



Bio-Inspired Sensing and Behavior for Planetary Surface Exploration

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Outline

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- Biological Background
- Sensor Fusion
- BISMARC
- Experimental Studies
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Introduction

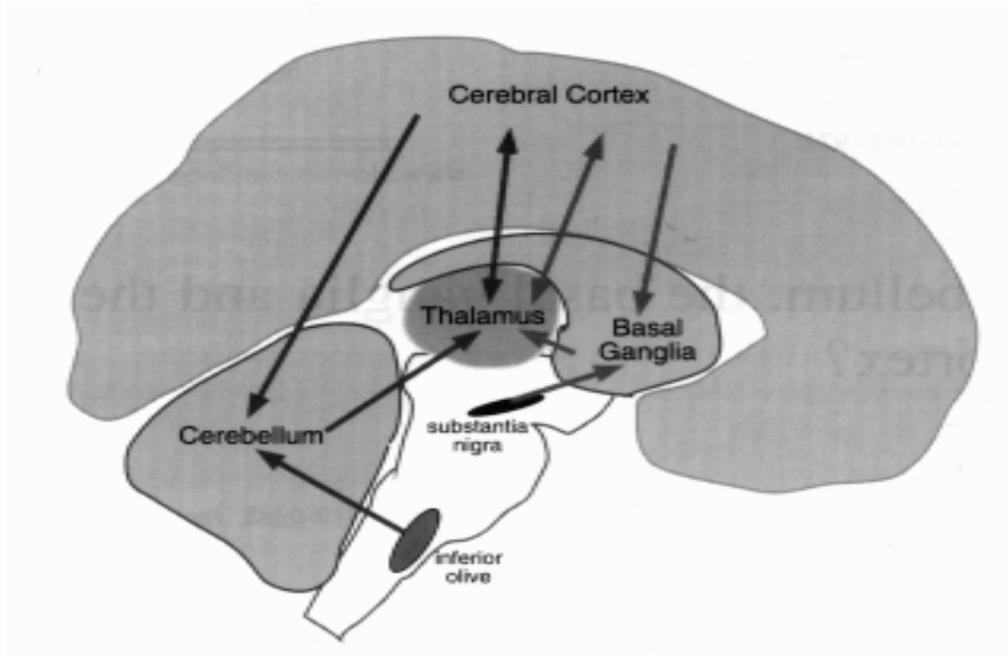
- Robotic missions beyond 2019 will probably be robotic presursors to a Mars manned habitat deployment.
- Such missions will require robust sensing and control systems for long duration activities
- Single rover missions will evolve into deployment of colonies of multiple, heterogeneous cooperating robots.



Visual Pathways

- Visual cortex viewed as four pathways
 - Motion: MCL of retina & LGN to orientation+direction-selective cells in layer 4B of area V1 and through thick stripes of area V2 into area V5
 - Dynamic form: MCL of retina & LGN to orientation-selective cells in layer 4B of area V1 and through thick stripes of area V2 into area V3
 - Color: PCL of retina & LGN into area V4 from blobs in layers 2 & 3 of area V1 through thin stripes of area V2
 - Form linked to color: PCL of retina & LGN into area V4 from interblobs in layers 2 & 3 of area V1 through interstripes of area V2

Biological Action Selection



- Basal ganglia and cerebellar cortex work by selectively pausing the tonic inhibition they normally exert on sites capable of activating sensory-motor pathways through frontal cortex.
- Basal ganglia complex (BGC) uses perceptual analyses provided by the cerebral cortex to decide which sites to disinhibit in the optic tectum (OT; homologous to the superior colliculus in mammals) which controls orienting and other actions in amphibians and terrestrial vertebrates.

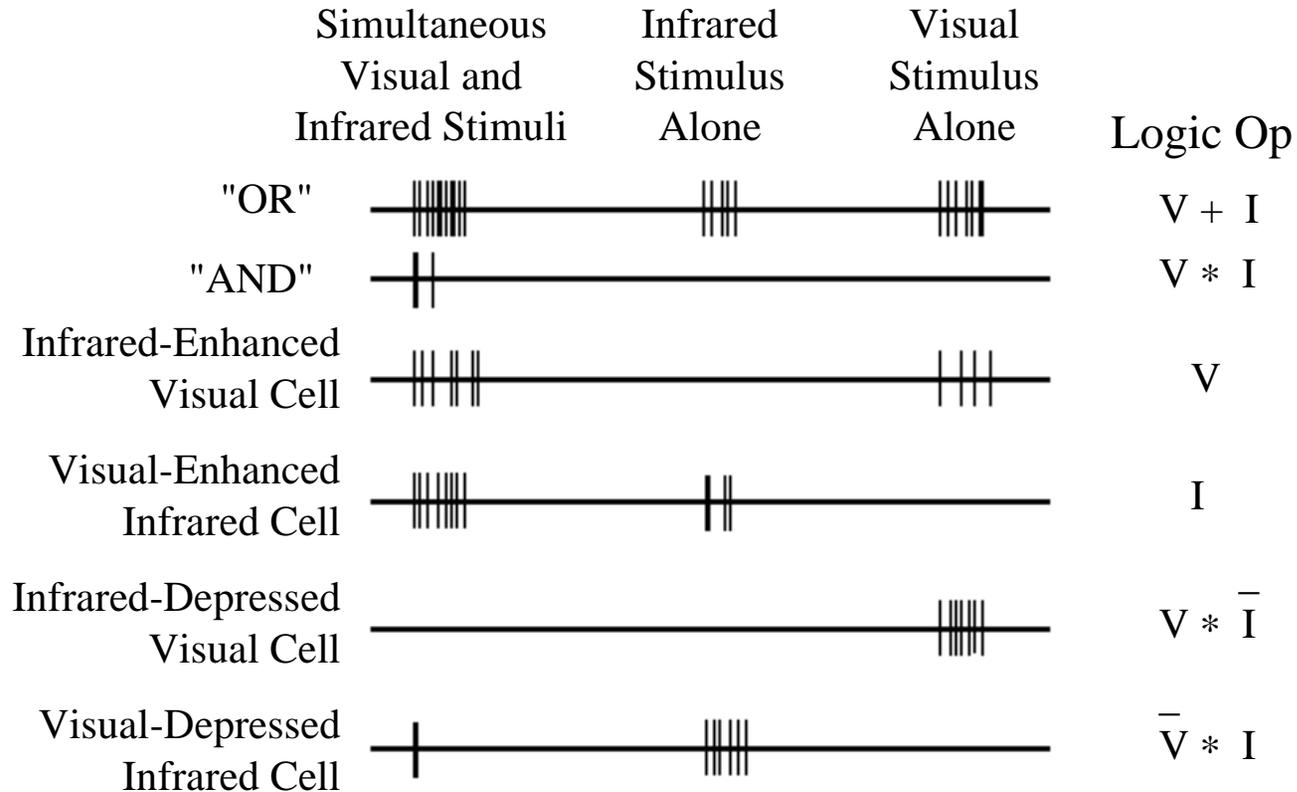
Biological Investigations



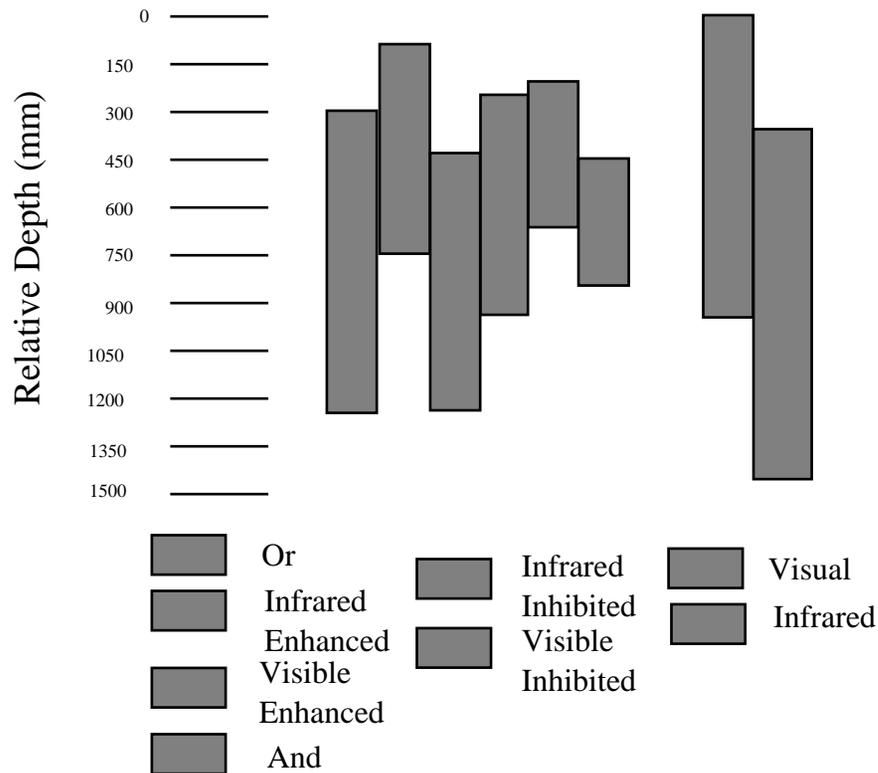
- Bullock & Diecke (1956) - extensive study of single neuron thermal properties
- Hartline, Kass & Loop (1978) - optic tectum mapping and existence of AND/OR bimodal neurons
- Newman & Hartline (1981) - existence of six types of bimodal neurons
- Terashima & Liang (1991) - thermal neuron properties in the LTTD

Bimodal Responses

Inputs		Bimodal Neuron					
Vis	IR	OR	AND	IRENH	VISENH	IRINH	VISINH
0	0	0.1	0.0	0.1	0.1	0.1	0.1
0	1	0.75	0.1	0.1	0.5	0.1	0.9
1	0	0.75	0.1	0.5	0.1	0.9	0.1
1	1	0.9	0.75	0.9	0.9	0.1	0.2



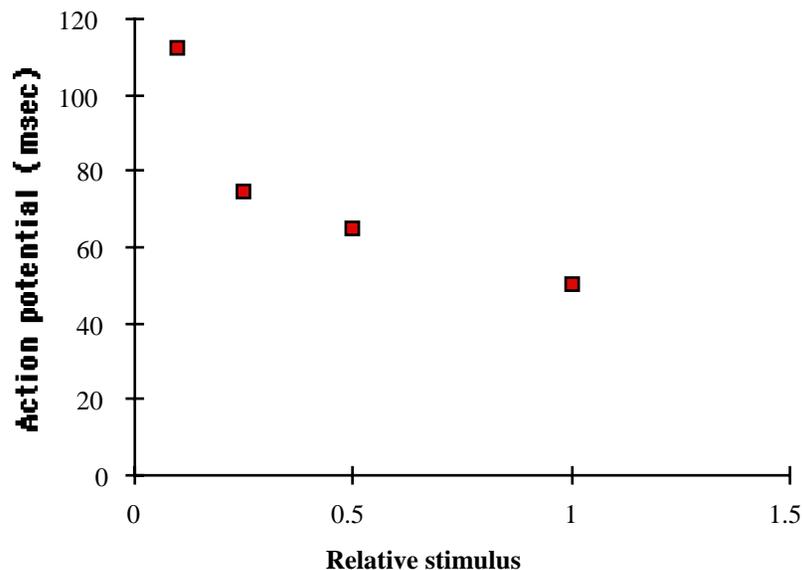
Organization of Neurons



- Zone from 450 to 650 mm contains all 8 types of neurons
- Interactions between different neuronal types leads to broader set of logic operations (ex. XOR)
- Interactions between networks of different neuronal types leads to set of image analysis operations

Motion Sensitivity

Latency of Response



- Thermal neurons exhibit nonlinear latency effects
- Stimulus with strong contrast to background causes rapid firing of neurons
- Highly non-linear decrease in firing frequency as contrast decreases
- Similar behavior seen in primate visual responses

Independent Arrays

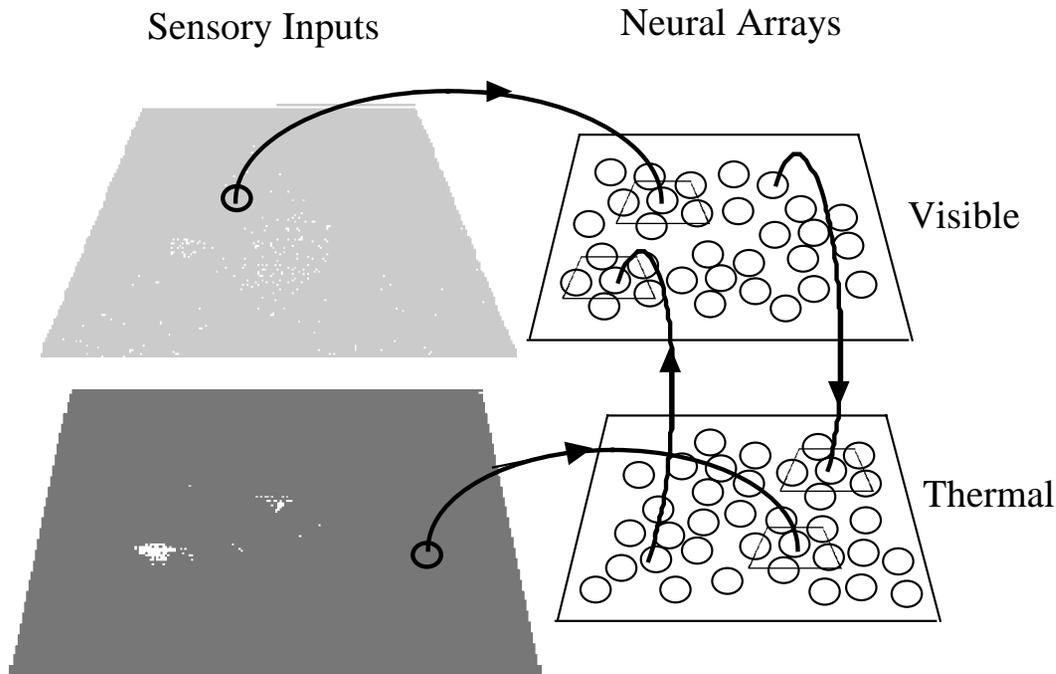


Original

Time (50 ms steps)

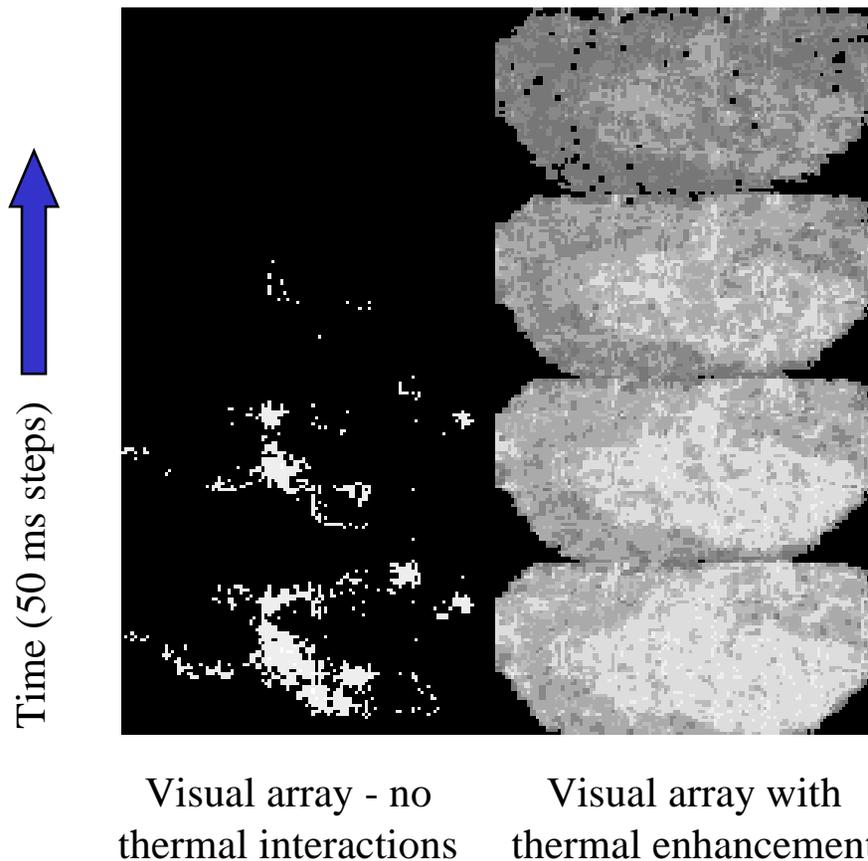
- Visible array quickly accommodates
- Thermal array enhances edges due to latency characteristics

Network Interactions



- Probabilistic feed from sensors to arrays with neighborhood at reception point
- Fibers between arrays can be excitatory or inhibitory
- Spatial registration between arrays and resolution of sensors controls specific result

Interacting Unimodal Neurons

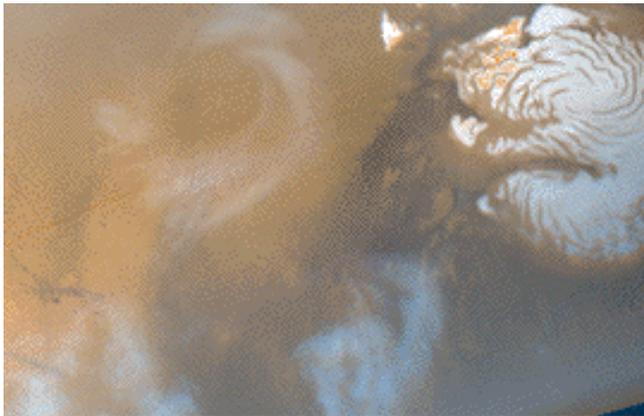


- Sensor array without interactions quickly accommodates and stops firing
- Excitatory interaction between arrays slows accommodation and enhances full field
- Type of dynamic multimodal gain control

Bimodal Temporal Analysis

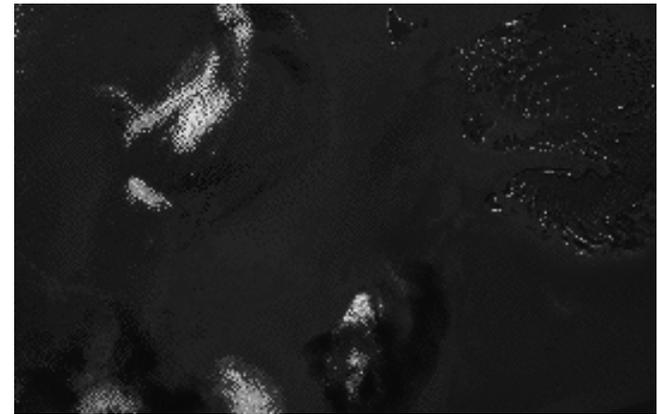
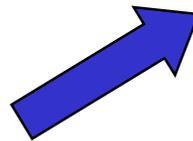
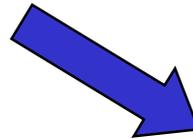


Image₁ : 4/30/1999



Image₂ : 5/01/1999

Clouds in North Polar
Region of Mars

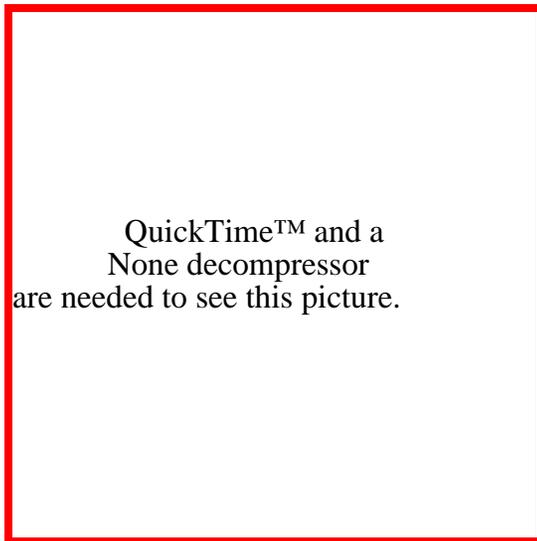


$$\text{Image}_1 * \overline{\text{Image}_2}$$

Dominant cloud patterns delineated
despite background variations



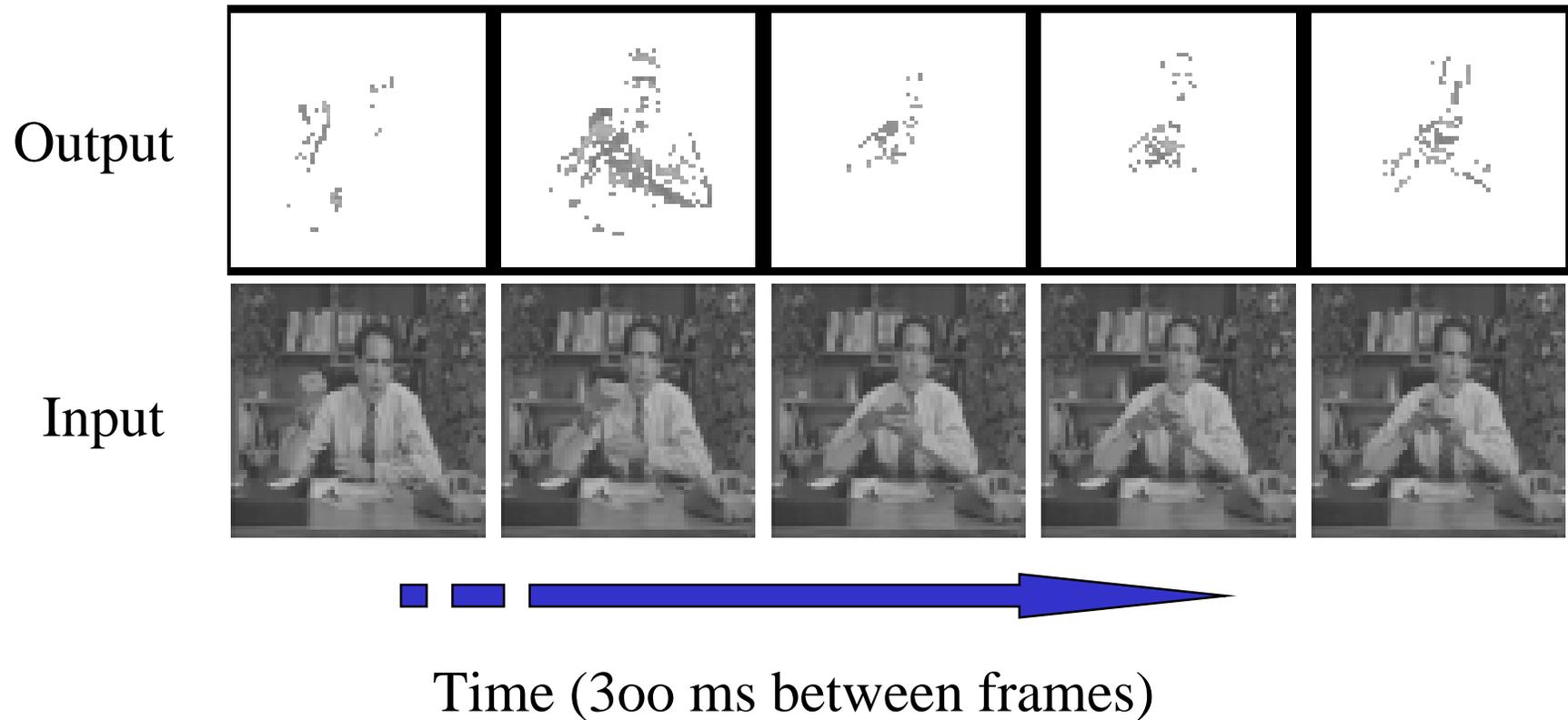
Array Processing



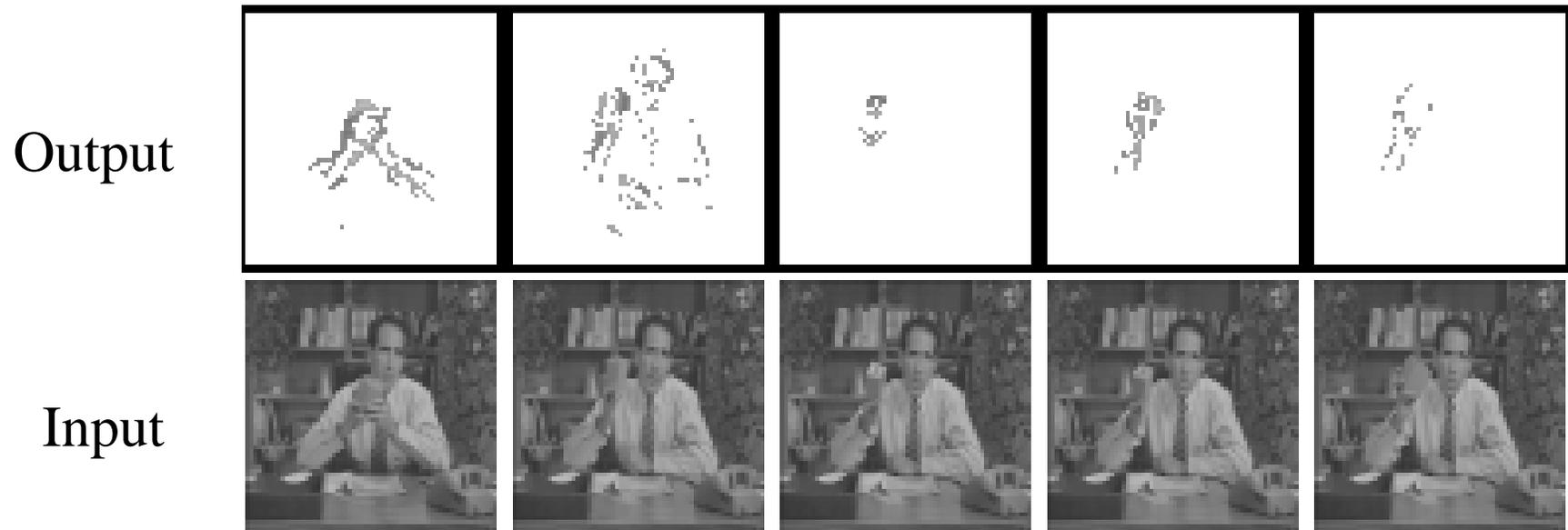
Salesman Sequence

- Primary motion is with right arm holding box
- Noise in image frames hampers straight frame difference analysis
- Textured background leads to occlusion/disocclusion problems for motion analysis

Array Output



Array Output (con't)



Time (300 ms between frames)

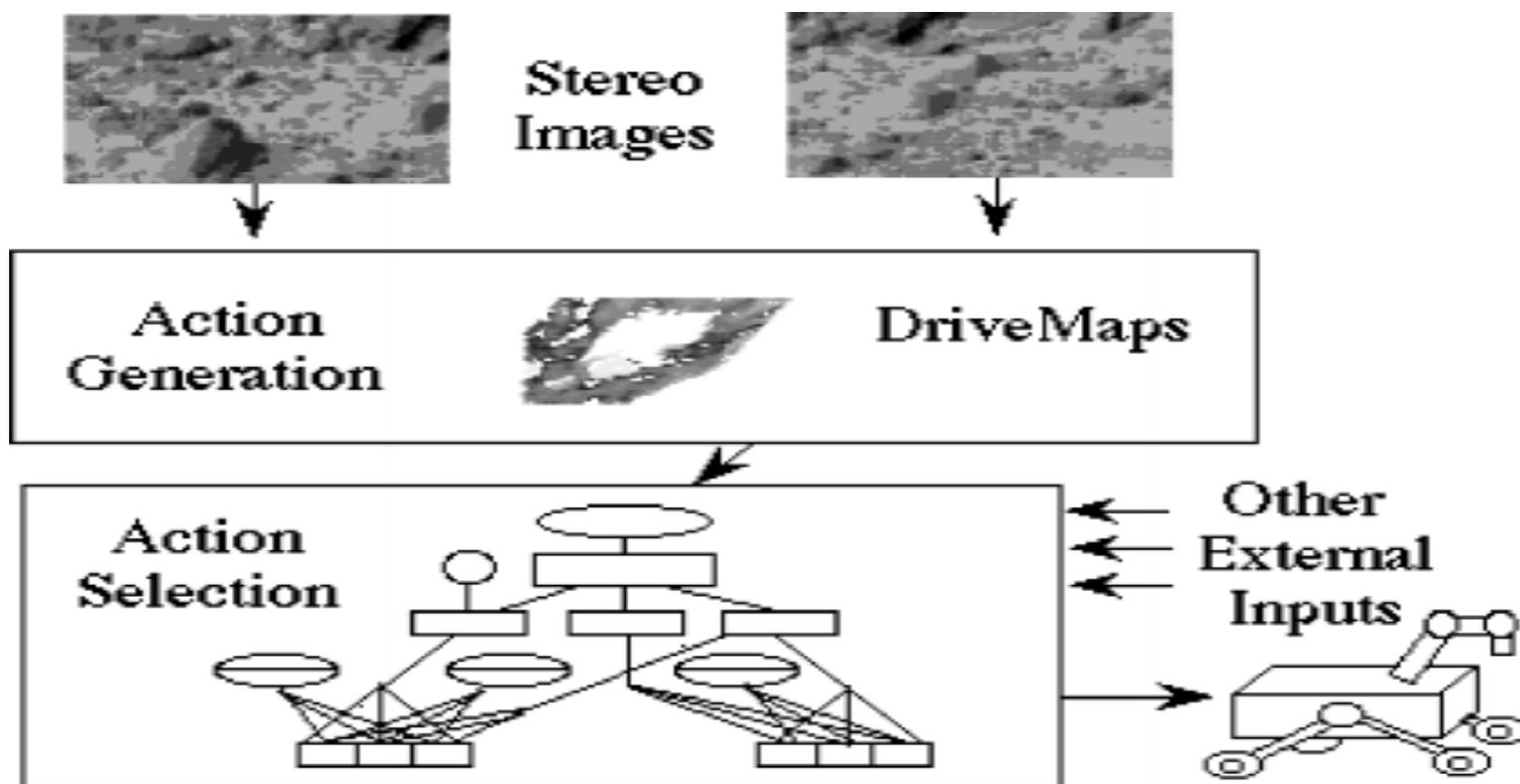


Behavior Generation



Biologically Inspired System for Map-based Autonomous Rover Control (BISMARC)

BISMARC Organization





Map Making

- Evidence for *place* cells in hippocampus for mapping environmental information using spatially non-contiguous populations
- Right hippocampus involved in route following in collaboration with landmark coding in left lateral prefrontal cortex [Maguire, et al 1997]
- Framework captured in BISMARC using landmark encoding coupled with actions leading to landmark

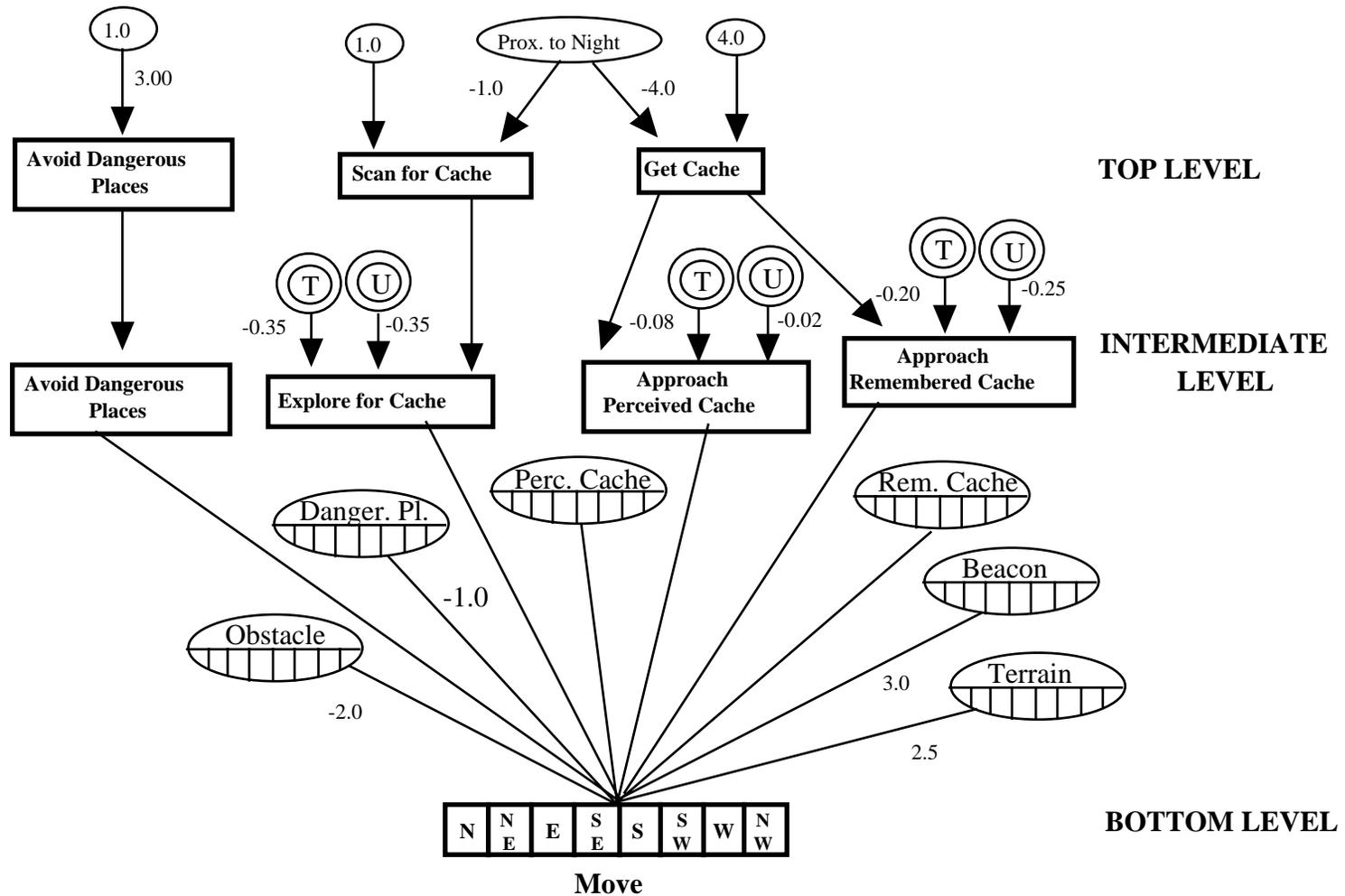
Memory Mechanism

- BISMARC has map-based memory similar to hippocampus
- Landmarks corresponding to obstacles and goals extensively mapped
- LTM stores landmarks for comparison to perceived inputs
- Probabilistic update of memories using perceived inputs

Desired Capabilities for Action Selection

- Low computational requirements
- Reactive even in uncertain environments
- No loss of internal state information
- Capable of combining conflicting behaviors
- Sensory input localized to decision modules where used

Move Subsystem



Activation Strength

$$A_S = P_d * (1.0 - \text{dist}) * (1.0 - P_u)$$

P_d is the normalized sensor input for sensor S

P_u is the perception uncertainty

dist is the normalized distance to a perceived object - combination of stereo and LTM traces

Experimental Setup

- Random starting positions and cache placement
- Timestep of 0.1s
- 10% loss of traction in rocky terrain
- 1km X 1km study area with 5 cm resolution
- Top speed of 15 cm/sec
- Cache acquisition time of 1 hour prior to return to lander

Experimental Setup (con't)

- Single scout rover
 - Color stereo cameras
 - 3 DOF manipulator
 - 1 week battery lifetime
- Two retrieval rovers
 - Grayscale stereo cameras
 - 5 DOF manipulator
 - 2 week battery lifetime

Summary of Experimental Results

- 2000 simulated missions with success defined as all four cache containers retrieved
- 98.9% mission success with no component failures
- 12% success rate with component failures and no fault tolerance
- 46% success rate with component failures and fault tolerance

Summary

- Rich set of computational operations can be realized with unimodal and bimodal neuron models
- Independent and interconnected networks of these neurons provide image analysis capabilities
- Developed fault tolerant autonomous control system for multiple planetary rovers
- 98.9% success rate in 2000 simulated multi-rover missions

Current Directions

- Replacement of heuristic action selection with basal ganglia models [with Steve Grossberg, BU]
- Comparison of system to theoretical Multiple Objective Behavior Control [Pirjanian (2000)]
- Integration of sensor fusion into action selection mechanism
- Port of system to SRR