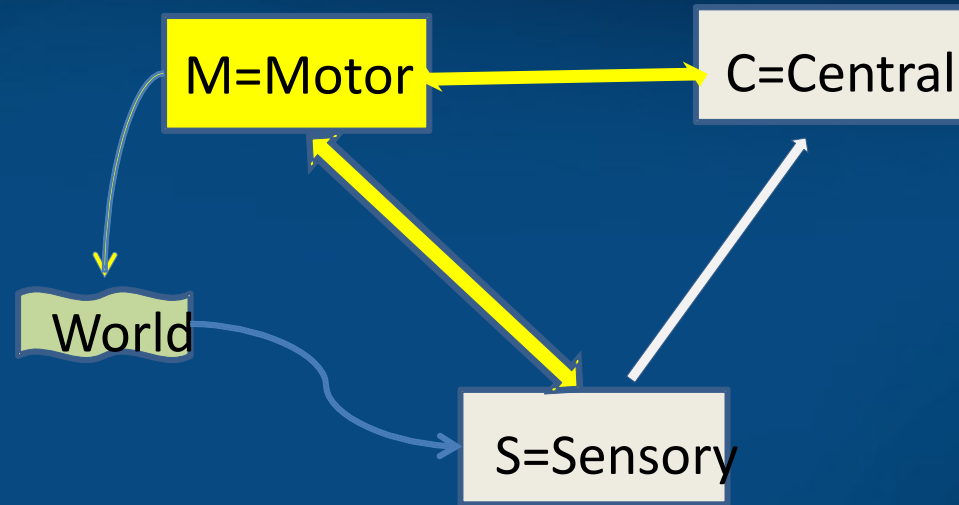
M, motor cortex, motor imagery & physical action.
Frontal cortex, basal ganglia.

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 $M \leftrightarrow C$,
sensory-motor processes $M \leftrightarrow S$.

Autistic people: processes at
the motor level $M \leftrightarrow M$,
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 $S \leftrightarrow S$ areas, vs.
coupling within central $C \leftrightarrow C$ areas.

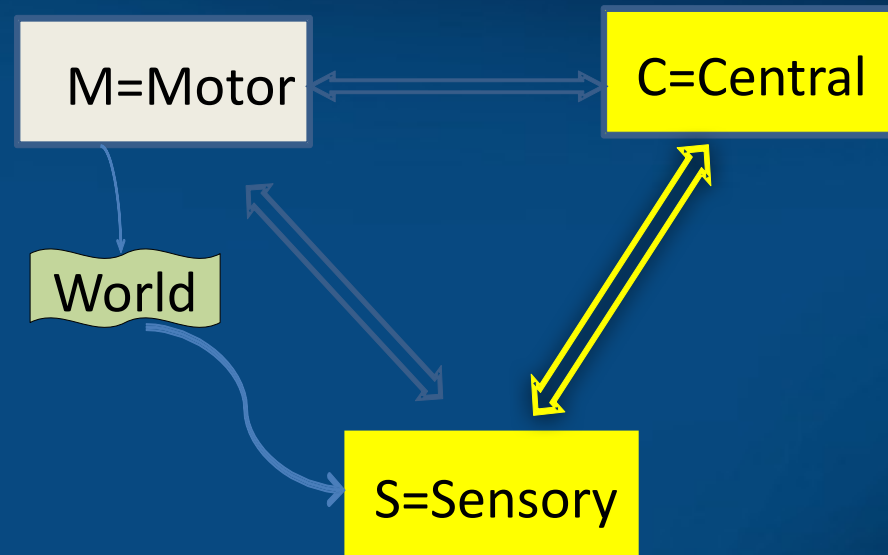
Strong $C \Rightarrow S$ leads to vivid imagery
dominated by sensory experience.

Autism: vivid detailed imagery,
no generalization.

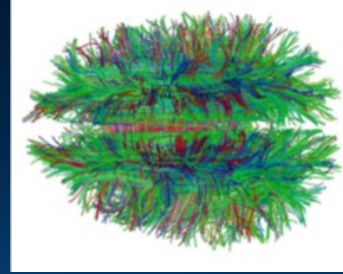
Attention = synchronization of neurons, limited to S, perception $S \leftrightarrow S$ strongly
binds attention \Rightarrow no chance for normal development.

Asperger syndrome strong $C \Rightarrow S$ activates sensory cortices preventing
understanding of metaphoric language.

If central $C \leftrightarrow C$ 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 $S \Rightarrow C$ and within $C \Leftrightarrow C$, weak connections from $S \Rightarrow M$ and $C \Rightarrow M$.

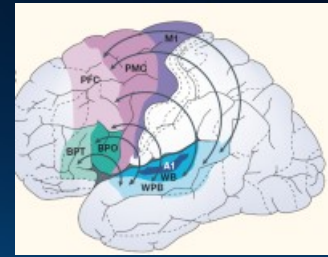
Convergers combine abstract conceptualization, active experimentation, using deductive reasoning in problem solving.
Strong $C \Leftrightarrow C$ and $C \Rightarrow M$ flow of activity.

Divergers focus on concrete experience $S \Leftrightarrow S$, strong $C \Leftrightarrow S$ connections and $C \Leftrightarrow C$ 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 $S \Leftrightarrow C \Leftrightarrow M$.

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.

Creativity with words



The simplest testable model of creativity (~ Campbell BVSR):

- create interesting novel words that capture some features of products;
- understand new words that cannot be found in the dictionary.

Model inspired by the putative brain processes when new words are being invented starting from some keywords priming auditory cortex.

Phonemes (allophones) are resonances, ordered activation of phonemes will activate both known words as well as their combinations; context + inhibition in the winner-takes-most leaves only a few candidate words.

Creativity = network+imagination (fluctuations)+filtering (competition)

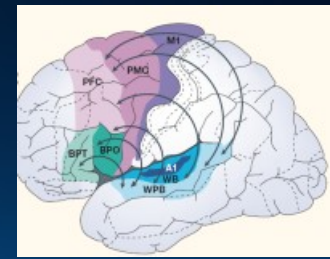
Imagination: chains of phonemes activate both word and non-word representations, depending on the strength of the synaptic connections. **Filtering:** based on associations, emotions, phonological/semantic density.

discoverity = {disc, disco, discover, verity} (discovery, creativity, verity)

digventure = {dig, digital, venture, adventure} new!

Visual: Google Deep Dream hallucinations – but video streams not natural.

Creativity with words



The simple

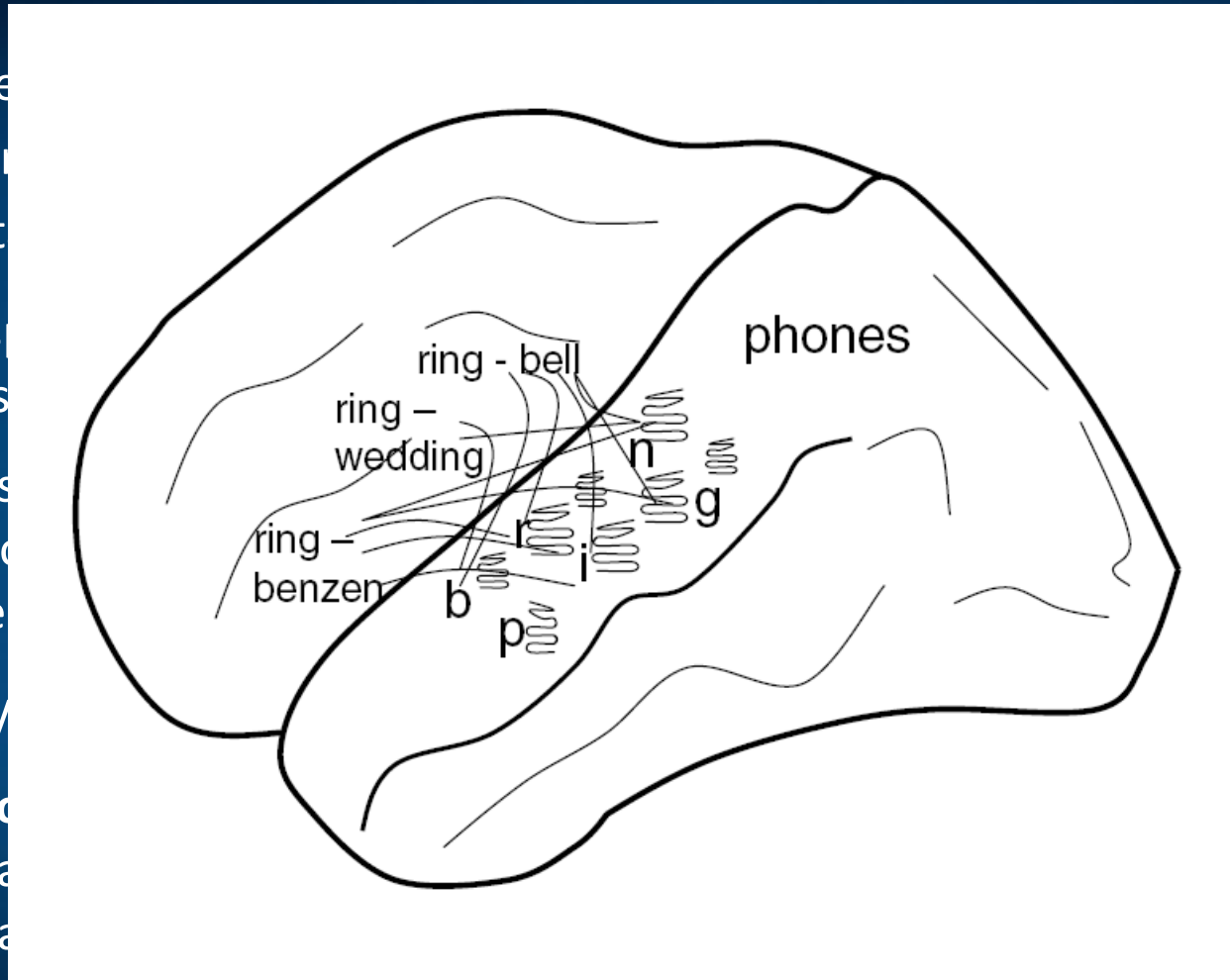
- create in
- underst

Model ins
invented s

Phonemes
activate b
the winne

Creativity

Imaginatio
representa
based on a



ucts;

e being

emes will
inhibition in

petition)

ons. **Filtering:**

discoverity = {disc, disco, discover, verity} (discovery, creativity, verity)

digventure = {dig, digital, venture, adventure} new!

Visual: Google Deep Dream hallucinations – but video streams not natural.

How to become an expert?

Textbook knowledge in medicine: detailed description of all possibilities.

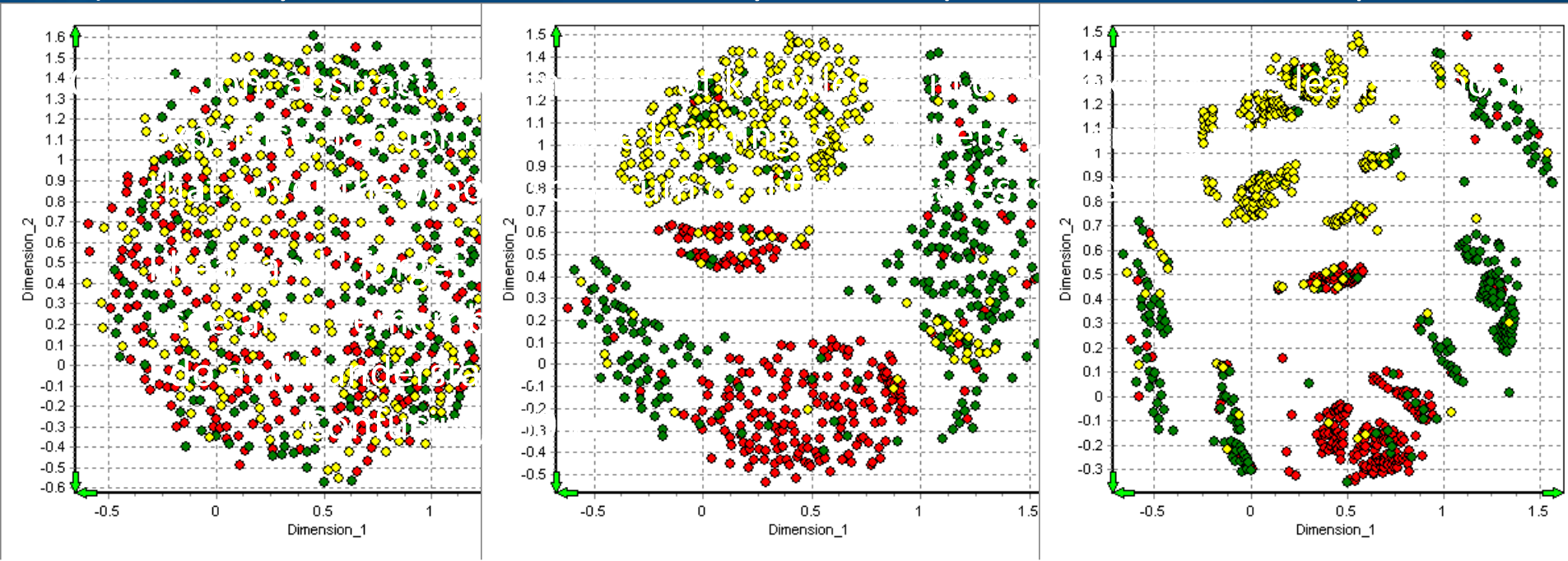
Effect: neural activation flows everywhere and correct diagnosis is impossible.

Correlations between observations forming prototypes are not firmly established.

Expert has only correct, “intuitive” associations; deep attractors = .

Example: 3 diseases, vector NLP on clinical case description, MDS visualization.

- 1) System that has been trained on textbook knowledge: weak attractors.
- 2) Same system that has learned later on real cases: deeper attr, still connected.
- 3) Same system that has learned only on description of real cases: deep attr.



Conspiracy in the brain



Slow and rapid scenarios are possible, here only rapid presented:

- 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 – strongly connected pathways.
- Conspiracy theories form around such associations, “frozen” pathways lead to brain activations forming strong attractors, distorting rational thinking.
- Such strong associations save brain energy and cannot be changed by rational arguments, that influence weaker associations only.
- This explanation becomes so obviously obvious ...

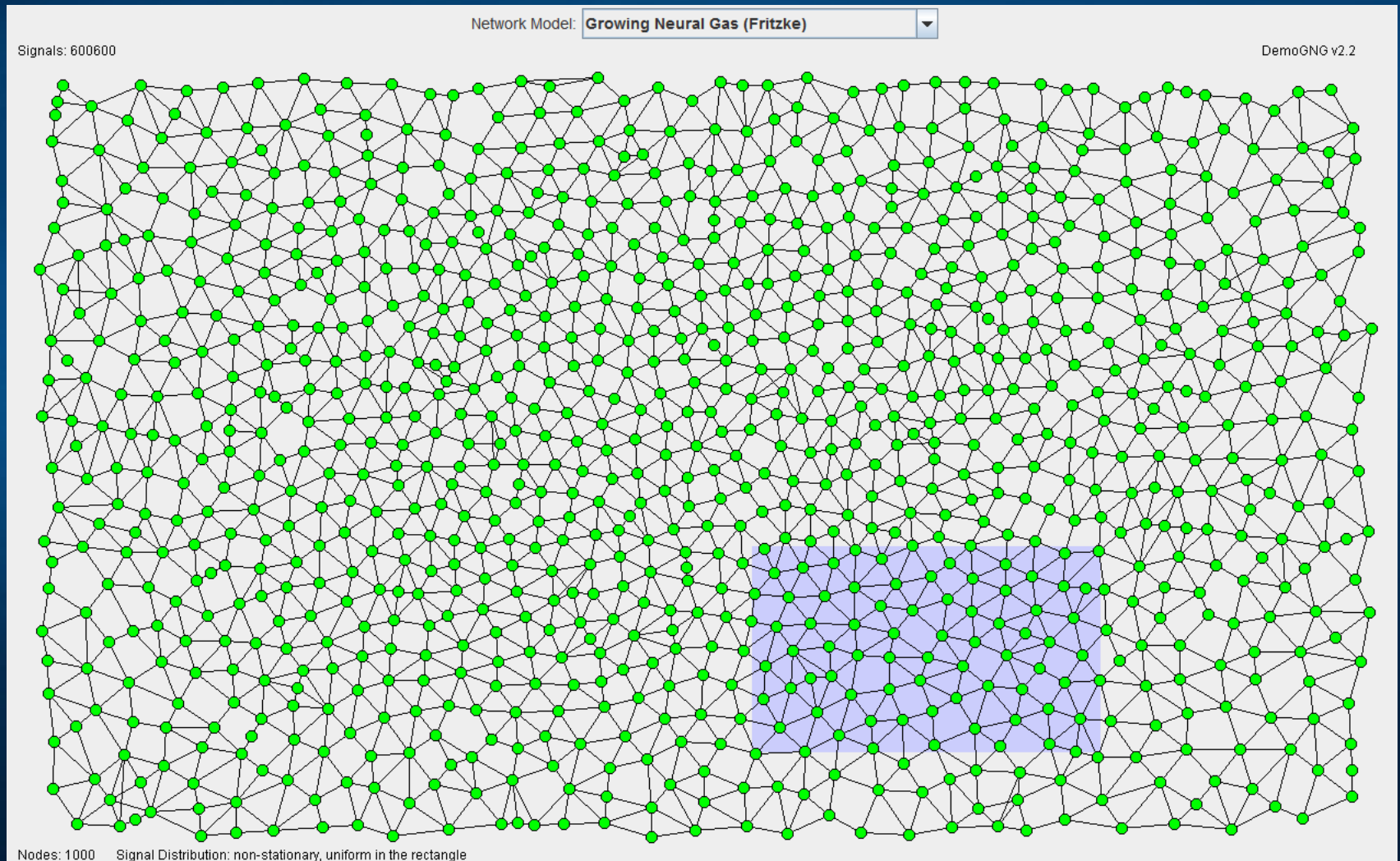


Model: concept vectors derived from a corpus + MDS or Growing Neural Gas visualization (Martinetz & Schulten, 1991).

Social cognitive neuroscience should go more in this direction.

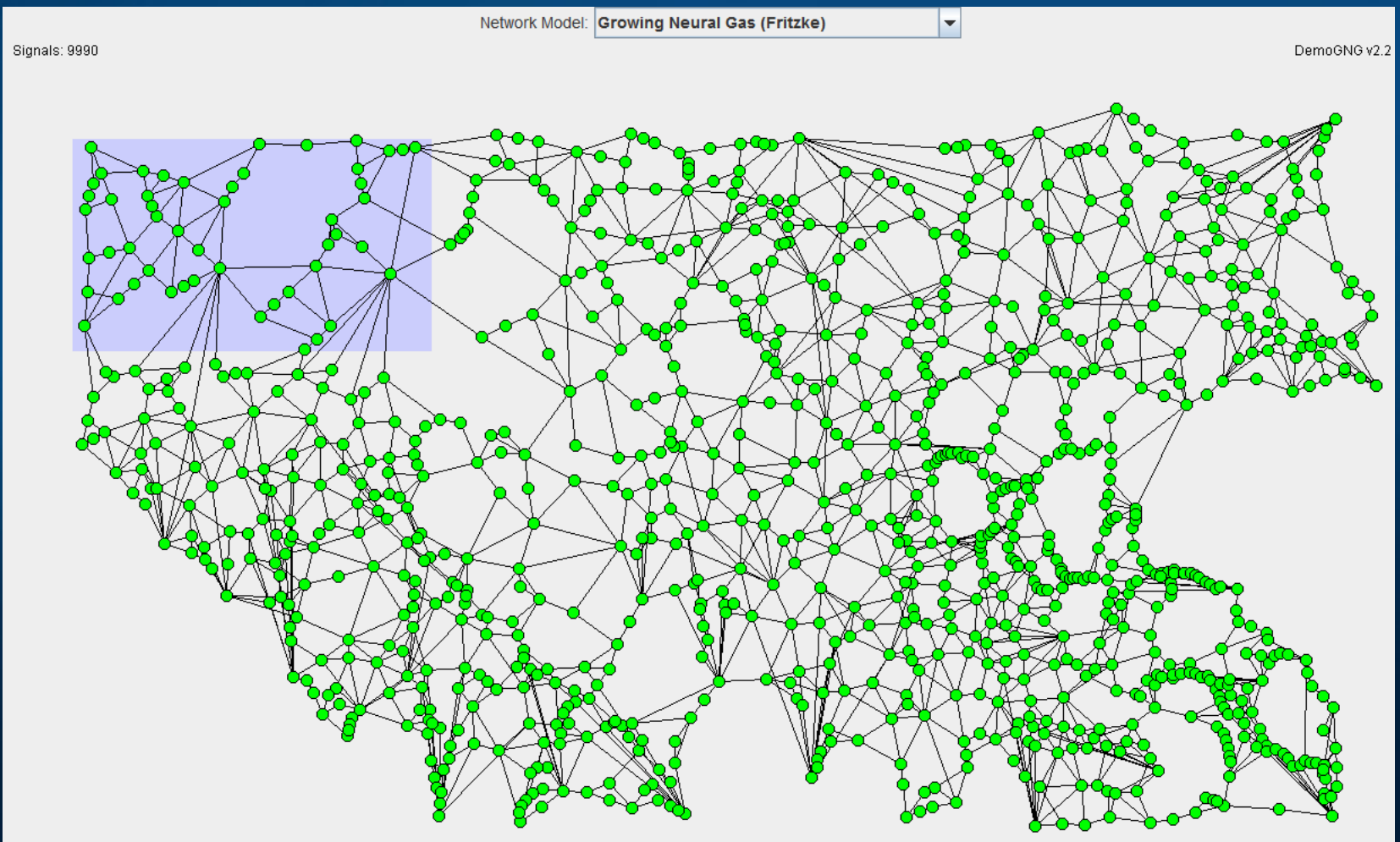
Internalization of environment

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



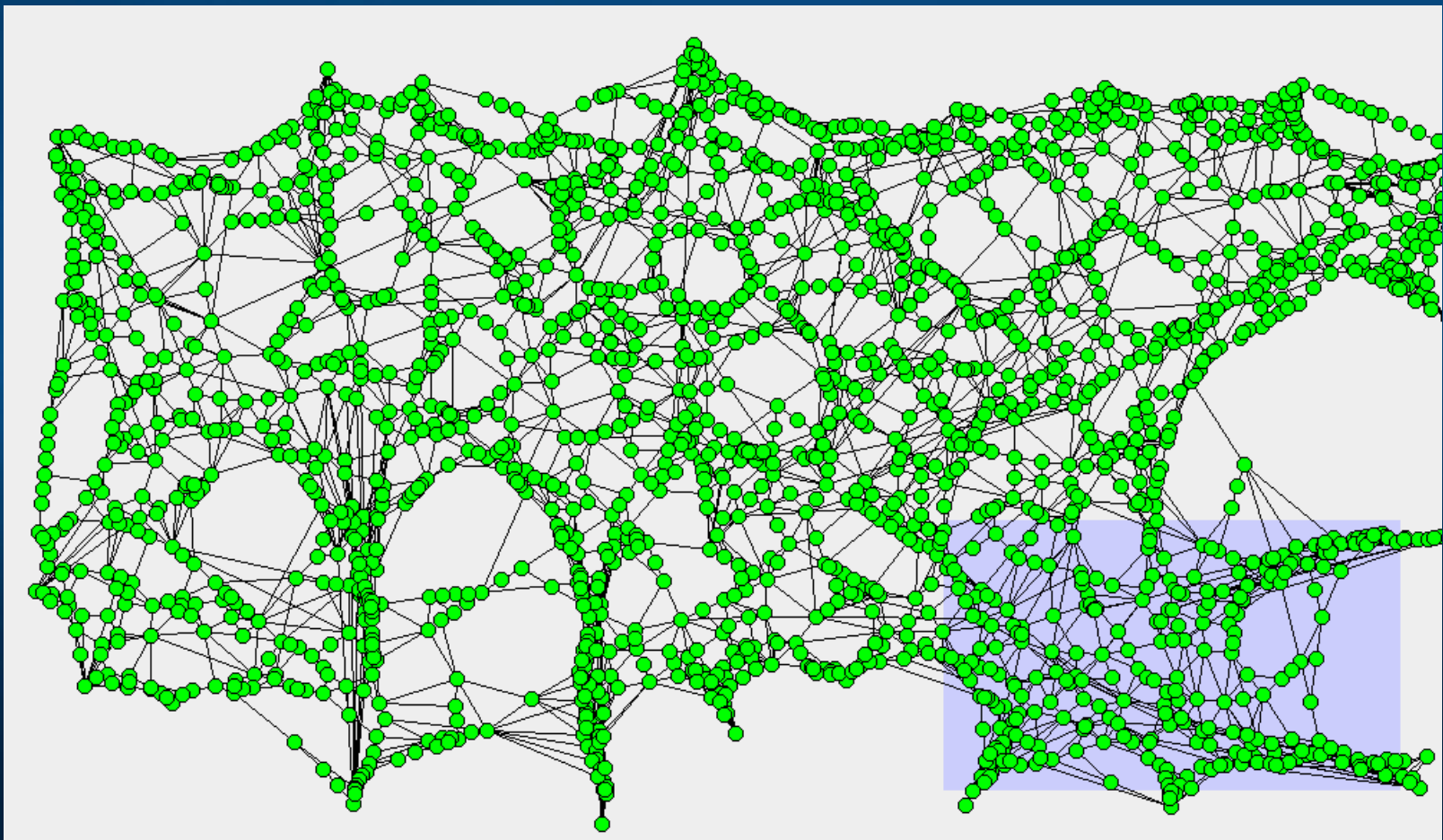
Extreme plasticity

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

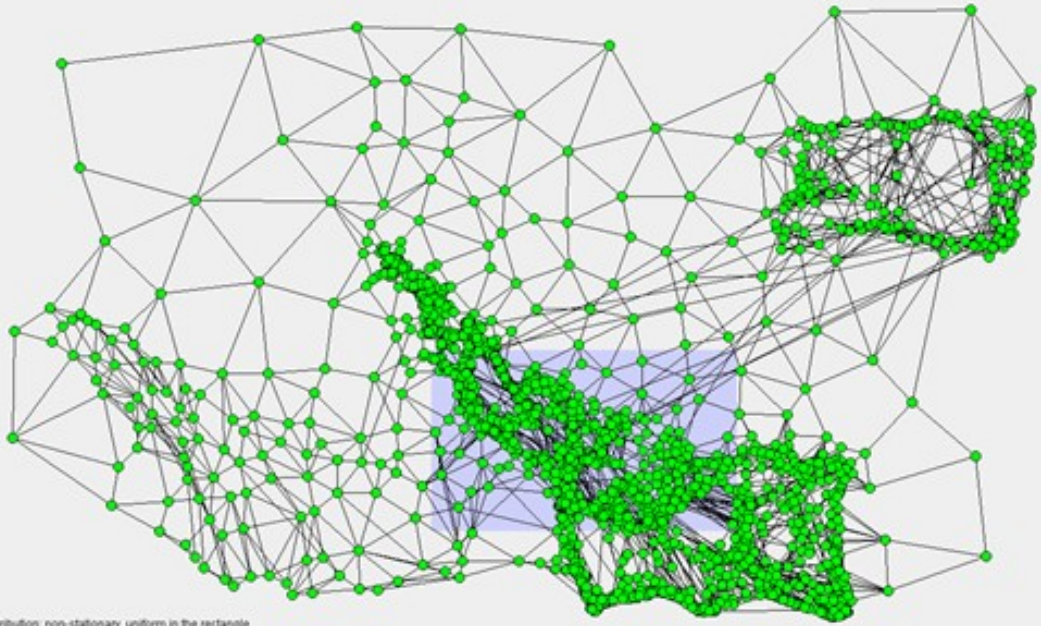
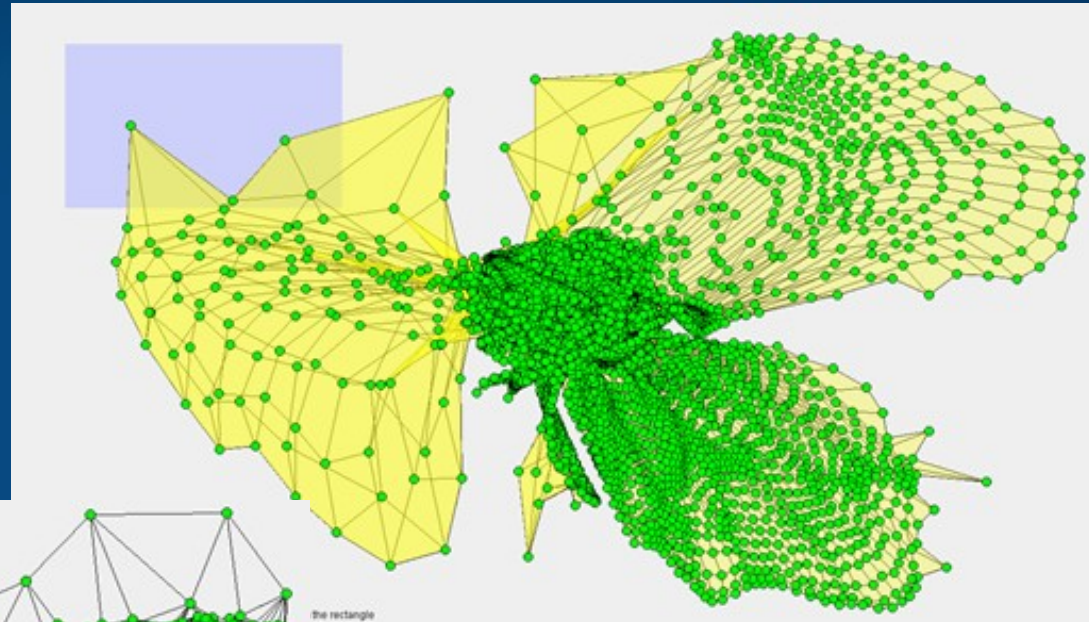
Illuminati, masons, Jews, UFOs, or twisted view of the world leaves big holes and admits simple explanations that save mental energy, creating „sinks” that attract many unrelated episodes.



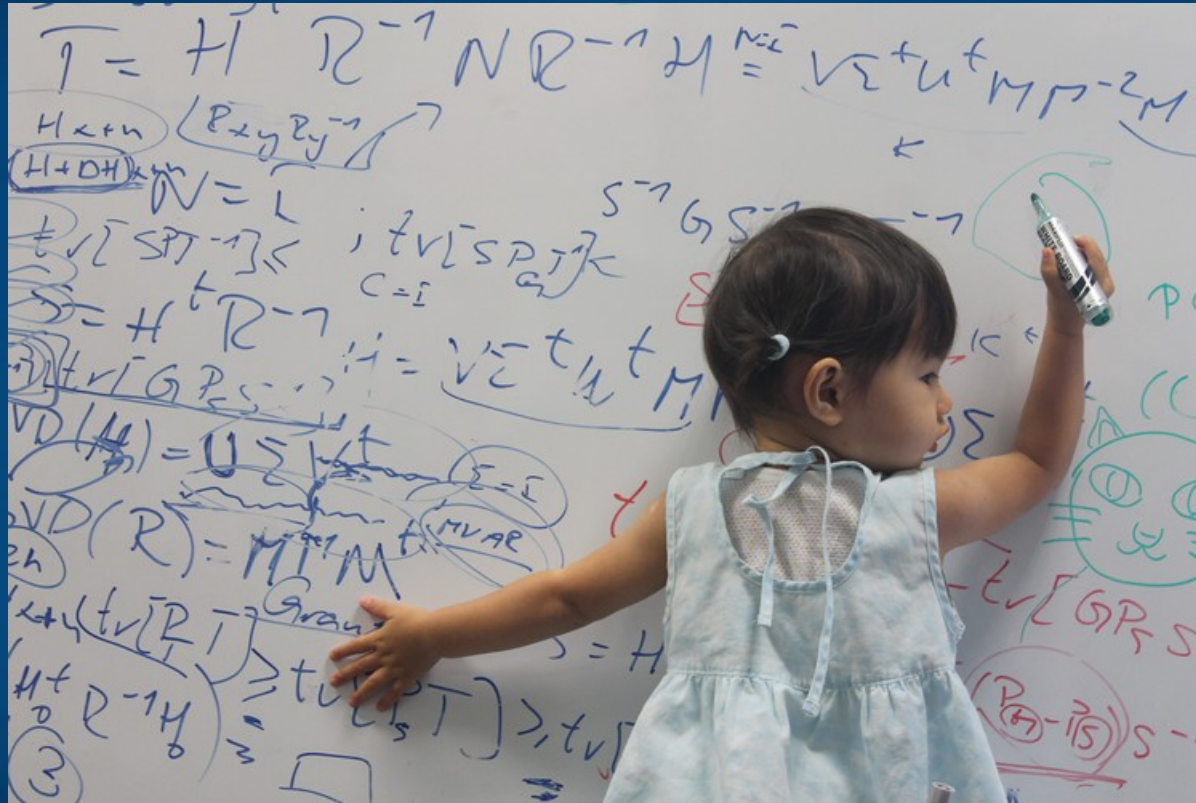
Memoids ...

Totally distorted world view,
mental processes are reduced
to a memplex ...

Ready to sacrifice oneself for a
great idea.

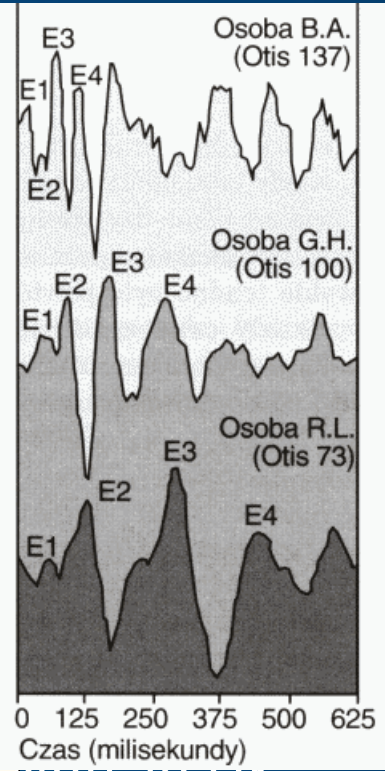
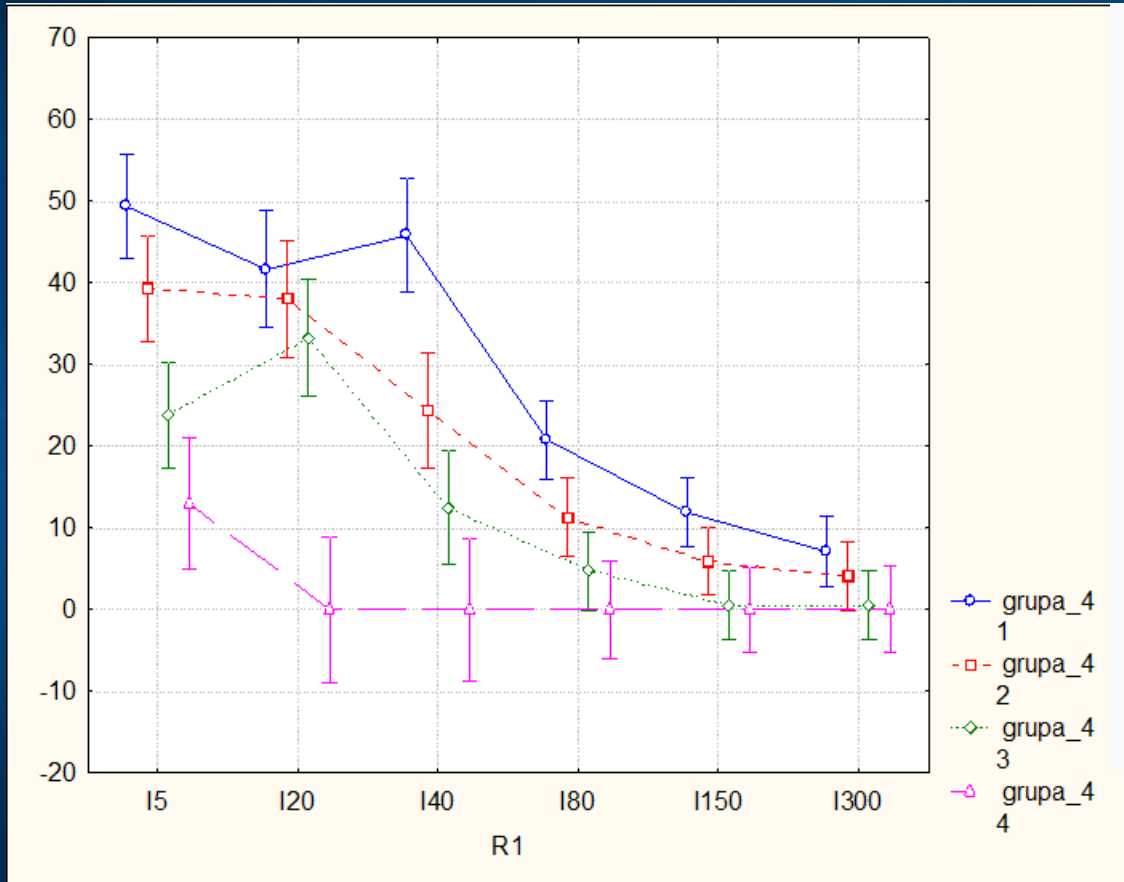
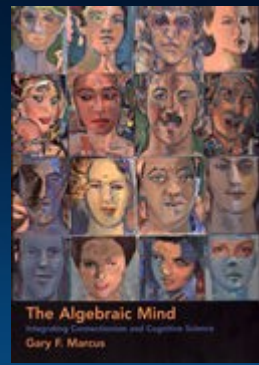


BabyLab, Neurocognitive Laboratory CMIT NCU



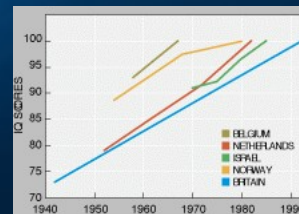
Development of speech perception in infants, discrimination of phonemes, development of auditory working memory – the key to unfold human potential, boost motivation and foundation for learning.

Abstract thinking



to very
ab).

brains?



Infants, syllables

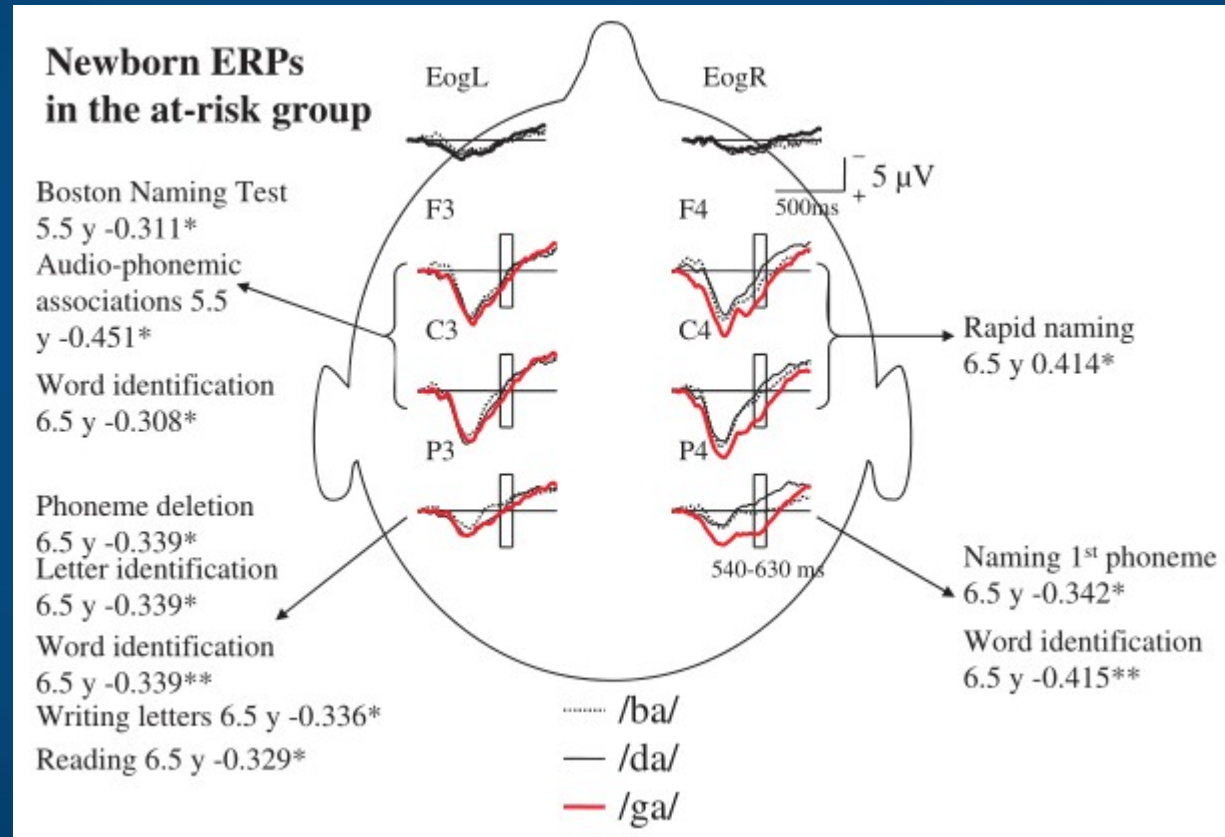


Brains of newborns react to ba/ga/da syllables in the 3–5 day of life in a way that allows for prediction of problems with learning to read years later.

(D. Molfesse, 2000).

Can we change it by training infants?

We hope so, this may be verified using ERPs. Infant's EEG is full of artifacts, big variance, longer phonemes give complex ERPs.



Infants, syllables



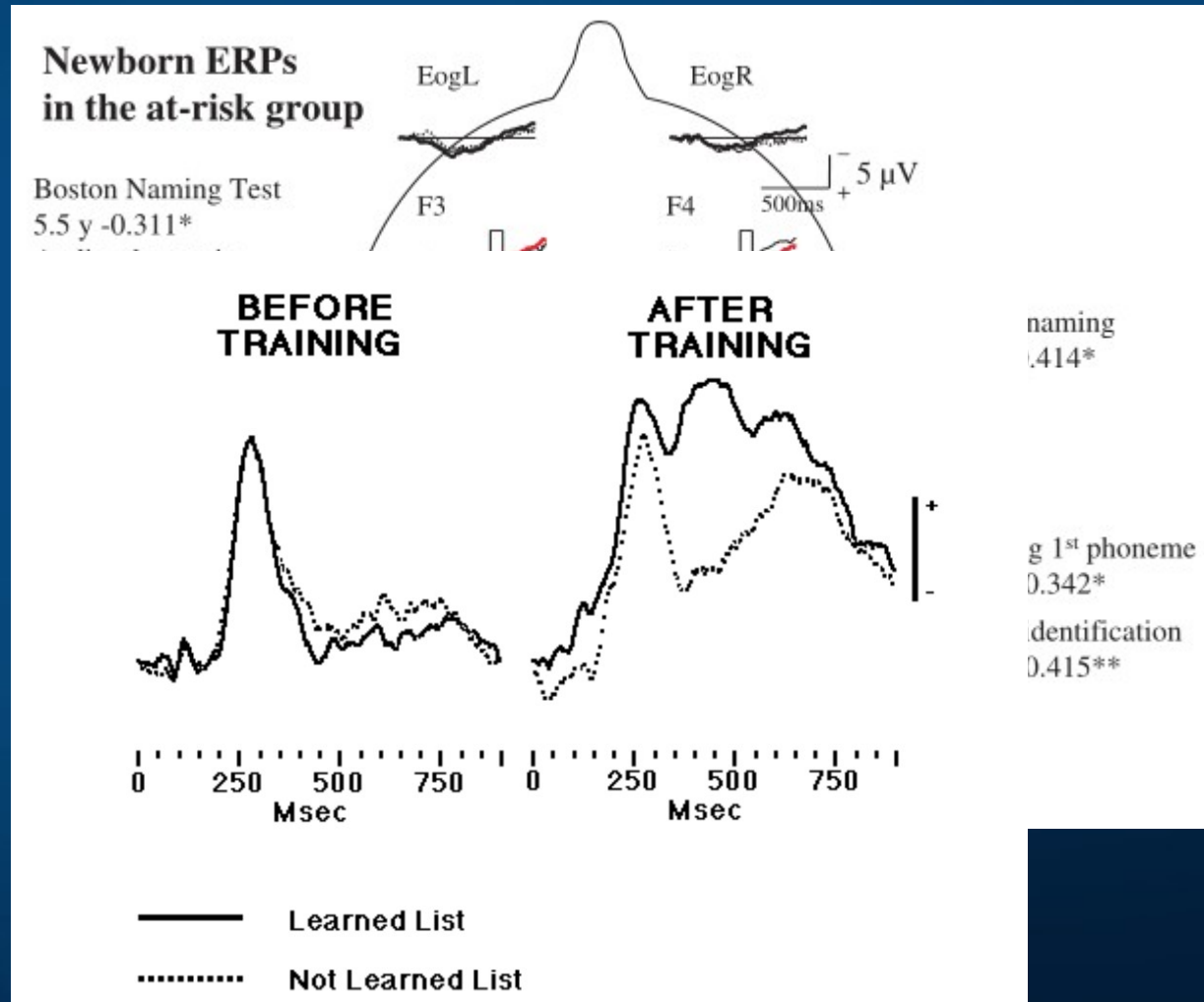
Brains of newborns react to ba/ga/da syllables in the 3–5 day of life in a way that allows for prediction of problems with learning to read years later.

(D. Molfesse, 2000).

Can we change it by training infants?

We hope so, this may be verified using ERPs.

Infant's EEG is full of artifacts, big variance, longer phonemes give complex ERPs.



Deaf people playing music?



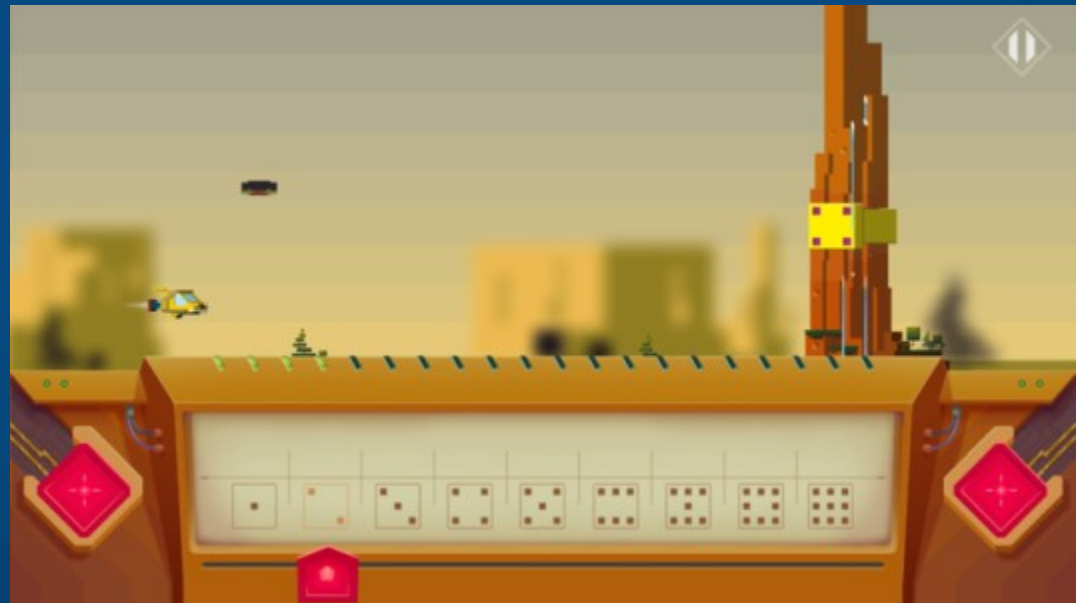
The World Hearing Institute (Warsaw) has been organizing music festivals where deaf people (mostly children) have performed. Speech understanding and music perception by deaf children **with cochlear implants** – filtering EEG artefacts.

Dyscalculia screening/therapy

Understanding numerosity, a new complex brain function, involves HIPS structure. **6-10%** of children in primary education suffer from dyscalculia, specific difficulties with learning mathematical concepts. Rarely diagnosed, most countries have no screening tests.

Goals:

1. Introduce screening test for the preschool/first class to identify children with the risk of dyscalculia.
 2. Short intensive training using computer game to associate mental number line with spatial dimensions.
- Further therapy is done by experts.

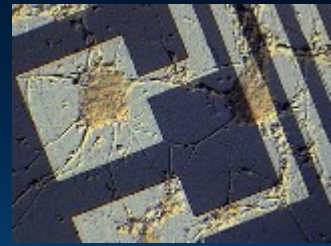


Understanding by creating brains

- “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.



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 $\sim 10^6$ neurons and $\sim 10^{10}$ 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 $\sim 16K$ synaptic inputs/neuron, integrated closed loop network-of-networks mimicking a distributed hierarchy of sensory, decision and motor cortical areas, linking perception to action.

Neuromorphic computers

Synapse 2015: IBM TrueNorth chip

~1M neurons and ¼G synapses, ok 5.4G tranzystorów.

NS16e module=16 chips=16M neurons, >4G synapses, requires only 1.1 W!

Scaling: 256 modules, ~4G neurons, ~1T= 10^{12} synapses < 300 W power!

IBM Neuromorphic System can reach **complexity of the human brain.**



Few Initiatives

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



IEEE SSCI The 4th IEEE Symposium on Computational Intelligence for Human-like Intelligence, Athens, Greece, 6-9.12.2016.

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

Brain-Mind Institute Schools, 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 (eds. Tan, Franklin, Duch).

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

Conclusions



Grand challenges are facing us
at every level!

Neurodynamics and neurocognitive phenomics
is the key.

Is there a shorter route
to understand human behavior?

I do not think so ...

Duch W, *Brains and Education: Towards Neurocognitive Phenomics* (2013)

Soul or brain: what makes us human?

Interdisciplinary Workshop, Torun

konferencja studencko-doktorancka
NeuroMania IV
28-29 maja 2016, Toruń


A stylized white line drawing of a cat's head in profile, facing right. Inside the head, a brain is depicted with a syringe needle inserted into it. The background is a solid teal color.A stylized globe with a grid of lines, set against a background of light rays and a blurred cityscape.

HOMO COMMUNICATIVUS
WSPÓŁCZESNE OBlicZA KOMUNIKACJI I INFORMACJI

Toruń, 24-25 VI 2013 r.

Two logos: a circular emblem with a sunburst pattern and a green square logo with a white geometric design.

Cognitivist Autumn in Toruń 2011
PHANTOMOLOGY:
the virtual reality of the body
2011 Torun, Poland

A detailed white line drawing of a human brain, viewed from a slightly elevated side angle.

Cognitivist Autumn in Toruń 2010
MIRROR NEURONS:
from action to empathy
April, 14-16 2010 Torun, Poland

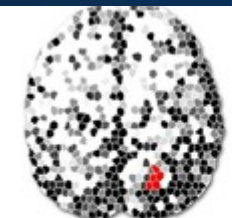
A stylized profile of a human head in shades of blue and white, facing right.

Infants, learning,
and cognitive
development.
29-30.10.16

Interdoctor: Disorders
of consciousness .
19-21.10.16

A silhouette of a human head in profile, filled with various colored puzzle pieces.

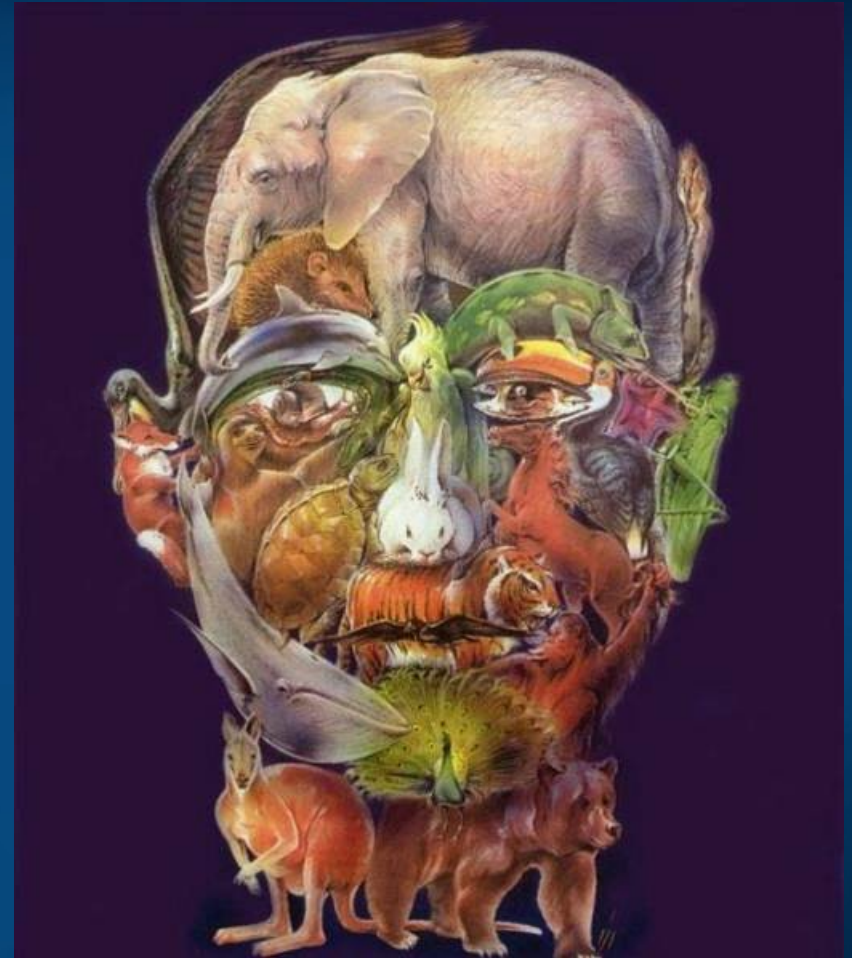
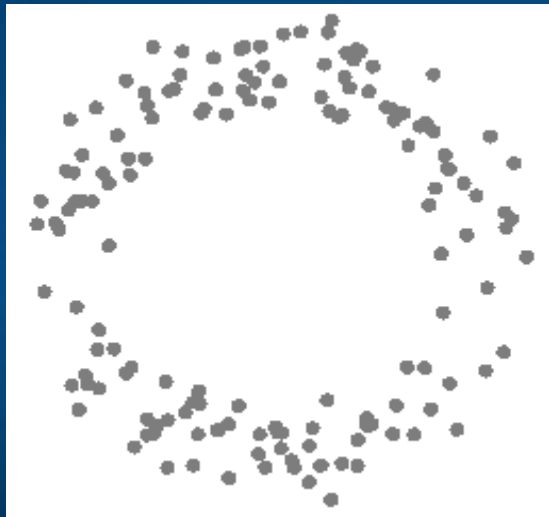
**COGNITIVIST
AUTUMN IN
TORUŃ**

A circular graphic composed of many small black and white dots, resembling a brain scan or a stylized brain.

NEURO

HISTORY OF ART

Thank you for
synchronization of
your neurons!



Google: Wlodziaw Duch
=> papers, talks, lectures ...

DI NCU Projects: CI



Computational intelligence (CI), main themes:

- Foundations of computational intelligence: meta-learning, transformation based learning, k-separability, learning hard boolean problems.
- Novel learning: projection pursuit networks, QPC (Quality of Projected Clusters), search-based neural training, Universal Learning Machines for transfer learning/learning from others (ULM), Support Feature Machines (SFM), almost Random Projection Machines (aRPM), and more ...
- Understanding of data: prototype-based rules, visualization of NN function and visualization of dynamic trajectories.
- 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.

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.