BIO-INSPIRED AND COGNITIVE NEURAL NETWORKS
for
data mining, tracking, fusion, prediction, evolution of languages and cultures

IJCNN 2007 Tutorial

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OUTLINE

1. Cognition, Complexity, and Logic
2. The Knowledge Instinct
   - -Neural Modeling Fields and Dynamic Logic
3. Higher Cognitive Functions
4. Integration of cognition and language
5. Evolution of cultures (future directions)

DETAILED OUTLINE

1. Cognition – integration of real-time signals and a priori knowledge

1.1. cognition
1.2. combinatorial complexity (CC) – a fundamental problem?
1.5. CC since 1950s
1.6. CC vs. logic
1.6.1. formal, multivalued and fuzzy logics
1.6.2. dynamic logic
1.6.3. Aristotle vs. Godel + Alexander the Great
1.7. mathematics vs. mind
1.8. structure of the mind: concepts, instincts, emotions, behavior
1.9. the knowledge instinct
1.9.1. need for learning
1.9.2. "knowledge emotion" = aesthetic emotion

2. Modeling Field Theory (NMF) of cognition

2.1. the knowledge instinct = max similarity
2.2. Similarity as likelihood, as information
2.3. Dynamic Logic (DL)
2.4. applications, examples
2.4.2 tracking
2.4.3 recognition
2.4.4 fusion
2.4.5 prediction, financial prediction

3. Higher cognitive functions

3.1. hierarchy of the mind
3.2. beautiful and sublime

4. Integration of cognition and language

4.1. language vs. cognition
4.2. integrated models
4.3. Symbols: integrated hierarchies

5. Evolution of Culture

6.1. Emotionality of languages and cultures
6.2. Evolution of cultures
6.5. English vs. Arabic
6.5. Terrorist's consciousness
6.6. Models of cultural evolution
6.6.1. Dynamic cultures
6.6.2 Traditional cultures
6.6.3 Interacting cultures
6.7 Role of music in evolution of the mind and culture
6.8 Science vs. religion

6. Future direction, predictions, testing, publications

COGNITION

- **Understanding the world around**
  - **Perception**
  - **Simple objects**
  - **Complex situations**

- **Integration of real-time signals and existing (a priori) knowledge**
  - **From signals to concepts**
  - **From less knowledge to more knowledge**

ALGORITHMIC DIFFICULTIES
A FUNDAMENTAL PROBLEM?

- **Cognition and language involve evaluating large numbers of combinations**
  - **Pixels -> objects -> scenes**

- Combinatorial Complexity (CC)
  - A general problem (since the 1950s)
    - Detection, recognition, tracking, fusion, situational awareness, 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

COMBINATORIAL COMPLEXITY SINCE the 1950s

- **CC was encountered for over 50 years**
- **Statistical pattern recognition and neural networks: CC of learning requirements**
- **Rule systems and AI, in the presence of variability : CC of rules**
  - **Minsky 1960s: Artificial Intelligence**
  - **Chomsky 1957: language mechanisms are rule systems**
- **Model-based systems, with adaptive models: CC of computations**
  - **Chomsky 1981: language mechanisms are model-based (rules and parameters)**
- **Current ontologies, "semantic web" are rule-systems**
  - **Evolvable ontologies : present challenge**

CC AND TYPES OF LOGIC

- CC is related to formal logic
  - Law of excluded middle (or excluded third)
  - Gödel proved that logic is “illogical,” “inconsistent” (1930s)
  - CC is Gödel's “incompleteness” in a finite system
- Fuzzy logic eliminated the “law of excluded third”
  - Fuzzy logic systems are either too fuzzy or too crisp
  - The mind fits fuzziness for every statement at every step => CC
- Logic pervades all algorithms and neural networks
  - rule systems, fuzzy systems (degree of fuzziness), pattern recognition, neural networks (training uses logical statements)

DYNAMIC LOGIC

- Dynamic Logic unifies formal and fuzzy logic
  - initial “vague or fuzzy concepts” dynamically evolve into “formal-logic or crisp concepts”
- Dynamic logic
  - based on a similarity between models and signals
- Overcomes CC of model-based recognition
  - fast algorithms

ARISTOTLE VS. GÖDEL
logic, forms, and language

- Aristotle
  - Logic: a supreme way of argument
  - Forms: representations in the mind
    - Form-as-potentiality evolves into form-as-actuality
    - Logic is valid for actualities, not for potentialities (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
- Aristotle and Alexander the Great

OUTLINE

- Cognition, complexity, and logic
  - Logic does not work, but the mind does
- The Mind and Knowledge Instinct
  - Neural Modeling Fields and Dynamic Logic
- Higher Cognitive Functions
- Integration of cognition and language
- Evolution of Cultures
- Future directions

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

- **Model-concepts always have to be adapted**
  - **lighting, surrounding, new objects and situations**
  - **even when there is no concrete “bodily” needs**
- **Instinct for knowledge and understanding**
  - **Increase similarity between models and the world**
- **Emotions related to the knowledge instinct**
  - **Satisfaction or dissatisfaction**
    - **change in similarity between models and world**
  - **Related not to bodily instincts**
    - **harmony or disharmony (knowledge-world): aesthetic emotion**

Neural Modeling Fields (NMF)

- **A mathematical construct modeling the mind**
  - Neural synaptic fields represent model-concepts
  - A loose hierarchy of more and more general concepts
  - At every level:
    - bottom-up signals, top-down signals (models)
    - KI, concepts-models, emotions, behavior
  - Concepts become input signals to the next level

NEURAL MODELING FIELDS

basic two-layer mechanism: from signals to concepts

- **Bottom-up signals**
  - Pixels or samples (from sensor or retina)

    $\mathbf{x}(n)$, n = 1,…,N

- **Top-down signals: concept-models** $\mathbf{M}_m(\mathbf{S}_m,n)$, parameters $\mathbf{S}_m$, m = 1, …;
  - Models predict expected signals from objects

- **Goal: learn models and understand signals (knowledge instinct)**

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 object-model with its contents (signal composition)
  - (1) $f(m|n) = r(m)\,\ell(n|m) \,/\, \sum_{m'} r(m')\,\ell(n|m')$

- **Improve parameter estimation**
  - (2) $\mathbf{S}_m = \mathbf{S}_m + \alpha \sum_n f(m|n)\,[\partial \ln \ell(n|m)/\partial \mathbf{M}_m]*[\partial \mathbf{M}_m/\partial \mathbf{S}_m]$
    - (α determines speed of convergence)
  - learn signal-contents of objects

- **Continue iterations (1)-(2). Theorem: MF is a converging system**

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

OUTLINE

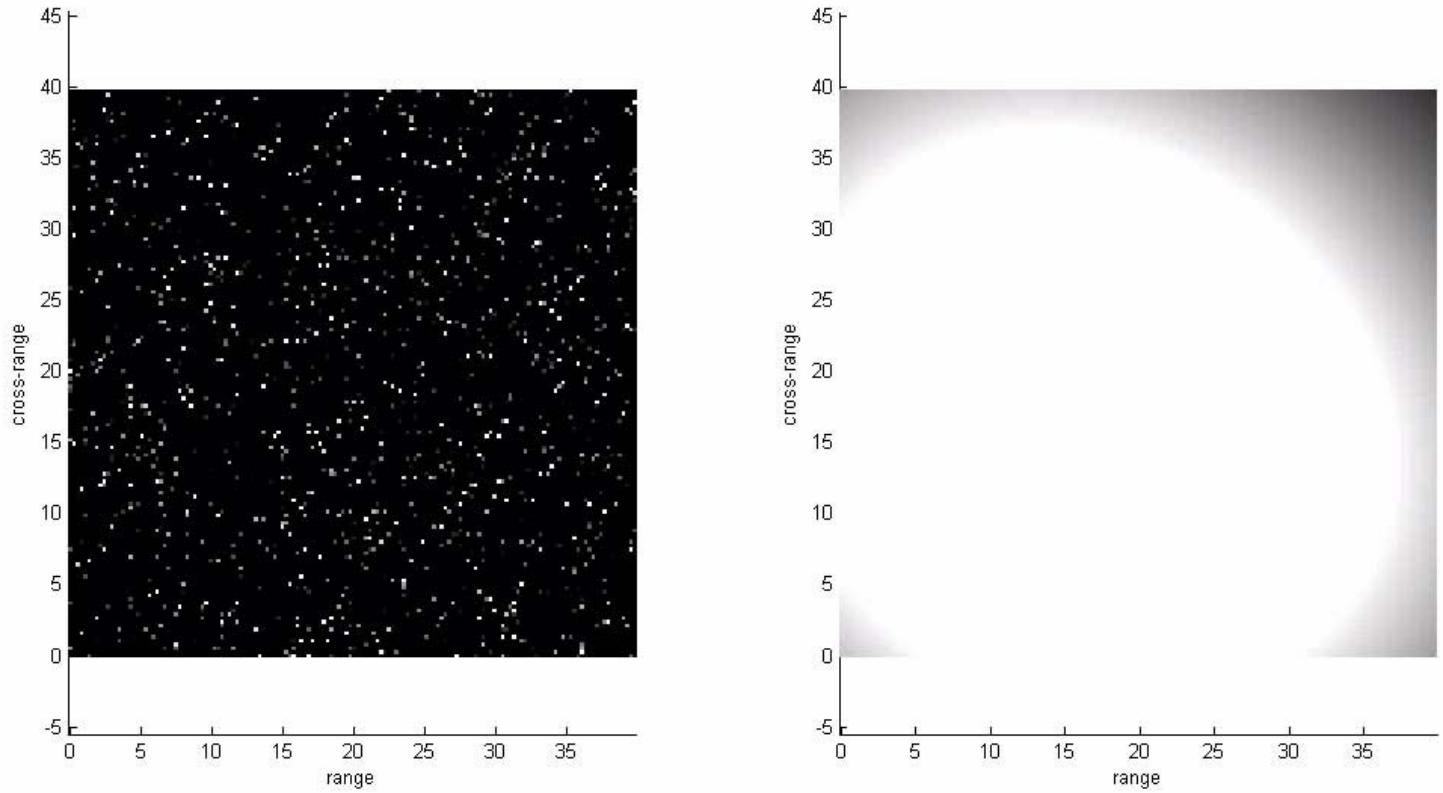
- Cognition, complexity, and logic
  - Logic does not work, but the mind does
- The Mind and Knowledge Instinct
  - Neural Modeling Fields and Dynamic Logic
  - Application examples
- Higher Cognitive Functions
- Integration of cognition and language
- Evolution of Cultures
- Future directions

APPLICATIONS

- **Many applications have been developed**
  - **Government**
  - **Medical**
  - **Commercial (about 25 companies use this technology)**
- **Sensor signals processing**
- **Financial market predictions**
  - **Market crash on 9/11 predicted a week ahead**
- **Internet search engines**
  - **Based on text understanding**
- **Evolving ontologies for Semantic Web**

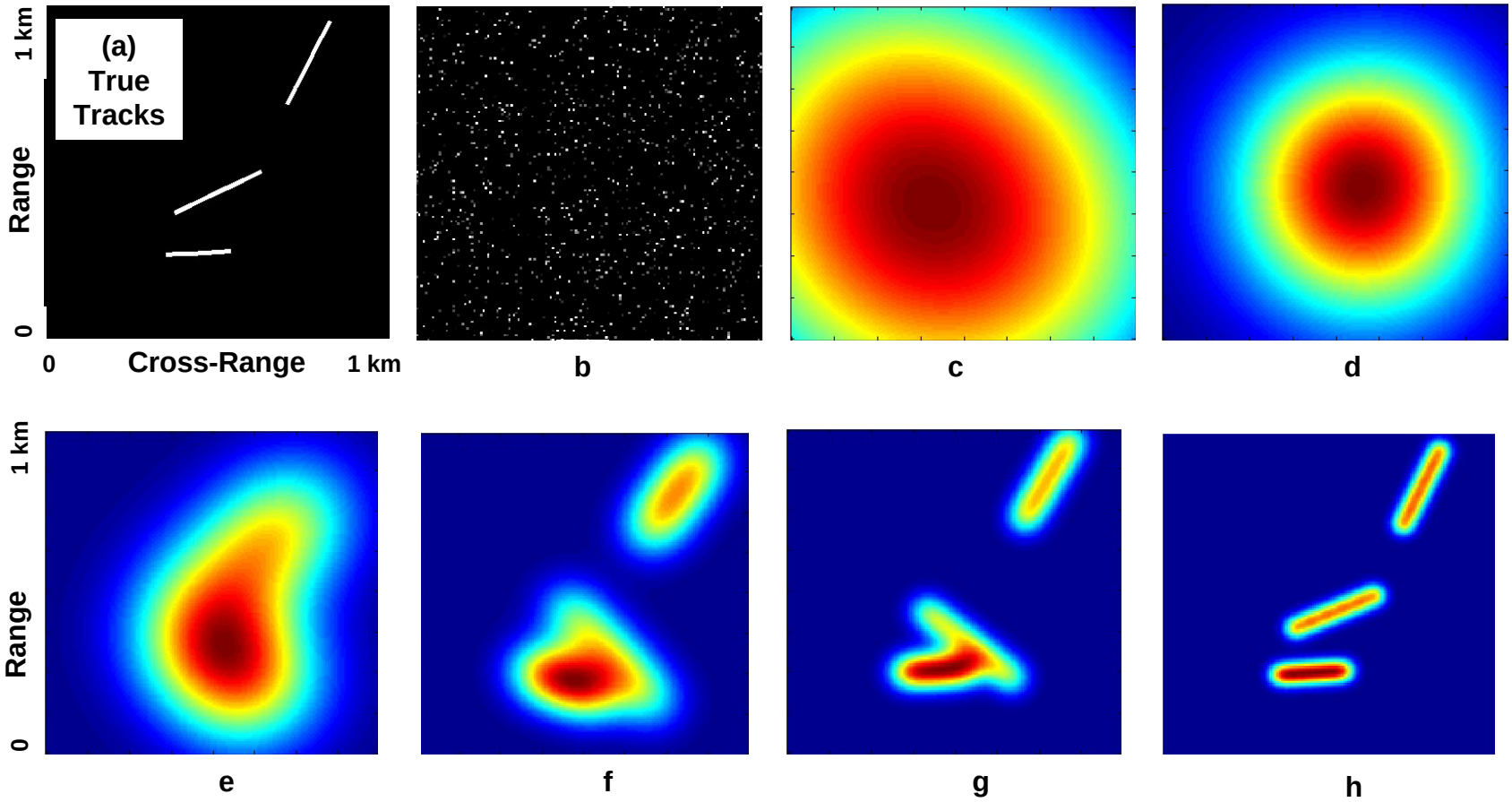
TRACKING AND DETECTION BELOW CLUTTER

DL starts with uncertain knowledge, and similar to human mind does not sort through all possibilities, but converges rapidly on exact solution



3 targets, 6 scans, signal-to-clutter, S/C ~ -3.0dB

TRACKING AND DETECTION BELOW CLUTTER



3 targets, 6 scans, 3000 data points, signal-to-clutter, S/C ~ -3.0dB

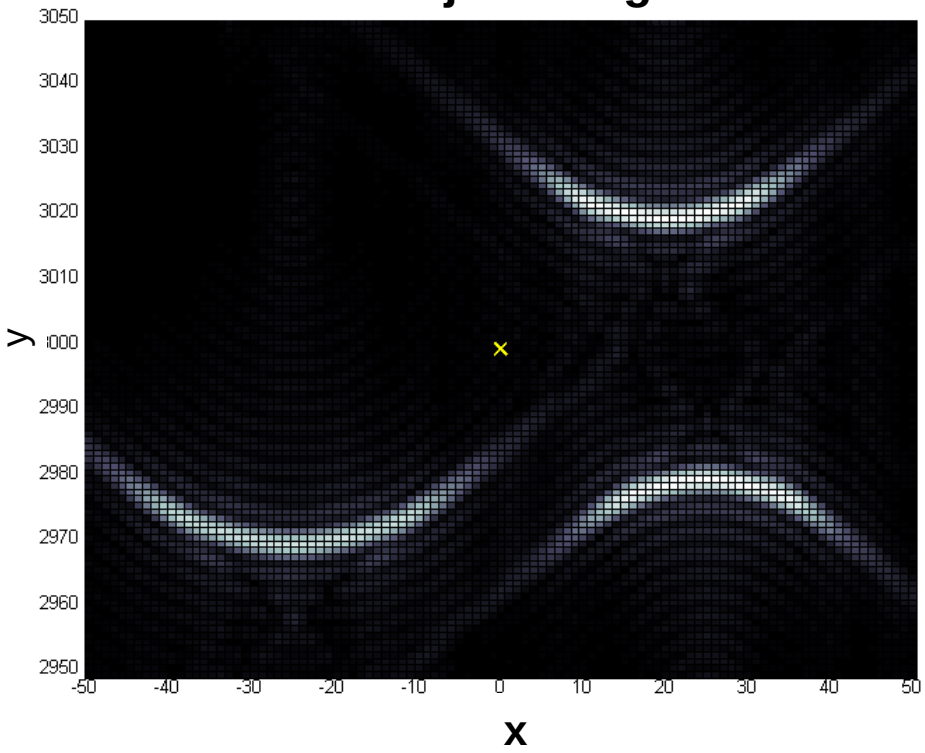
Complexity: MHT~M^N ~10^{1700}; DL ~ 10^6, Improvement in S/C about 100 times

IMAGE PATTERNS BELOW CLUTTER

Three objects in noise

	object 1	object 2	object 3
SCR	- 0.70 dB	-1.98 dB	-0.73 dB

3 Object Image



3 Object Image + Clutter

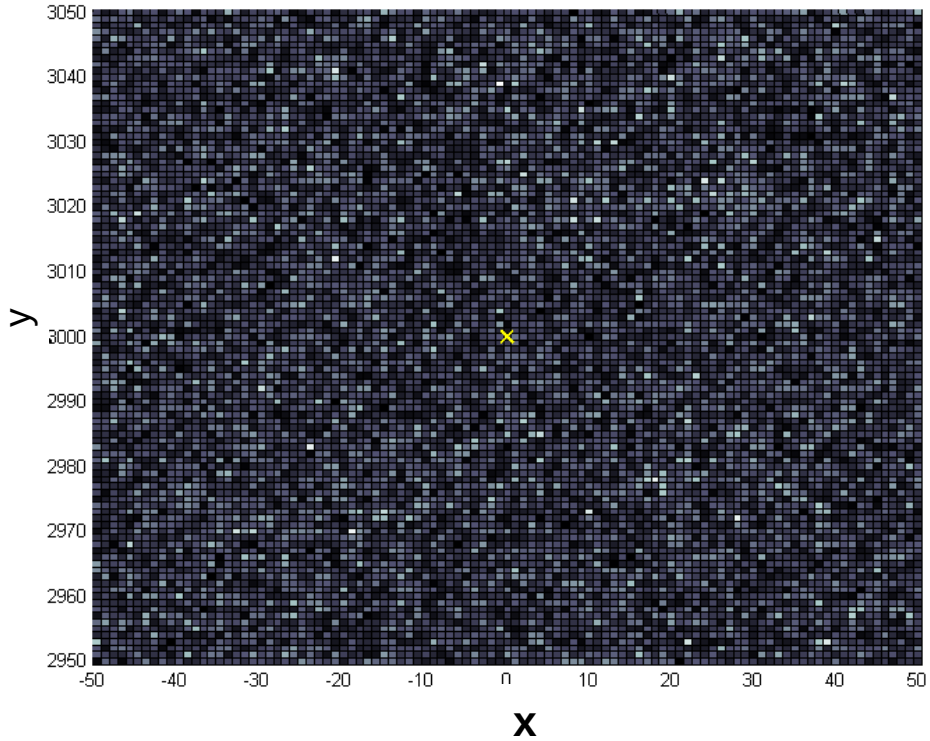


IMAGE PATTERNS BELOW CLUTTER

DL starts with uncertain knowledge, and similar to human mind does not sort through all possibilities like an MHT, but converges rapidly on exact solution

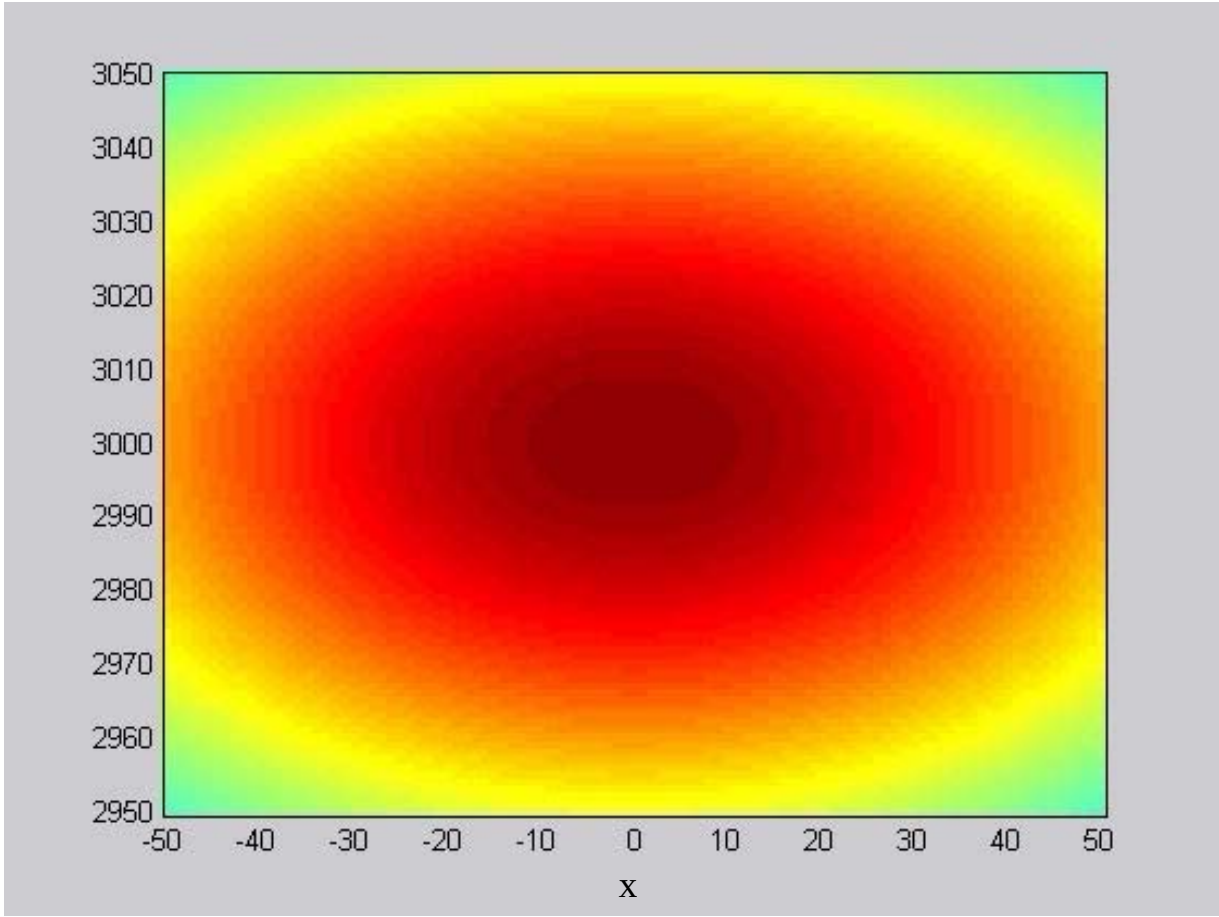
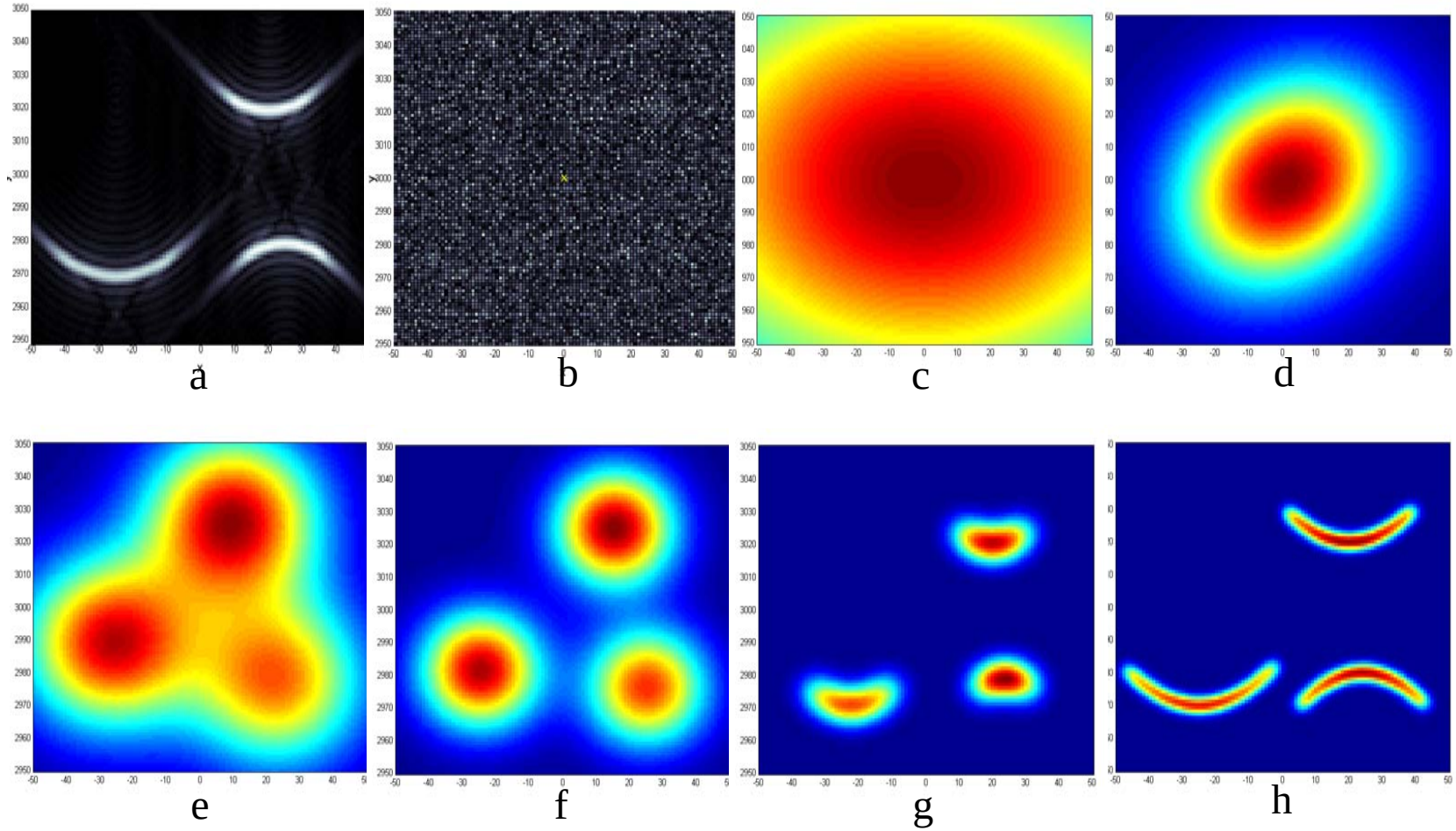


IMAGE PATTERNS BELOW CLUTTER
(dynamic logic iterations see note-text)



3 targets, 10,000 data points, signal-to-clutter, S/C ~ 0.5

Complexity: MHT~M^N ~10^{5000}; DL ~ 10^6, Improvement in S/C about 100 times

SENSOR FUSION

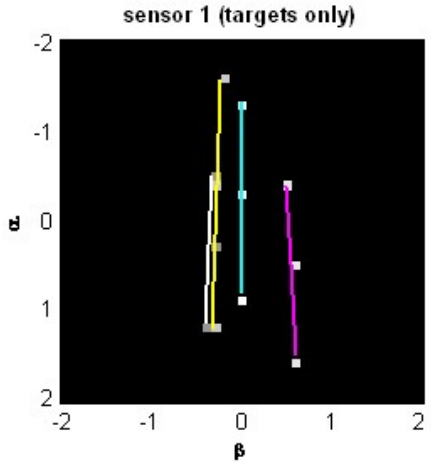
- **The difficult part of sensor fusion is association of data among sensors**

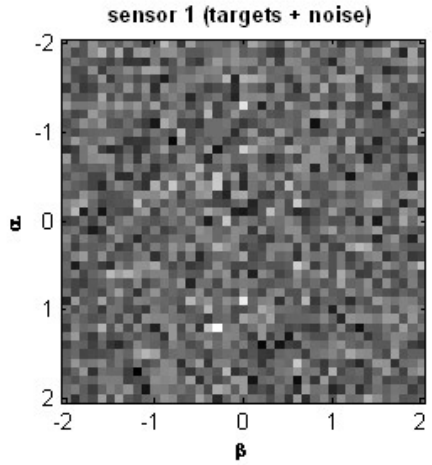
- **Which sample in one sensor corresponds to which sample in another sensor?**
  - **The most difficult: concurrent detection, tacking, and fusion**

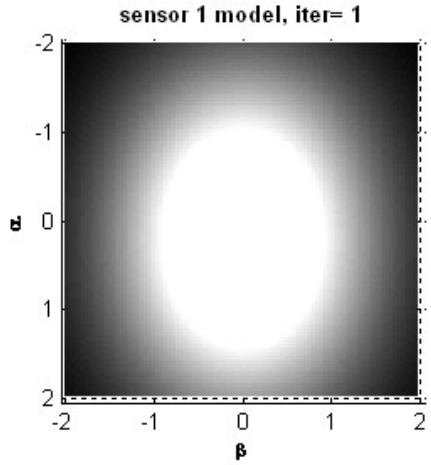
Source: UAS Roadmap 2005-2030

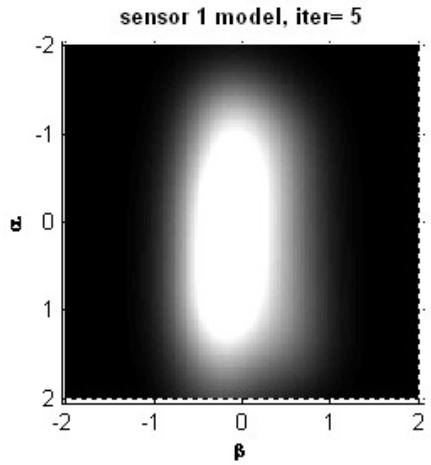
UNCLASSIFIED

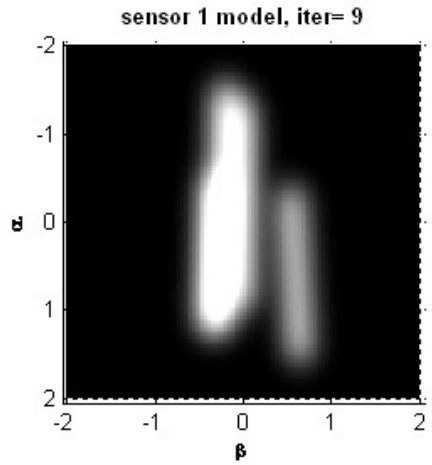
Sensor 1 (of 3): Models Evolve to find targets using all 3 sensors

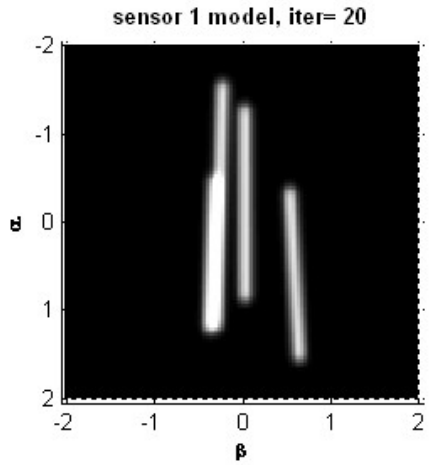




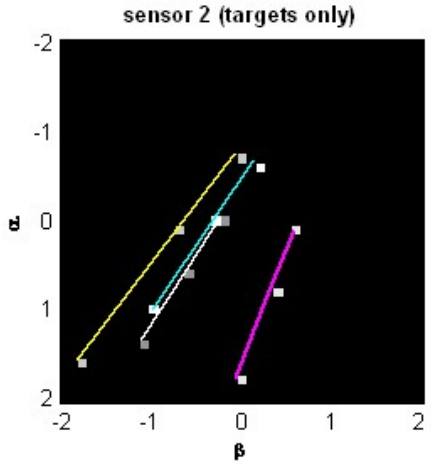


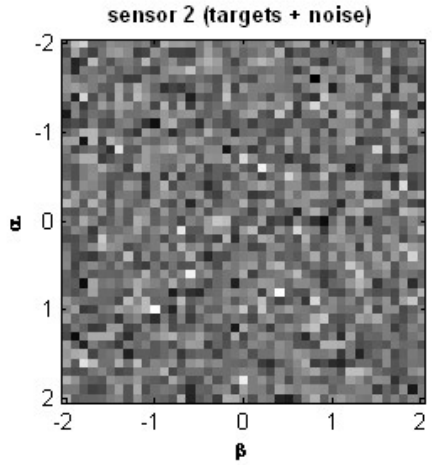


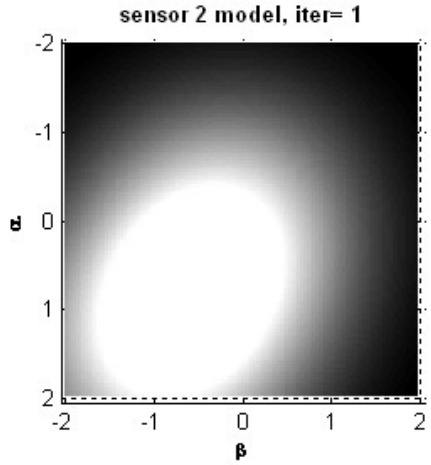


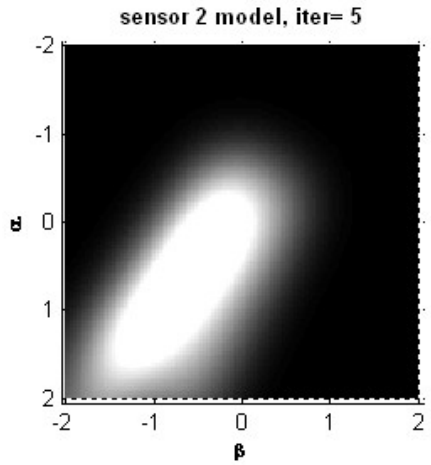


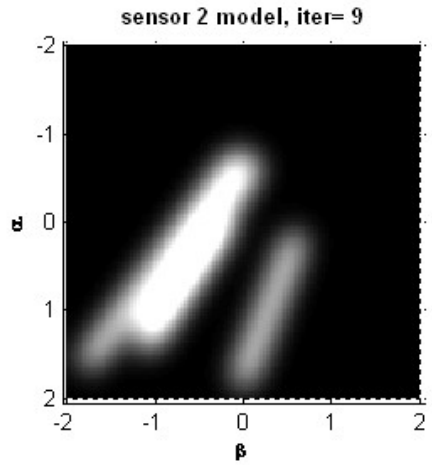
Sensor 2 (of 3): Models Evolve to find targets using all 3 sensors

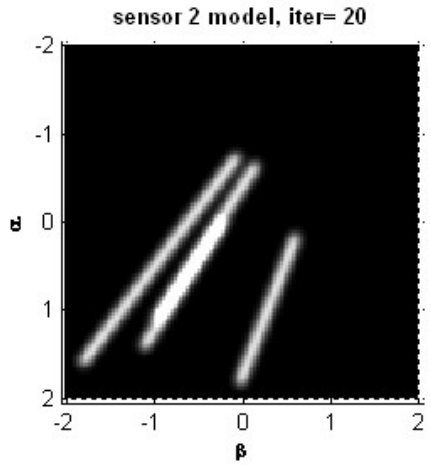




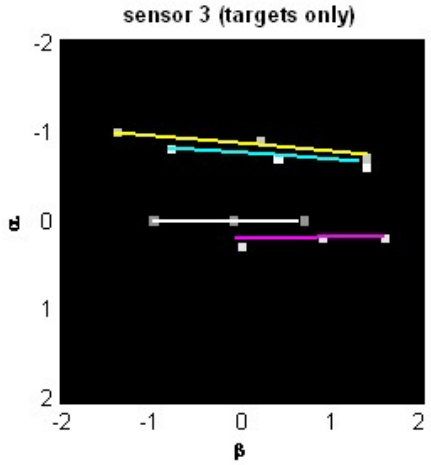


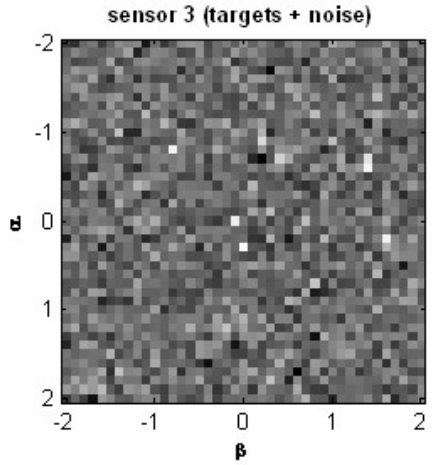


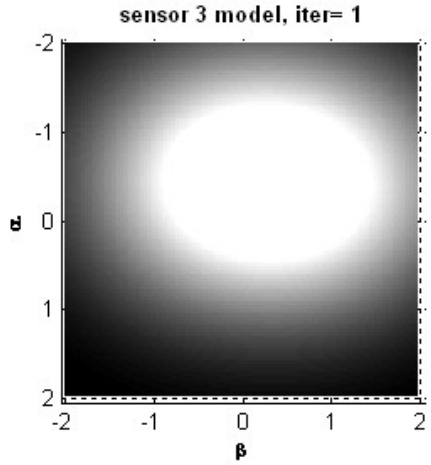


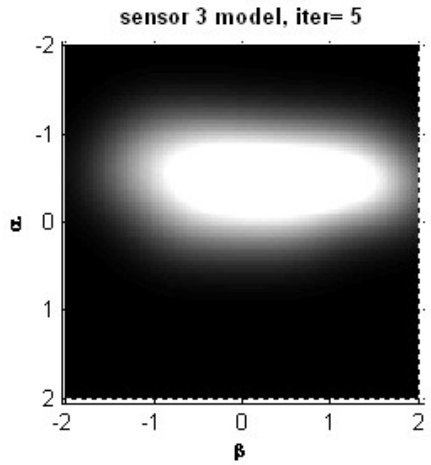


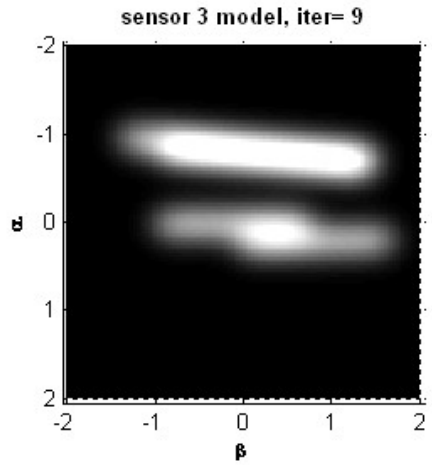
Sensor 3 (of 3): Models Evolve to find targets using all 3 sensors

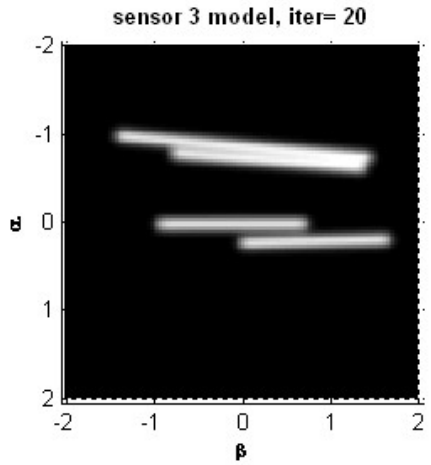






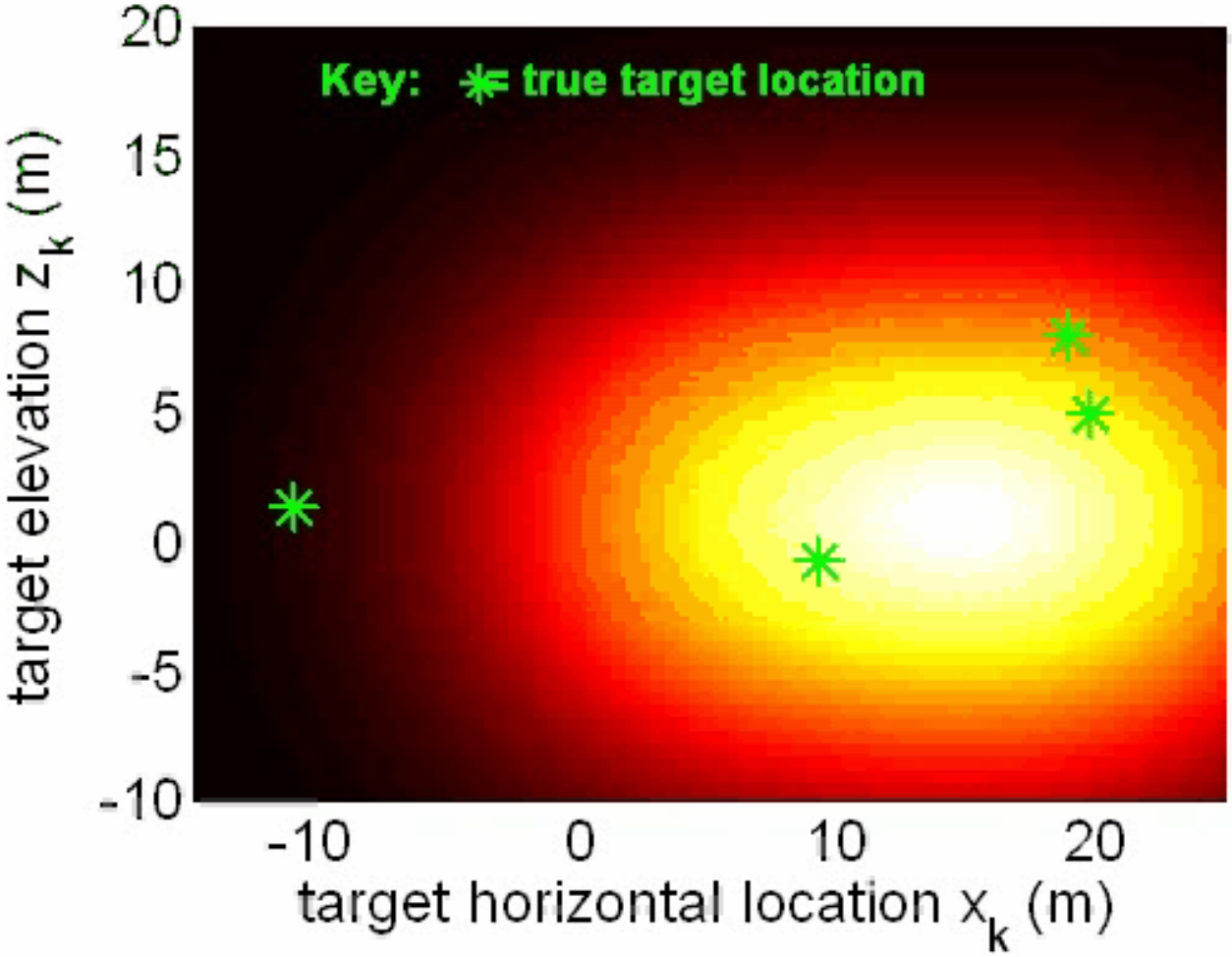






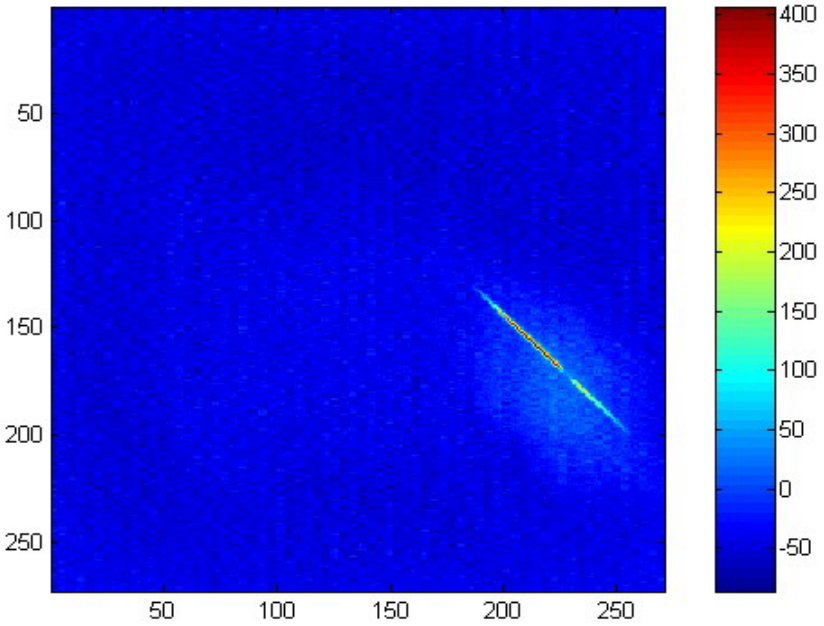
NAVIGATION, FUSION, TRACKING, AND DETECTION

(this is the basis for the previous 3 figures, all fused in x,y,z, coordinates; double-click on the blob to play movie)

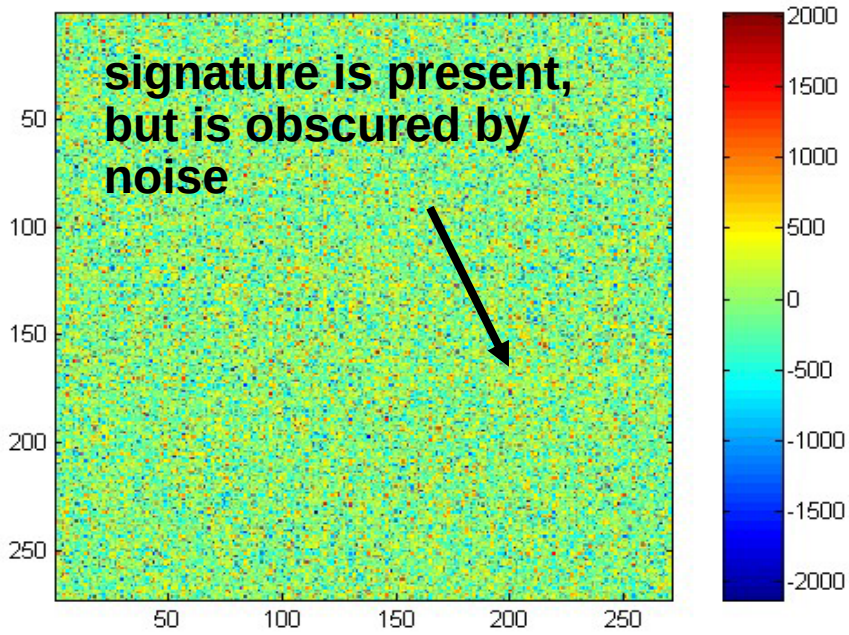


DETECTION IN A SEQUENCE OF IMAGES

Signature + low noise level (SNR= 25dB)

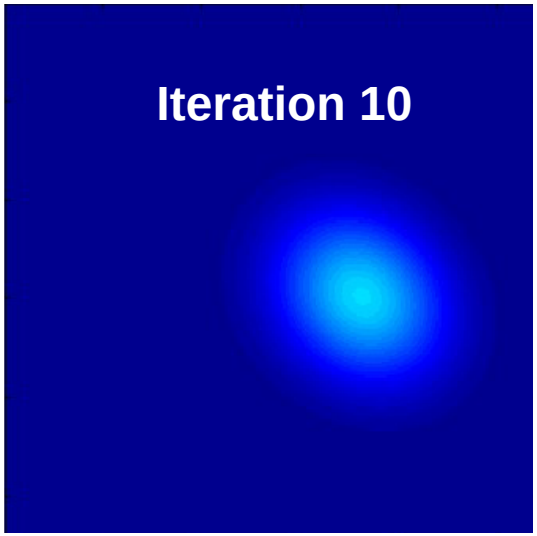


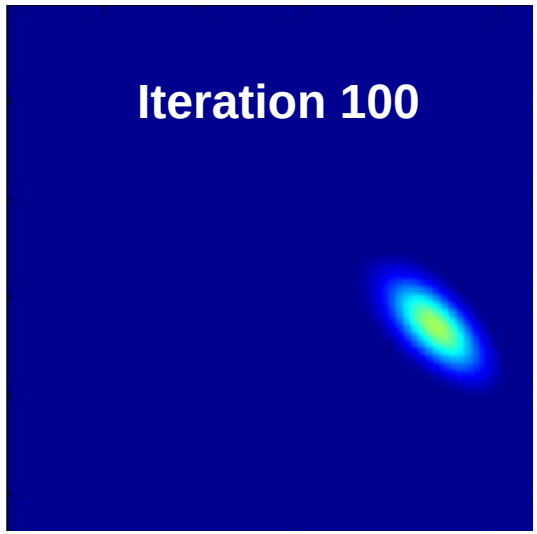
Signature + high noise level (SNR= -6dB)

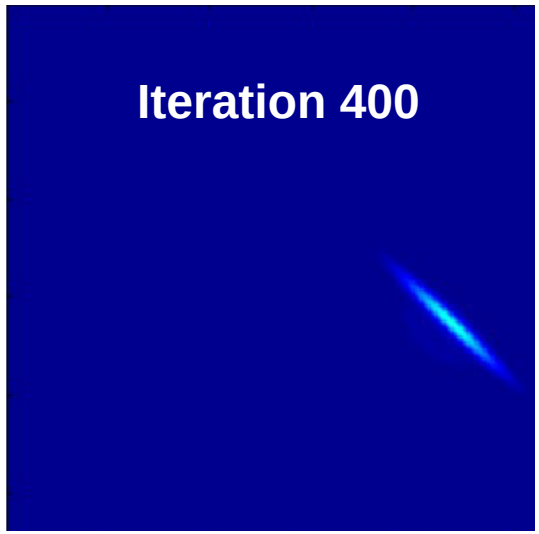


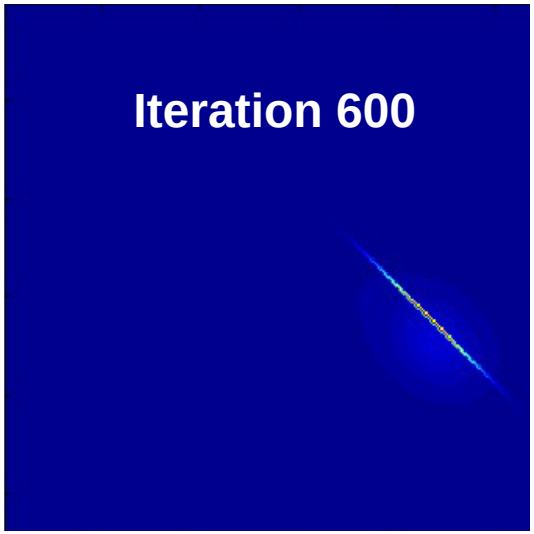
DETECTION IN IMAGE SEQUENCE

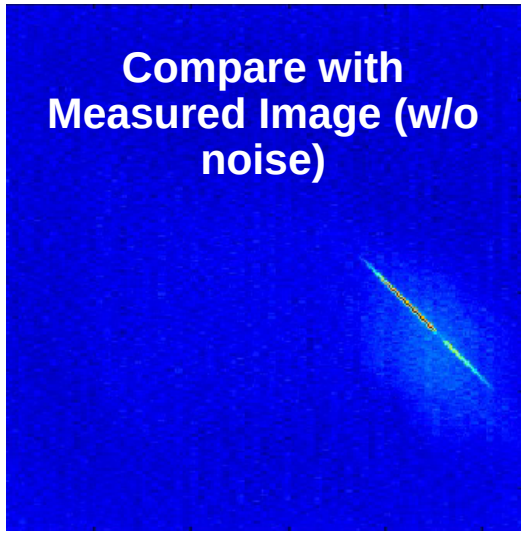
TEN ROTATION FRAMES WERE USED





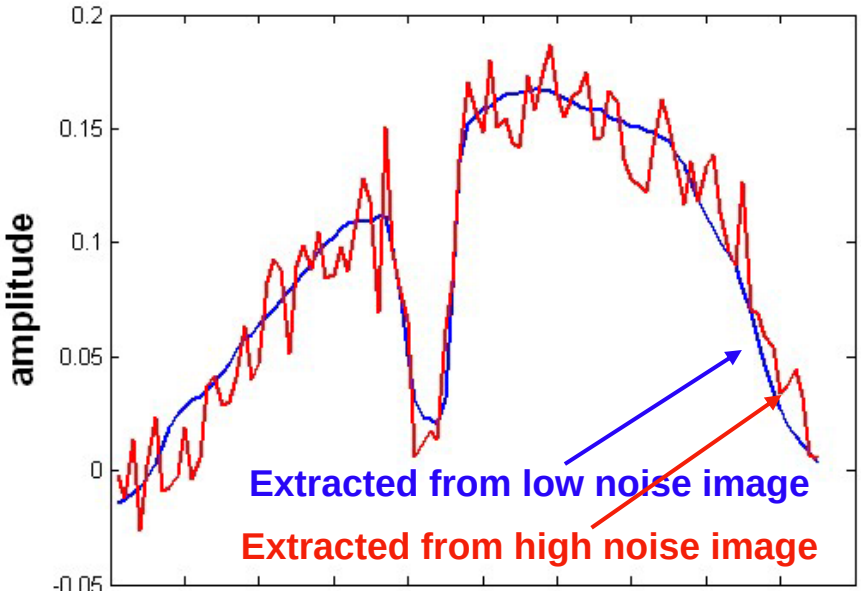




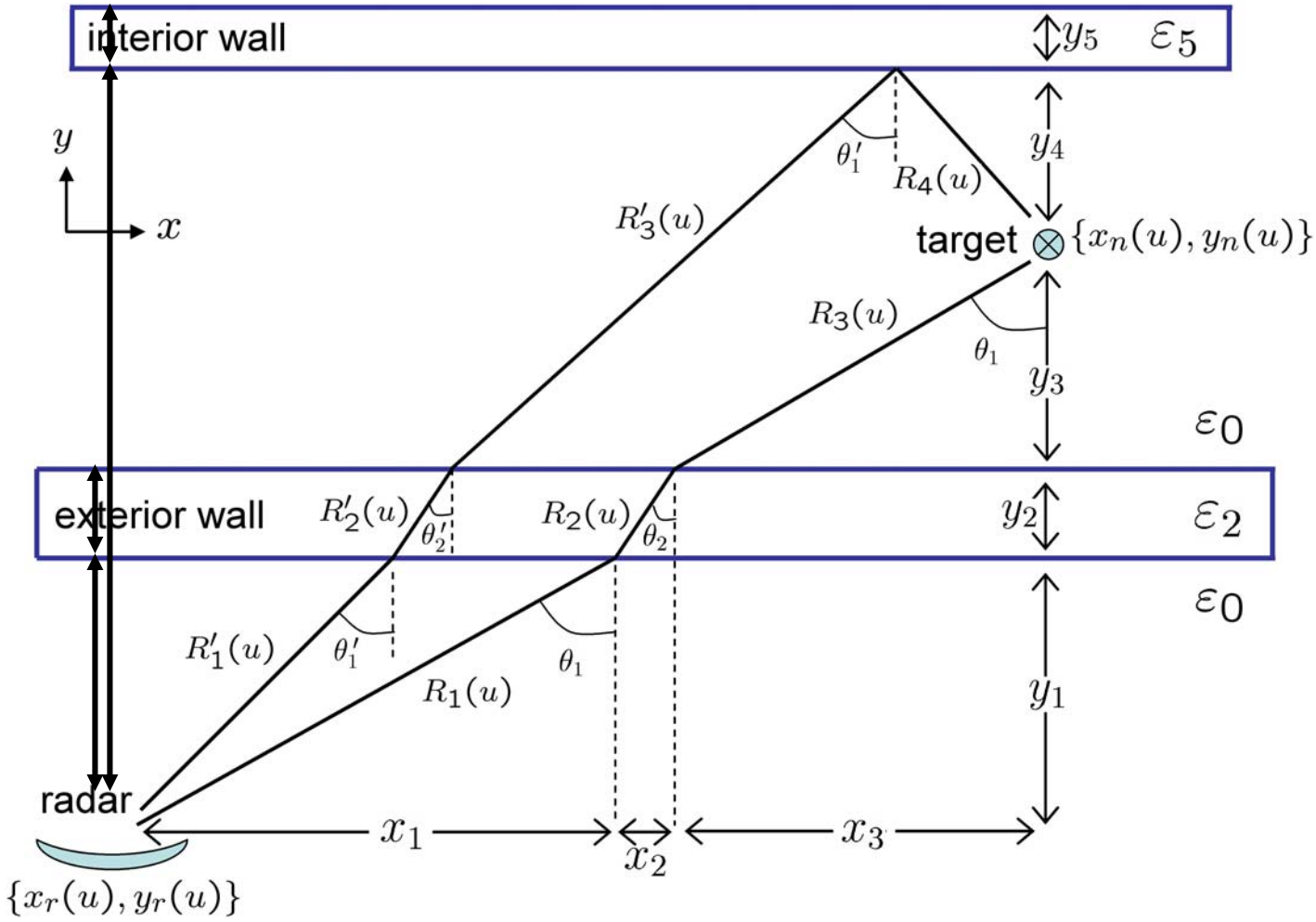


- **Upon convergence, model parameters are estimated**
- **Four models were used. Only one became associated with the target**

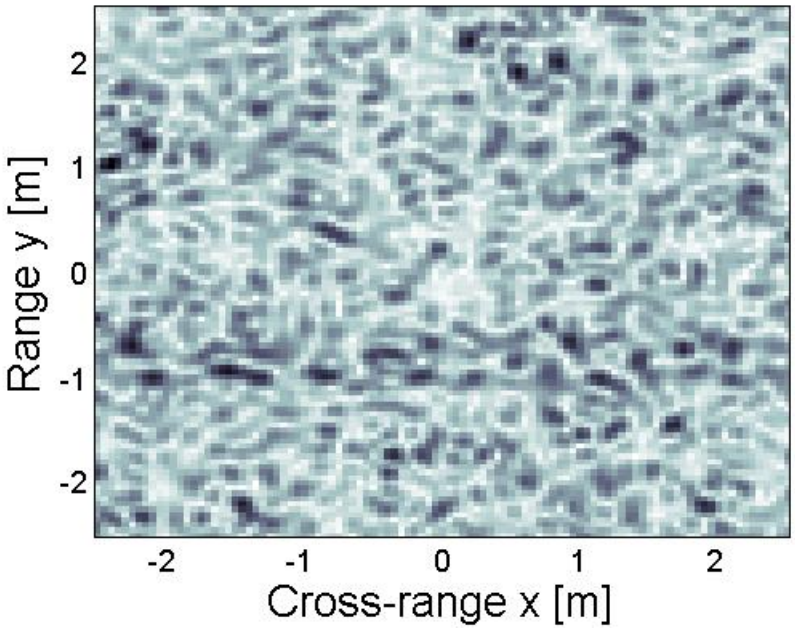
TARGET SIGNATURE



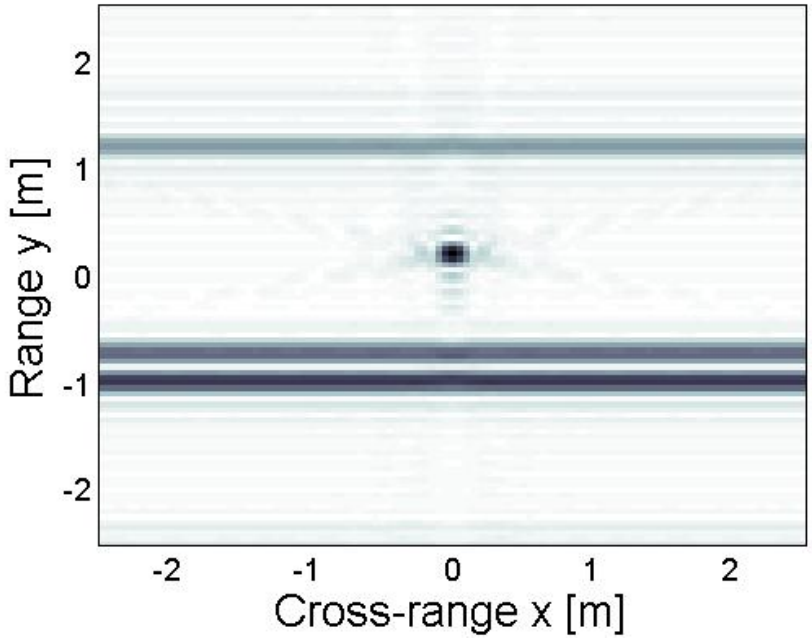
RADAR IMAGING THROUGH WALLS



RADAR IMAGING THROUGH WALLS



Standard SAR imaging does not work
Because of refraction, multi-paths and clutter



Estimated model, work in progress
Remains:
-increase convergence area
-increase complexity of scenario
-adaptive control of sensors

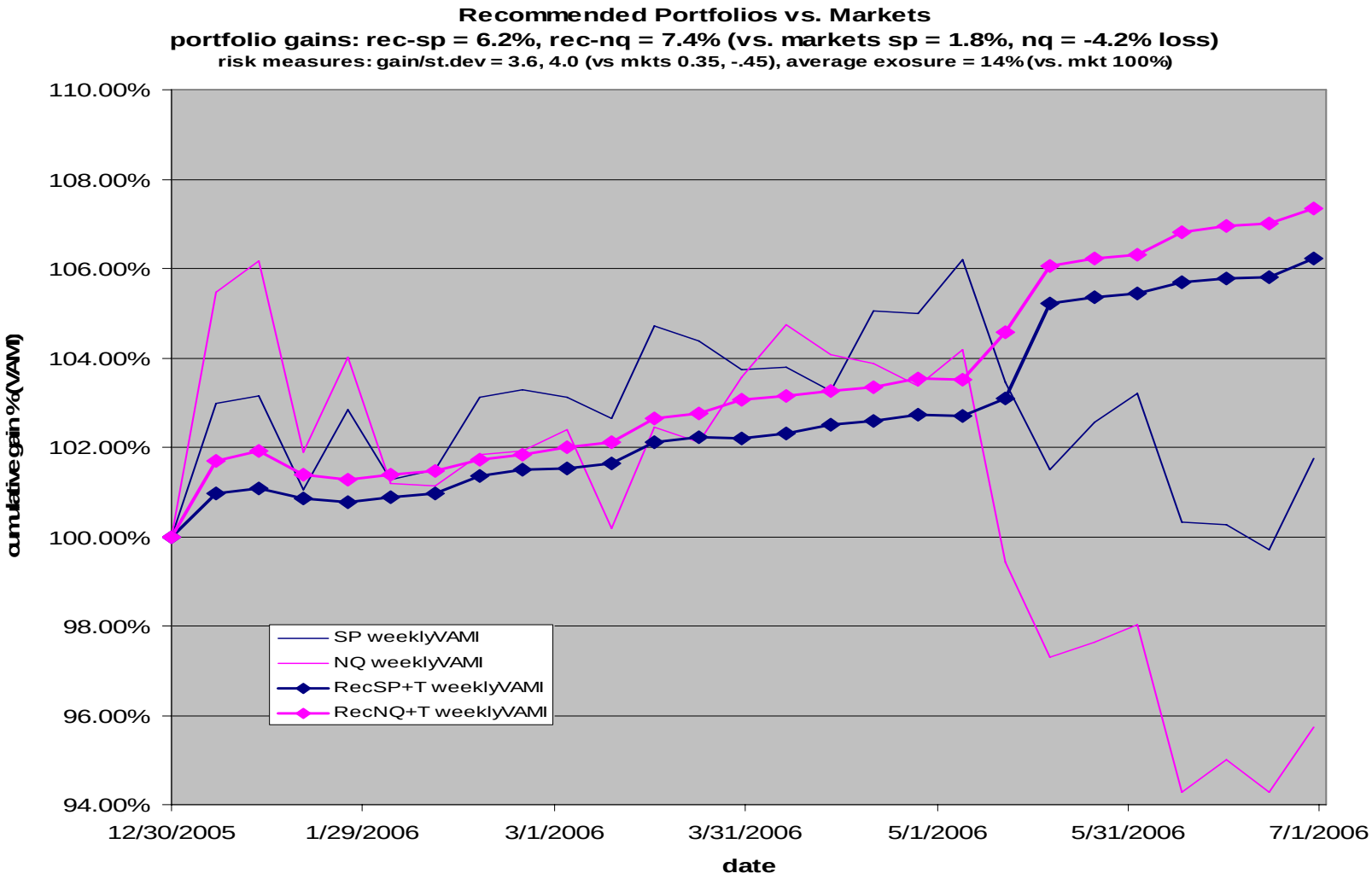
PREDICTION

- **Simple: linear regression**
  - **y(x) = Ax+b**
  - **Multi-dimensional regression: y,x,b - vectors, A - matrix**
- **Solution to linear regression (well known)**
  - **Estimate means <y>, <x>, and x-y covariance matrix C**
  - **$A = C_{yx}\, C_{xx}^{-1}$; b = <y> - A<x>**
- **Difficulties**
  - **No sufficient data to estimate C**
  - **Non-linear y(x), unknown shape**
  - **y(x) changes regime (from up to down)**
    - **this is the most important event (financial prediction)**

NMF/DL PREDICTION

- **General non-linear regression (GNLR)**
  - $y(x) = \sum_m f(m|n)\, y_m(x) = \sum_m f(m|n)\,(A_m x + b_m)$
  - A_m and b_m are similar to A,b in linear regression with one change: all $\sum_n(\ldots)$ are changed into $\sum_n f(m|n)(\ldots)$
- **Interpretation**
  - m are "regimes" or "processes", f(m|x) determines influence of regime m at point x
- **Applications**
  - Detection of y(x) regime change (e.g. financial prediction or control)

FINANCIAL MARKET PREDICITION

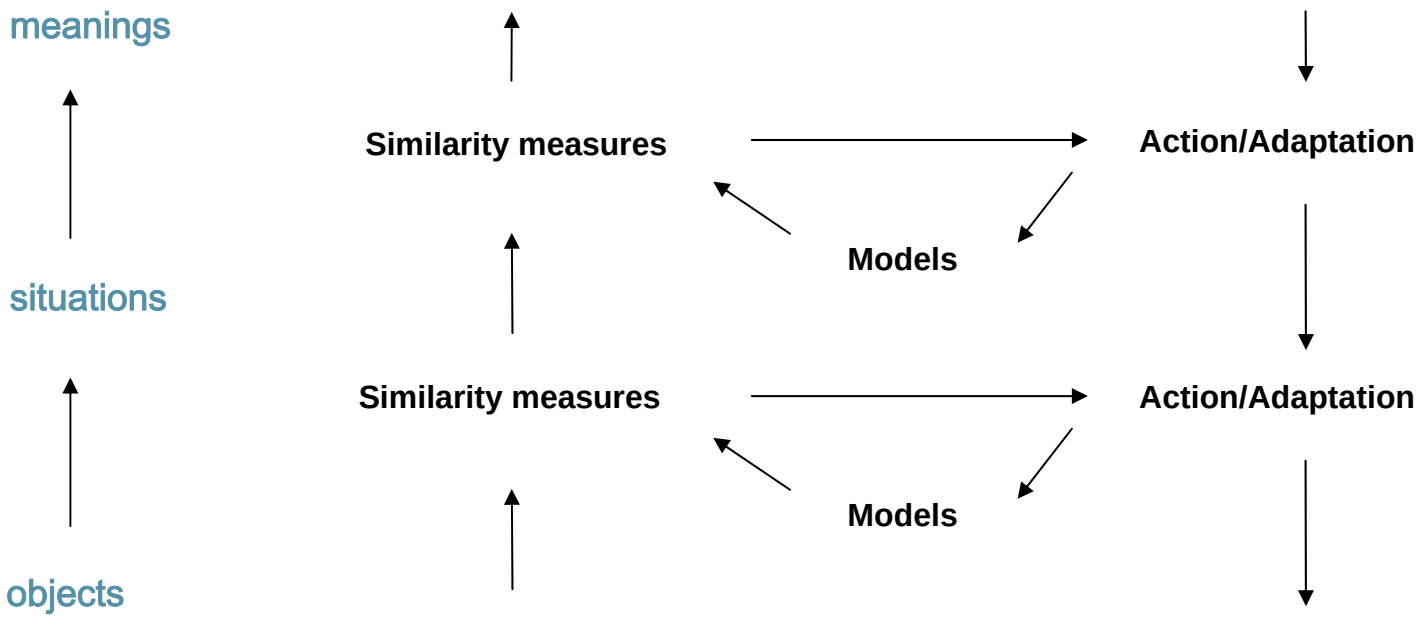


OUTLINE

- Cognition, complexity, and logic
- The Mind and Knowledge Instinct
- Higher Cognitive Functions
- Integration of cognition and language
- Evolution of Cultures
- Future directions

HIGHER COGNITIVE FUNCTIONS

- **Abstract models are at higher levels of hierarchy**
- **At every level**
  - **Bottom-up signals are lower-level-concepts**
  - **Top-down signals are concept-models**
  - **Behavior-actions (including adaptation)**



CONSCIOUSNESS AND UNCONSCIOUS

- Jung: conscious concepts and unconscious archetypes
- Grossberg: models in a resonant state reach consciousness
- NMF: fuzzy mechanisms (DL) are unconscious, crisp concept-models, adapted and matched to data are conscious
  - Higher, abstract concepts are less conscious

AESTHETIC EMOTIONS

- Not related to bodily satisfaction
- Satisfy instincts for knowledge
  - Improve world understanding
- Not just what artists do
- Guide every perception and cognition process
- Perceived as feeling of harmony-disharmony
  - satisfaction-dissatisfaction
- Maximize similarity between models and world
  - between our understanding of how things ought to be and how they actually are in the surrounding world; Kant: aesthetic emotions

BEAUTY

- Harmony is an elementary aesthetic emotion
  - higher aesthetic emotions are involved in the development of more complex “higher” models
- The highest forms of aesthetic emotion, beautiful
  - related to the most general and most important models
  - models of the meaning of our existence, of our purposiveness
  - beautiful object stimulates improvement of the highest models of meaning
- Beautiful “reminds” us of our purposiveness
  - Kant called beauty “aimless purposiveness”: not related to bodily purposes
  - he was dissatisfied by not being able to give a positive definition: knowledge instinct
  - absence of positive definition remained a major source of confusion in philosophical aesthetics till this very day
- Beauty is separate from sex, but sex makes use of all our abilities, including beauty

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LANGUAGE vs. COGNITION

- **“Nativists”, - since the 1950s**
  - **Language is a separate mind mechanism (Chomsky)**
  - **Pinker: language instinct**

- **“Cognitivists”, - since the 1970s**
  - **Language depends on cognition**
  - **Talmy, Elman, Tomasello…**

- **“Evolutionists”, - since the 1980s**
  - **Hurford, Kirby, Cangelosi…**
  - **Language transmission between generations**

- **NMF / DL was extended to language ~ 2000**

- **Co-evolution of language and cognition**

WHAT WAS FIRST COGNITION OR LANGUAGE?

- **How language and thoughts come together?**
- **Logical, conscious**
  - **“final results” ~ logical concepts**
- **Language seems completely conscious**
  - **A child at 5 knows about “good” and “bad” guys**
  - **Are these conscious concepts?**
- **Unconscious**
  - **fuzzy mechanisms of language and cognition**
- **Logic:**
  - **Same mechanisms for L. & C.**
  - **Did not work (←CC)**
- **Sub-conceptual, sub-conscious integration**

INTEGRATED LANGUAGE AND COGNITION

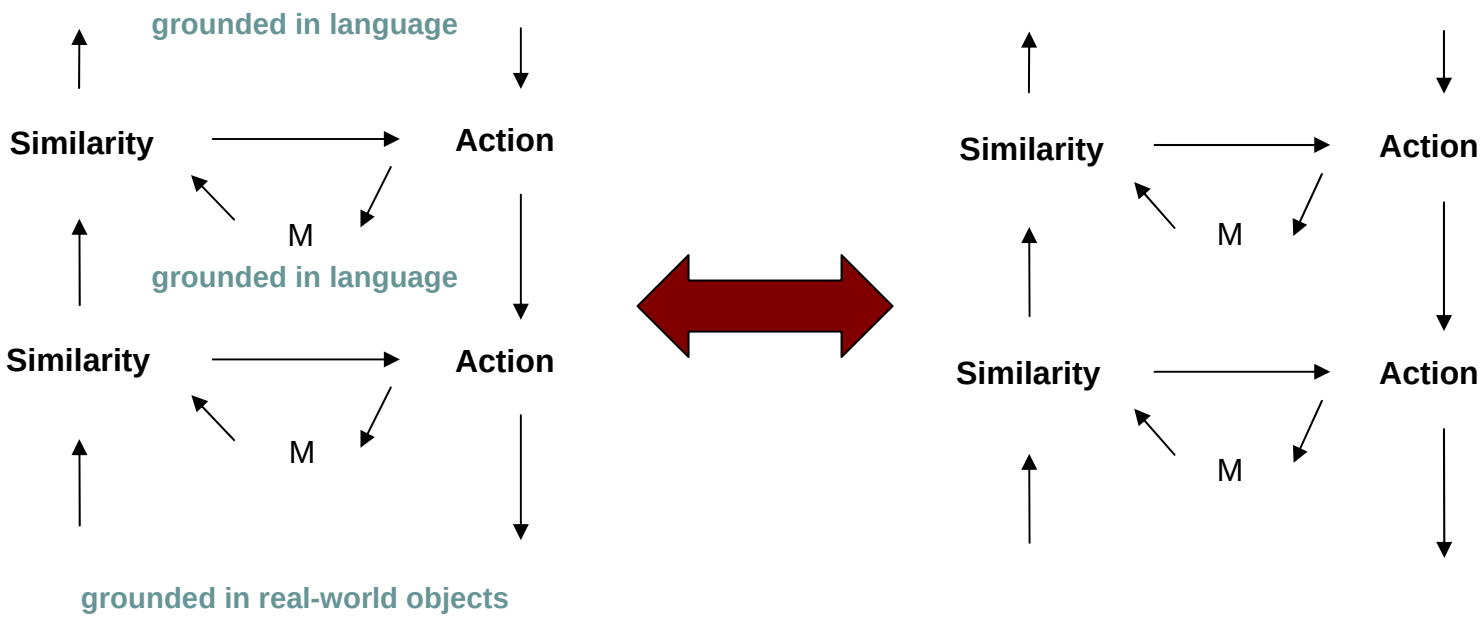
- **Where language and cognition come together?**
  - **A fuzzy concept m has linguistic and cognitive-sensory models**
    - $M_m = \{ M_m^{cognitive}, M_m^{language} \}$;
  - **Language and cognition are fused at fuzzy pre-conceptual level**
    - **before concepts are learned**
- **Understanding language and sensory data**
  - **Initial models are fuzzy blobs**
  - **Language models have empty "slots" for cognitive model (objects and situations) and v.v.**
  - **Different speed of learning L. and C.**
  - **Language participates in cognition and v.v.**
- **L & C help learning and understanding each other**
  - **Help associating signals, words, models, and behavior**

SYMBOLIC ABILITY

- **Integrated hierarchies of Cognition and Language**
  - **High level cognition is only possible due to language**
  - **Language is only possible due to cognition**

cognition

language



OUTLINE

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EMOTIONS IN LANGUAGE

- Animal vocal tract
  - controlled by old (limbic) emotional system
  - involuntary
- Human vocal tract
  - controlled by two emotional centers: limbic and cortex
  - Involuntary and voluntary
- Human voice determines emotional content of cultures
  - Emotionality of language is in its sound: melody of speech

CULTURE AND LANGUAGE

- Animal consciousness
  - Undifferentiated, few vague concepts
  - No mental “space” between thought, emotion, and action
- Evolution of human consciousness and culture
  - More differentiated concepts
  - More mental “space” between thoughts, emotions, and actions
  - Created by evolution of language
- Language, concepts, emotions
  - Language creates concepts
  - Still, colored by emotions

EVOLUTION OF CULTURES

- The knowledge instinct
  - Two mechanisms: differentiation and synthesis

- Differentiation
  - At every level of the hierarchy: more detailed concepts
  - Separate concepts from emotions

- Synthesis
  - Knowledge has to make meaning, otherwise it is useless
  - Diverse knowledge is unified at the higher level in the hierarchy
  - Connect concepts and emotions
    - **Connect language and cognition**
    - **Connect high and low: concepts acquire meaning at the next level**

LANGUAGE EMOTIONS AND CUTURES

- 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 identity crisis
- Arabic language (Synthesis > Diff.)
  - –Strong connection between conceptual and emotional
  - –Cultural immobility, but strong feel of identity (synthesis)

TERRORIST'S CONSCIOUSNESS

- Ancient consciousness was "fused"
  - Concepts, emotions, and actions were one
    - Undifferentiated, fuzzy psychic structures
  - Psychic conflicts were unconscious and projected outside
    - Gods, other tribes, other people

- Complexity of today's world is "too much" for many
  - Evolution of culture and differentiation
    - Internalization of conflicts: too difficult
  - Reaction: relapse into fused consciousness
    - Undifferentiated, fuzzy, but simple and synthetic

- The recent terrorist's consciousness is "fused"
  - European terrorists in the 19th century
  - Fascists and communists in the 20th century
  - Current Moslem terrorists

MODELS OF CULTURAL EVOLUTION

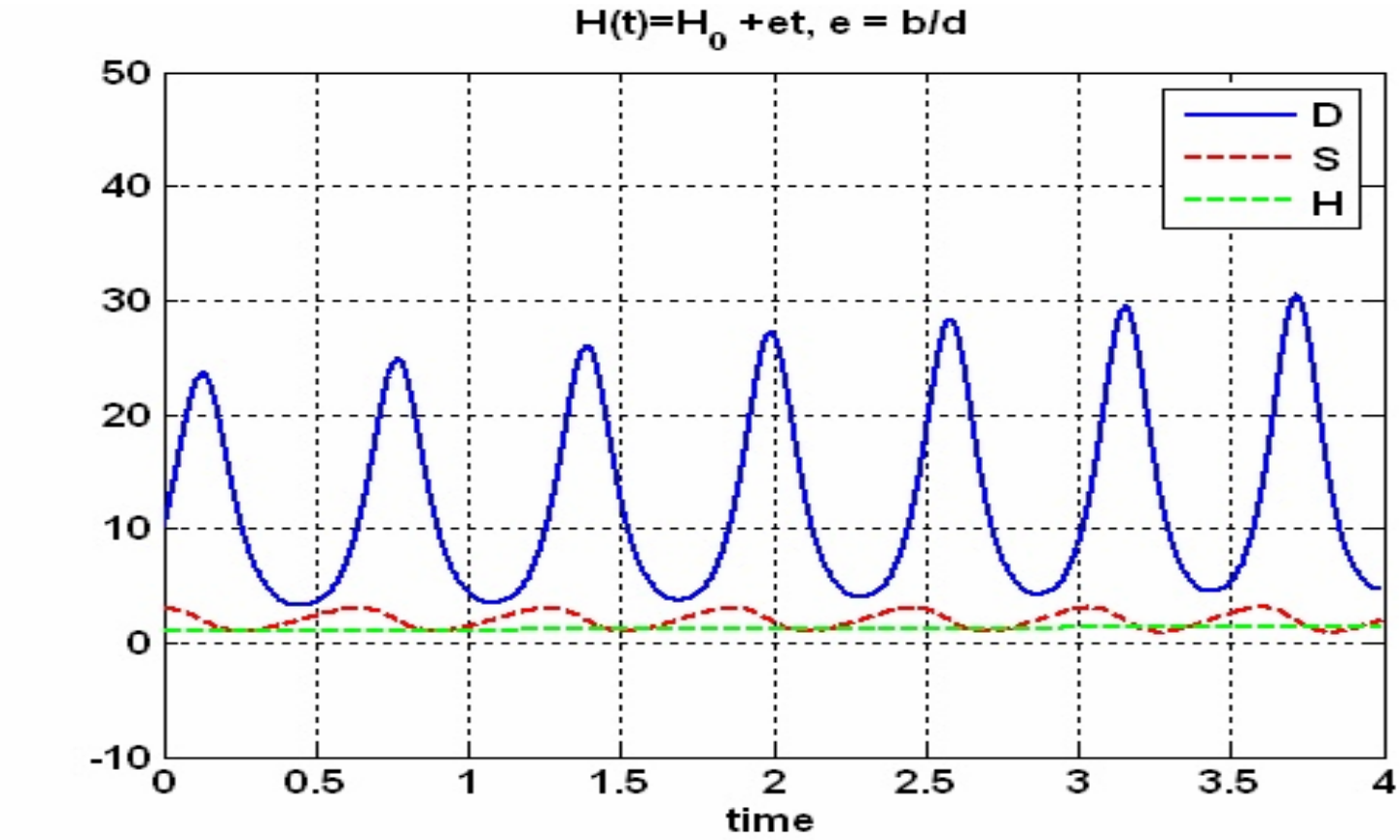
- **Differentiation, D, synthesis, S, hierarchy, H**

$$dD/dt = a\,D\,G(S); \quad G(S) = (S - S0)\exp(-(S-S0)/S1)$$

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

$$H = H0 + e*t$$

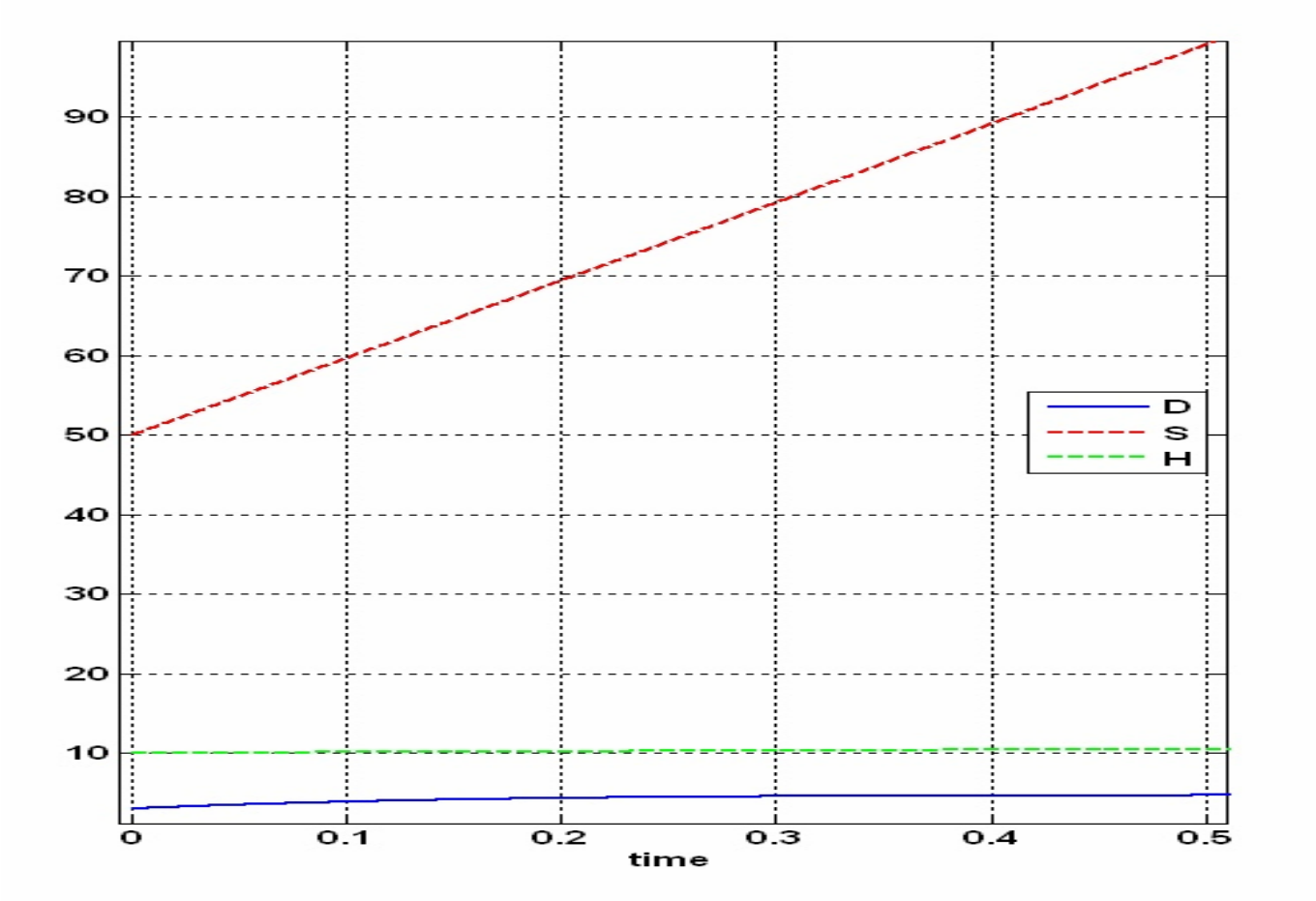
DYNAMIC CULTURE



Average synthesis, high differentiation; oscillating solution

Knowledge accumulates; no stability

TRADITIONAL CULTURE



High synthesis, low differentiation; stable solution

Stagnation, stability increases

INTERACTING CULTURES

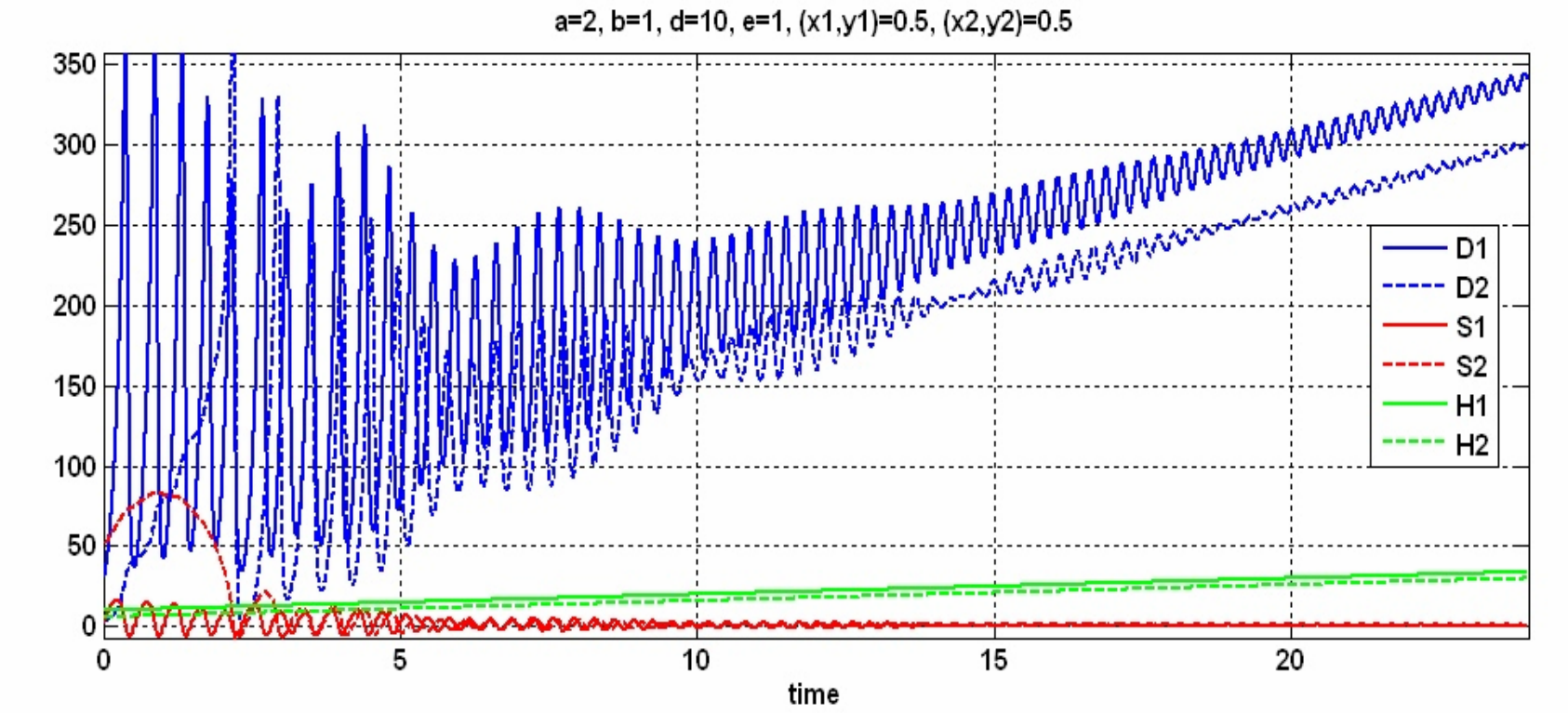
- **Two cultures**
  - **dynamic and traditional**
  - **slow exchange by D and S**

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

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

$$H_k = H0_k + e_k * t$$

INTERACTING CULTURES



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

Knowledge accumulation + stability

ROLE OF MUSIC IN EVOLUTION OF THE MIND

- **Melody of human voice contains vital information**
  - About people's world views and mutual compatibility
  - Exploits mechanical properties of human inner ear
    - Consonances and dissonances
- **Tonal system evolved (14th to 19th c.) for**
  - Differentiation of emotions
  - Synthesis of conceptual and emotional
  - Bach integrates personal concerns with "the highest"
- **Pop-song is a mechanism of synthesis**
  - Integrates conceptual (lyric) and emotional (melody)
  - Also, differentiates emotions
  - Bach concerns are too complex for many everyday needs
  - Human consciousness requires synthesis immediately
- **Rap is a simplified, but powerful mechanism of synthesis**
  - Exactly like ancient Greek dithyrambs of Dionysian cult

SCIENCE VS. RELIGION

- Science ⟺ causal mechanisms
- Religion ⟺ teleology (purpose)
- Wrong!
  - In basic physics causality and teleology are equivalent
  - The principle of minimal energy is teleological
  - More general, min. Lagrangian
- The knowledge instinct
  - Teleological principle in evolution of the mind and culture
  - Dynamic logic is a causal law equivalent to the KI
  - Causality and teleology are equivalent

FUTURE DIRECTIONS
research, predictions and testing of NMF/DL

- Mathematical development
  - DL in Hierarchy, mechanisms of Synthesis
  - Add emotions to computer models of language evolution
- Psycholinguistic tests
  - Measure emotionality of various languages in labs
- Mathematical-simulation tests
  - Joint evolution of language and cognition
- Historical linguistics
  - Concurrent evolution of languages, consciousness, and cultures
- Music
  - Direct effect on emotions, mechanism of synthesis
  - Concurrent evolution of music, consciousness, and cultures
- Improve human condition around the globe
  - Diagnose cultural states (up, down, stagnation), measure D, S, H
  - Develop predictive cultural models, integrate spiritual and material causes
  - Identify language and music effects that can advance consciousness and reduce tensions
- Semantic Web and Cyberspace
  - Adaptive ontologies
  - Learn from human users
  - Acquire cultural knowledge
  - Enable culturally-sensitive communication
  - Help us understand ourselves
  - Help us understand each other

PUBLICATIONS

280 publications
- recent: CI Magazine

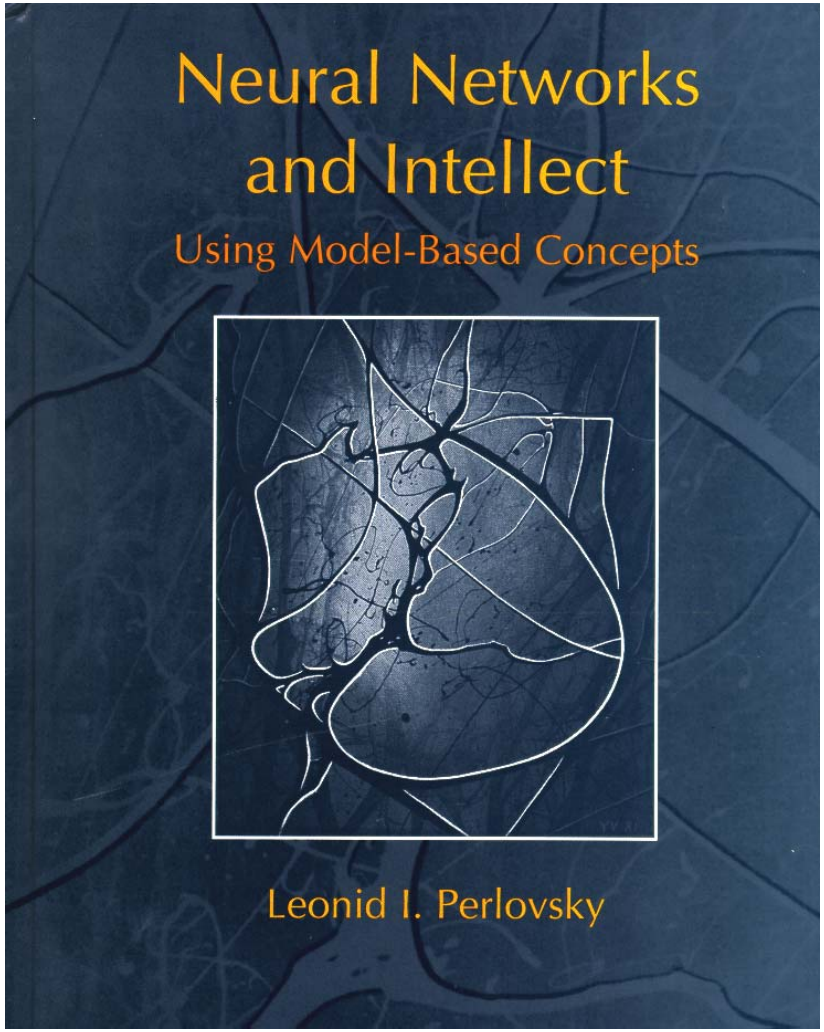
OXFORD UNIVERSITY PRESS
(2001; 3rd printing)

2007:

The Knowledge Instinct
Basic Books

Neurodynamics of High Cognitive Functions
with Prof. Kozma, Springer

Sapient Systems
with Prof. Mayorga, Springer



BACK UP

- Predictions and testing of the theory
- Humboldt: Inner linguistic form (~1830s)

PREDICTIONS AND TESTING of NMF/DL theory of the mind

- **Experimental testing**
  - Neural, psychological, and psycholinguistic labs
  - Simulation of multi-agent evolving systems
- **Instinctual learning mechanisms**
- **Ongoing and future research:**
  - similarity measure as a foundation of knowledge and language instincts
  - mechanisms of model parameterization and parameter adaptation
  - dynamics of fuzziness during perception/cognition/learning
  - mechanisms of language and cognition integration
  - emotionality of languages and cultures
  - mechanisms of differentiation and synthesis
  - mechanisms of cultural evolution
  - role of music in synthesis and in cultural evolution

INNER LINGUISTIC FORM HUMBOLDT, the 1830s

- **In the 1830s Humboldt discussed two types of linguistic forms**
  - **words' outer linguistic form (dictionary) – a formal designation**
  - **and inner linguistic form (???) – creative, full of potential**

- **This remained a mystery for rule-based AI, structural linguistics, Chomskyan linguistics**
  - **rule-based approaches using the mathematics of logic make no difference between formal and creative**

- **In NMF / DL there is a difference**
  - **static form of learned (converged) concept-models**
  - **dynamic form of fuzzy concepts, with creative learning potential, emotional content, and unconscious content**