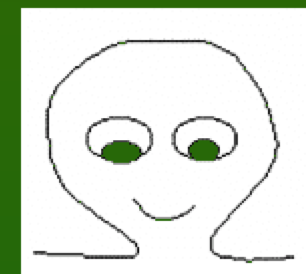
Neurolinguistics
What do we want to achieve?



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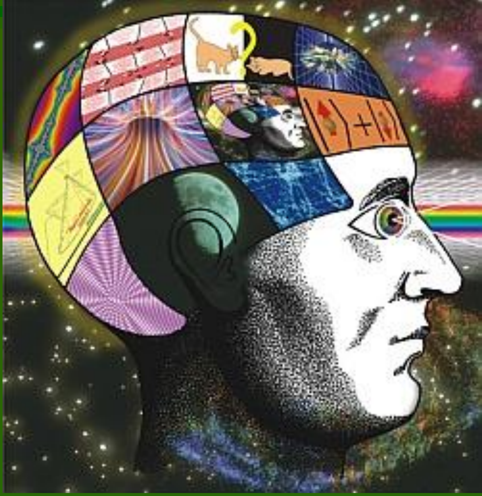
Google: W. Duch

45th Poznań Linguistic Meeting (PLM2015),

The problem



How do brains, using massively parallel computations, represent knowledge and perform thinking?

- **L. Boltzmann** (1899): “All our ideas and concepts are only internal pictures or if spoken, combinations of sounds.” „The task of theory consists in constructing an image of the external world that exists purely internally …”.
- **L. Wittgenstein** (Tractatus 1922): thoughts are pictures of how things are in the world, propositions point to pictures.
- **Kenneth Craik** (1943): the mind constructs "small-scale models" of reality to anticipate events, to reason, and help in explanations.
- **P. Johnson-Laird** (1983): mental models are psychological representations of real, hypothetical or imaginary situations.
- **J. Piaget**: humans develop a context-free deductive reasoning scheme at the level of elementary FOL.

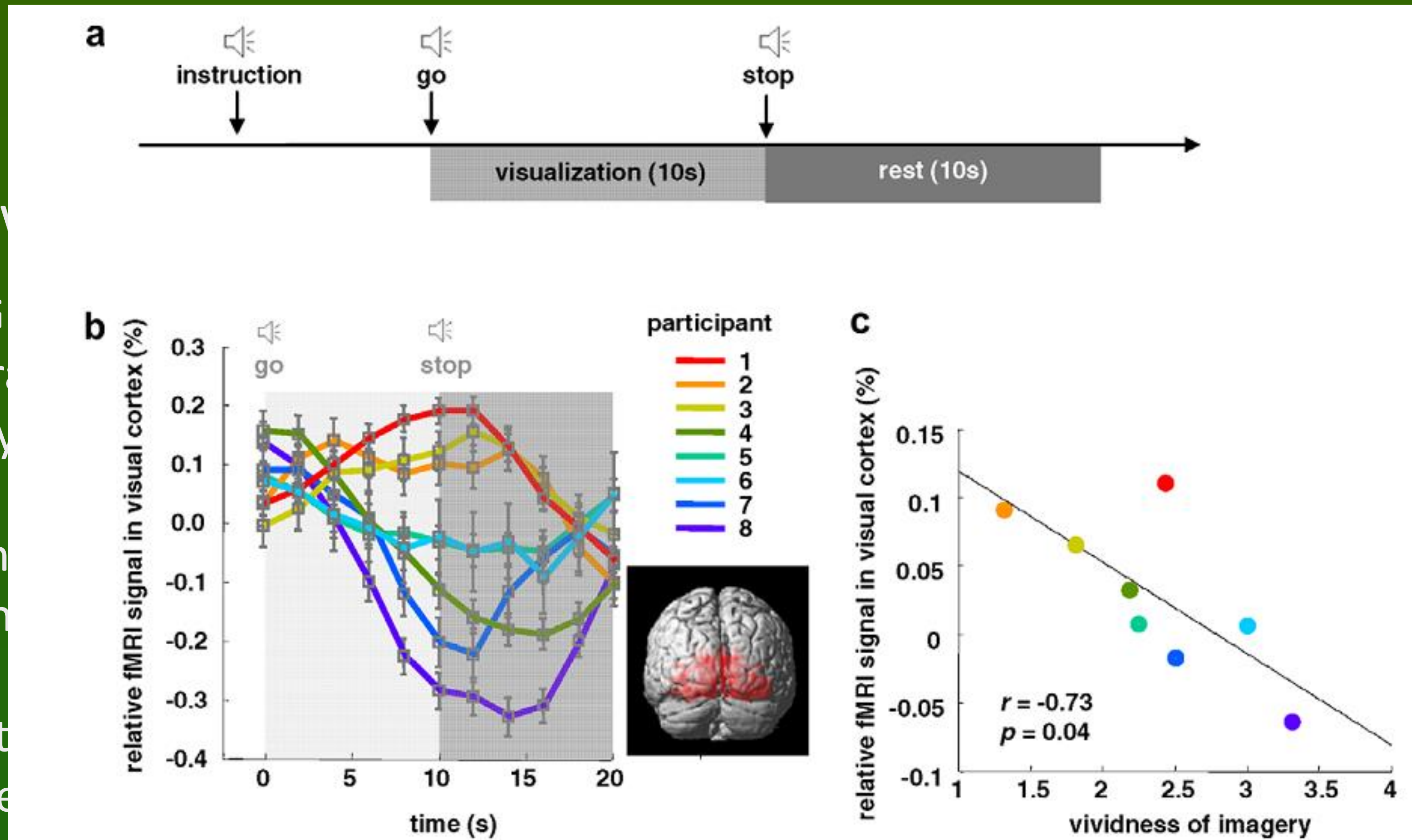
Pictures? Logic? Both? What really happens in the brain?

How and

- Borst, G
  structur
  Memory

The presen
information

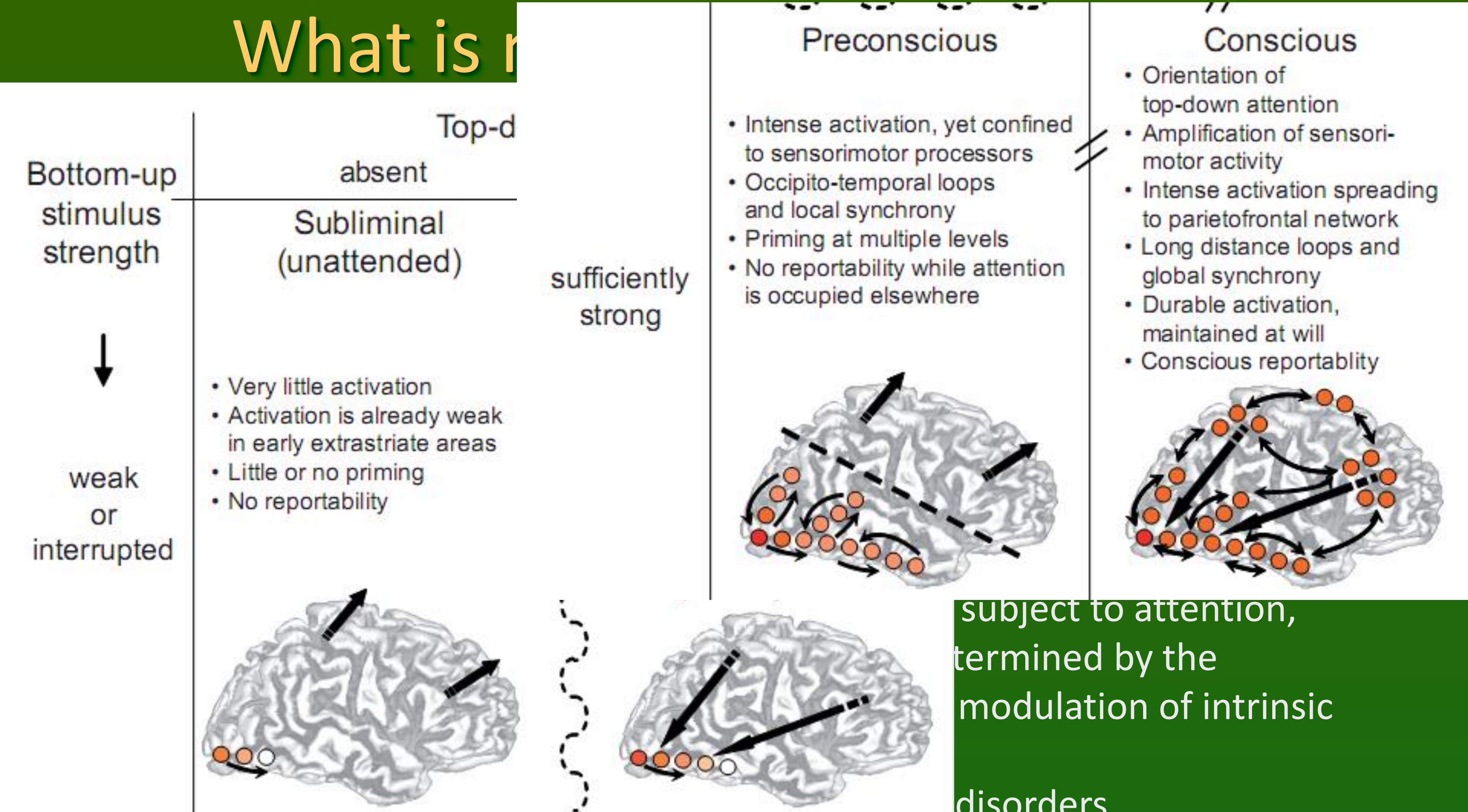
- Cui, X et
  measure



Reported Vividness of Visual Imagination (VVIQ) correlates well with the early visual cortex activity relative to the whole brain activity measured by fMRI (r=-0.73), and the performance on a novel psychophysical task.
Findings emphasize the importance of examining individual subject variability.

Poor perceptual imagery: why? Weak top-down influences?
Unable to draw from memory, describe details, faces, notice changes, etc.

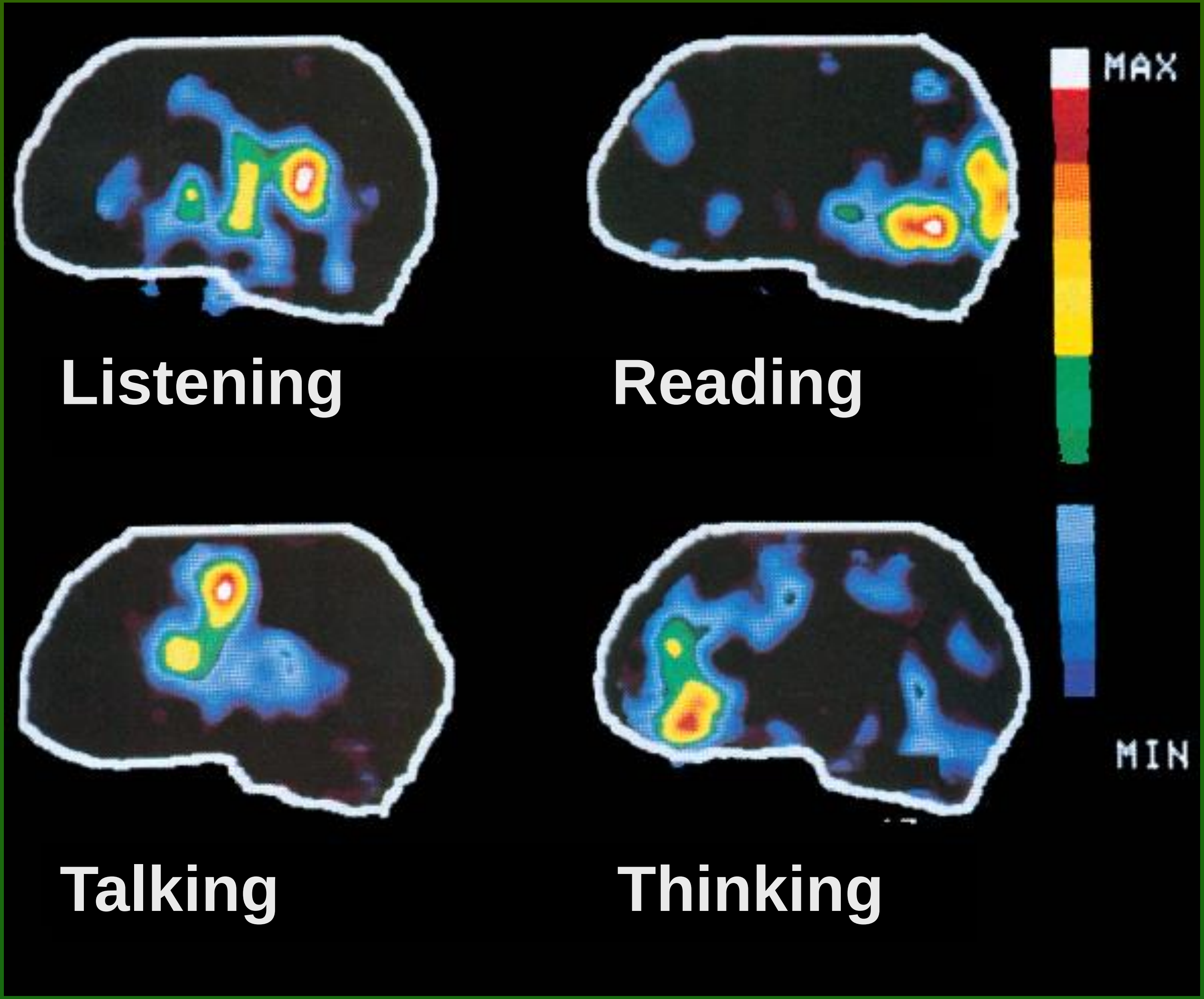
What is r



subject to attention,
termined by the
modulation of intrinsic

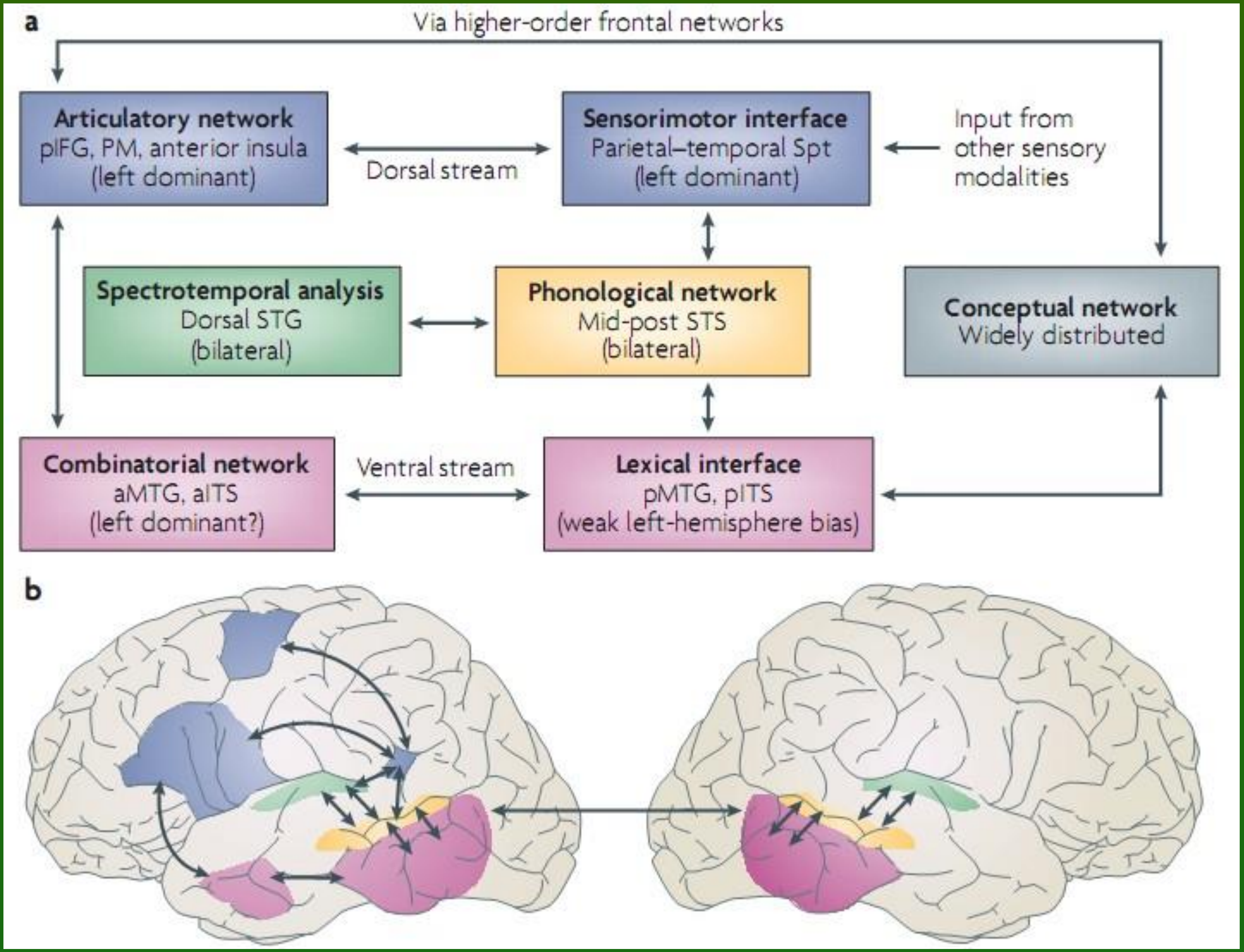
disorders.

Dehaene et al, Conscious, preconscious, and subliminal processing, TCS 2006
Bottom-up strength & top-down attention combined leads to 4 brain states with both stimulus and attention required for conscious reportability. No imagery?



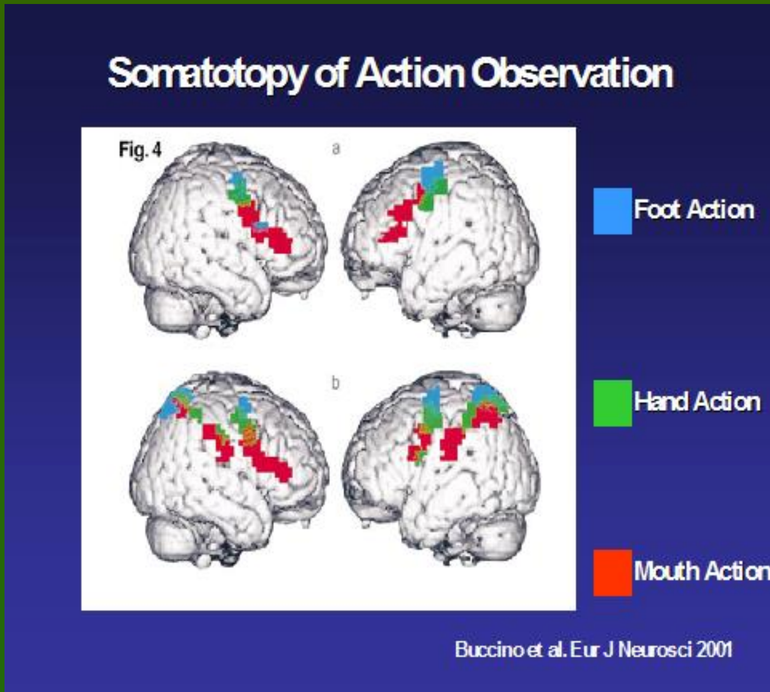
Listening
Reading
Talking
Thinking
MAX
MIN

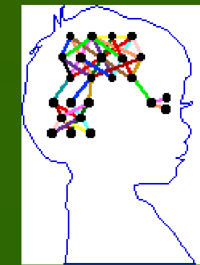
Speech in the brain



How should a concept meaning be represented?

s in the brain





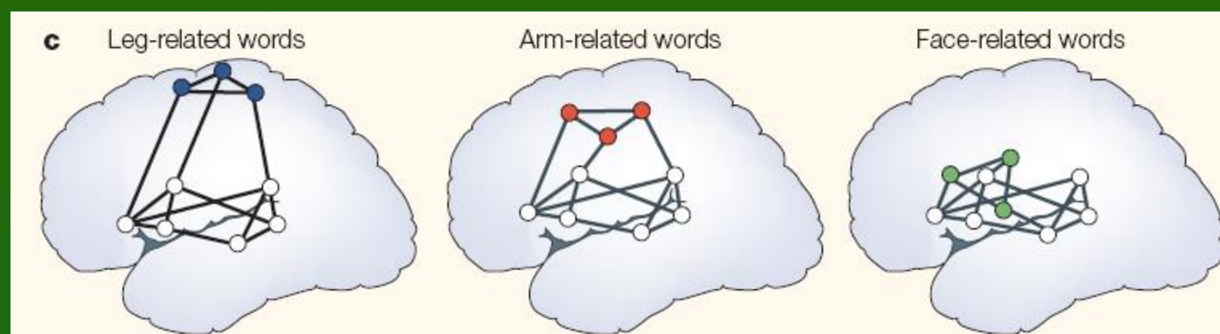
how that most likely categorical,
re used, not the acoustic input.

> words => semantic concepts.

des semantic by 90 ms (from N200 ERPs).

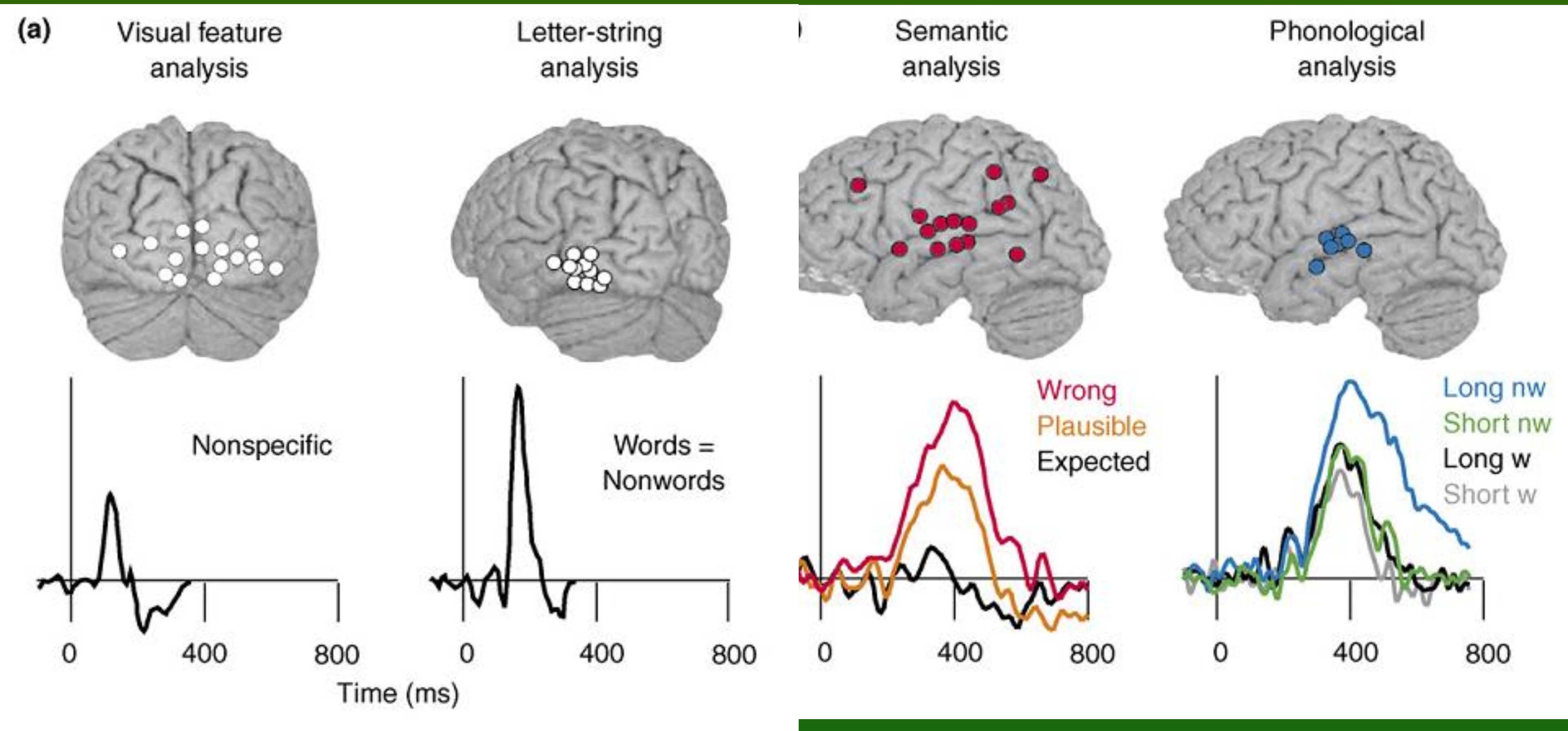
uroscience of Language. On Brain Circuits of
ridge University Press.

Action-perception networks inferred from ERP and fMRI



Left hemisphere: precise representations of symbols, including phonological components; right hemisphere? Sees clusters of concepts.

Reading Brain

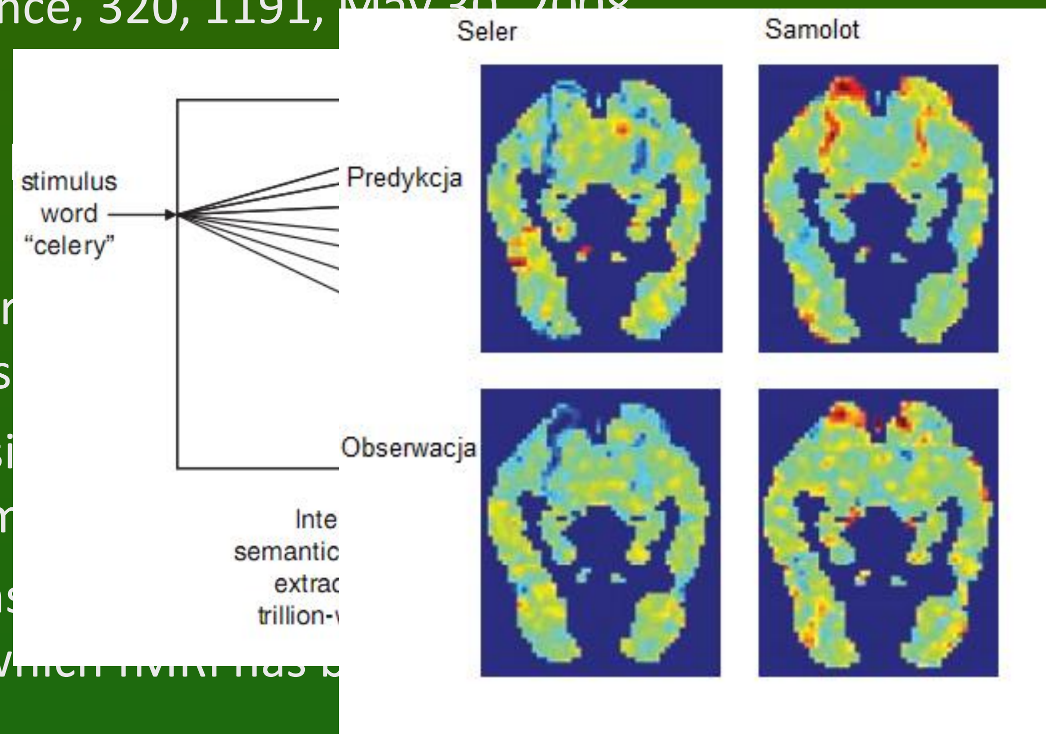


R. Salmelin, J. Kujala, Neural representation of language: activation versus long-range connectivity. TICS 10(11), 519-525, 2006 (MEG activity patches)

Neuroimaging words

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

- Clear differences between fMRI about different nouns.
- Reading words and seeing the dr presumably reflecting semantics
- Although individual variance is si of different people, a classifier m
- Model trained on ~10 fMRI scans activity for over 100 nouns for w



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

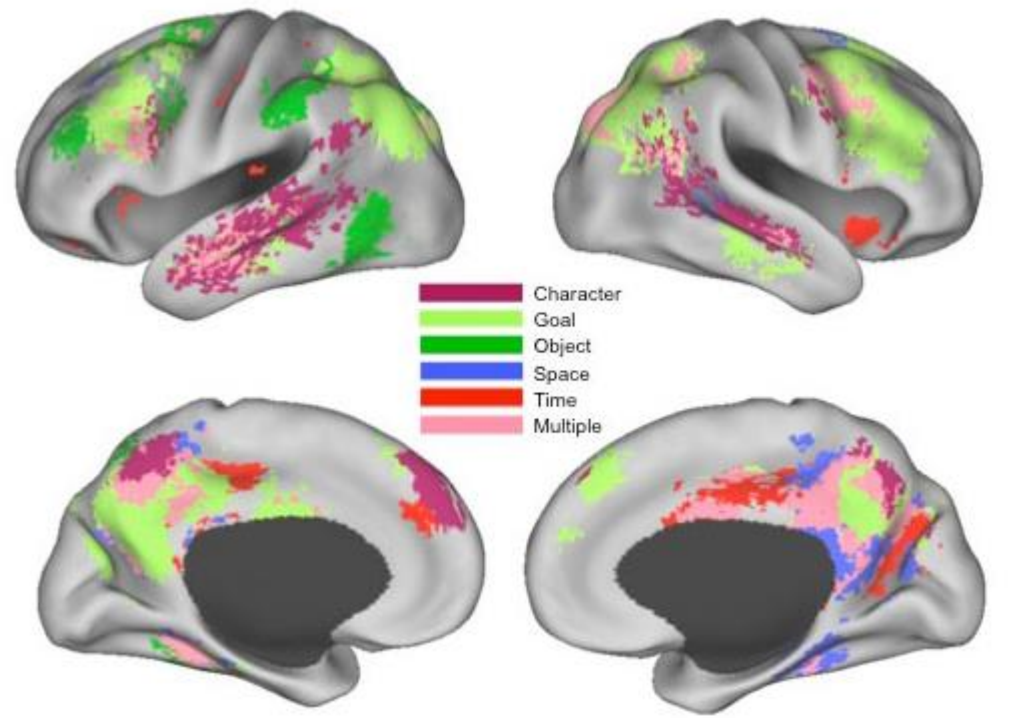
In future: I may know what you'll think before you will know it yourself! Intentions may be known seconds before they become conscious!

Nicole Speer et al.
Reading Stories Activates Neural Representations of Visual and Motor Experiences.
Psychological Science (2010, in print).
Meaning: always slightly different, depending on the context, but still may be clusterized into relatively samll number of distinct meanings.

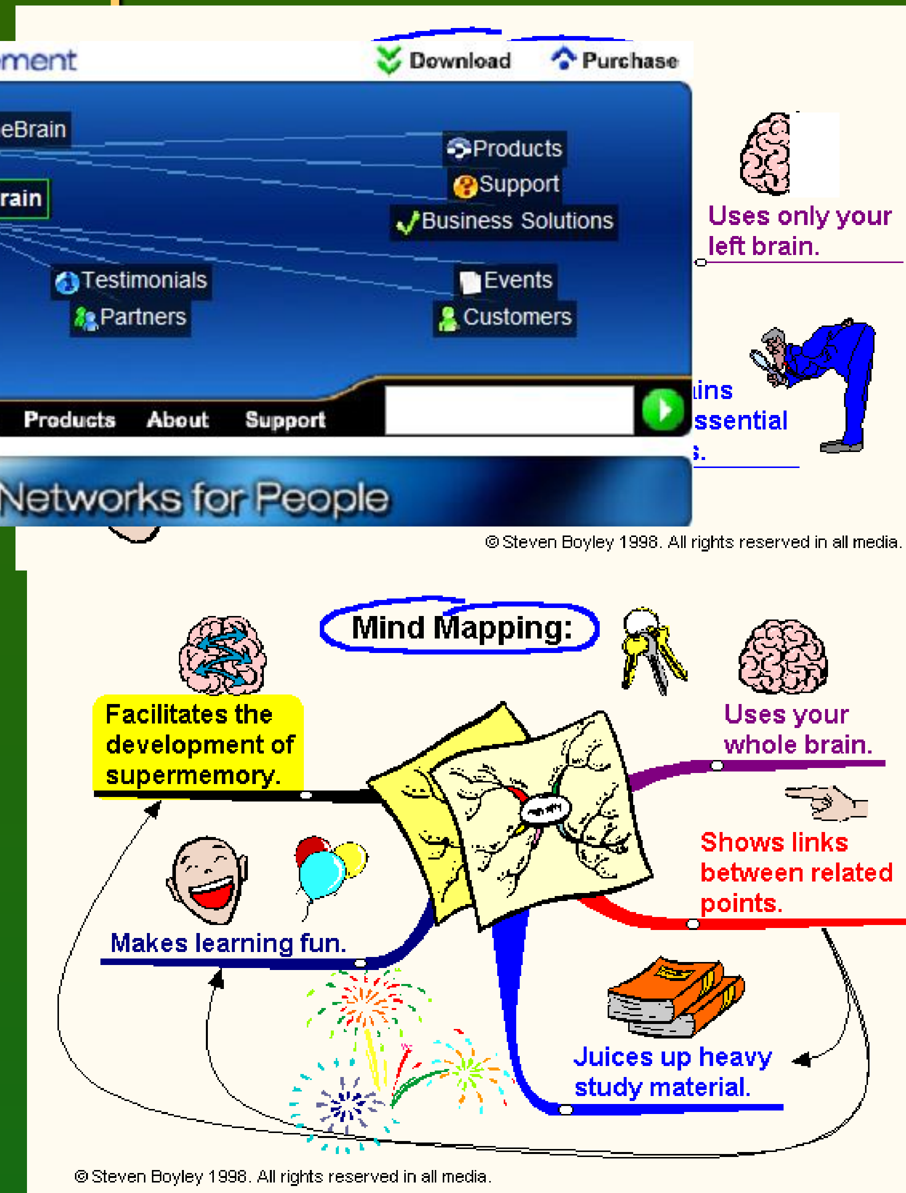
A

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



Brain maps



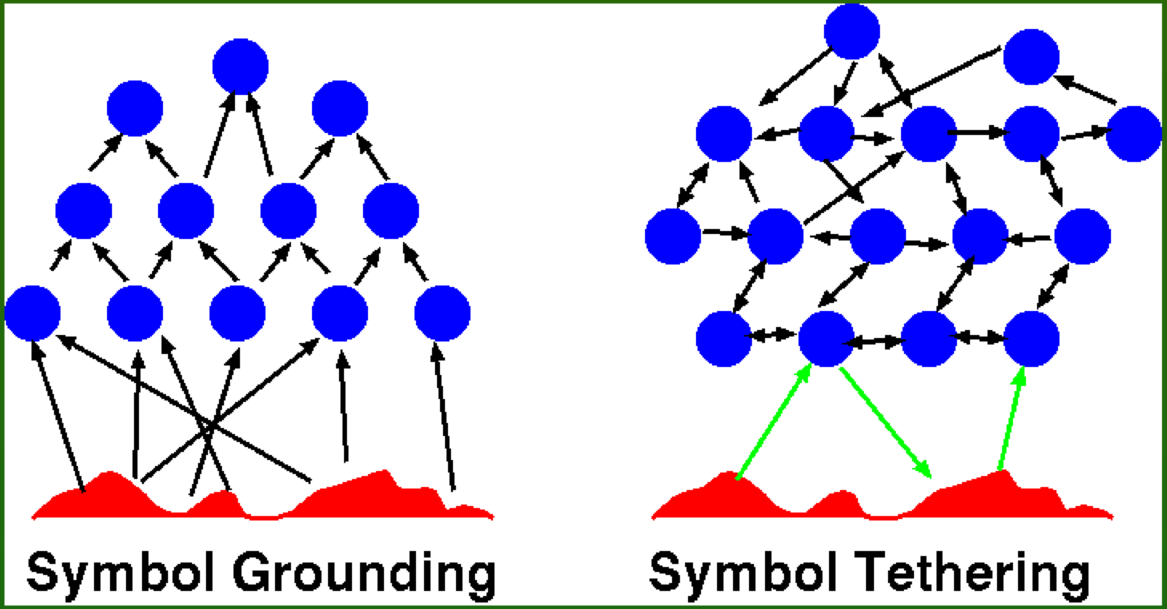
interface making hierarchical maps of Internet links.

- Other software for graphical representation of info.
- Our implementation (Szymanski): Wordnet, Wikipedia graphs extension to similarity is coming.

Where is the meaning?

How should a concept meaning be represented?

- No representations, only senso-motoric embodiment (robotics).
- Only some concepts have shared meaning through embodiment.



Aaron Sloman (2007): only simple concepts come from our "being in the world"experience, others are compounds, abstract.
David Hume gave good example: "golden mountain".

Not symbol grounding but symbol tethering, meaning from mutual interactions.

Logic and language

Logic arguments: if both X and Z then not Y, or If Y then either not X ot not Z, sentential connectives

Linguistic arguments: It was X that Y saw Z take, or Z was seen by Y taking X, phrasal verbs.

The ability to use logic and understand language may dissociate.

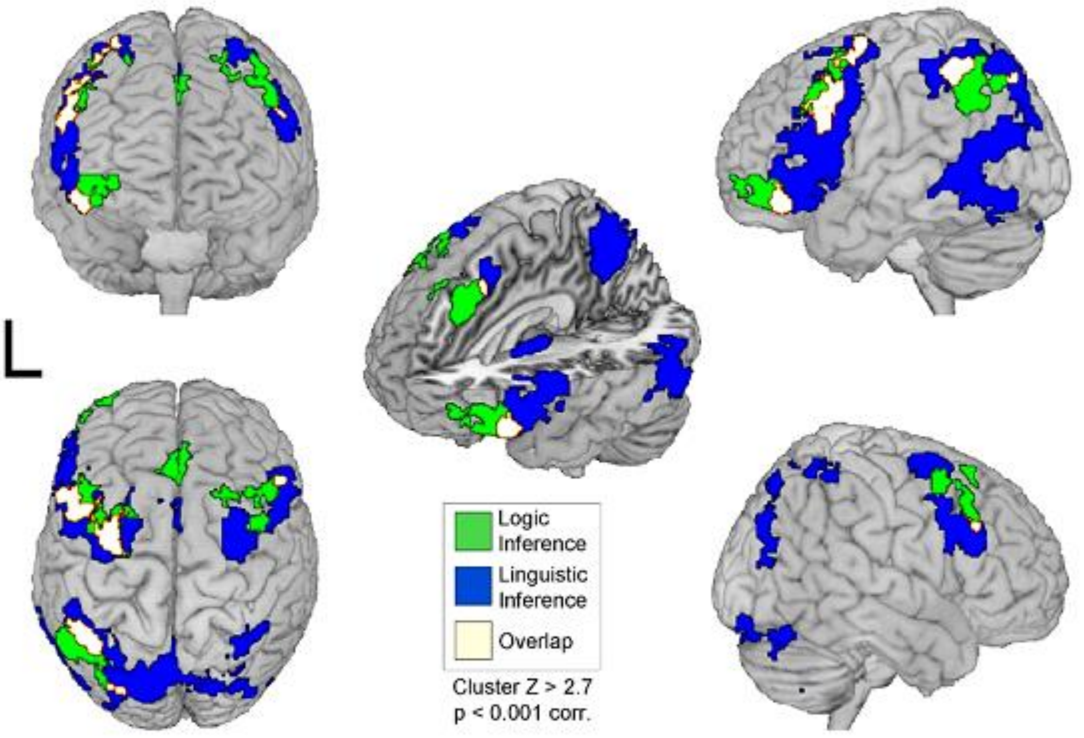
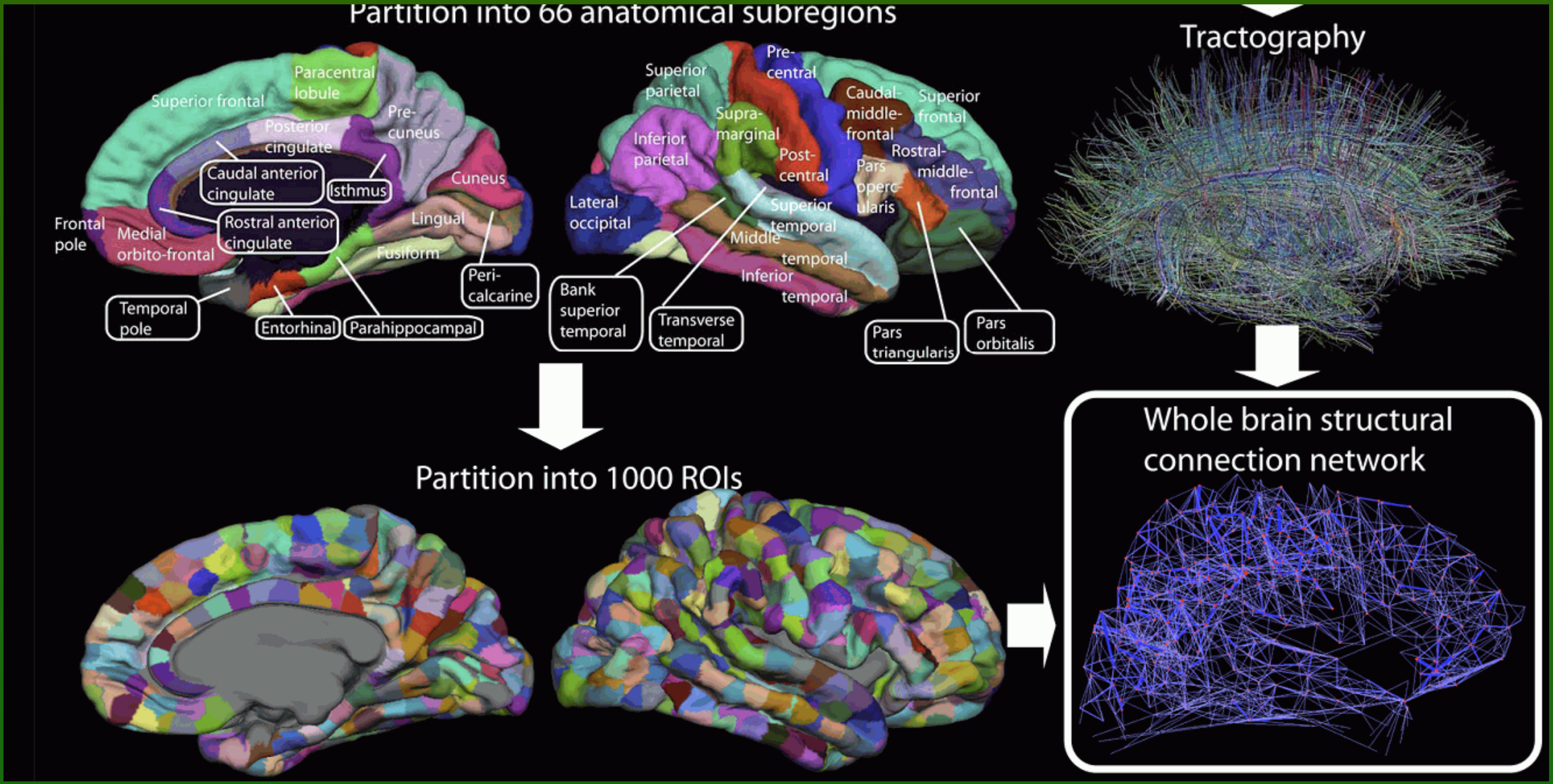


Fig. 1. Inference minus grammar contrast. Mean group activity for logic arguments (green/yellow) and linguistic arguments (blue/yellow).

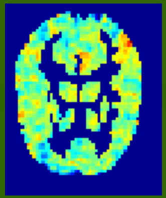
M.M. Monti, L.M. Parsons, D.N. Osherson, The boundaries of language and thought: neural basis of inference making. PNAS 2009

Connectome



Partition into 66 anatomical subregions
Paracentral lobule
Superior frontal
Posterior cingulate
Pre-cuneus
Caudal anterior cingulate
Isthmus
Cuneus
Frontal pole
Medial orbito-frontal
Rostral anterior cingulate
Lingual
Fusiform
Peri-calcarine
Temporal pole
Entorhinal
Parahippocampal
Superior parietal
Pre-central
Caudal-middle-frontal
Superior frontal
Supra-marginal
Inferior parietal
Post-central
Pars operc-ularis
Rostral-middle-frontal
Lateral occipital
Superior temporal
Middle temporal
Inferior temporal
Bank superior temporal
Transverse temporal
Pars triangularis
Pars orbitalis
Tractography
Partition into 1000 ROIs
Whole brain structural connection network

Hidden concepts



- **Language**, symbols in the brain: phonological labels associated with protypes of distributed activations of the brain.

Helps to structure the flow of brain states in the thinking process.

Do we have conscious access to all brain states that influence thinking?

Right hemisphere activations just give us the feeling wrong something here.

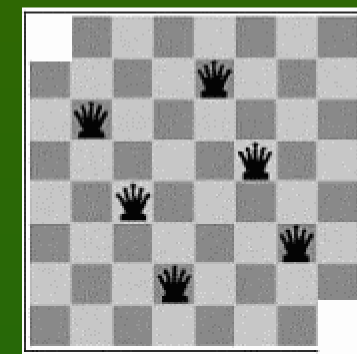
- Right hemisphere is as busy as left – concepts without verbal labels?
- Evidence: insight phenomena, intuitive understanding of grammar, etc.

Can we describe verbally natural categories?

- Yes, if they are rather distinct: see 20 question game.
- Is object description in terms of properties sufficient and necessary?
- Not always. Example: different animals and dog breeds.
- 20Q-game: weak question (seemingly unrelated to the answer) may lead to precise identification! RH may contribute to activation enabling associations

Problems requiring insights

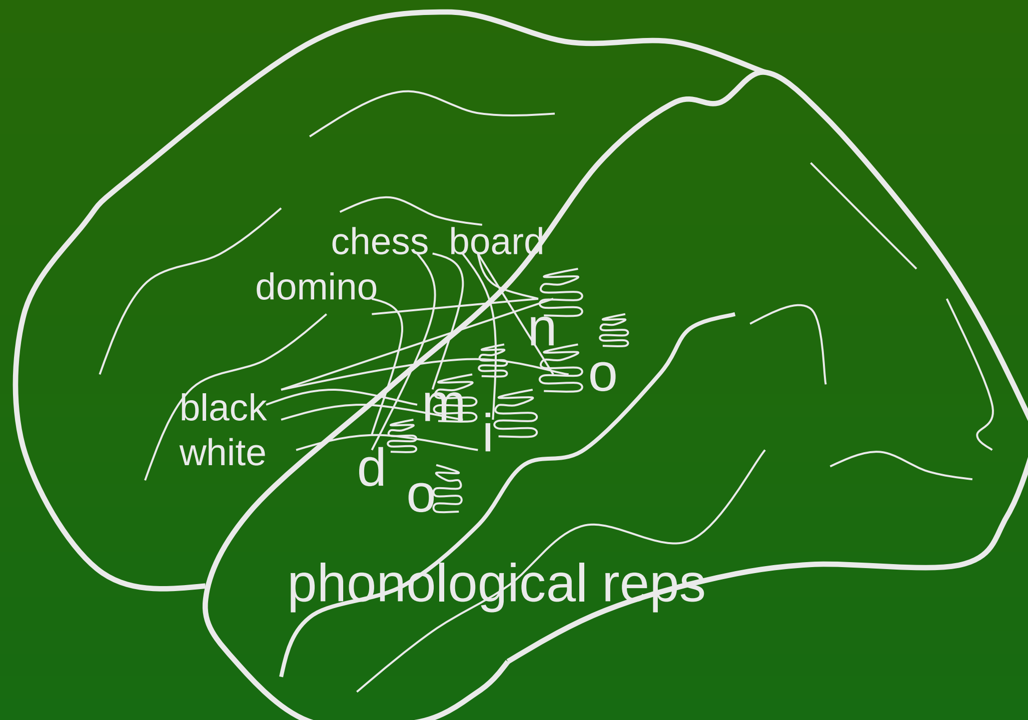
Given 31 dominos  and a chessboard with 2 corners removed, can you cover all board with dominos?



Analytical solution: try all combinations.

Does not work … to many combinations to try.

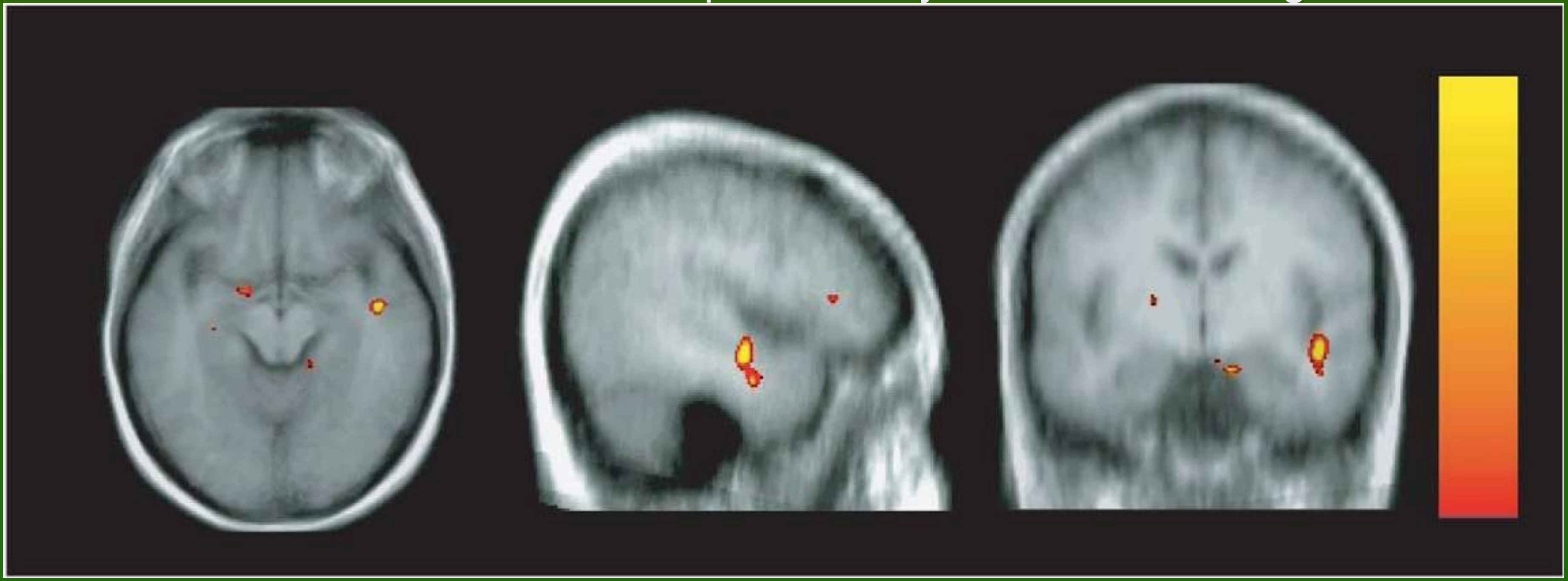
Logical, symbolic approach has little chance to create proper activations in the brain, linking new ideas: otherwise there will be too many associations, making thinking difficult.



Insight <= right hemisphere, meta-level representations without phonological (symbolic) components ... counting?

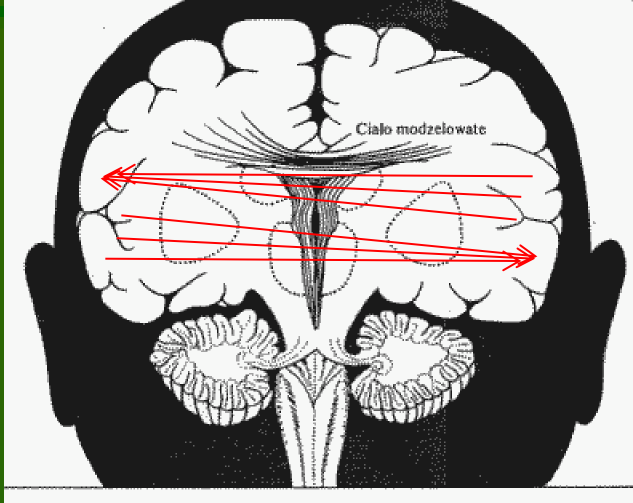
Insights and brains

Activity of the brain while solving problems that required insight and that could be solved in schematic, sequential way has been investigated.



An increased activity of the right hemisphere anterior superior temporal gyrus (RH-aSTG) was observed during initial solving efforts and insights. About 300 ms before insight a burst of gamma activity was observed, interpreted by the authors as „making connections across distantly related information during comprehension ... that allow them to see connections that previously eluded them”.

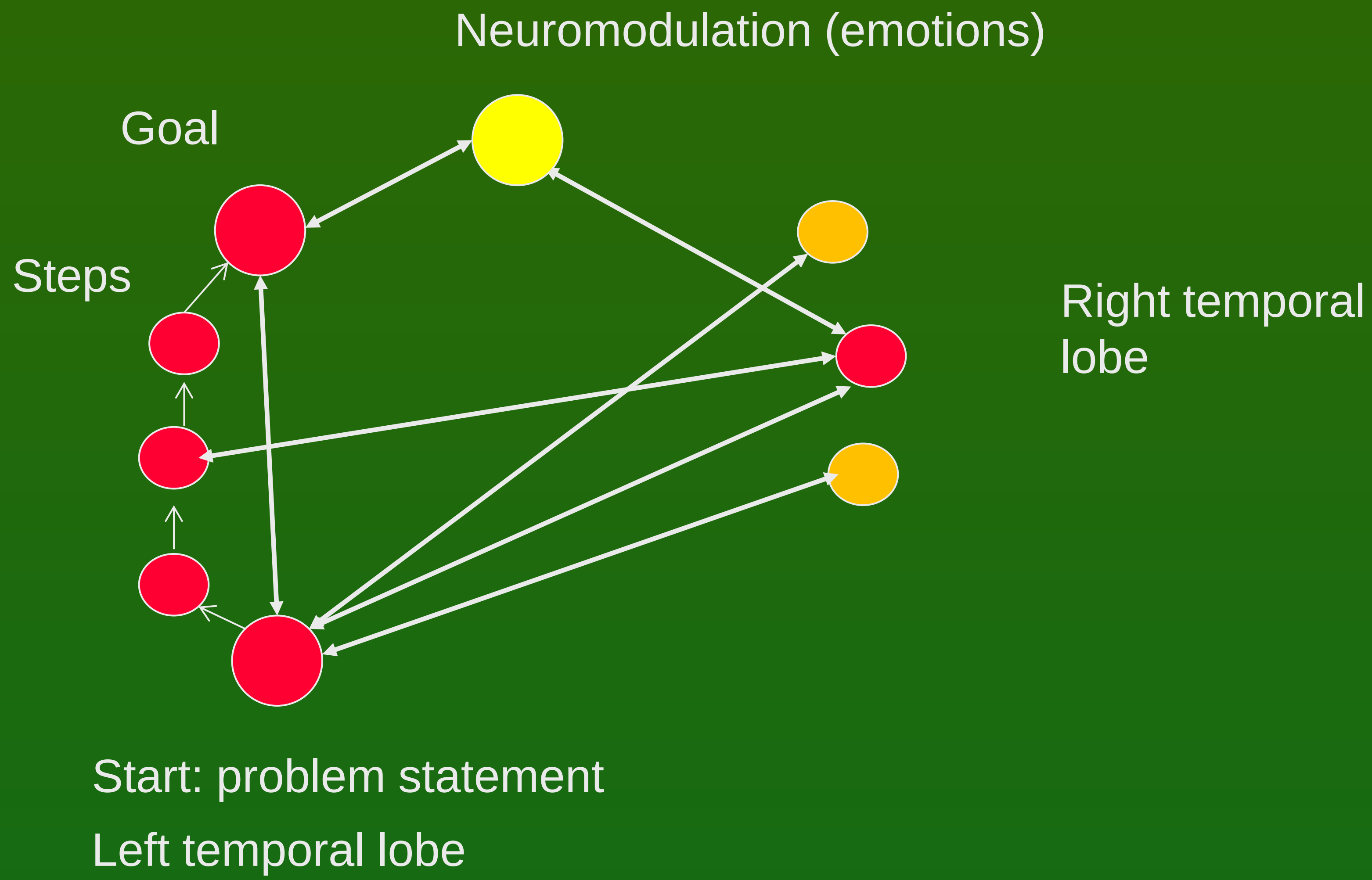
Insight interpreted



What really happens? My interpretation:

- LH-STG represents concepts, S=Start, F=final
- understanding, solving = transition, step by step, from S to F
- if no connection (transition) is found this leads to an impasse;
- RH-STG ‘sees’ LH activity on meta-level, clustering concepts into abstract categories (cosets, or constrained sets);
- connection between S to F is found in RH, leading to a feeling of vague understanding;
- gamma burst increases the activity of LH representations for S, F and intermediate configurations; feeling of imminent solution arises;
- stepwise transition between S and F is found;
- finding solution is rewarded by emotions during Aha! experience; they are necessary to increase plasticity and create permanent links.

Solving problems with insight



Dog breeds

329 breeds in 10 categories:

Sheepdogs and Cattle Dogs; Pinscher and Schnauzer; Spitz and Primitive; Scenthounds; Pointing Dogs; Retrievers, Flushing Dogs and Water Dogs; Companion and Toy Dogs; Sighthounds

Write down properties and try to use them in the 20-question game to recognize the breed … fails!

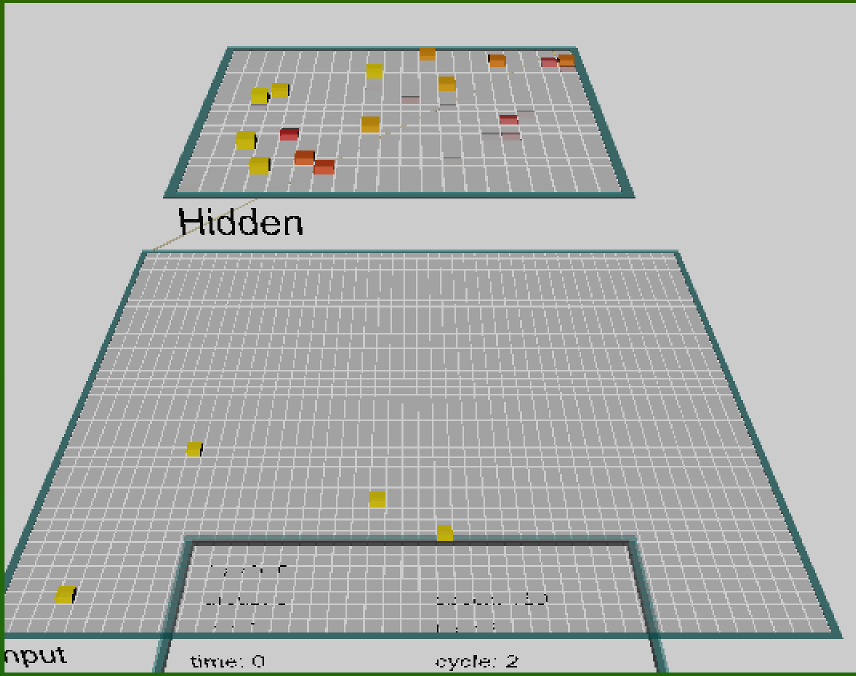
Visually each category is quite different,
all traditional categorizations are based on behavious and features that are not easy to observe.

- Ontologies do not agree with visual similarity.
- Brains discover it easily => not all brain states have linguistic labels.

Dog behavior

Simple mindless network

Inputs = words, 1920 selected from a 500 pages book (O'Reilly, Munakata, Explorations book, this example is in Chap. 10). 20x20=400 hidden elements, with sparse connections to inputs, each hidden unit trained using Hebb principle, learns to react to correlated or similar words. For example, a unit may point to synonyms: act, activation, activations.



Compare distribution of activities of hidden elements for two words A, B, calculating $\cos(A,B) = A*B/|A||B|$.

Activate units corresponding to several words: A="attention", B="competition", gives cos(A,B)=0.37. Adding "binding" to "attention" gives cos(A+C,B)=0.49.

This network is used on multiple choice test.

Multiple-choice Quiz

0.	neural activation function	5.	attention
A	spiking rate code membrane potential pt	A	competition inhibition selection binding
B	interactive bidirectional feedforward	B	gradual feature conjunction spatial invariance
C	language generalization nonwords	C	spiking rate code membrane potential point
1.	transformation	6.	weight based priming
A	emphasizing distinctions collapsing diffs	A	long term changes learning
B	error driven hebbian task model based	B	active maintenance short term residual
C	spiking rate code membrane potential pt	C	fast arbitrary details conjunctive
2.	bidirectional connectivity	7.	hippocampus learning
A	amplification pattern completion	A	fast arbitrary details conjunctive
B	competition inhibition selection binding	B	slow integration general structure
C	language generalization nonwords	C	error driven hebbian task model based
3.	cortex learning	8.	dyslexia
A	error driven task based hebbian model	A	surface deep phonological reading problem
B	error driven task based	B	speech output hearing language nonwords
C	gradual feature conjunction spatial invar	C	competition inhibition selection binding
4.	object recognition	9.	past tense
A	gradual feature conjunction spatial invar	A	overregularization shaped curve
B	error driven task based hebbian model	B	speech output hearing language nonwords
C	amplification pattern completion	C	fast arbitrary details conjunctive

Questions are numbered, each has 3 choices.

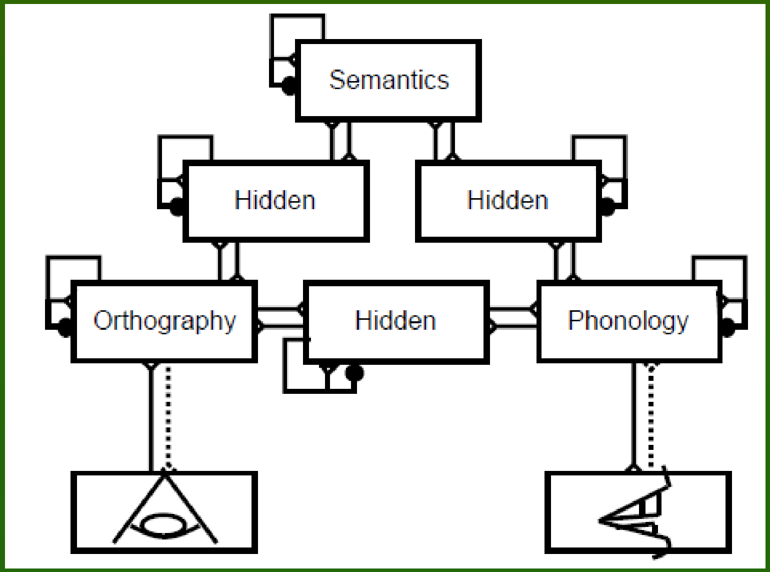
Network gives an intuitive answer, based purely on associations, for example what is the purpose of “transformation”: A, B or C.

Network correctly recognizes 60-80% of such questions, more than that requires some understanding …

Reading and dyslexia

Phonological dyslexia: deficit in reading pronounceable nonwords (e.g., "nust" (Wernicke).

Deep dyslexia like phonological dyslexia + significant levels of semantic errors, reading for ex. "dog" as "cat".



Surface dyslexia: preserved ability to read nonwords, impairments in retrieving semantic information from written words, difficulty
in reading exception, low-frequency words, ex. "yacht."
Surface dyslexia - visual errors, but not semantic errors. .

Double route model of dyslexia includes orthography, phonology, and semantic layers, direct ortho=Phono route and indirect
ortho => semantics => phono, allowing to pronounce rare words.

Model of reading

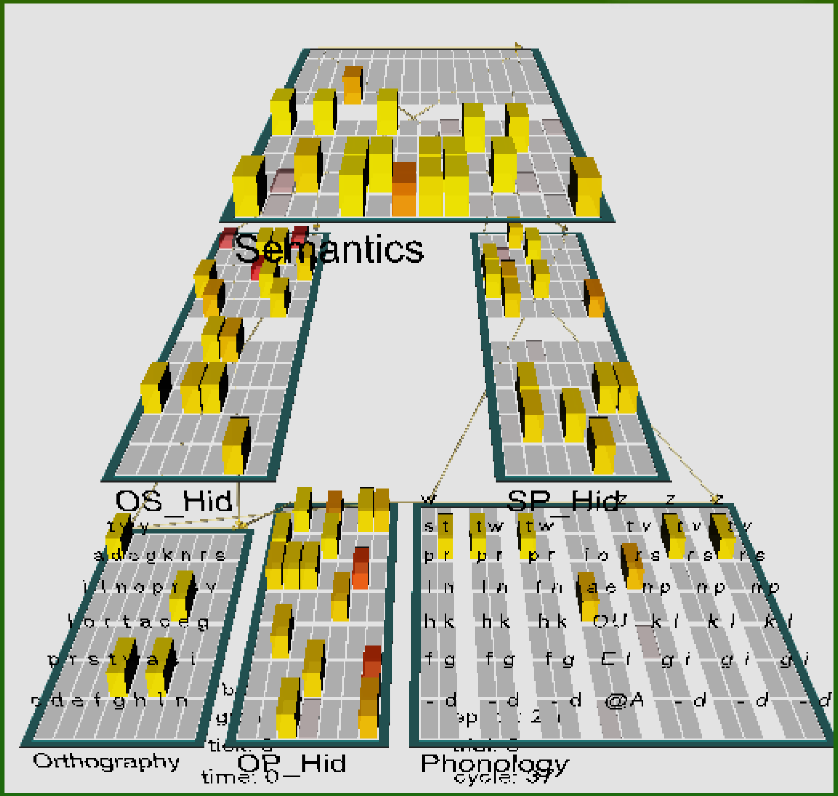
Emergent neural simulator:

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.



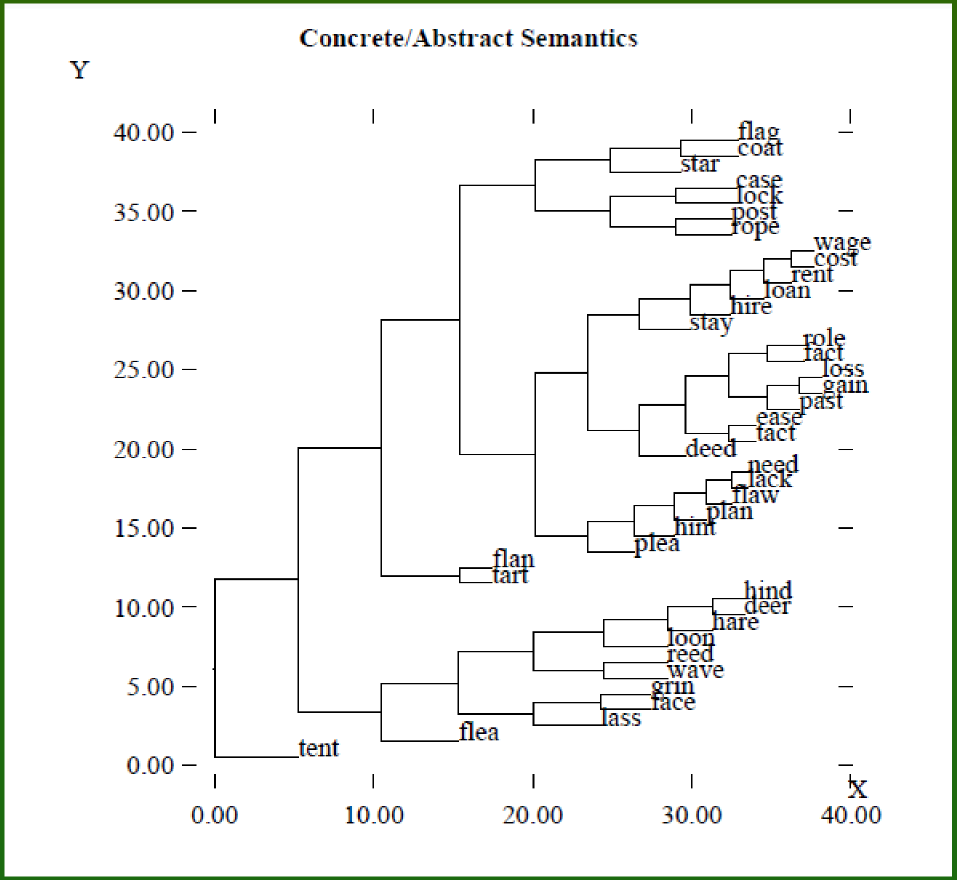
Learning: mapping one of the 3 layers to the other two.

Fluctuations around final configuration = attractors representing concepts.

How to see properties of their basins, their relations?

Words to read

Conc	Phon	Abst	Phon
tart	tttartt	tact	ttt@ktt
tent	tttentt	rent	rrrentt
face	fffAsss	fact	fff@ktt
deer	dddErrr	deed	dddEddd
coat	kkkOttt	cost	kkkostt
grin	grrinnn	gain	gggAnnn
lock	lllakkk	lack	lll@kkk
rope	rrrOppp	role	rrrOlll
hare	hhhArrr	hire	hhhIrrr
lass	lll@sss	loss	lllosss
flan	fllonnn	plan	pll@nnn
hind	hhhIndd	hint	hhhintt
wave	wwwAvvv	wage	wwwAjjj
flea	fllE---	plea	pllE---
star	sttarrr	stay	sttA---
reed	rrrEddd	need	nnnEddd
loon	lllUnnn	loan	lllOnnn
case	kkkAsss	ease	---Ezzz
flag	fll@ggg	flaw	fllo---
post	pppOstt	past	ppp@stt

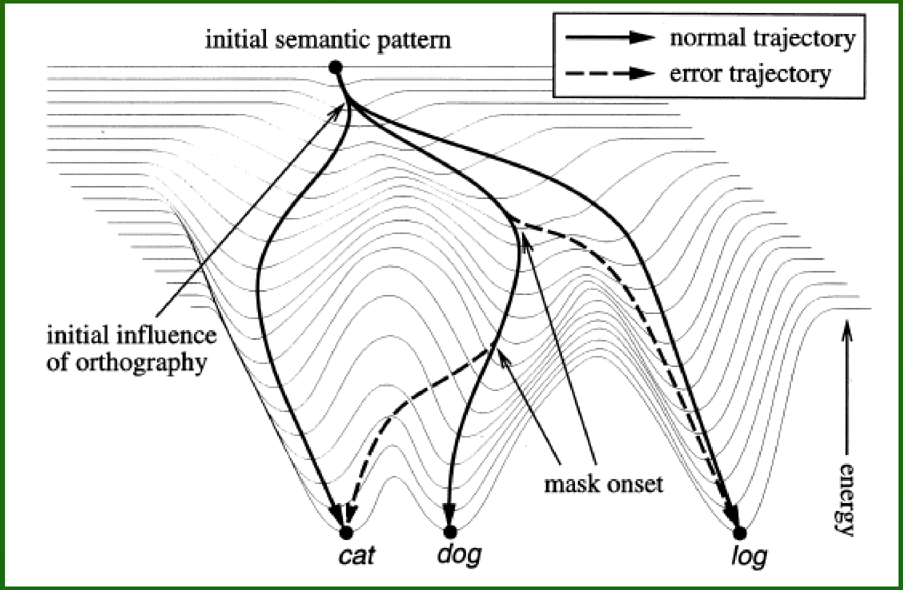


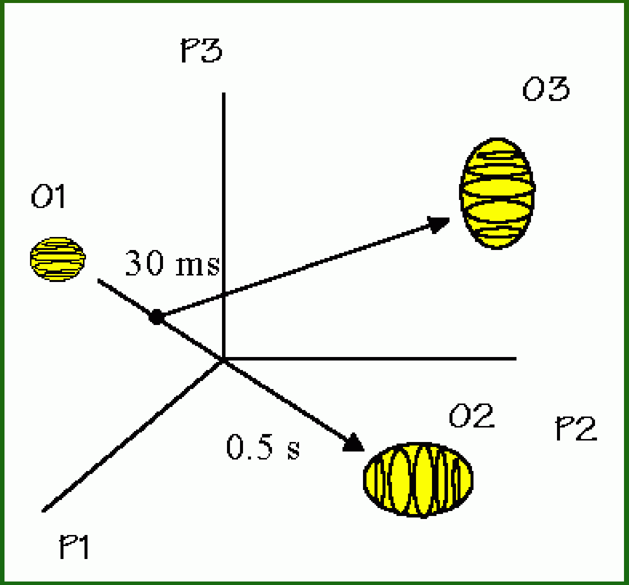
40 words, 20 abstract & 20 concrete; dendrogram shows similarity in phonological and semantic layers after training.

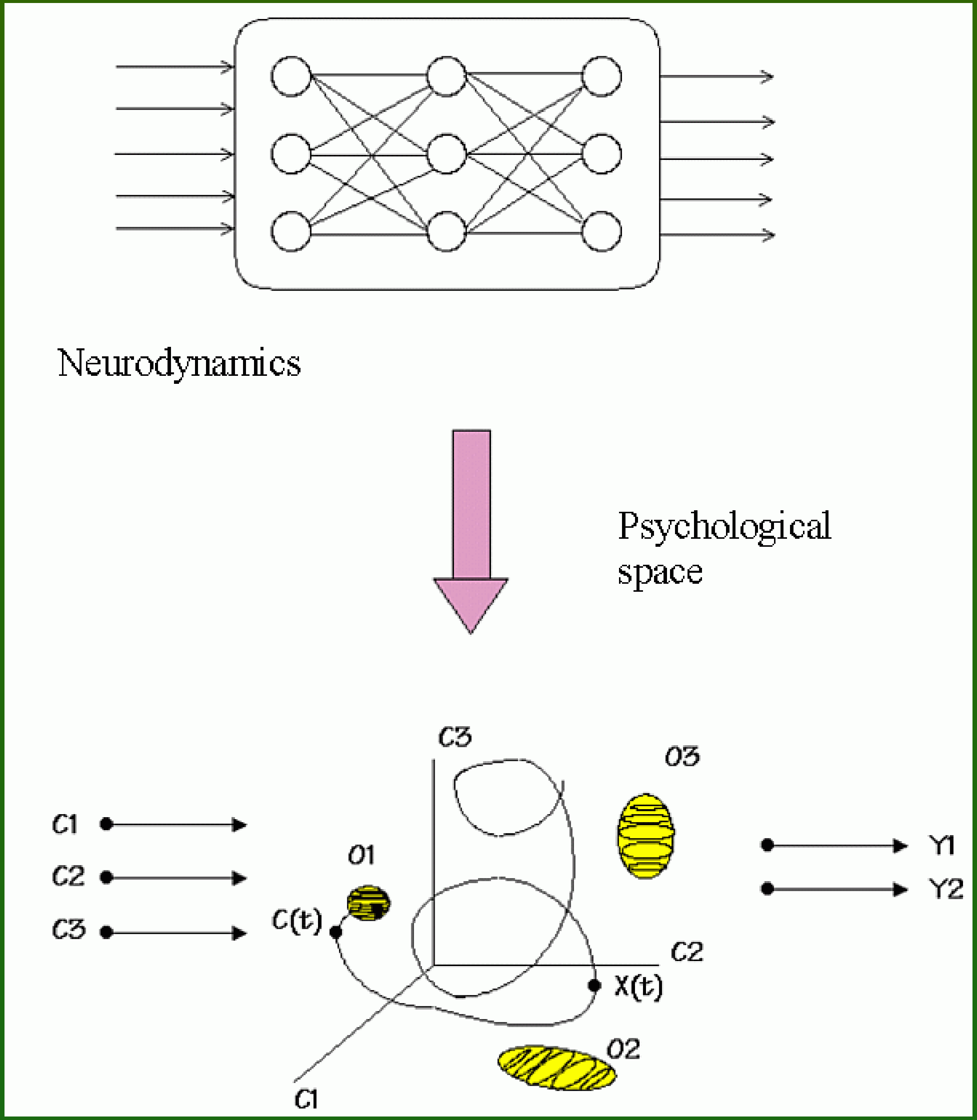
Energies of trajectories

P.McLeod, T. Shallice, D.C. Plaut,
Attractor dynamics in word recognition: converging evidence from errors by normal subjects, dyslexic patients and a connectionist model.
Cognition 74 (2000) 91-113.

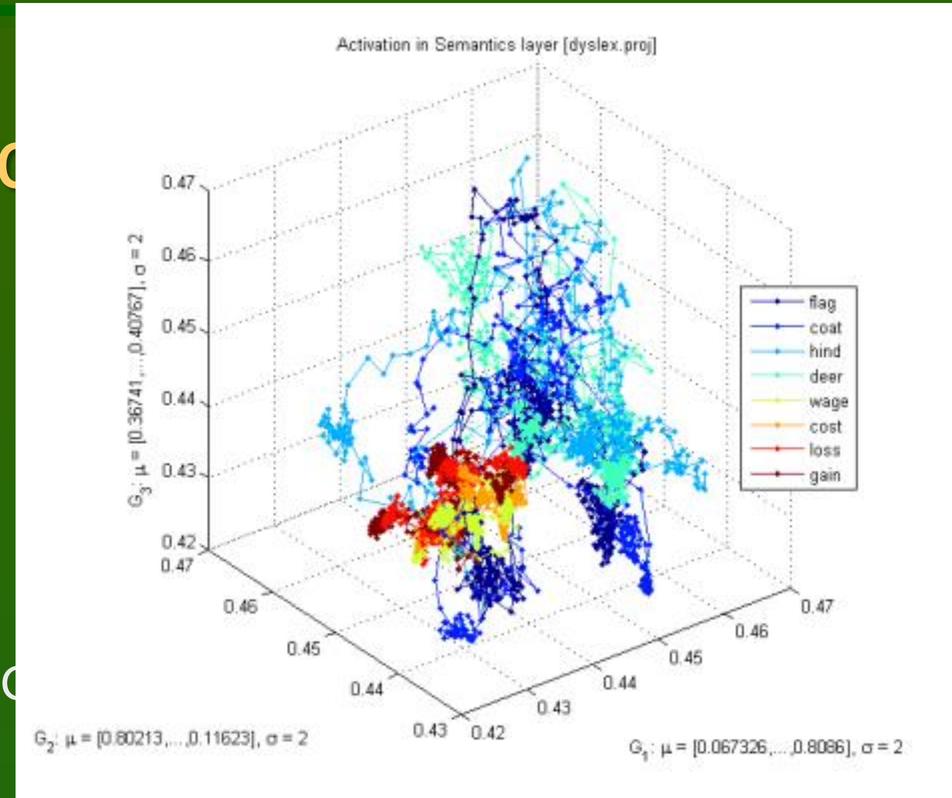
New area in psycholinguistics: investigation of dynamical cognition, influence of masking on semantic and phonological errors.






Neurodynamics
Psychological space
C3
O3
C1
C2
C3
O1
C(t)
Y1
Y2
C2
X(t)
O2
C1

Attrac



Attention results from:

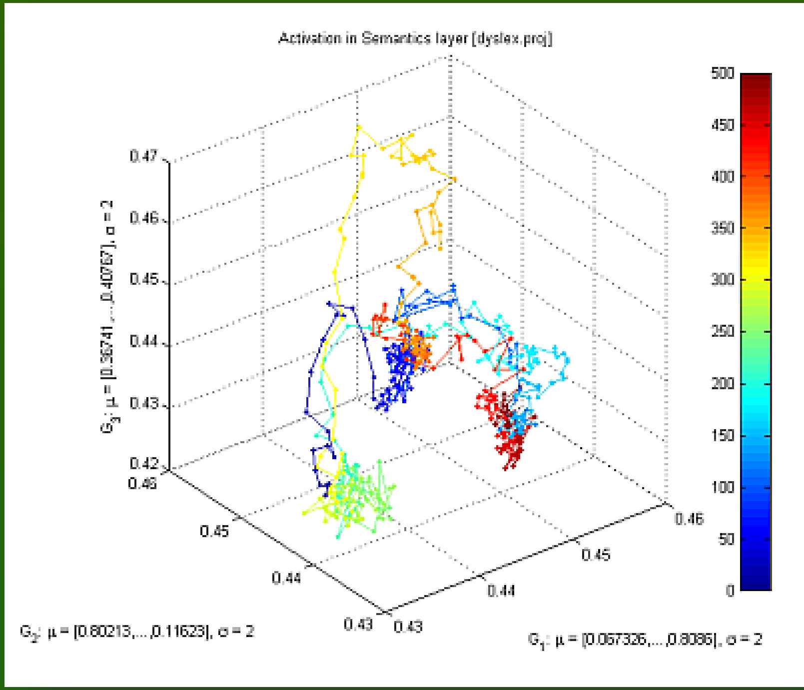
- inhibitory competition,
- bidirectional interactive processing,
- multiple constraint satisfaction.

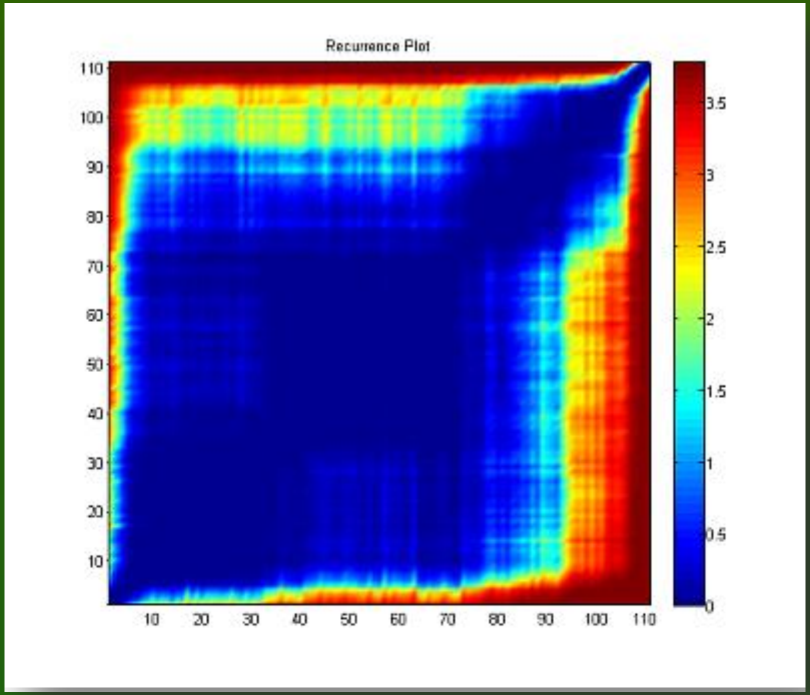
Basins of attractors: input activations {LC

- 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).

Recurrence plots

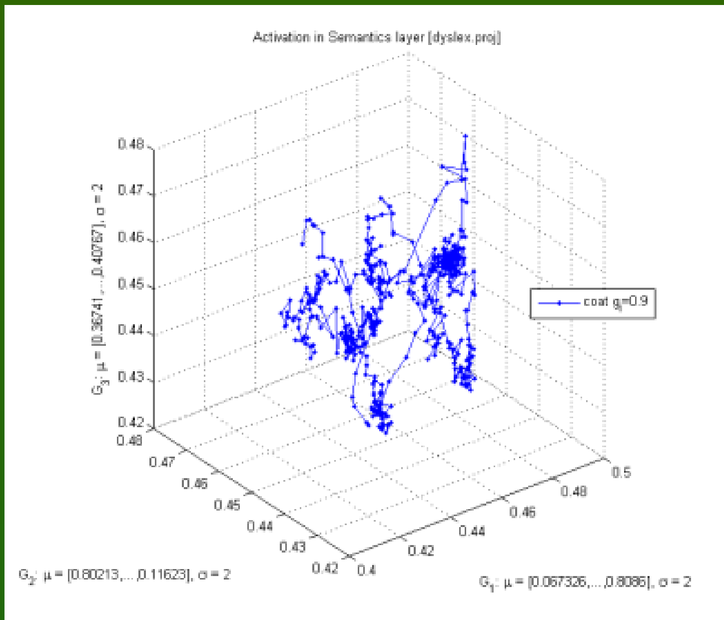


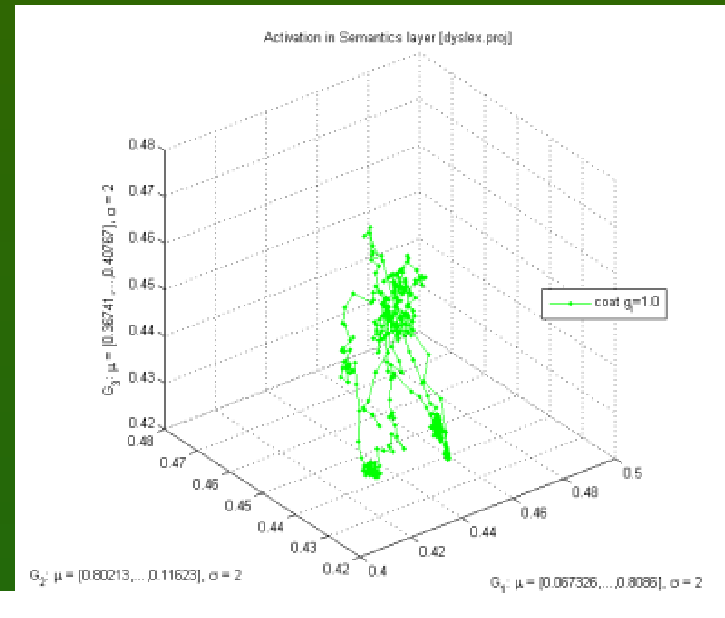


Starting from the word "flag", with small synaptic noise (var=0.02), the network starts from reaching an attractor and moves to another one (frequently quite distant), creating a "chain of thoughts".

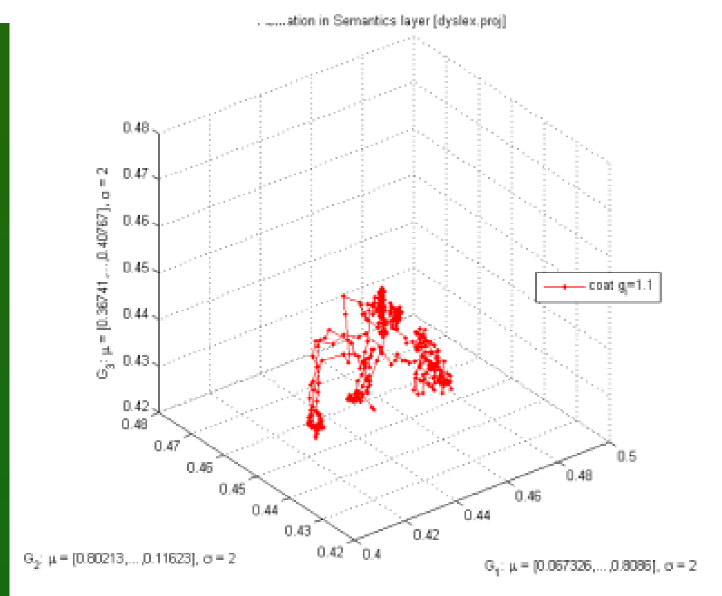
Same trajectories displayed with recurrence plots, showing roughly 5 larger basins of attractors and some transient points.

Inhibition





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

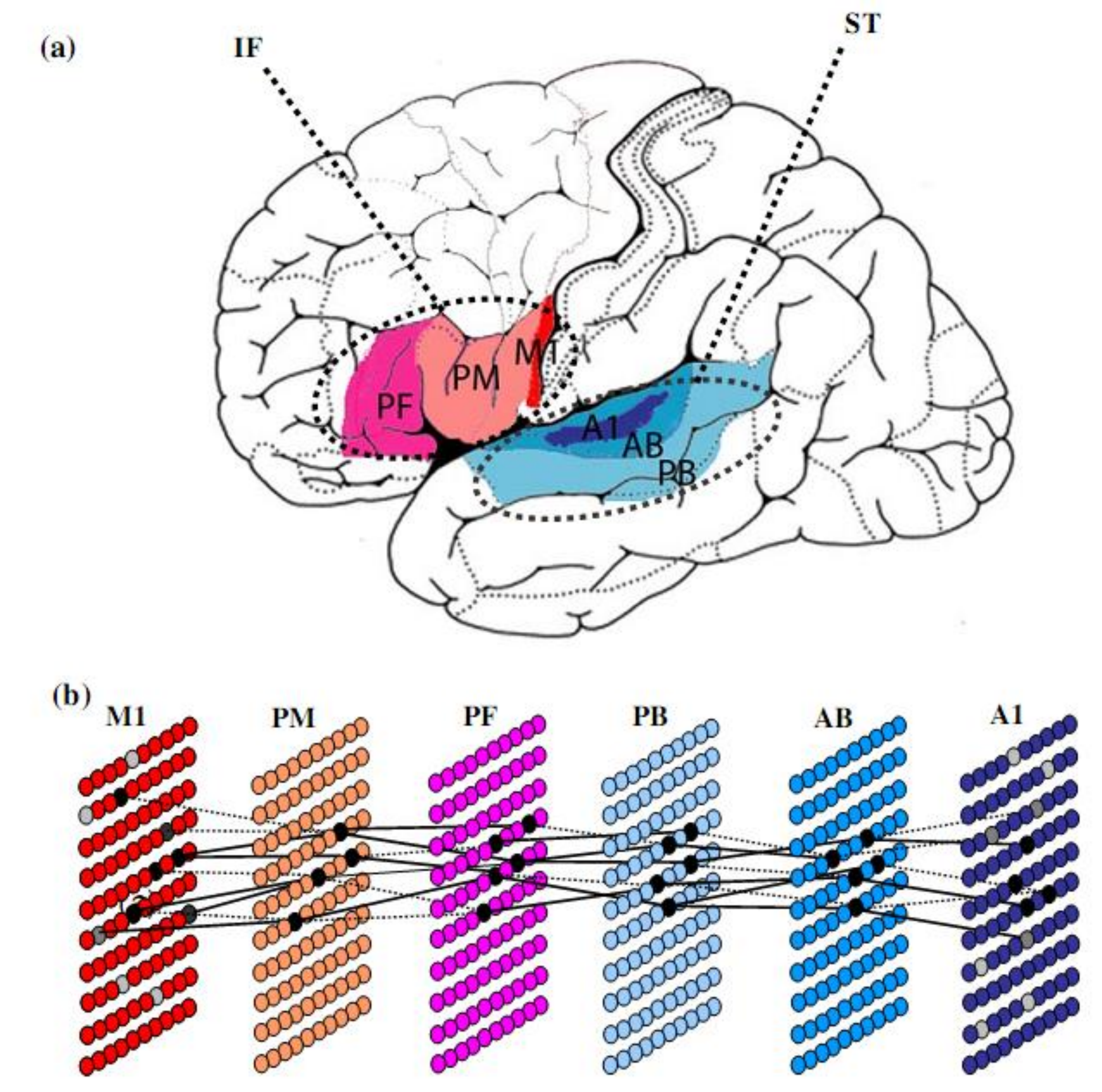


Strong inhibition, empty head …

A better model

Garagnani et al. Recruitment and consolidation of cell assemblies for words by way of Hebbian learning and competition in a multi-layer neural network, Cognitive Comp. 1(2), 160-176, 2009.

Primary auditory cortex (A1), auditory belt (AB), parabelt (PB, Wernicke's area), inferior pre-frontal (PF) and premotor (PM, Broca), primary motor cortex (M1).



Garagnani et al. conclusions

"Finally, the present results provide evidence in support of the hypothesis that words, similar to other units of cognitive processing (e.g. objects, faces), are represented in the human brain as distributed and anatomically distinct action-perception circuits."

"The present results suggest that anatomically distinct and distributed action-perception circuits can emerge spontaneously in the cortex as a result of synaptic plasticity. Our model predicts and explains the formation of lexical representations consisting of strongly interconnected, anatomically distinct cortical circuits distributed across multiple cortical areas, allowing two or more lexical items to be active at the same time. Crucially, our simulations provide a principled, mechanistic explanation of where and why such representations should emerge in the brain, making predictions about the spreading of activity in large neuronal assemblies distributed over precisely defined areas, thus paving the way for an investigation of the physiology of language and memory guided by neurocomputational and brain theory."

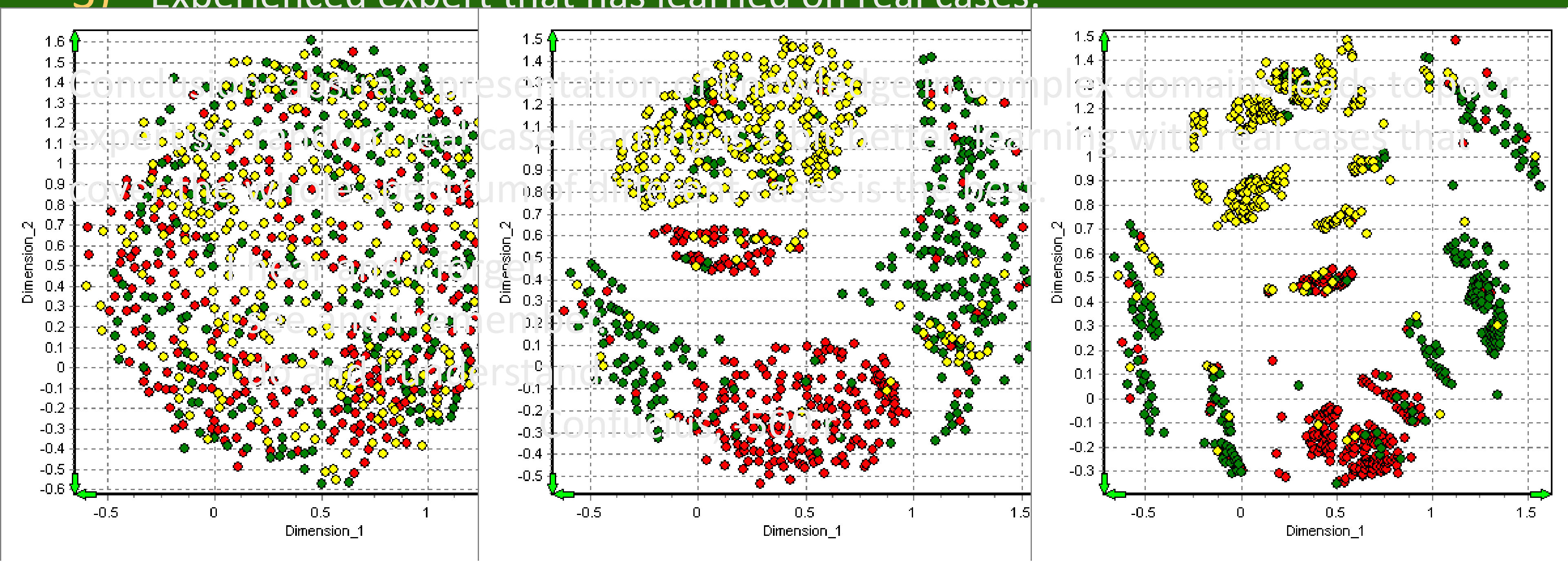
How to become an expert?

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 correct associations.

Example: 3 diseases, clinical case description, MDS description.

1) System that has been trained on textbook knowledge.
2) Same system that has learned on real cases.
3) Experienced expert that has learned on real cases.



Conclusion: abstract presentation of knowledge in complex domains leads to poor expertise, random real case learning is a bit better, learning with real cases that cover the whole spectrum of different cases is the best.

I hear and I forget.
I see and I remember.
I do and I understand.
Confucius, 500 r.

Mental models

Kenneth Craik, 1943 book “The Nature of Explanation”, G-H Luquet attributed mental models to children in 1927.

P. Johnson-Laird, 1983 book and papers.

Imagination: mental rotation, time ~ angle, about 60º/sec.

Internal models of relations between objects, hypothesized to play a major role in cognition and decision-making.

AI: direct representations are very useful, direct in some aspects only!

Reasoning: imaging relations, “seeing” mental picture, semantic?

Systematic fallacies: a sort of cognitive illusions.

- If the test is to continue then the turbine must be rotating fast enough to generate emergency electricity.
- The turbine is not rotating fast enough to generate this electricity.
- What, if anything, follows? Chernobyl disaster …

If A=>B; then ~B => ~A, but only about 2/3 students answer correctly..

Mental models summary

The mental model theory is an alternative to the view that deduction depends on formal rules of inference.

1. MM represent explicitly what is true, but not what is false; this may lead naive reasoner into syst

2. Large number of complex models =>

3. Tendency to focus on a few possible conclusions and irrational decisions.

Cognitive illusions are just like visual illusi

M. Piattelli-Palmarini, Inevitable Illusions: Our Minds (1996)

R. Pohl, Cognitive Illusions: A Handbook Thinking, Judgement and Memory (20

Amazing, but mental models theory ignore learning in any form! How and why do we reason the way we do?

I'm innocent! My brain made me do it!

Mental models

Easy reasoning A=>B, B=>C, so A=>C

- All mammals suck milk.
- Humans are mammals.
- => Humans suck milk. Simple associative process, easy to simulate.

... but almost no-one can draw conclusion from:

- All academics are scientist.
- No wise men is an academic.
- What can we say about wise men and scientists?

Surprisingly only ~10% of students get it right after days of thinking.

No simulations explaining why some mental models are so difficult.

Why is it so hard? What really happens in the brain?

Try to find a new point of view to illustrate it.

P-spaces

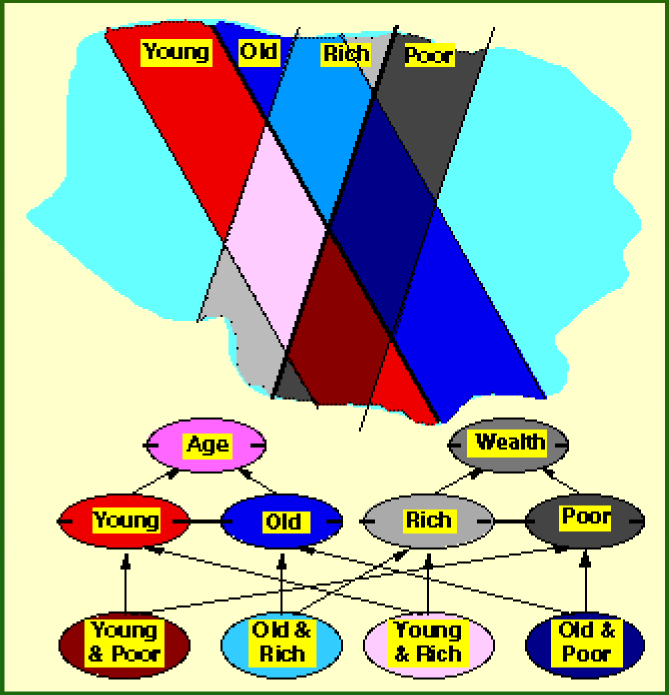
Psychological spaces: how to visualize inner life?

K. Lewin, The conceptual representation and the measurement of psychological forces (1938), cognitive dynamic movement in phenomenological space.

George Kelly (1955):
personal construct psychology (PCP), geometry of psychological spaces as alternative to logic.

A complete theory of cognition, action, learning and intention.

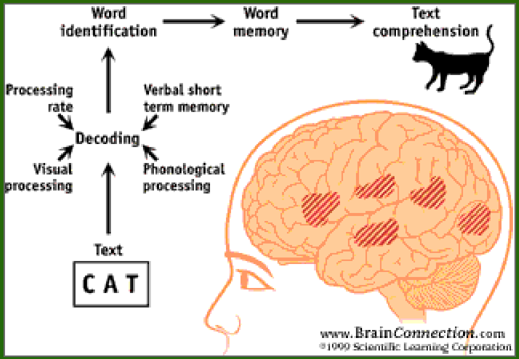
PCP network, society, journal, software … quite active group.



Many things in philosophy, dynamics, neuroscience and psychology, searching for new ways of understanding cognition, are relevant here.

P-space definition

P-space: region in which we may place and classify elements of our experience, constructed and evolving,
„a space without distance”, divided by dichotomies.



P-spaces should have (Shepard 1957-2001):

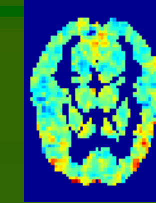
- minimal dimensionality;
- distances that monotonically decrease with increasing similarity.

This may be achieved using multi-dimensional non-metric scaling (MDS), reproducing similarity relations in low-dimensional spaces.

Many Object Recognition and Perceptual Categorization models assume that objects are represented in a multidimensional psychological space; similarity between objects ~ 1/distance in this space.

Can one describe the state of mind in similar way?

Neurocognitive reps.



How to approach modeling of word (concept) w representations in the brain? Word $w = (w_f, w_s)$ has

- phonological (+visual) component w_f, word form;
- extended semantic representation w_s, word meaning;
- is always defined in some context *Cont* (enactive approach).

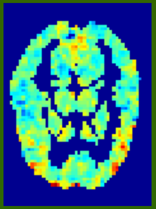
$\Psi(w, Cont, t)$ evolving prob. distribution (pdf) of brain activations. Hearing or thinking a word w , or seeing an object labeled as w adds to the overall brain activation in a non-linear way.

How? Maximizing overall self-consistency, mutual activations, meanings that don’t fit to current context are automatically inhibited.

Result: almost continuous variation of this meaning.

This process is rather difficult to approximate using typical knowledge representation techniques, such as connectionist models, semantic networks, frames or probabilistic networks.

Approximate reps.



States $\Psi(w,Cont) \Leftrightarrow$ lexicographical meanings:

- clusterize $\Psi(w,Cont)$ for all contexts;
- define prototypes $\Psi(w_k,Cont)$ for different meanings w_k.

A1: use spreading activation in semantic networks to define Ψ.
A2: take a snapshot of activation Ψ in discrete space (vector approach).

Meaning of the word is a result of priming, spreading activation to speech, motor and associative brain areas, creating affordances.

$\Psi(w,Cont)$ ~ quasi-stationary wave, with phonological/visual core activations w_f and variable extended representation w_s selected by *Cont*.

$\Psi(w,Cont)$ state into components, because the semantic representation

E. Schrödinger (1935): best possible knowledge of a whole does not include the best possible knowledge of its parts! Not only in quantum case. Left semantic network *LH* contains w_f coupled with the *RH*.

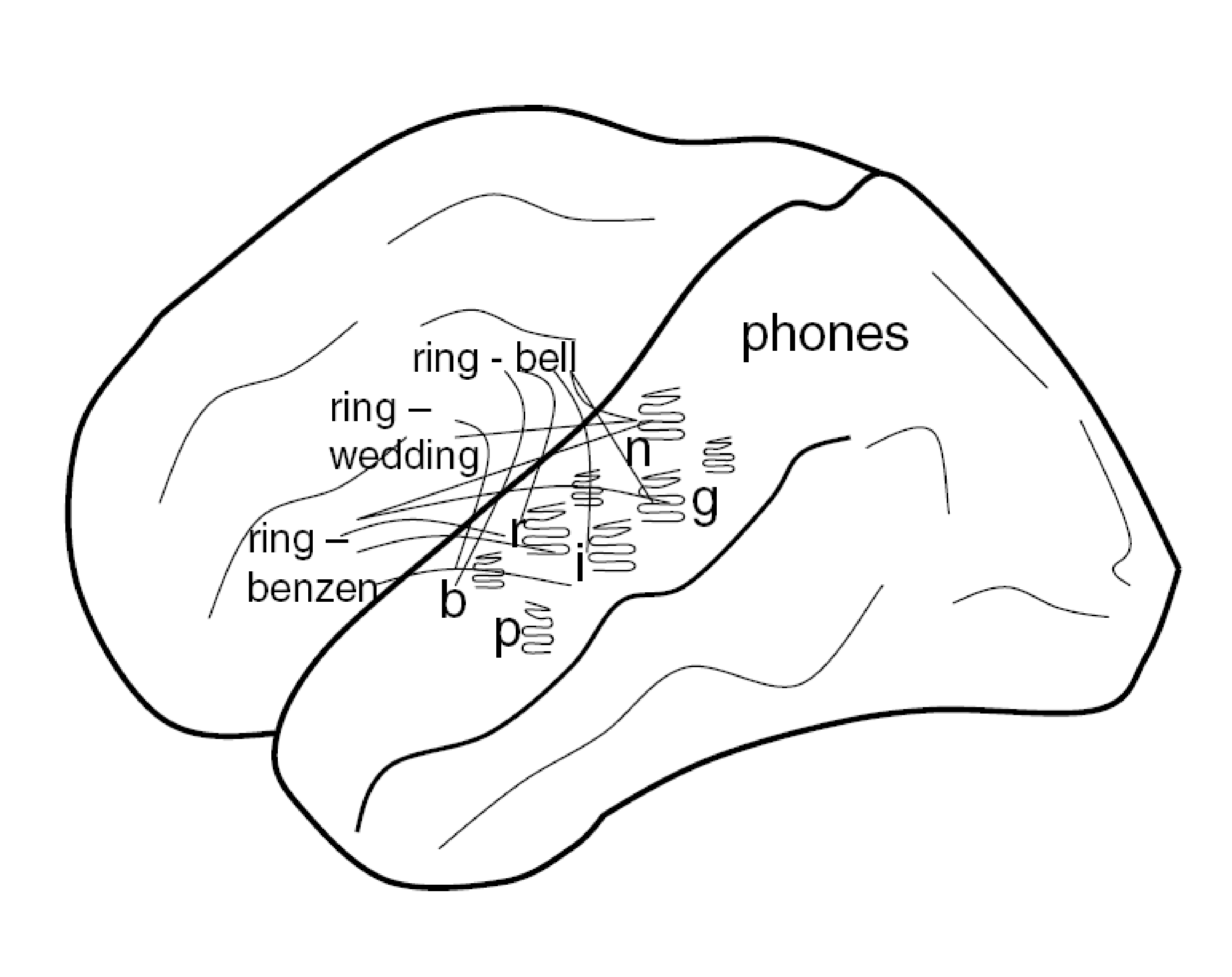
Semantic => vector reps

Some associations are subjective, some are universal.

How to find the activation pathways in the brain? Try this algorithm:

- Perform text pre-processing steps: stemming, stop-list, spell-checking ...
- Map text to some ontology to discover concepts (ex. UMLS ontology).
- Use relations (Wordnet, ULMS), selecting those types only that help to distinguish between concepts.
- Create first-order cosets (terms + all new terms from included relations), expanding the space – acts like a set of filters that evaluate various aspects of concepts.
- Use feature ranking to reduce dimensionality of the first-order coset space, leave all original features.
- Repeat last two steps iteratively to create second- and higher-order enhanced spaces, first expanding, then shrinking the space.

Result: a set of **X** vectors representing concepts in enhanced spaces, partially including effects of spreading activation.



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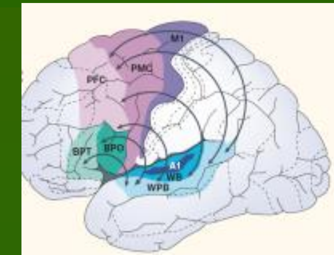


hes, pay attention to

tterns of activations.

parallel both words and

ptic connections.

antic density.

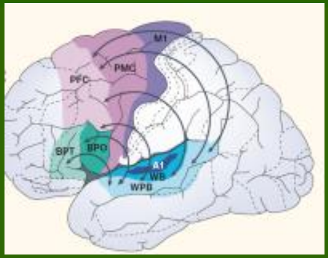
Start from keywords priming phonological representations in the auditory cortex; spread the activation to concepts that are strongly related.

Use inhibition in the winner-takes-most to avoid false associations.

Find fragments that are highly probable, estimate phonological probability.

Combine them, search for good morphemes, estimate semantic probability.

Creativity with words



The simplest testable model of creativity:

- 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.

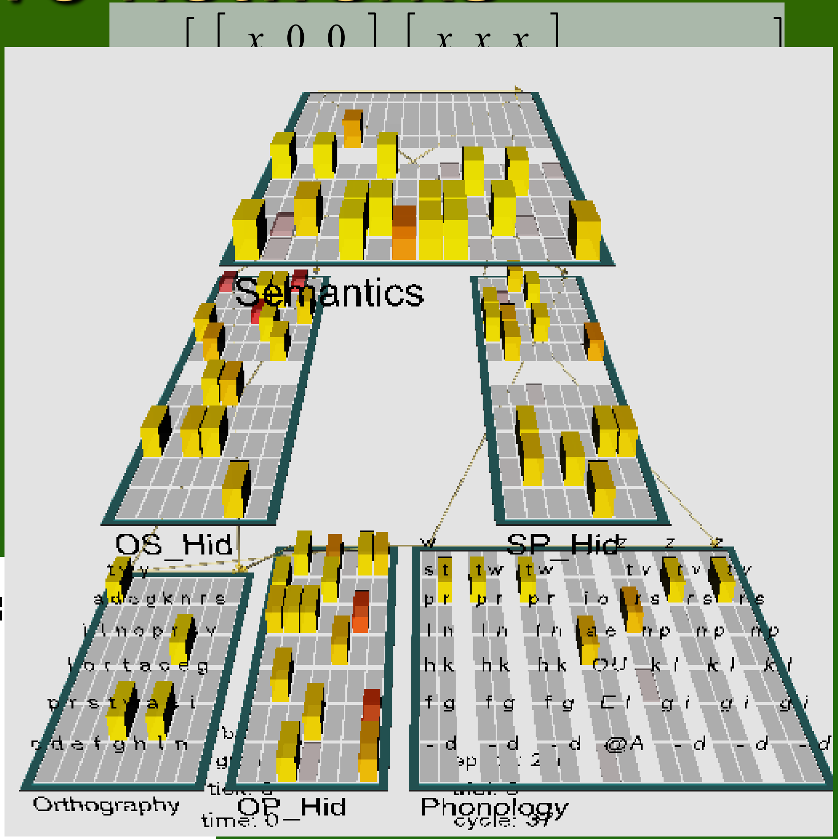
discoverity = {disc, disco, discover, verity} (discovery, creativity, verity)
digventure ={dig, digital, venture, adventure}   new!
Server: http://www-users.mat.uni.torun.pl/~macias/mambo/index.php

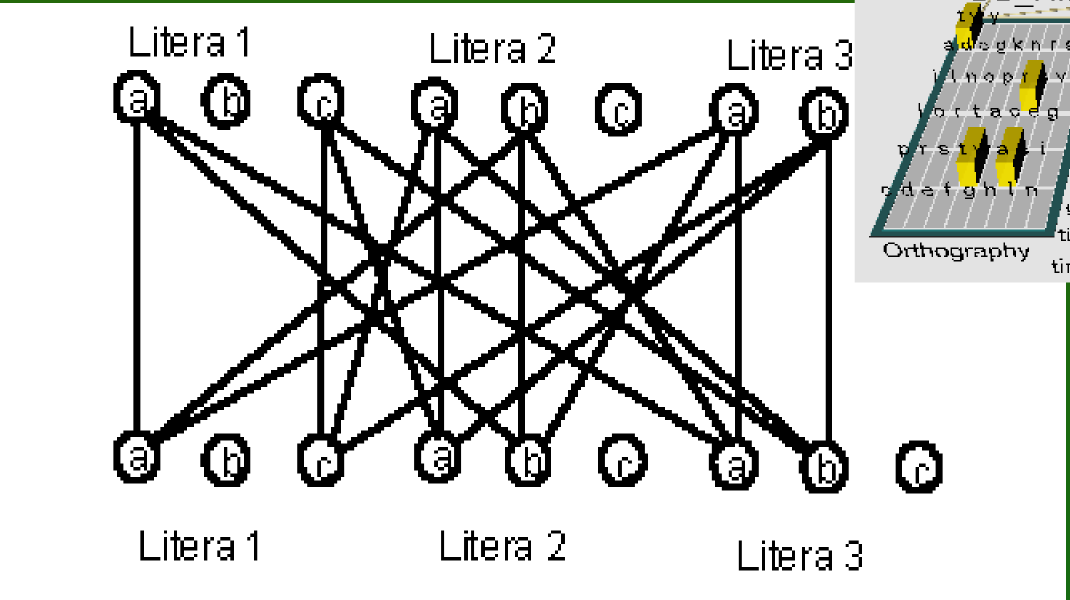
Autoassociative networks

Simplest networks:

- binary correlation matrix,
- probabilistic $p(a_i,b_j|w)$

Major issue: rep. of symbols, morphemes, phonology …





Words: experiments

A real letter from a friend:

I am looking for a word that would capture the following qualities: portal to new worlds of imagination and creativity, a place where visitors embark on a journey discovering their inner selves, awakening the Peter Pan within. A place where we can travel through time and space (from the origin to the future and back), so, its about time, about space, infinite possibilities.
FAST!!! I need it soooooooooooooooooooooon.

creativital, creatival (creativity, portal), used in creatival.com
creativery (creativity, discovery), creativery.com (strategy+creativity)
discoverity = {disc, disco, discover, verity} (discovery, creativity, verity)
digventure ={dig, digital, venture, adventure} still new!
imativity (imagination, creativity); infinitime (infinitive, time)
infinition (infinitive, imagination), already a company name
portravel (portal, travel); sportal (space, sport, portal), taken
timagination (time, imagination); timativity (time, creativity)
tivery (time, discovery); trime (travel, time)

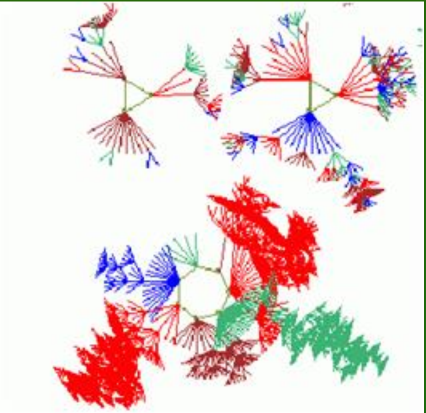
Server at: http://www-users.mat.uni.torun.pl/~macias/mambo

Static Platonic model

Newton introduced space-time, arena for physical events.

Mind events need psychological spaces.

Goal: integrate neural and behavioral information in one model, create model of mental processes at intermediate level between psychology and neuroscience.



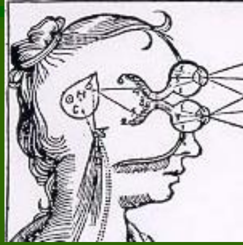
Static version: short-term response properties of the brain, behavioral (sensomotoric) or memory-based (cognitive).

Approach:

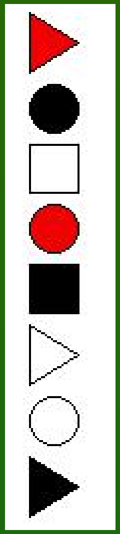
- simplify neural dynamics, find invariants (attractors), characterize them in psychological spaces;
- use behavioral data, represent them in psychological space.

Applications: object recognition, psychophysics, category formation in low-D psychological spaces, case-based reasoning.

Learning complex categories



Categorization is quite basic, many psychological models/experiments.
Multiple brain areas involved in different categorization tasks.
Classical experiments on rule-based category learning:
Shepard, Hovland and Jenkins (1961), replicated by Nosofsky *et al.* (1994).



Problems of increasing complexity; results determined by logical rules.
3 binary-valued dimensions:
shape (square/triangle), color (black/white), size (large/small).
4 objects in each of the two categories presented during learning.

Type I - categorization using one dimension only.
Type II - two dim. are relevant, including exclusive or (XOR) problem.
Types III, IV, and V - intermediate complexity between Type II - VI.
All 3 dimensions relevant, "single dimension plus exception" type.
Type VI - most complex, 3 dimensions relevant, enumerate, no simple rule.

Difficulty (number of errors made): Type I < II < III ~ IV ~ V < VI
For n bits there are 2^n binary strings 0011…01; how complex are the rules (logical categories) that human/animal brains still can learn?

Canonical neurodynamics.

What happens in the brain during category learning?
Complex neurodynamics <=> simplest, canonical dynamics.
For all logical functions one may write corresponding equations.

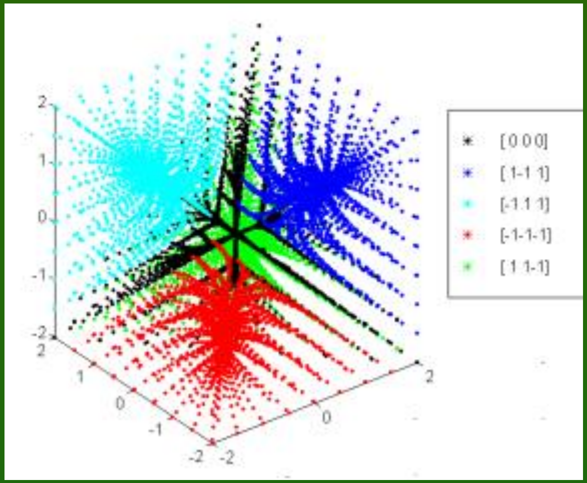
For XOR (type II problems) equations are:

$$V(x,y,z) = 3xyz + \frac{1}{4}\left(x^2+y^2+z^2\right)^2$$

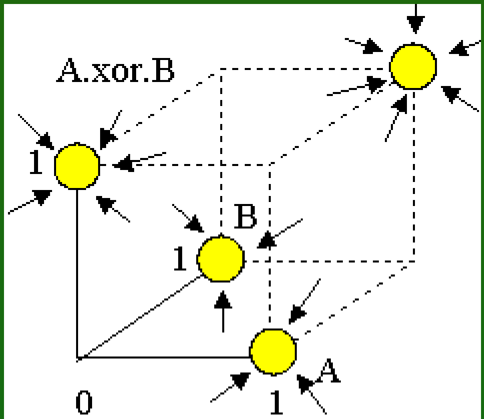
$$\dot{x} = -\frac{\partial V}{\partial x} = -3yz - \left(x^2+y^2+z^2\right)x$$

$$\dot{y} = -\frac{\partial V}{\partial y} = -3xz - \left(x^2+y^2+z^2\right)y$$

$$\dot{z} = -\frac{\partial V}{\partial z} = -3xy - \left(x^2+y^2+z^2\right)z$$



Corresponding feature space for relevant dimensions A, B



Inverse based

Relative frequencies (base rates) of catego

if on a list of disease and symptoms diseas
symptoms is 3 times more common as R,
then symptoms PC => C, I => C (base rate

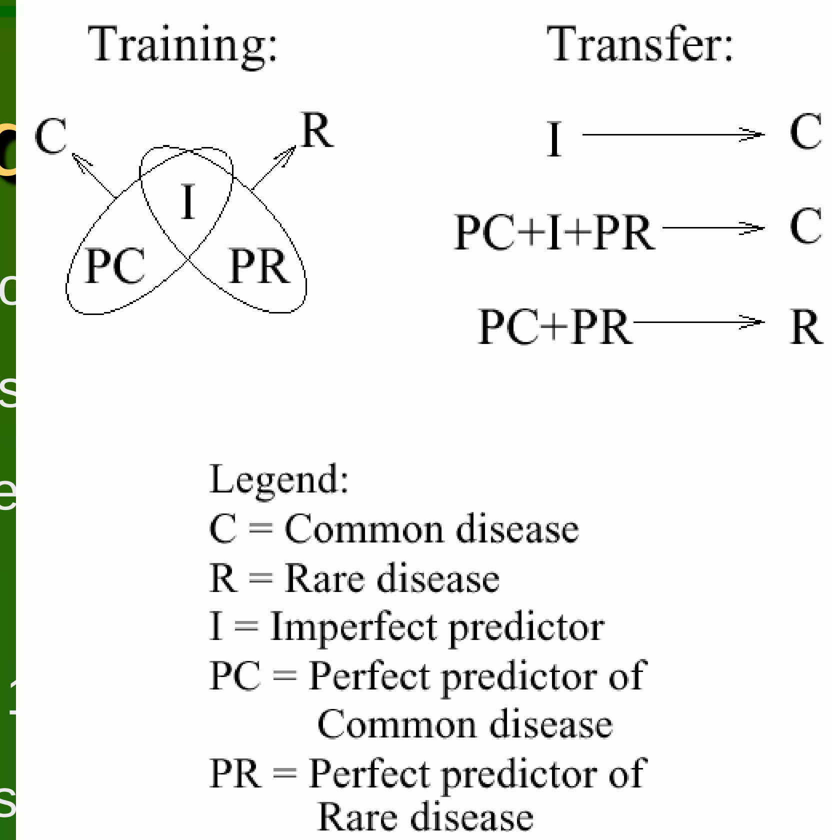
Predictions contrary to the base:
inverse base rate effects (Medin, Edelson 1

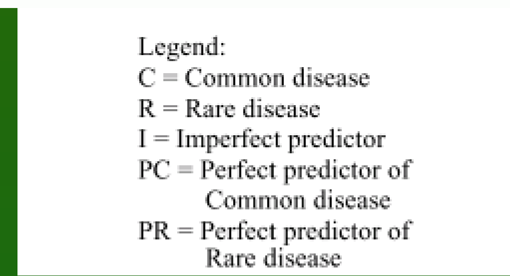
Although PC + I + PR => C (60% answers
PC + PR => R (60% answers)

Why such answers?
Psychological explanations are not convincing.

Effects due to the neurodynamics of learning?

I am not aware of any dynamical models of such effects.



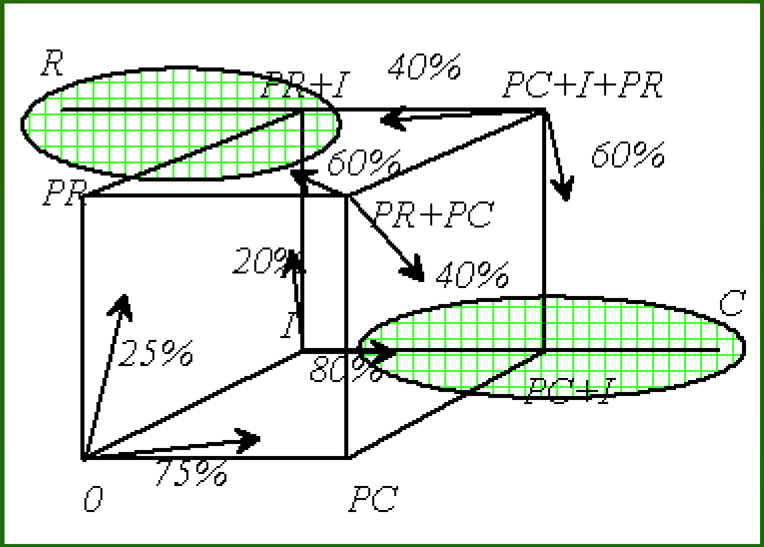


IBR neurocognitive explanation

Psychological explanation:
J. Kruschke, Base Rates in Category Learning (1996).

PR is attended to because it is a distinct symptom, although PC is more common.

Basins of attractors - neurodynamics;
PDFs in P-space {C, R, I, PC, PR}.



PR + PC activation leads more frequently to R because the basin of attractor for R is deeper.

Construct neurodynamics, get PDFs.
Unfortunately these processes are in 5D.

Prediction: weak effects due to order and timing of presentation (PC, PR) and (PR, PC), due to trapping of the mind state by different attractors.

Learning

Point of view

Neurocognitive	Psychology
I+PC more frequent => stronger synaptic connections, larger and deeper basins of attractors.	Symptoms I, PC are typical for C because they appear more often.
To avoid attractor around I+PC leading to C, deeper, more localized attractor around I+PR is created.	Rare disease R - symptom I is misleading, attention shifted to PR associated with R.

Probing

Point of view

Neurocognitive	Psychology
Activation by I leads to C because longer training on I+PC creates larger common basin than I+PR.	I => C, in agreement with base rates, more frequent stimuli I+PC are recalled more often.
Activation by I+PC+PR leads frequently to C, because I+PC puts the system in the middle of the large C basin and even for PR geadients still lead to C.	I+PC+PR => C because all symptoms are present and C is more frequent (base rates again).
Activation by PR+PC leads more frequently to R because the basin of attractor for R is deeper, and the gradient at (PR,PC) leads to R.	PC+PR => R because R is distinct symptom, although PC is more common.

Mental model dynamics

Why is it so hard to draw conclusions from:

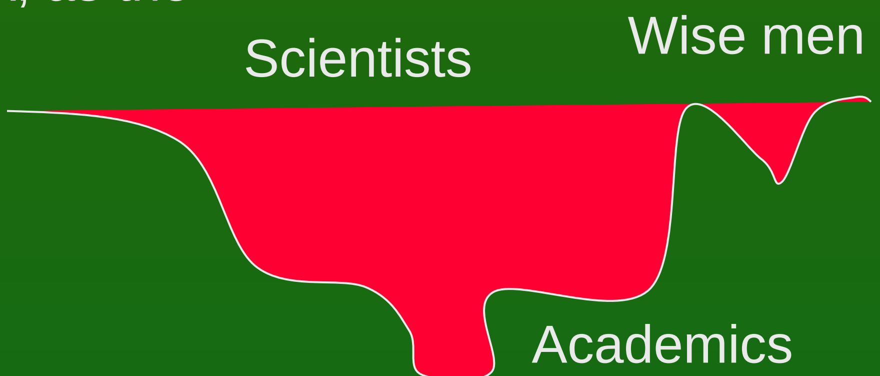
- All academics are scientist.
- No wise men is an academic.
- What can we say about wise men and scientists?

All A’s are S, ~ W is A;   relation S <=> W ?

What happens with neural dynamics?

Basins of A is larger than B, as B is a subtype of A, and thus has to inherit most properties that are associated with A.
Attractor for B has to be within A.
Thinking of B makes it hard to think of A, as the

Basins of attractors for the
3 concepts involved;
basin for “Wise men” has unknown
relation to the other basins.

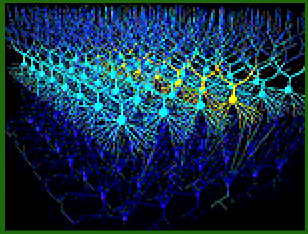


Some connections

Geometric/dynamical ideas related to mind may be found in many fields:

Neuroscience:
D. Marr (1970) “probabilistic landscape”.
C.H. Anderson, D.C. van Essen (1994): Superior Colliculus PDF maps
S. Edelman: “neural spaces”, object recognition, global representation space approximates the Cartesian product of spaces that code object fragments, representation of similarities is sufficient.

Psychology:
K. Levin, psychological forces.
G. Kelly, Personal Construct Psychology.
R. Shepard, universal invariant laws.
P. Johnson-Laird, mind models.



Folk psychology: to put in mind, to have in mind, to keep in mind (mindmap), to make up one's mind, be of one mind ... (space).

More connections

AI: problem spaces - reasoning, problem solving, SOAR, ACT-R, little work on continuous mappings (MacLennan) instead of symbols.

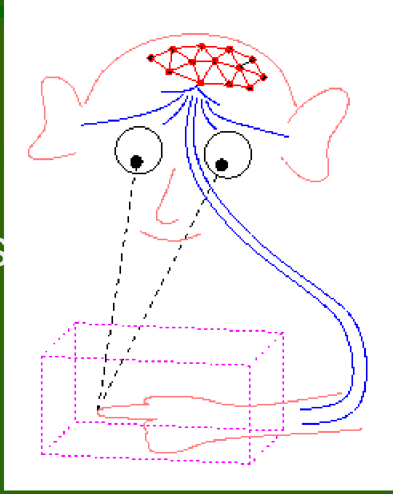
Engineering: system identification, internal models inferred from input/output observations – this may be done without any parametric assumptions if a number of identical neural modules are used!

Philosophy:
P. Gärdenfors, Conceptual spaces
R.F. Port, T. van Gelder, ed. Mind as motion (MIT Press 1995)

Linguistics:
G. Fauconnier, Mental Spaces (Cambridge U.P. 1994).
Mental spaces and non-classical feature spaces.
J. Elman, Language as a dynamical system; J. Feldman neural basis;
Stream of thoughts, sentence as a trajectory in P-space.

Psycholinguistics: T. Landauer, S. Dumais, Latent Semantic Analysis, Psych. Rev. (1997) Semantic for 60 k words corpus requires about 300 dim.

Conclusions



Understanding of reasoning requires a model of brain proces
mind => logic and reasoning.

Simulations of the brain may lead to mind functions,
but we still need conceptual understanding.

Psychological interpretations and models are confabulations!
They provide wrong conceptualization of real brain processes.

Low-dimensional representation of mental/brain events are needed.

Complex neurodynamics => dynamics in P-spaces, visualization helps.

Is this a good bridge between mind and brain?

Mind models, psychology, logic … do not even touch the truth.

However, P-spaces may be high-dimensional, so hard to visualize.

How to describe our inner experience (Hurlburt & Schwitzgebel 2007)?

Still I hope that at the end of the road physics-like theory of events in
mental spaces will be possible, explaining higher cognitive functions.

Thank you for lending your ears ...

Google: W. Duch => Papers/presentations/projects