

LANGUAGE, COGNITION, AND CULTURAL EVOLUTION

ICFC Conference

5-7 Oct 2009, Madeira, Portugal



Leonid Perlovsky

Harvard University and the AF Research Lab

<http://leonid-perlovsky.com/>



OUTLINE

- Language and Cognition
- Computational Complexity
- Dynamic Logic
 - Engineering example: recognition
- The Knowledge Instinct
 - Higher cognitive functions: beautiful, sublime
- Language and Emotion: Evolution of cultures
 - Emotional Sapir-Whorf Hypothesis



INTEGRATED LANGUAGE AND COGNITION



- **How language and cognition interact**
 - Words and objects: zillions of combinations, how do we learn correct ones?
 - **Each concept has linguistic and cognitive** dual model
 - $M_m = \{ M_m^{\text{cognitive}}, M_m^{\text{language}} \};$
 - Language and cognition are **fused at vague pre-conceptual level**
 - **before words and concepts are learned**
- **Language and cognition mechanisms**
 - In a new-born mind, concept-models are **dual** fuzzy blobs
 - **Language is learned “ready-made” from surrounding language**
 - Language models have empty “slots” for cognitive model (objects and situations)
 - **Cognitive concepts are learned to match language models**

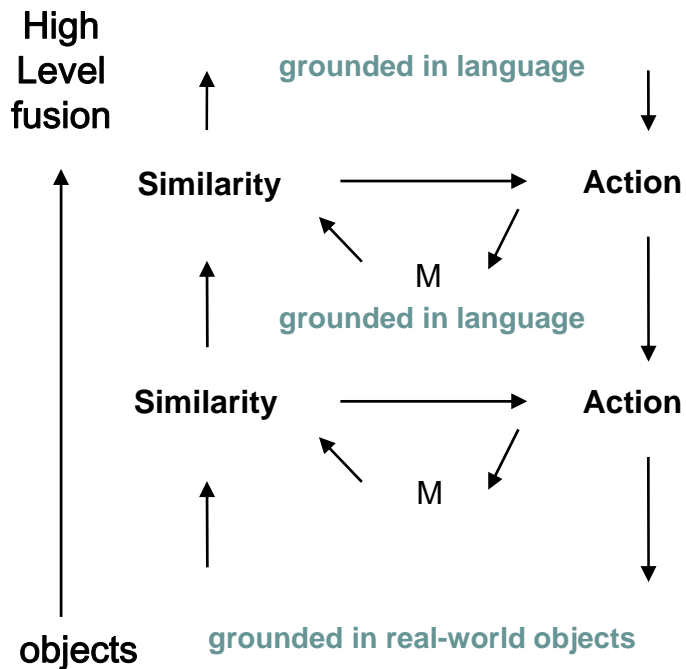


INTEGRATED HIERARCHIES

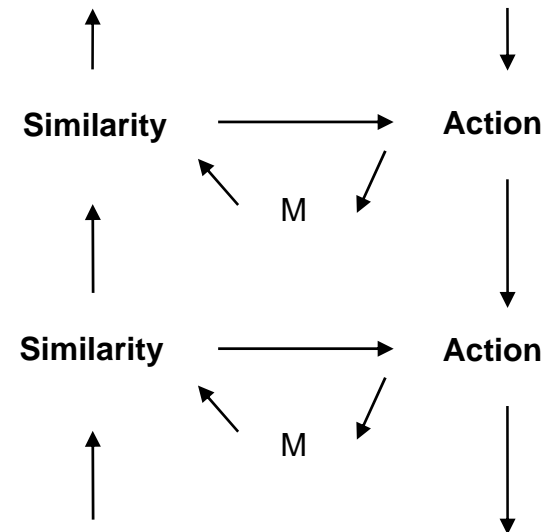


- High level cognition is **only possible due to language**

Cognition



Language





COMPUTATIONAL COMPLEXITY



- Cognition and language involve **evaluating large numbers of combinations**
 - Pixels -> objects -> scenes
 - Sounds -> words -> phrases
- Combinatorial Complexity (CC)
 - A general problem (since the 1950s)
 - Detection, recognition, tracking... language...
 - **Pattern recognition, neural networks, rule systems...**
- Combinations of 100 elements are 100^{100}
 - This number > the size of the Universe
 - > all the events in the Universe during its entire life



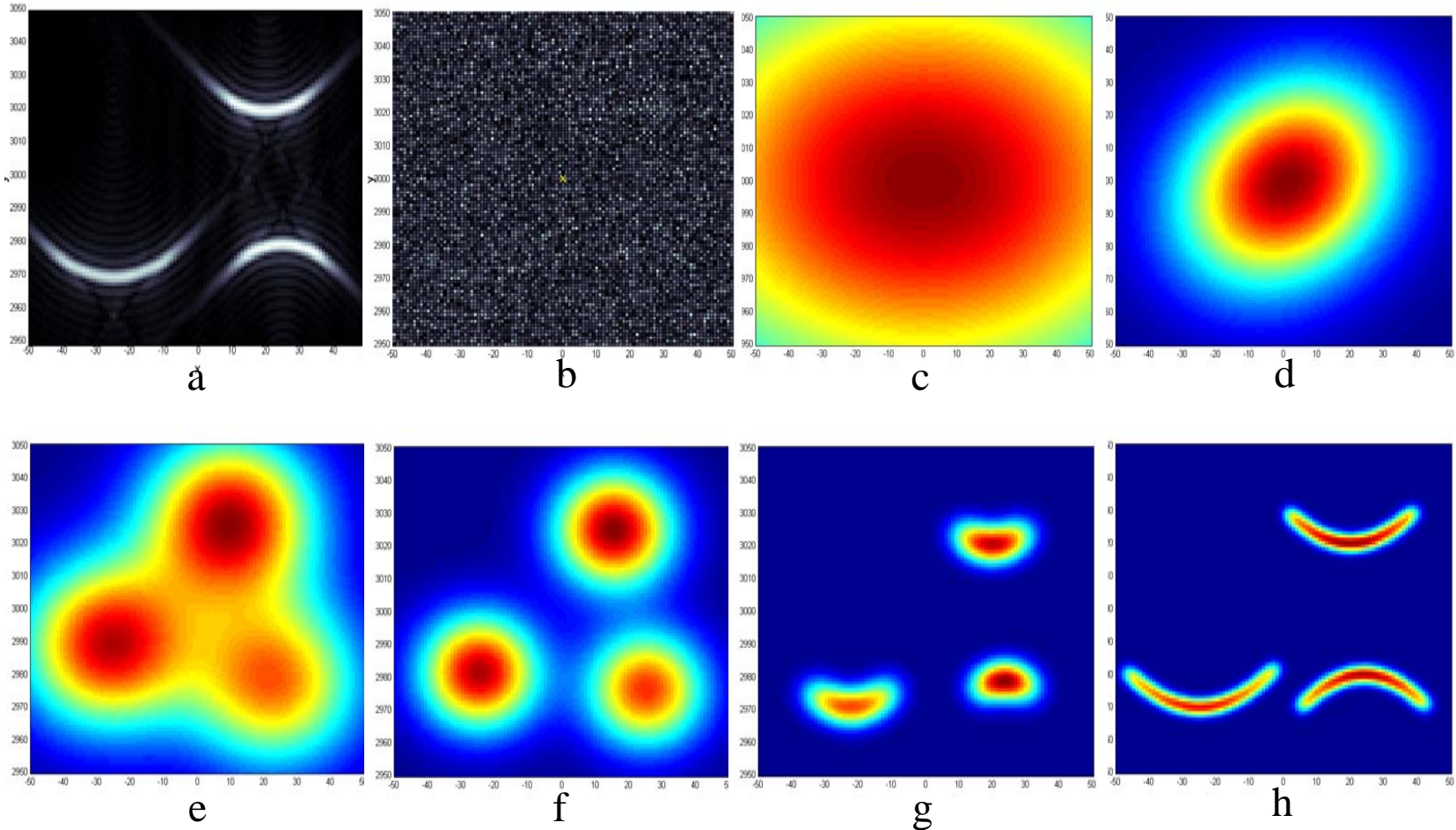
DYNAMIC LOGIC (DL)



- DL unifies formal and fuzzy logic
 - A process-logic “from fuzzy to crisp”
- Maximizes similarity between models and signals
- Overcomes CC -> **fast algorithms**
- Proven in neuroimaging experiments (Bar, 2006)
 - Initial representations-memories are **vague-fuzzy**
 - “close-eyes” experiment



EXAMPLE: RECOGNITION DL “from vague to crisp”



Signal / Clutter ratio ~ 100 times improvement



APPLICATIONS



- Data mining
- Inverse problems
- Financial predictions
- Search engines understanding language
- Proven in neuroimaging experiments (Bar, 2006)
 - Initial representations-memories are **vague-fuzzy**
 - “close-eyes” experiment



ARISTOTLE VS. GÖDEL



- Aristotle
 - **Logic**: a supreme way of argument
 - **Forms**: representations in the mind
 - Form-as-potentiality evolves into form-as-actuality
 - **Potentialities are not logical -> logical actualities, (Dynamic Logic)**
 - **Language and thinking are closely linked**
- From Boole to Russell: formalization of logic
 - Logicians eliminated from logic uncertainty of language
 - Hilbert: formalize rules of mathematical proofs forever
- Gödel (the 1930s)
 - Logic is not consistent
 - Any statement can be proved true and false
- Aristotle and Alexander the Great



RECOGNITION



- 2007 Gabor Award
 - The top engineering award from International Neural Network Society (INNS)
- 2007 John L. McLucas Award
 - The top scientific award from the US Air Force
- 2000 Best Paper Award, Zvezda, Russian literary and philosophical essay monthly journal
- Elected to the Board of Governors of INNS
- Invited to Editorial Boards of 6 journals



OUTLINE

- Language and Cognition
- Computational Complexity
- Dynamic Logic
 - Engineering example: recognition
- **The Knowledge Instinct**
 - Higher cognitive functions: beautiful, sublime
- Language and Emotion: Evolution of cultures
 - Emotional Sapir-Whorf Hypothesis



THE MIND, KNOWLEDGE INSTINCT



- **Mechanisms of the mind:**
 - Instincts, Emotions, Concepts, Behavior, Hierarchy
 - Emotions indicate satisfaction of instinctual needs
 - Described mathematically
 - concepts=models
- **The knowledge instinct (KI)**
 - Concept-models always have to be adapted
 - **Increase similarity** between models and the world
 - Emotions: satisfaction of instincts
 - Aesthetic emotions: satisfaction of KI
 - harmony between concepts and the world



BIBLE, NOBEL PRIZE, LANGUAGE



- **Why Adam expelled from paradise ?**
 - Did not want to think (true-false)
 - Choose ready-made **rules** (good-bad, Maimonides, 13th c.)
- **Nobel Prize 2002, Kahneman (and Tversky)**
 - Decisions are basically irrational
 - Not KI, but **rules**-heuristics
 - KI-cortex (OFC), rules-amygdala (DL &LP)
- **Language vs. irrational-rules**
 - Language contains wealth of cultural knowledge, **rules**
 - Remember: opened eyes hide vague mental images
 - Similarly **language hide vague abstract concepts**



EVOLUTION OF CULTURES



- The knowledge instinct
 - Two **mechanisms**: **differentiation and synthesis**
- Differentiation
 - At every level of the hierarchy: more **detailed** concepts
 - **Separates concepts from emotions**
- Synthesis
 - **Connects concepts and emotions (knowledge and life)**
 - **Connects** language and cognition
 - Created in the hierarchy: concepts acquire **meaning** at the next level
- Evolutionary dynamics
 - **Complex interaction of opposing mechanisms**



CULTURE AND LANGUAGE



- Culture is transmitted through language
- Examine mechanisms of
 - Language and cognition
 - Language and emotion



EMOTIONAL SAPIR-WHORF HYPOTHESIS



- **Language affects thinking and behavior**
 - Bhartrihari 5th CE (India), Humboldt 1836, Nietzsche 1876
 - Benjamin Whorf and Edward Sapir in the 1930s
 - E.g., people better **perceive colors**, which have **words** in their language
- **Recent history**
 - “Out of favor.” Chomsky separated language and cognition
 - Recent resurgence of interest
- **We have to understand cultural differences**
 - “European” thinking is not the only way
- **Emotional differences are no less important than semantical**

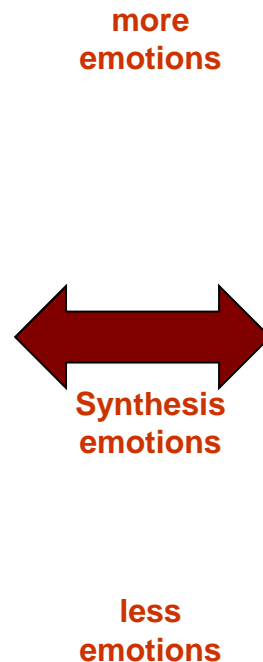
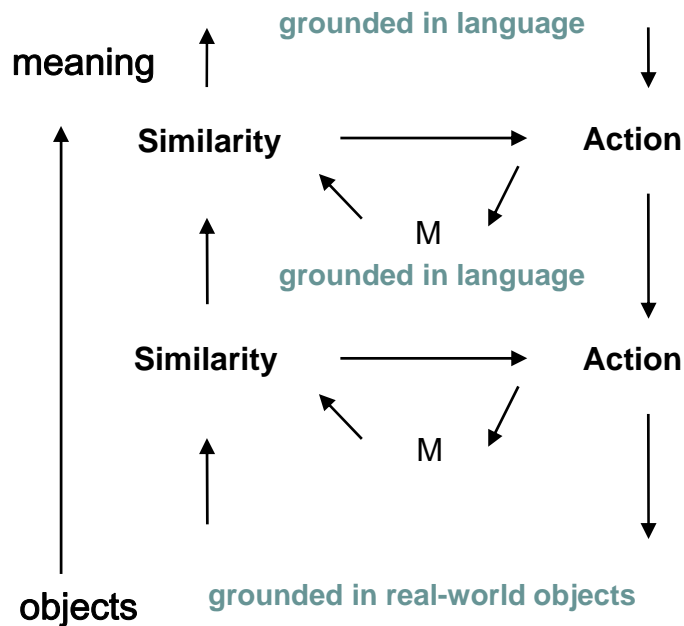


EMOTIONS IN INTEGRATED HIERARCHIES

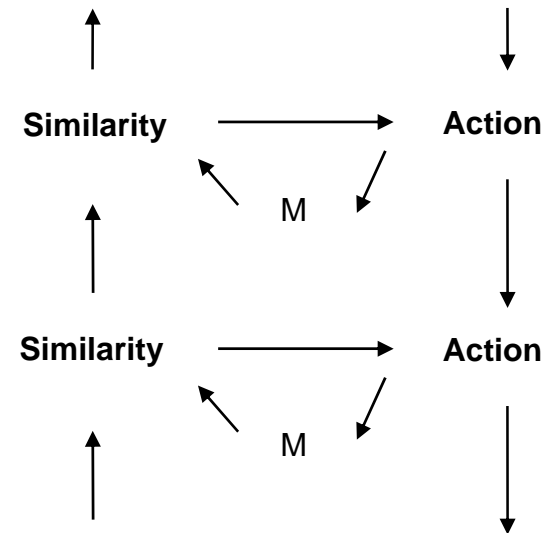


- Look top-down: **differentiation**, more detailed concept-models, **less emotions**
- Look bottom-up: **synthesis**, unifying general models, **more emotions**
- **At the top: meaning and purpose, emotions of the beautiful and sublime**

Cognition



Language





EMOTIONS IN LANGUAGES



- **Animals**

- **Undifferentiated concepts-emotions-behaviors-vocalization**
- Vocal tract is controlled from ancient emotional limbic system

- **Human language evolution**

- Language evolved toward semantics and **less emotions**
- Still emotions are needed, otherwise, no synthesis, no meaning
- Two emotional centers: limbic (involuntary) and cortex (conscious)
- Emotionality: in voice sound (melody of speech)

- **Emotional differences among languages**

- All languages evolved toward less emotionality
- **More semantic flexibility, but potential to lose meanings**
- “Too fast” evolution => lose meaning
- “Too slow” evolution => culture stagnates
- **Speed is determined by grammar, by inflections**



LANGUAGE EMOTIONS AND CULTURES



- **Conceptual content of culture:** words, phrases
Easily borrowed among cultures
- **Emotional content of culture**
In voice sound (melody of speech)
Determined by grammar
Cannot be borrowed among cultures
- **English** language (Diff. > Synthesis)
Weak connection between conceptual and emotional (since 15 c)
Pragmatic, high culture, but may lead to crises (lost meaning)
- **Arabic** language (Synthesis > Diff.)
Strong connection between conceptual and emotional
Cultural immobility, but strong feel of identity and purpose



MODELS OF CULTURAL EVOLUTION



- **Differentiation, D, synthesis, S, hierarchy, H**

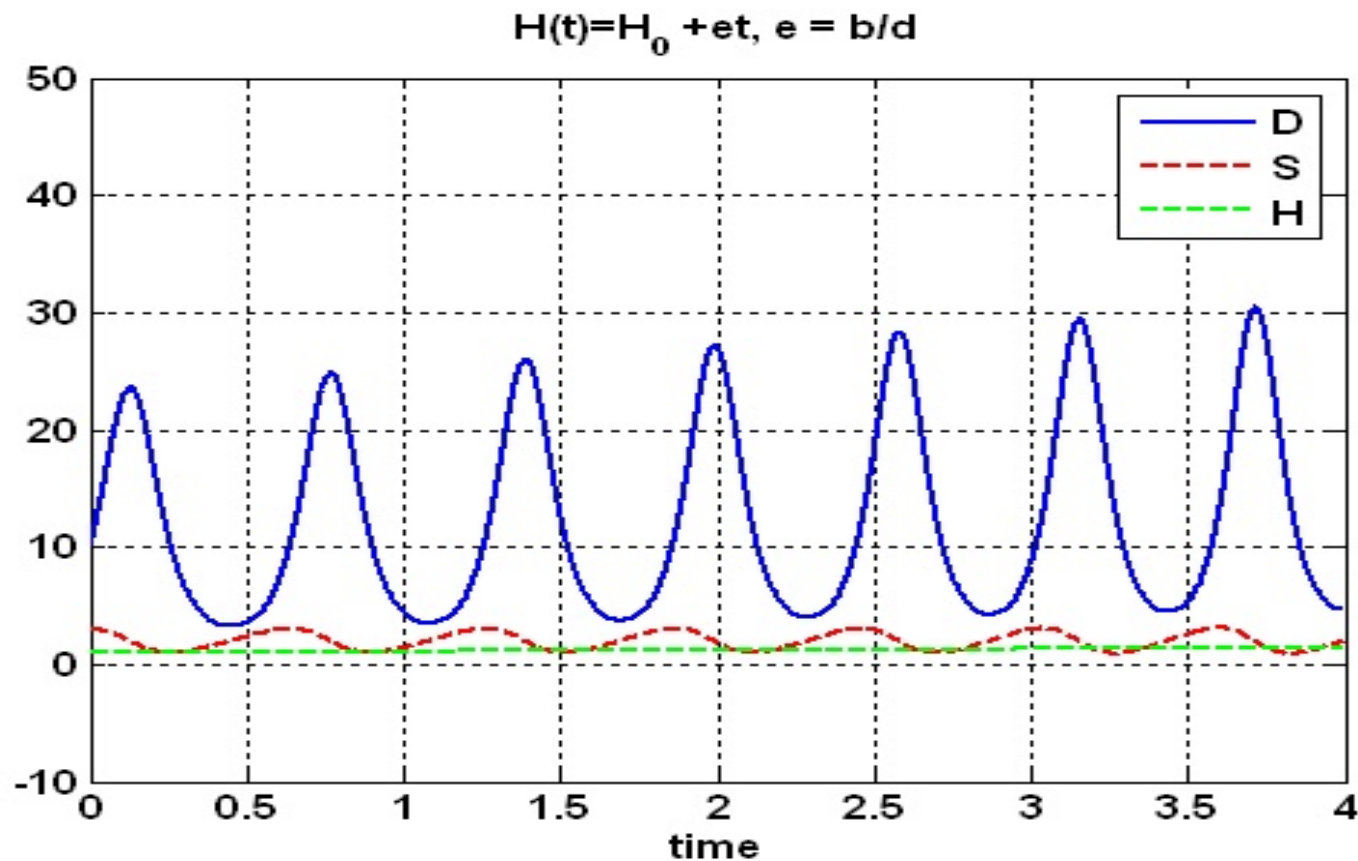
$$dD/dt = a D G(S); \quad G(S) = (S - S_0) \exp(-(S - S_0) / S_1)$$

$$dS/dt = -bD + dH$$

$$H = H_0 + e^*t$$



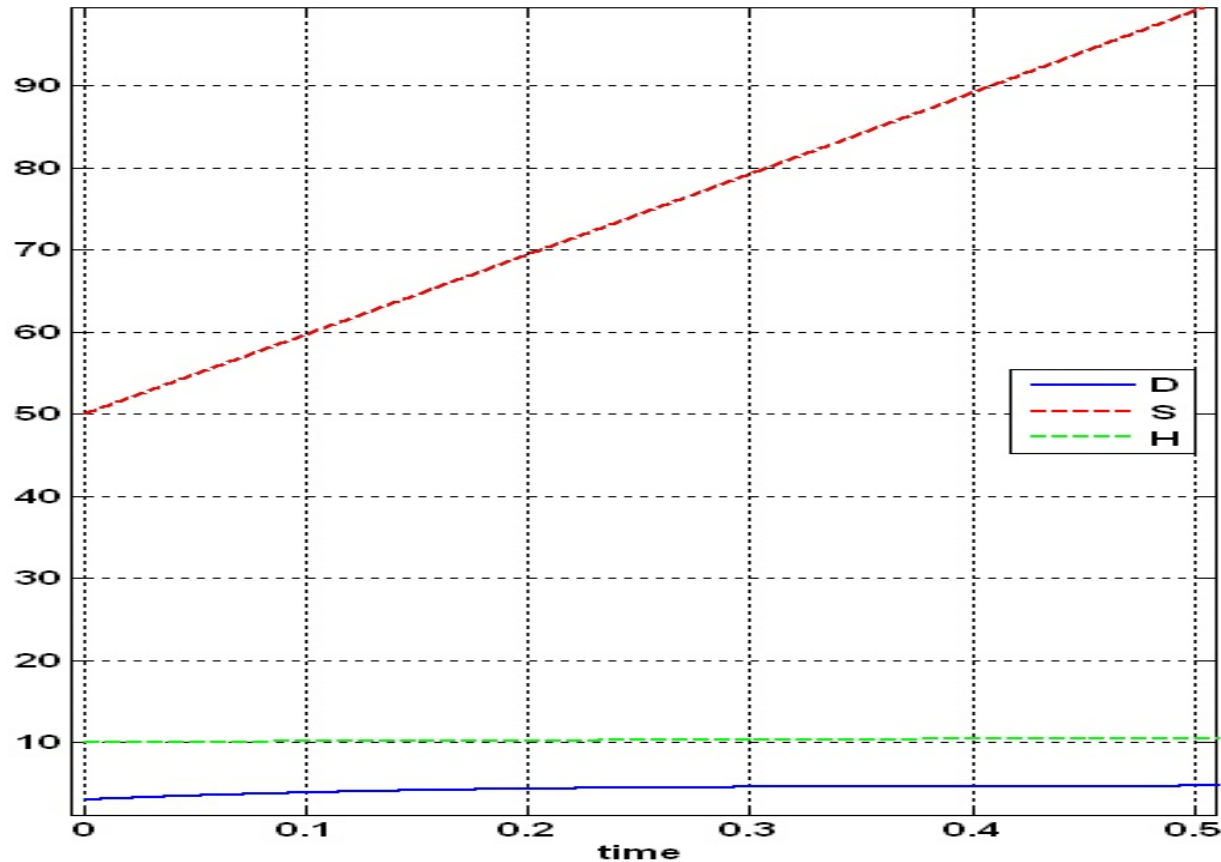
DYNAMIC CULTURE



Average synthesis, high differentiation; oscillating solution
Knowledge accumulates; no stability



TRADITIONAL CULTURE



High synthesis, low differentiation; stable solution
Stagnation, stability increases



INTERACTING CULTURES



- **Two cultures**
 - **dynamic and traditional**
 - **slow exchange by D and S**

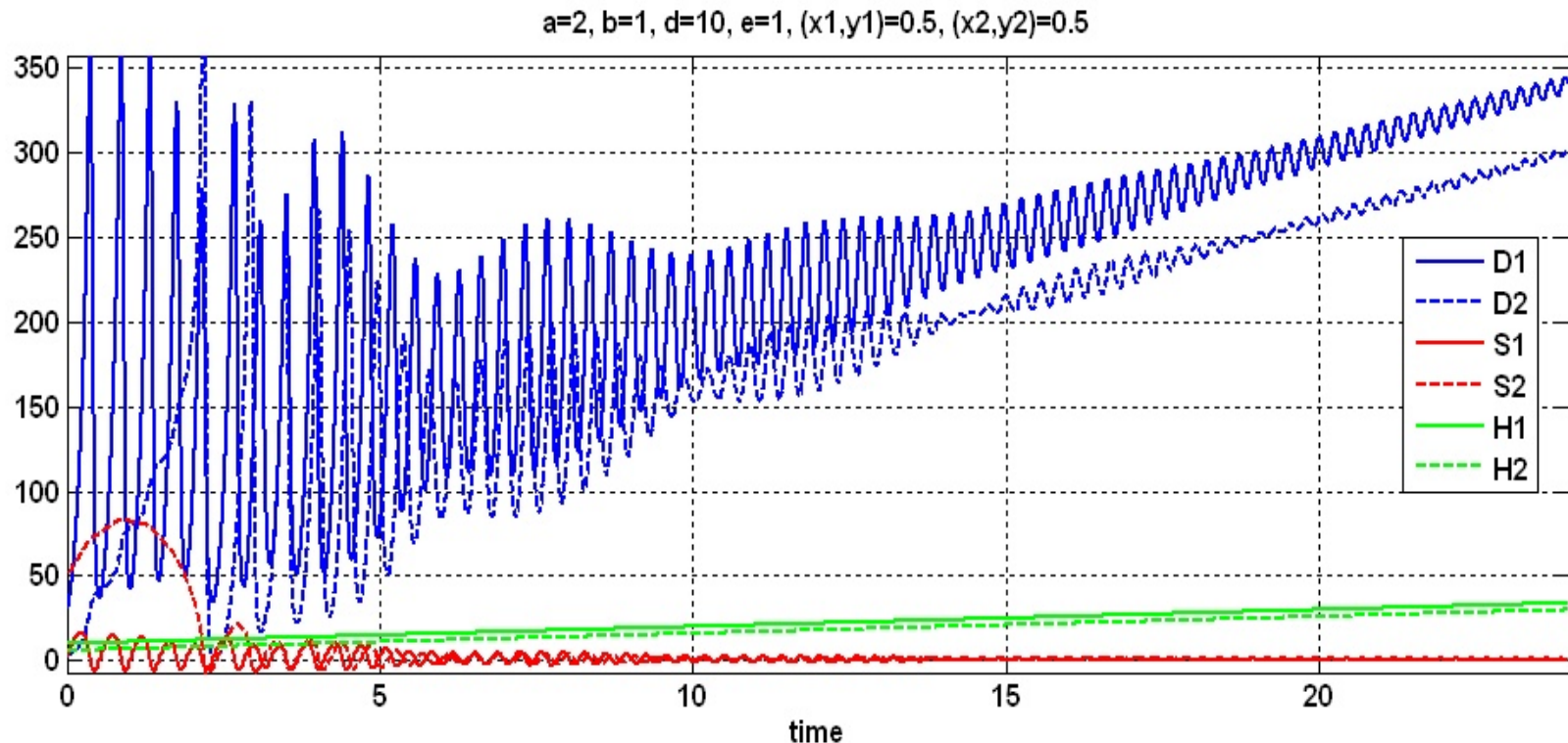
$$dD_k/dt = a_k D_k G(S_k) + x_k D_{\underline{k}}$$

$$dS_k/dt = -b_k D_k + d_k H_k + y_k S_{\underline{k}}$$

$$H_k = H0_k + e_k * t$$



INTERACTING CULTURES



- 1) Early: Dynamic culture affects traditional culture, no reciprocity
- 2) Later: 2 dynamic cultures stabilize each other

Knowledge accumulation + stability



PUBLICATIONS

330 publications

3 books

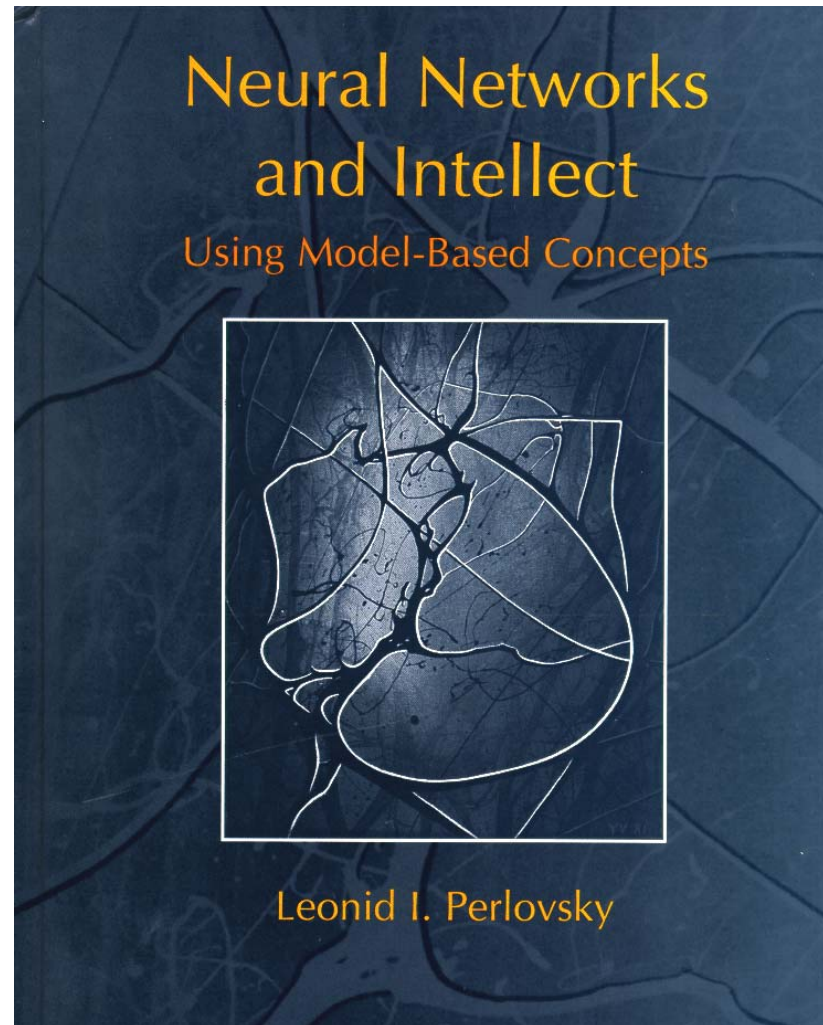
OXFORD UNIVERSITY PRESS
(2001; 3rd printing)



Neurodynamics of High Cognitive Functions
with Prof. Kozma, Springer, 2007

Sapient Systems
with Prof. Mayorga, Springer, 2007

2010:
Dynamic Logic, Springer
The Knowledge Instinct, Yale University Press





FUTURE DIRECTIONS

research, predictions and testing



- **Improve human condition and understanding around the globe**
 - Develop predictive cultural models, integrate spiritual and material causes, measure D, S, H
 - Identify language and music effects that can advance consciousness and reduce tensions
- **Mathematical development**
 - KI in the hierarchy, detailed models synthesis, combine with language and emotions
 - Multi-agent simulations
- **Psycholinguistic experiments**
 - Measure emotionality of various languages in labs
- **Music: theoretical and experimental**
 - Direct effect on emotions, mechanisms of synthesis
 - Concurrent evolution of music, consciousness, and cultures
- **Brain imaging**
 - Brain regions used by different cultures, languages, music
 - Neural mechanisms connecting language and cognition
- **Semantic Web and Cyberspace**
 - Adaptive ontologies
 - Learn from human users, acquire cultural knowledge
 - Enable culturally-sensitive communication
 - Help us understand each other and ourselves



BACK-UP



- **Structure of the mind**
- **Neural Modeling Fields**
- **Dynamic logic**
- **Neuro-imaging experimental confirmation**
- **Beautiful and sublime**



STRUCTURE OF THE MIND

- **Concepts**
 - Models of objects, their relations, and situations
 - Evolved to satisfy instincts
- **Instincts**
 - Internal sensors (e.g. sugar level in blood)
- **Emotions**
 - Neural signals connecting instincts and concepts
 - e.g. a hungry person sees food all around
- **Behavior**
 - Models of goals (desires) and muscle-movement...
- **Hierarchy**
 - Concept-models and behavior-models are organized in a “loose” hierarchy



NEURAL MODELING FIELDS

from signals to concepts



- **Bottom-up signals**

- Pixels or samples (from sensor or retina)
 $\mathbf{x}(n), n = 1, \dots, N$

- **Top-down concept-models**

$\mathbf{M}_m(\mathbf{S}_m, n)$, parameters $\mathbf{S}_m, m = 1, \dots;$

- Models predict expected signals from objects

- **The knowledge instinct = maximize similarity between signals and models**

$$L = \ell(\{\mathbf{x}\}) = \prod_n \sum_m \ell(\mathbf{x}(n) \mid \mathbf{M}_m)$$

- M^N items: all associations of pixels and models (\Rightarrow CC)
- New mathematical technique, DL, overcame this difficulty



DYNAMIC LOGIC (DL)

non-combinatorial max of knowledge



- **Start with a set of signals and unknown object-models**
 - any parameter values \mathbf{S}_m
 - associate models with signals (**vague**)
 - (1) $f(m|n) = r(m) \ell(n|m) / \sum_{m'} r(m') \ell(n|m')$
- **Improve parameter estimation**
 - (2) $\mathbf{S}_m = \mathbf{S}_m + \alpha \sum_n f(m|n) [\partial \ln \ell(n|m) / \partial \mathbf{M}_m]^* [\partial \mathbf{M}_m / \partial \mathbf{S}_m]$
- **Continue iterations (1)-(2). Theorem: MF is a converging system (**from vague to crisp**)**
 - similarity increases on each iteration
 - **aesthetic emotion** is positive during learning



DL AND BRAIN IMAGING



- **Neuro-imaging experiments proved that the brain works as predicted by dynamic logic**
- **Bar et al (2006), Harvard University proved**
 - Bottom-up signals (from eye retina) interact with top-down signals (from memory-models)
 - Initial top-down signals are **vague**
 - These interactions are unconscious
- **Barsalou et al (2006), Emory University proved**
 - Distributed vague representations in the mind



BEAUTIFUL AND SUBLIME



- The highest aesthetic emotion, beautiful
 - improvement of the highest models (at the top of the hierarchy)
 - feel emotion of beautiful
- Beautiful “reminds” us of our purposiveness
 - the “top” model unifies all our knowledge
 - vague
 - we perceive it as our purpose (“aimless purposiveness”)
- Beauty is separate from sex
 - sex uses all our abilities, including beauty
- Religiously sublime is related to behavior