THE UNIVERSITY OF MEMPHIS

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A Road to the Principles: Taking the Brain's Perspective

- Agenda
  - Solving engineering problem(s) using principles in biology of brain (vision)
  - Summarize the panel's goals

- Example
  - Considering Biology of Vision To Solve A Challenging Engineering Problem

WHY?

- Unprecedented growth in complexity for sensor systems due to --
  - increased computer processing capabilities
  - new understanding of low-level sensor phenomenology
  - improved signal processing and information fusion algorithms
  - expanded communication infrastructure
- Biological organisms routinely accomplish --
  - difficult sensing and decision-making tasks in a holistic manner
  - implying efficient underlying mechanisms to process information

WHAT?

- The inspiration is biological vision that …
  - consists of highly coordinated distributed hierarchical modular functional units
  - performs vast and complex sensory and motor activities; and
  - for the most part, is accurate and fast enough to accomplish required functions.

- Our Objective is to investigate ‘just’ two such computational vision functions ...
  - distortion invariance
  - attention-driven reinforcement learning

HOW?
DISTORTION INVARINACE IN BIOLOGY

- Brain's Sensory Recognition Functionalities:
  - Hundreds of tasks. Some examples -
    - Shape, color, depth, orientation, scale, rotation, spatial and temporal dynamics
    - Refinement/re-focusing
    - Communication among sensory organs
- The interest in biology is for:
  - Distortions such as rotation, scale, translation, illumination, aspect, pose, clutter- invariance .....

HOW?
ATTENTION IN BIOLOGY

- The attention mechanism:
  - an integral part of biological information processing systems
  - may provide a reliable tool for selective information processing
- The interest in biology is for:
  - allocation of computational resources in terms of where, what, and how to sense and process information
    - Guided by attention for effective learning

HOW?
LEARNING IN BIOLOGY

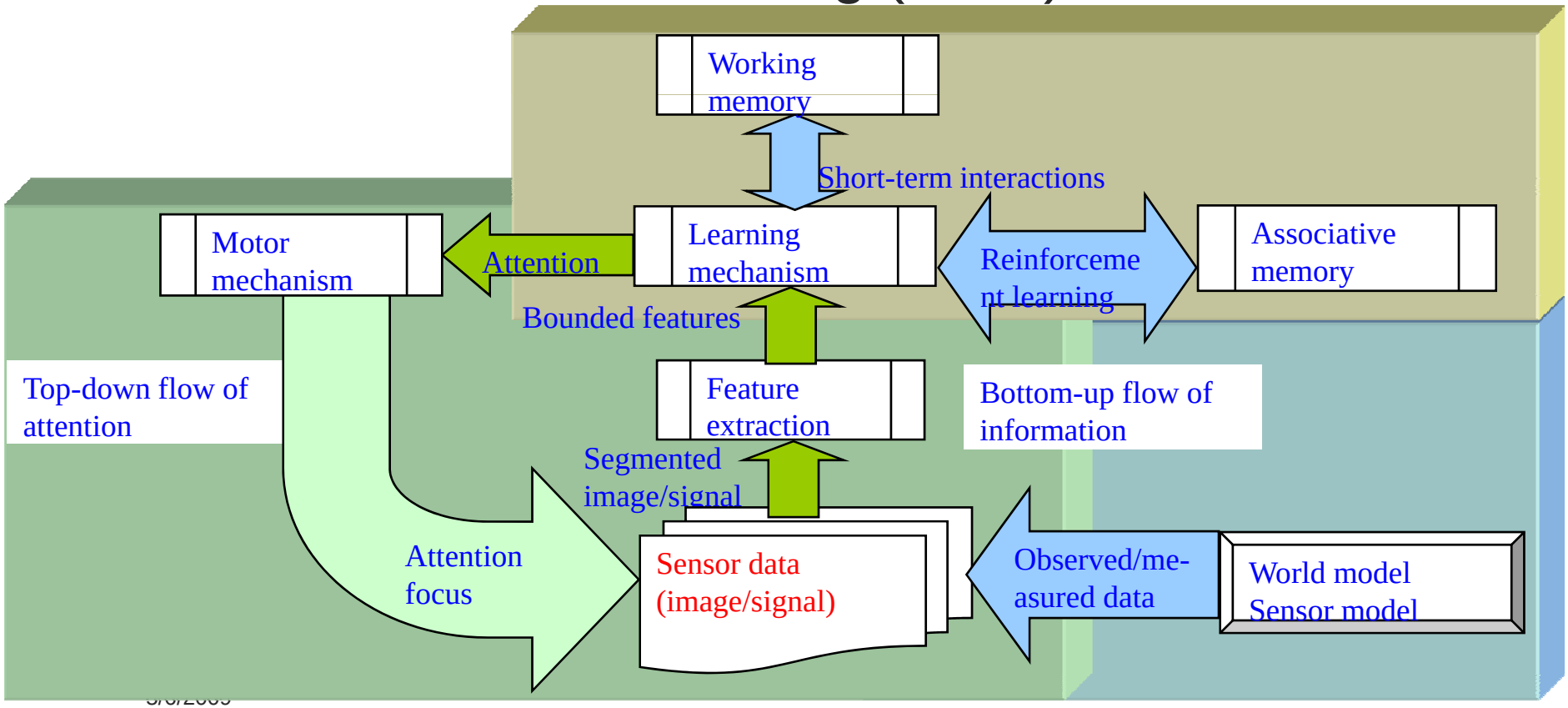
Three types of learning exist in the biological vision system:

- Unsupervised learning in cerebral cortex;
- Supervised learning in cerebellum;
- Reinforcement learning in the basal ganglia.

All learning in the brain forms a rapid parallel forward recognition.

AN ENGINEERING CARTOON

- A notional model of Attention driven Invariance and Reinforcement learning (I&RL)



HOW?
In Engineering

- We propose a biologically inspired vision model for Automatic Target Recognition (ATR) with I&RL
  - The ATR is implemented in Adaptive Critic Design (ACD) framework.
    - Such ATR implementation can be viewed as an adaptive optimal control of dynamic stochastic systems
    - ACD provides a good infrastructure for approximation of the dynamic programming
  - Two learning algorithms are implemented:
    - Heuristic Dynamic Programming (HDP) and Dual Heuristic dynamic Programming (DHP).

HDP-BAESED ATR

- HDP is one type of Adaptive Critic Design (ACD).
- Three major components in HDP:
  - Action network
  - Critic network
  - ATR plant.

NETWORK STRUCTURE OF HDP

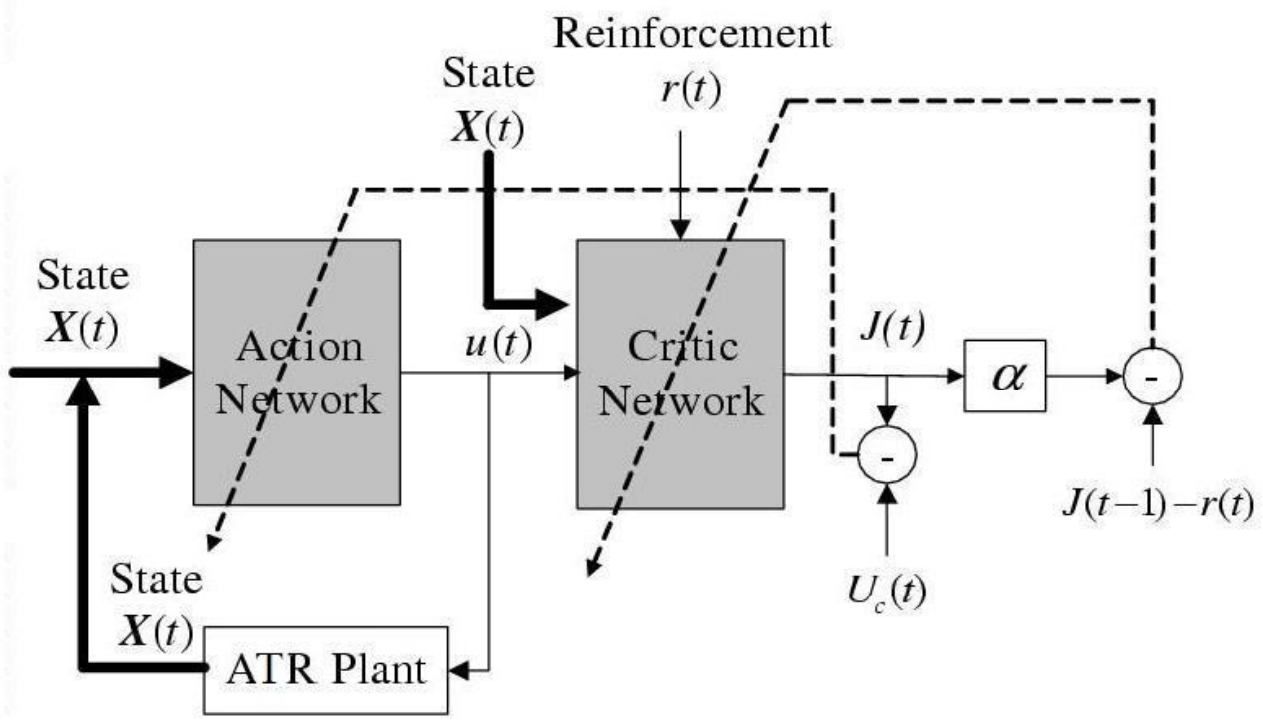


Figure 2: Schematic diagram for HDP design

DHP-BASED ATR

Major three components in DHP:

- Action network
- Critic network
- ATR plant

Two back-propagation (BP) to compute:

- MSJ: model state Jacobian
- MCJ: model control Jacobian

NETWORK STRUCTURE OF DHP

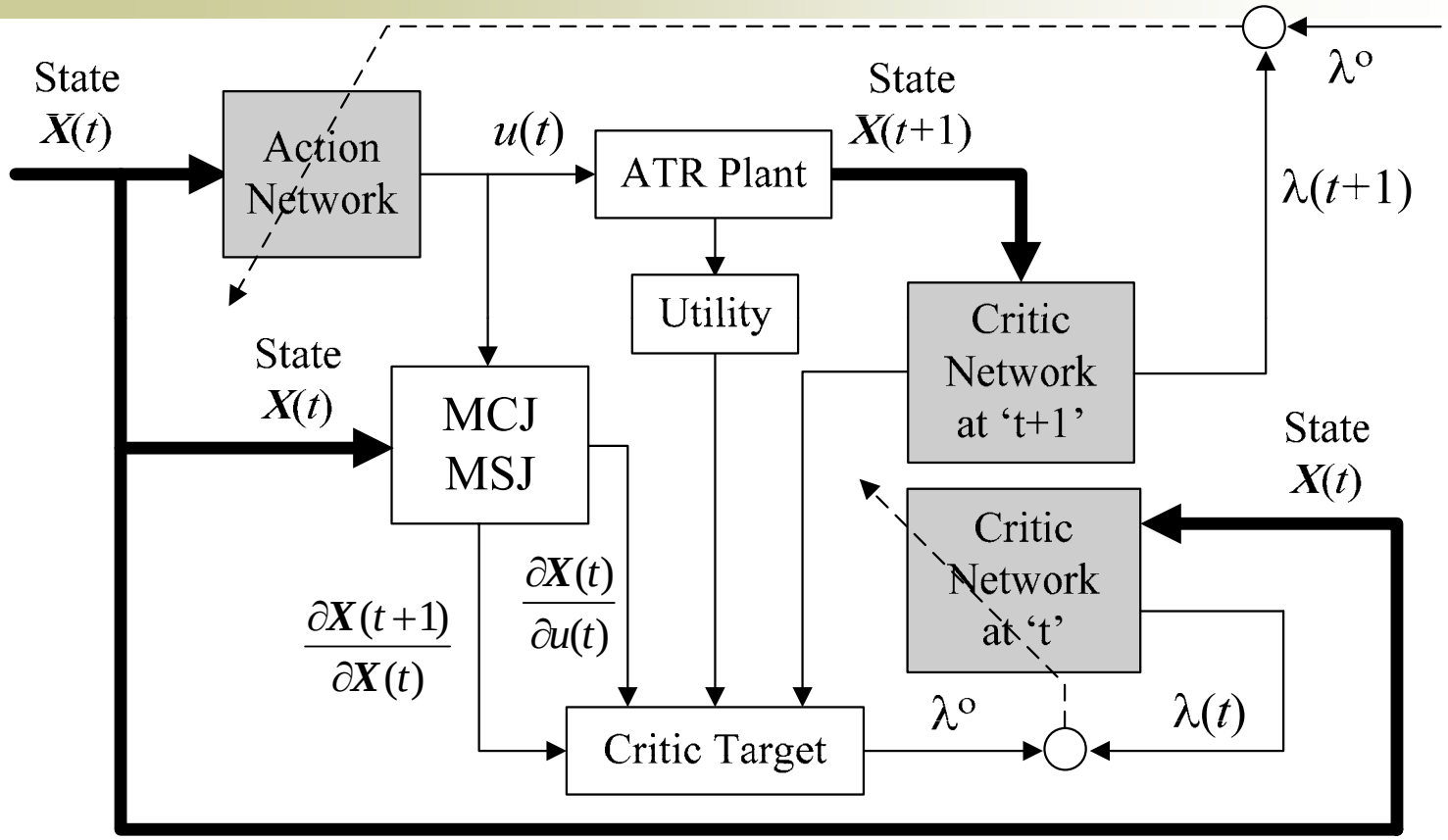


Figure 4: Schematic diagram for DHP design

SIMULATION EXPERIMENT

- HDP-ATR and DHP-ATR are compared statistically
  - For 5 different image transformations with synthetic distortions of a monkey face image
  - For face authentication using out-of-plane rotation of 2-D face data in UMIST database.

MULTI-RESOLUTION

- An imitation of attention-driven pattern recognition in human cognitive process.
- The multi-resolution image bank is constructed using Daubechie's level 4 wavelet.

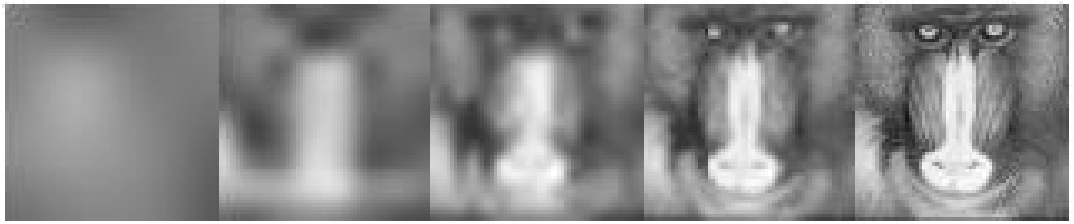
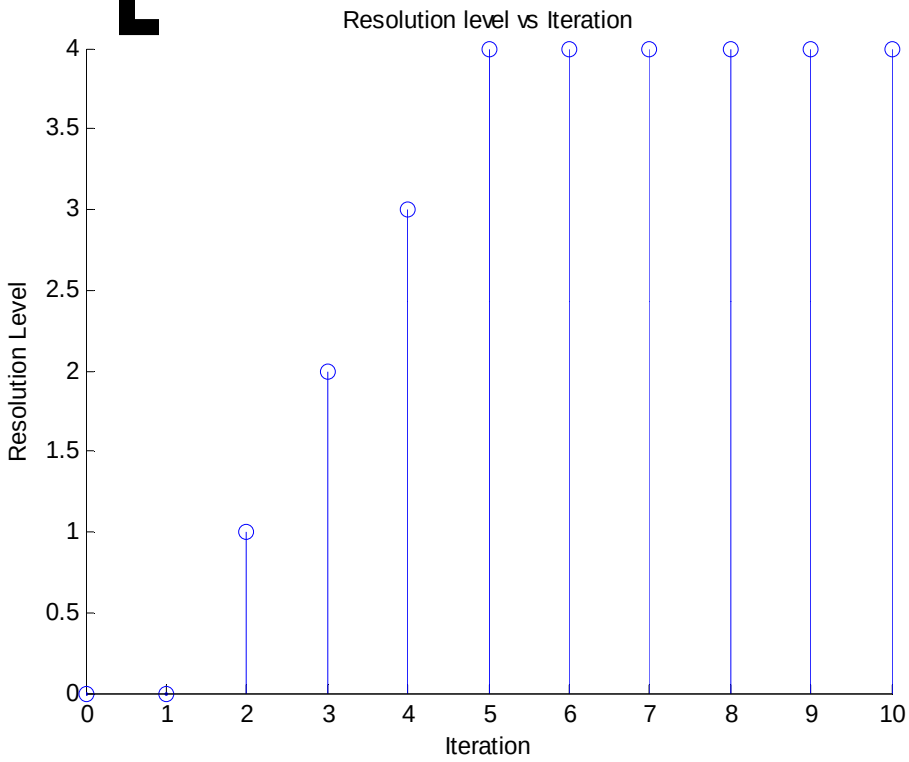
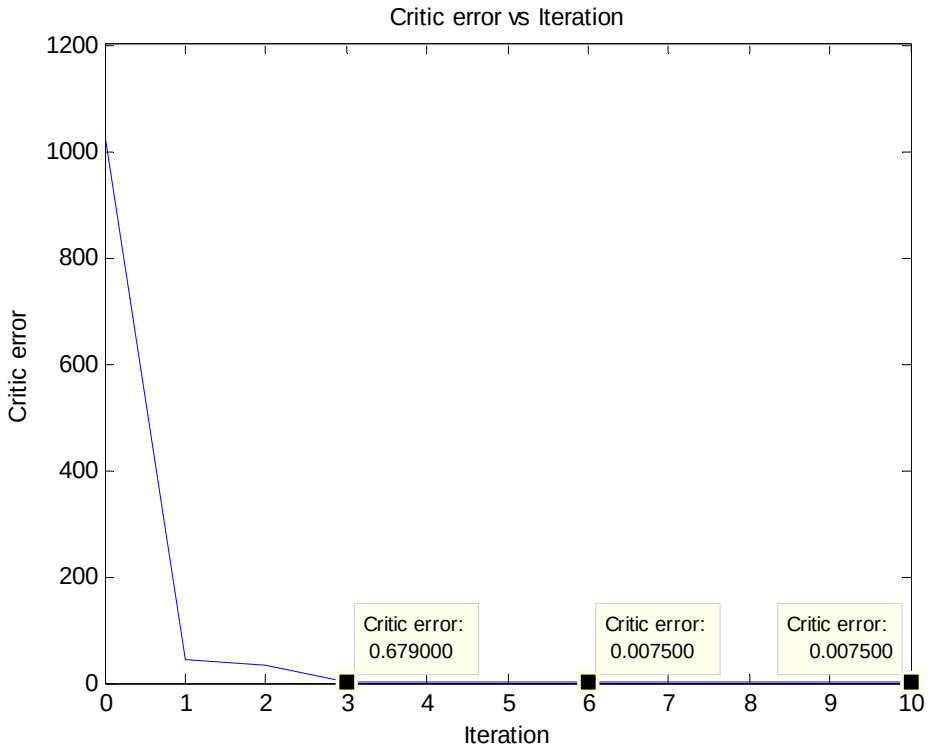


Figure 5: Multi-resolution image bank

HDP for MULTI-RESOLUTION



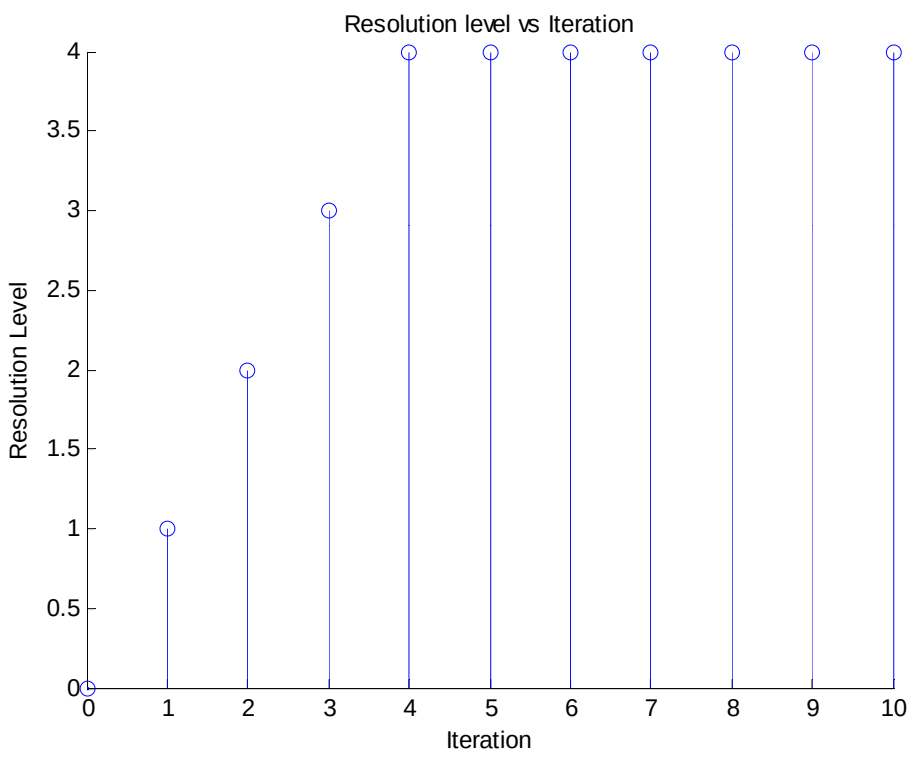
(a) Resolution level



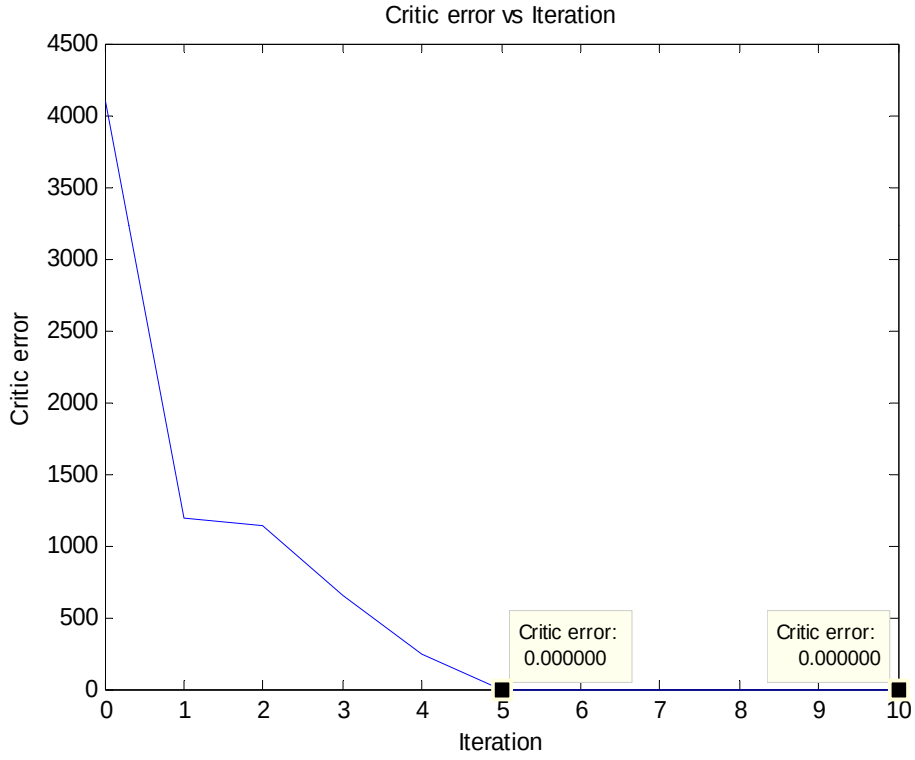
(b) Critic error

Figure 6: HDP learning of multi-resolution ATR

DHP for MULTI-RESOLUTION



(a) Resolution level



(b) Critic error

Figure 7: DHP learning of multi-resolution ATR

COMPARISON OF HDP and DHP

Table 1: Comparison of different transformations

Algorithm	Transformation	One trial		Three trials		
		Success rate	Average steps	Success rate	Average trials	Average steps
HDP	Multi-Resolution	84%	6.14	89%	1.01	6.42
	180° rotation	84%	11.96	93%	1.29	13.78
	Translation	79%	6.41	97%	1.22	7.15
	Scale	87%	5.97	99%	1.16	6.75
	Occlusion	83%	6.20	97%	1.27	7.73
	AVERAGE	**83%**	**7.34**	**95%**	**1.19**	**8.37**
DHP	Multi-resolution	55%	6.04	96%	1.80	6.28
	180° rotation	57%	11.30	88%	2.10	11.48
	Translation	64%	6.07	80%	2.06	6.55
	Scale	56%	5.82	76%	2.18	6.34
	Occlusion	48%	5.71	88%	2.15	6.74
	AVERAGE	**56%**	**6.99**	**86%**	**2.06**	**7.48**

FACE AUTHENTICATION

- We evaluate the HDP and DHP learning using 2-D face data from the UMIST database.
- Each image sequence used captures the 90° out-of-plane rotation for the 20 subjects in the face database.

Figure 20: Image sequence for subject ‘1a’ in UMIST database

FACE AUTHENTICATION DISCUSSION

- Success rate:
  - Overall HDP across all subjects are higher;
  - DHP achieves 100% success rate more often for individual subjects.

A trade-off between robustness in general and accuracy in particular.

CONCLUSION

- Implementation of a plausible (and effective) bio-inspired ATR engineering model for
  - Both bottom-up and top down vision processing
  - Seamless integration of I&RL
- DHP-based ATR outperforms that of HDP in specific cases, but is not as robust as HDP as far as success rate is concerned.
- Comparison of HDP and DHP demonstrates a trade-off in design of learning algorithms.

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RELATED PUBLICATIONS

1. Khan M. Iftekharuddin, Yaqin Li and Faraz Siddiqui, *"A biologically inspired neural network model to transformation invariant object recognition, "* Proc. SPIE Conference on Optics and Photonics for Information Processing (OP311), San Diego, CA, U.S.A., August 26–30, 2007.
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Outline of panel discussion

- Do you think there is a single dominant functional/operational principles of brain function and biological intelligence? Why?
- What is (are) your favorite principle(s) of brain function/biological intelligence, and why do you think so?
- If you think our current ideas are lacking in any way, what kind of breakthroughs would be needed, in which fields?
  - thoeretical/conceptual breakthrough (conceptual framework, etc.
  - mathematical breakthrough (new mathematical formalism)
  - experimental breakthrough (experimental methodology)
  - technological breakthrough (new imaging method, new ways to measure activity, new ways to stimulate, etc.)