COGNITIVE ALGORITHMS
Concepts, Emotions, Cultures

Cognitive Aspects of Decision Making workshop
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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)
    \[ x(n), n = 1, \ldots, N \]

- **Top-down concept-models**
  - \( M_m(S_m,n), \) parameters \( S_m, m = 1, \ldots \);
  - Models predict expected signals from objects

- **The knowledge instinct = maximize similarity between signals and models**
  \[
  L = \sum L_x = \prod x \sum (x(n) | M_m) 
  \]
  - \( M^N \) items: all associations of pixels and models (=>CC)
  - Dynamic logic overcomes this difficulty
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SLOW MOVING TARGETS IN SAR

<table>
<thead>
<tr>
<th>Three targets in clutter</th>
<th>object 1</th>
<th>object 2</th>
<th>object 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/C</td>
<td>-0.70 dB</td>
<td>-1.98 dB</td>
<td>-0.73 dB</td>
</tr>
</tbody>
</table>

3 Target Image + Clutter

3 Target Image
SLOW MOVING TARGETS IN SAR

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

GMTI TRACKING AND DETECTION BELOW CLUTTER

Multiple Hypothesis Testing "logical" complexity $\sim 10^{6000};$ DL complexity $\sim 10^6;$ S/C $\sim 18$ dB improvement
• Sensor navigation, detection, tracking, and fusion
  - 3 sensors
  - All data are processed simultaneously
  - Multiple Hypothesis Testing "logical" complexity $\sim 10^{17000}$

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

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

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

![Diagram](Image)

- Similarity measures
- Action/Adaptation
- Models

meanings

situations

objects
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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
    • \( M_m = \{ M_m^{\text{cognitive}}, M_m^{\text{language}} \} \)
  – 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…

Cognition-sensing

Language-comm
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

\[ \frac{dD}{dt} = a \ D \ \frac{G(S)}{G(S)} = (S - S_0) \ \exp\left(-\frac{S - S_0}{S_1}\right) \]

\[ \frac{dS}{dt} = -bD + dH \]

\[ H = H_0 + e^t \]

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

\[
\begin{align*}
dD_k/dt &= a_k D_k G(S_k) + x_k D_k \\
dS_k/dt &= -b_k D_k + d_k H_k + y_k S_k \\
H_k &= H_0 + e_k * t
\end{align*}
\]
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
  – $L = \ell(\{x\}) = \prod \ell(x(n))$
  – $\ell(x(n)) = \sum r(m) \ell(x(n) | M_m(S_m,n))$
  – $\ell(x(n) | M_m(S_m,n))$ 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 $S_m$
  – associate models with signals (vague)
  – (1) $f(m|n) = r(m) \ell(n|m) / \sum r(m’) \ell(n|m’)$

• Improve parameter estimation
  – (2) $S_m = S_m + \alpha \sum f(m|n) [\partial \ln \ell(n|m)/\partial M_m][\partial M_m/\partial S_m]$

• Continue iterations (1)-(2). Theorem: MF is a converging system
  - similarity increases on each iteration
  - aesthetic emotion is positive during learning
• 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.

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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.