COGNITIVE ALGORITHMS
Concepts, Emotions, Cultures

Cognitive Aspects of Decision Making workshop

22-24 September 2008, Washington DC

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OUTLINE

- AI, combinatorial complexity, and logic
- Cognition, the knowledge instinct, and dynamic logic
- Detection, tracking, fusion (cognition)
- Evolution of cultures

COMBINATORIAL COMPLEXITY OF AI
50 years of difficulties

- Detect signal in noise and clutter at the farthest possible distance
- AI, detection, exploitation, fusion, tracking
  - Requires association (pixels<->objects)
    - If 1 object, no noise: (1) detect pixels, (2) detect objects, (3) recognize targets
  - Joint detection-discrimination-classification…
- Combinatorial Complexity (CC)
  - Need to evaluate large numbers of combinations (pixels<->objects)
  - A general problem (since the 1950s)
    - SP, detection, recognition, tracking, fusion, exploitation, situational awareness,…
    - Pattern recognition, neural networks, rule systems…
- Combinations of 100 elements are 100^{100}
  - Larger than the number of particles in known Universe
    - Greater than all the elementary events in the Universe during its entire life
- CC prevented development of intelligent algorithms

DYNAMIC LOGIC
a mathematical breakthrough

- CC is related to logic
  - CC is Gödel's "incompleteness" in a finite system
  - Logic pervaded all algorithms and neural networks in the past
    - rule systems, fuzzy systems (degree of fuzziness), pattern recognition, neural networks (training uses logical statements)
- Dynamic Logic is a process-logic
  - "from vague to crisp" (statements, targets, decisions…)
  - Not a "statement logic"
- Overcomes CC
  - Fast algorithms
- Experimentally proven in brain imaging

THE MIND, KNOWLEDGE INSTINCT, AND DL

- **Mechanisms of the mind:**
  - **Instincts, Emotions, Concepts, Behavior, Hierarchy**
  - **Described mathematically (concepts=models)**

- **The knowledge instinct**
  - **Concept-models always have to be adapted**
  - **Increase similarity between models and the world**
  - **Emotions: (dis)harmony between concepts and the world**

NEURAL MODELING FIELDS

from signals to concepts

- **Bottom-up signals**
  - Pixels or samples (from sensor or retina)
    $\mathbf{x}(n)$, n = 1,…,N

- **Top-down concept-models**
  $\mathbf{M}_m(\mathbf{S}_m,n)$, parameters $\mathbf{S}_m$, m = 1, …;
  - 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 (=>CC)
  - Dynamic logic overcomes this difficulty

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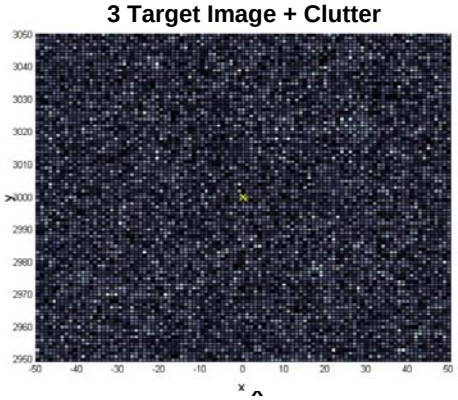
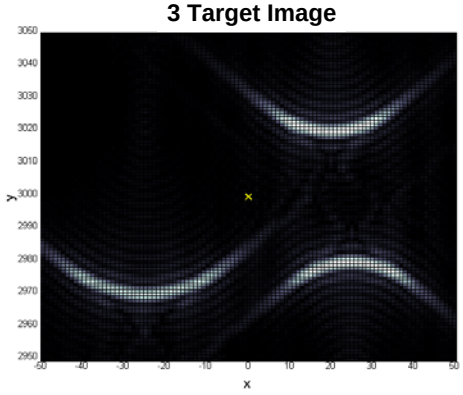
SLOW MOVING TARGETS IN SAR

Three targets in clutter	object 1	object 2	object 3
S/C	- 0.70 dB	-1.98 dB	-0.73 dB

3 Target Image + Clutter



3 Target Image



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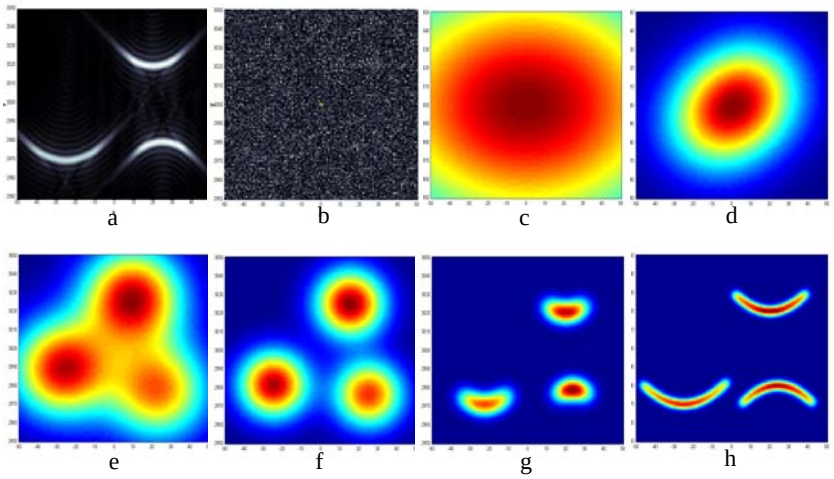
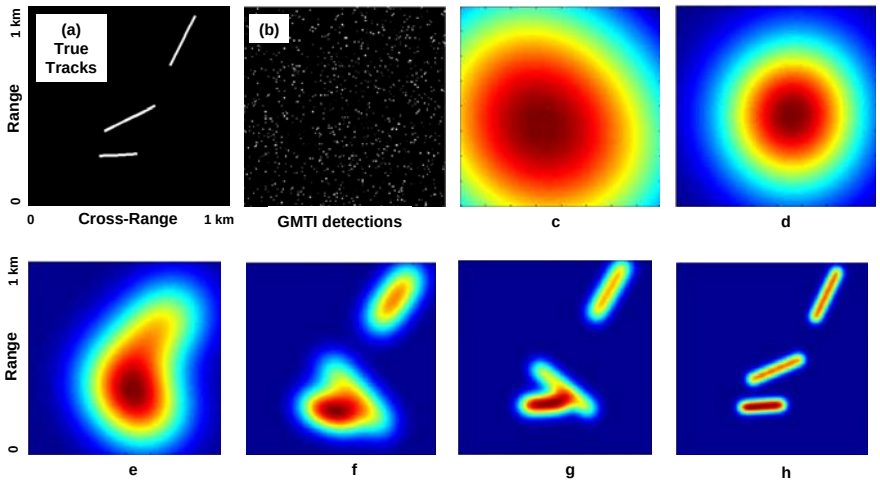


Multiple Hypothesis Testing "logical" complexity ~ 10^{6000}; DL complexity ~ 10^{6};
S/C ~ 17 dB improvement

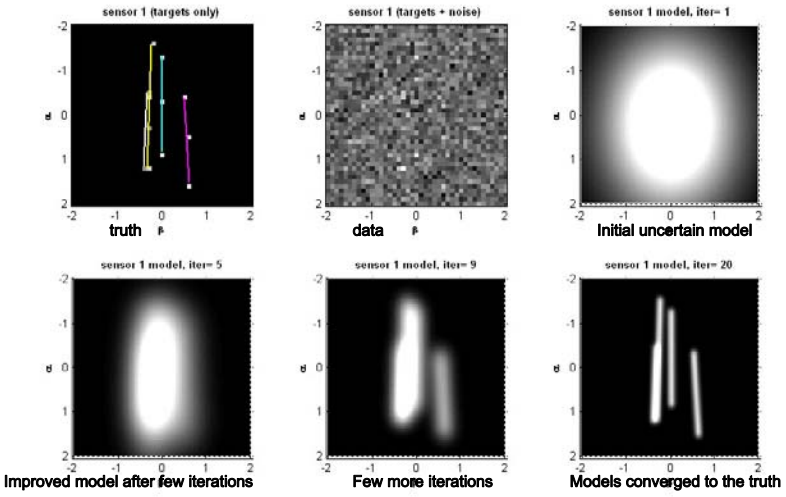
GMTI TRACKING AND DETECTION BELOW CLUTTER



Multiple Hypothesis Testing "logical" complexity ~ 10^{1800}; DL complexity ~ 10^{6};
S/C ~ 18 dB improvement

- Sensor navigation, detection, tracking, and fusion
  - 3 sensors
  - All data are processed simultaneously
  - Multiple Hypothesis Testing "logical" complexity ~ 10^{17000}

Sensor 1 (of 3): Model Evolves to Locate Target Tracks in Image Data



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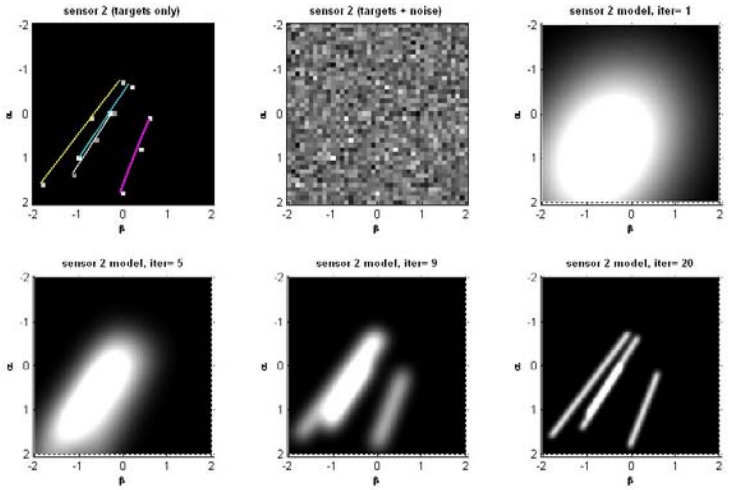
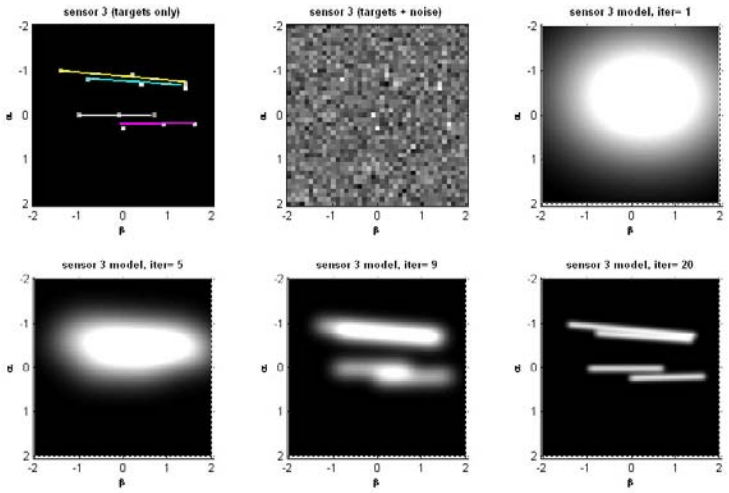
Sensor 2 (of 3): Model Evolves to Locate Target Tracks in Image Data



UNCLASSIFIED

Sensor 3 (of 3): Model Evolves to Locate Target Tracks in Image Data



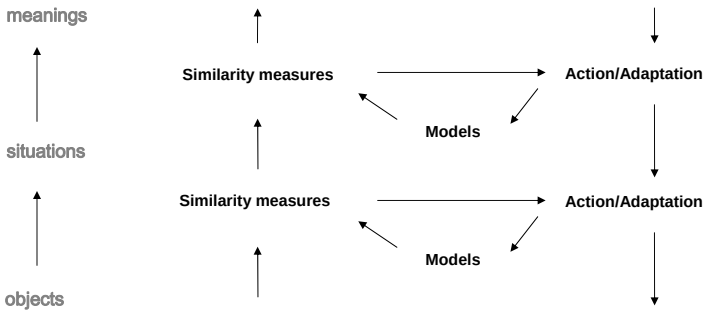
UNCLASSIFIED

PEER RECOGNITION

- 2007 Gabor Award
  - The top engineering award from International Neural Network Society (INNS)
- Elected to the Board of Governors of INNS (2008-2010)
- 2007 John L. McLucas Award
  - The top scientific award from the US Air Force

HIGHER COGNITIVE FUNCTIONS

- **Abstract models are at higher levels of the hierarchy**
  - **Higher level concepts are general, vague, less conscious**
  - **Meaning and purpose are created when higher level concepts unify lower-level knowledge**
  - **Beautiful is an emotion related to improving these models**
  - **Religiously sublime feelings are related to models of behavior**



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CULTURE AND LANGUAGE

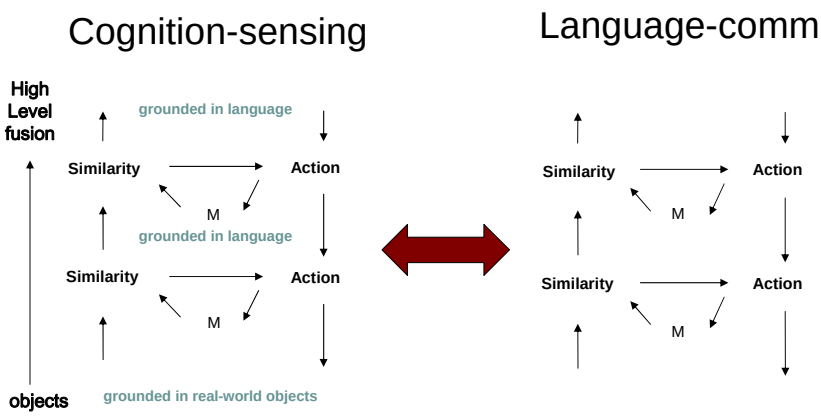
- Culture is transmitted through language
- Examine mechanisms of
  - Language and cognition
  - Language and emotion

INTEGRATED LANGUAGE AND COGNITION

- **How language and cognition interact**
  - **Each concept m has linguistic and cognitive dual model**
    - $\mathbf{M}_m = \{ \mathbf{M}_m^{\text{cognitive}}, \mathbf{M}_m^{\text{language}} \}$;
  - **Language and cognition are fused at vague pre-conceptual level**
    - **before concepts are learned**
- **Language and cognition mechanisms**
  - **Initial concept-models are fuzzy blobs**
  - **Language models have empty "slots" for cognitive model (objects and situations)**
  - **Language is learned "ready-made" from surrounding language**
    - **Computer-human interaction**
  - **Cognitive concepts are learned to match language models**

INTEGRATED HIERARCHIES

- High level cognition (integration) is only possible due to language
  - Situational awareness, layered sensing…



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

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 crisis (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

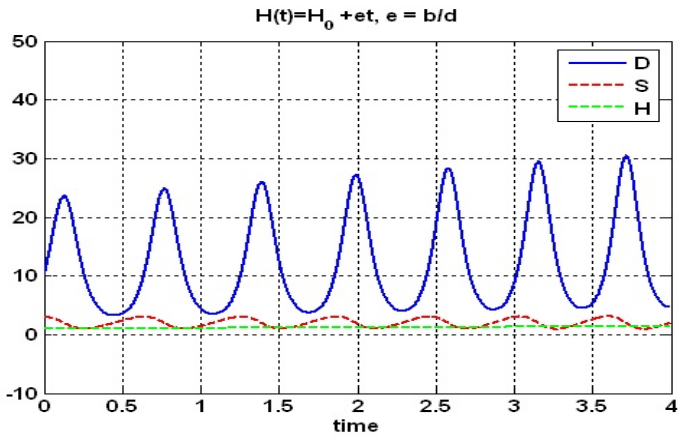
- **Differentiation, D, synthesis, S, hierarchy, H**

dD/dt = a D G(S); **G(S) = (S - S0) exp(-(S-S0) / S1)**

dS/dt = -bD + dH

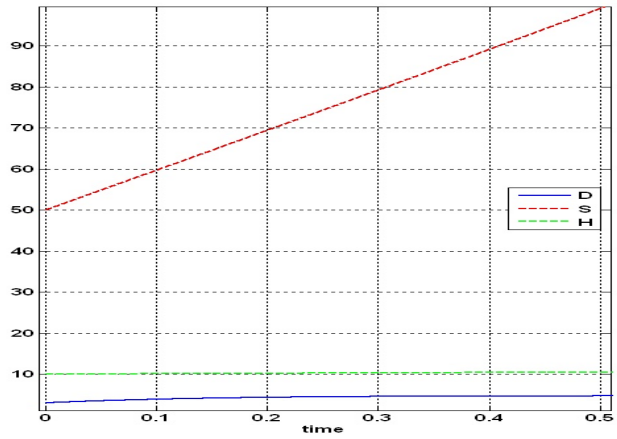
H = H0 + e*t

DYNAMIC CULTURE



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

TRADITIONAL CULTURE



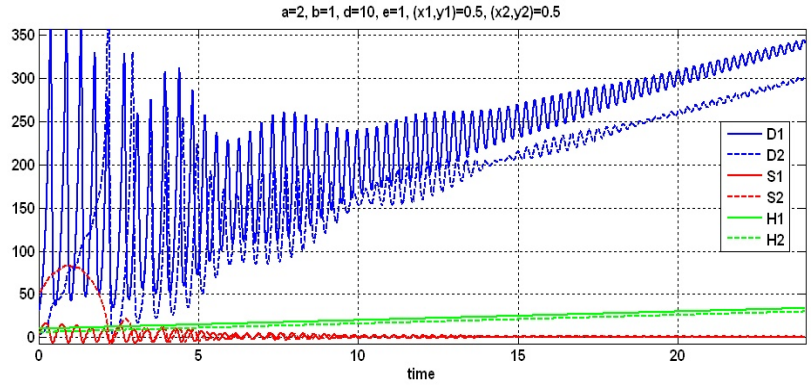
High synthesis, low differentiation; stable solution
Stagnation, stability increases

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

300 publications

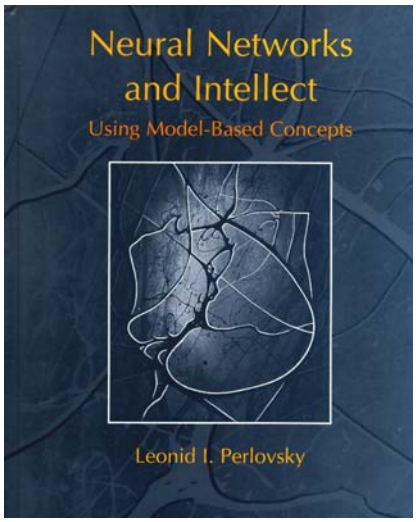
3 books

OXFORD UNIVERSITY PRESS
(2001; 3rd printing)

Neurodynamics of High Cognitive Functions
with Prof. Kozma, Springer

Sapient Systems
with Prof. Mayorga, Springer

2009:
The Knowledge Instinct
Yale University Press



FUTURE DIRECTIONS

research, predictions and testing of NMF/DL

- 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
  - Workshop planned at Harvard University, leading to a funded program
- Mathematical development
  - KI in the hierarchy, mechanisms of Synthesis
  - Add emotions to computer models of language evolution
  - Joint evolution of language and cognition, multi-agent simulations
- Psycholinguistic experiments
  - Measure emotionality of various languages in labs , funded at BU
- Music: theoretical and experimental
  - Direct effect on emotions, mechanisms of synthesis
  - Concurrent evolution of music, consciousness, and cultures, initial publications
- 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

- **CC vs. Logic**
- **Structure of the mind**
- **The knowledge instinct**
- **Dynamic logic**
- **Neuro-imaging experimental confirmation**
- **Beautiful and sublime**

CC vs. LOGIC

- CC is related to formal logic
  - Gödel proved that logic is "illogical," "inconsistent" (1930s)
  - CC is Gödel's "incompleteness" in a finite system
- Fuzzy logic
  - How to select degree of fuzziness?
  - The mind fits fuzziness for every process => CC
- Logic pervades all algorithms and neural networks
  - rule systems, fuzzy systems (degree of fuzziness), pattern recognition, neural networks (training uses logic)

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**

THE KNOWLEDGE INSTINCT

- **The knowledge instinct = maximization of similarity between signals and models**
- **Similarity between signals and models, L**
  - $L = \ell(\{\mathbf{x}\}) = \prod_n \ell(\mathbf{x}(n))$
  - $\ell(\mathbf{x}(n)) = \sum_m r(m)\, \ell(\mathbf{x}(n) \mid \mathbf{M}_m(\mathbf{S}_m,n))$
  - $\ell(\mathbf{x}(n) \mid \mathbf{M}_m(\mathbf{S}_m,n))$ is a conditional similarity for x(n) given m
    - {n} are not independent, M(n) may depend on n'
- **CC: L contains M^N items: all associations of pixels and models (LOGIC)**

DYNAMIC LOGIC (DL)
non-combinatorial solution

- **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**

  - similarity increases on each iteration
  - aesthetic emotion is positive during learning

DL AND BRAIN MECHANISMS

- **In 2007 neuro-imaging experiments proved that the brain works as predicted by dynamic logic**
- **A group of scientists from 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**
- **DL: Untapped potential for AFRL and DoD**

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