

Neuromorphic VLSI-Based Models of the Bat Echolocation System

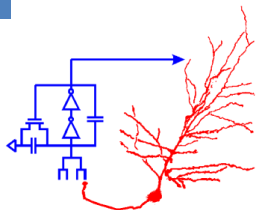
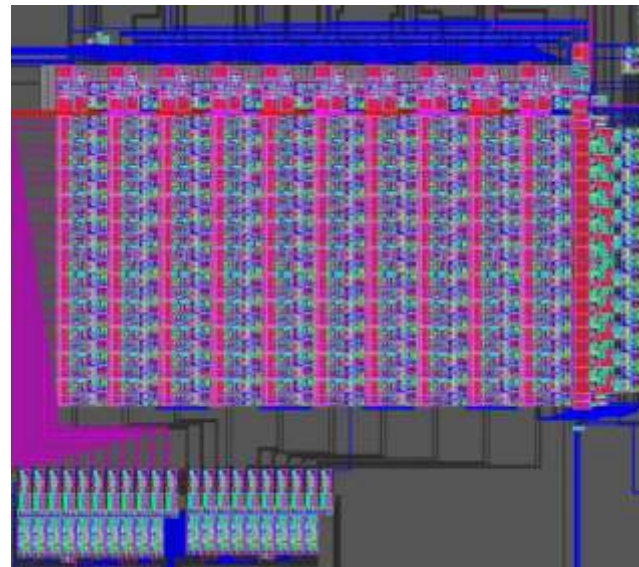
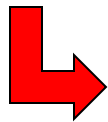
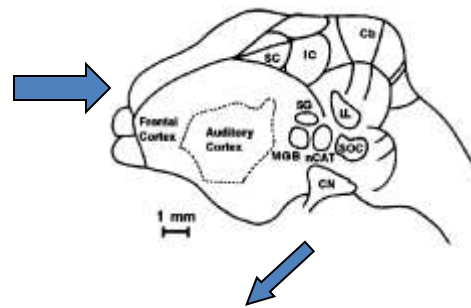
Timothy K. Horiuchi

University of Maryland, College Park

Electrical and Computer Engineering Dept.

Institute for Systems Research

Neuroscience and Cognitive Science Program





Eptesicus fuscus : the big brown bat



Bats are interesting to neuroscientists because:

- their brains are characteristically mammalian
- audition is being used a bit like vision
- ecological diversity has driven form/function diversity
- echolocation is a sampled sensory system => state estimation
- auditory brainstem neurons code echoes with a single spike.

Contributors / Collaborators

Computational Sensorimotor Systems Lab



**Tarek
Massoud**



**Chetan
Bansal**



UG: Laura
Freyman



**Hisham
Abdalla**



UG: Khai Lai

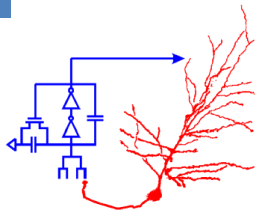
No photo:

GRA:
Ju Geethanjali



**Intelligent
Servosystems
Laboratory**
P.S. Krishnaprasad

**Auditory
Neuroethology
Laboratory**
Cynthia Moss



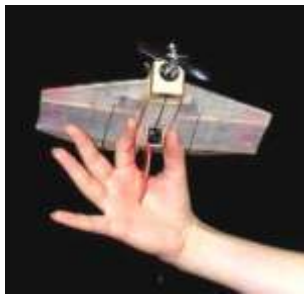


Photo: Hill Valley Adventures, TX

Bats are of interest to the aerial robotics community because of their ability to maneuver and hunt in cluttered 3D environments using echolocation.

Bats are also known to use vision in flight, making them a good animal models for thinking about multimodal sensory fusion.

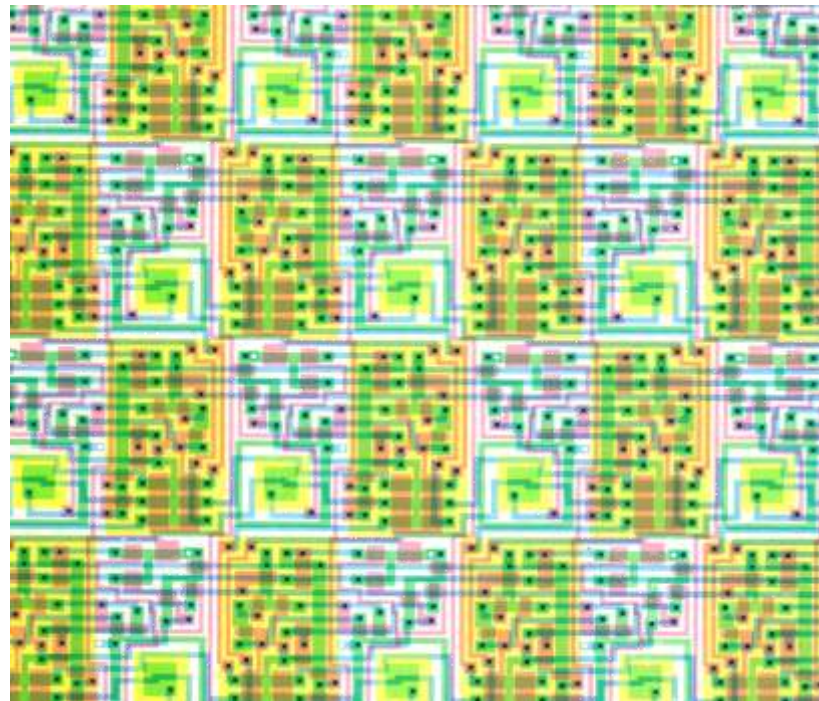
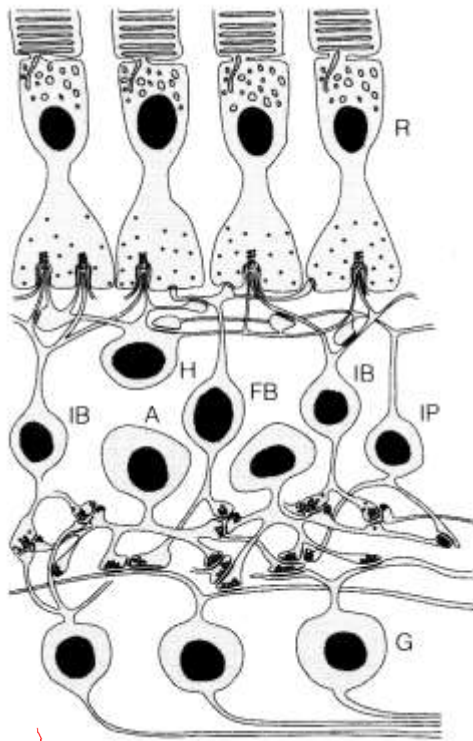


photo: "World of Bats"

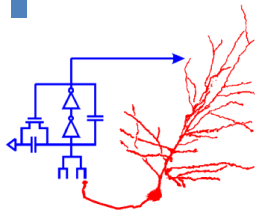
What is Neuromorphic VLSI ?

Neurons + **Morphology** + **VLSI** = **Neuromorphic VLSI**

an example: Silicon Retina



from Mead, 1989

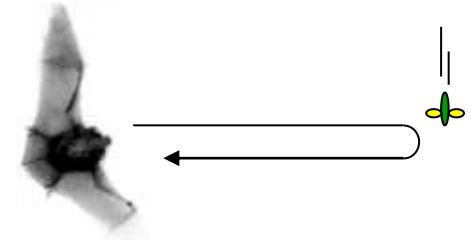


Projects in the lab

Sonar Front End



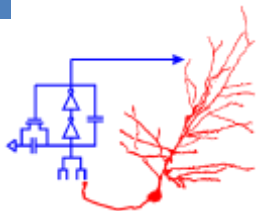
Estimating Range (Inferior Colliculus neurons)



Estimating Azimuth & Elevation

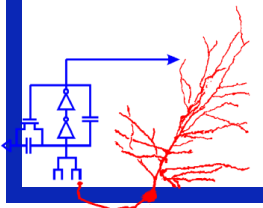


Combining Echoes for Collision Avoidance

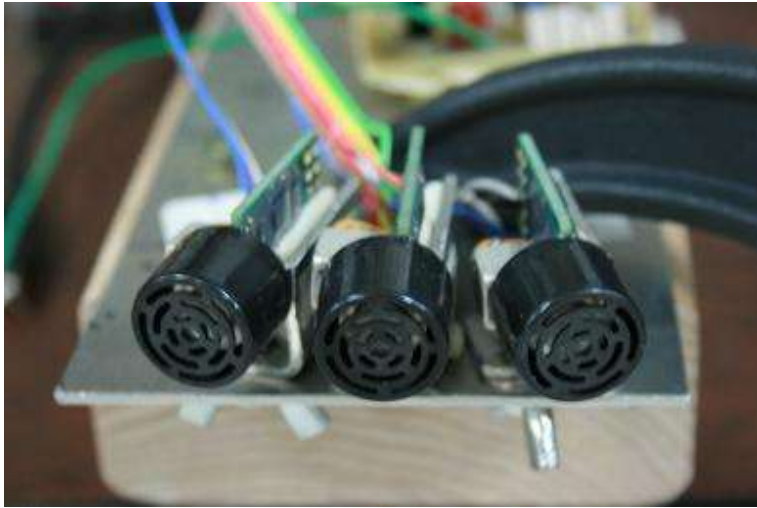


Planned Collaborations and Contributions to the MURI team

1. Development of a single-chip implementation of neurally-inspired, real-time 2D and 3D sonar localization systems.
2. Exploration of a real-time Bayesian-like sensory fusion framework and implementation using a spiking neural architecture in VLSI.
3. Development of an integrated optic flow/echolocation spatial perceptual system.
4. Development of an active, task-dependent sensory system based on a spatial attention framework. (e.g., navigation vs. station keeping vs. tracking)
5. Exploration of neurally-inspired, VLSI implementations of new obstacle avoidance algorithms.



Basic Approach



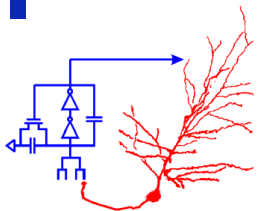
N=3 Narrowband Transmitter/Receivers

Can transmit in different directions (patterns & neck)
Uses multidimensional spatial cues for localization
Envelope of waveform encoded logarithmically

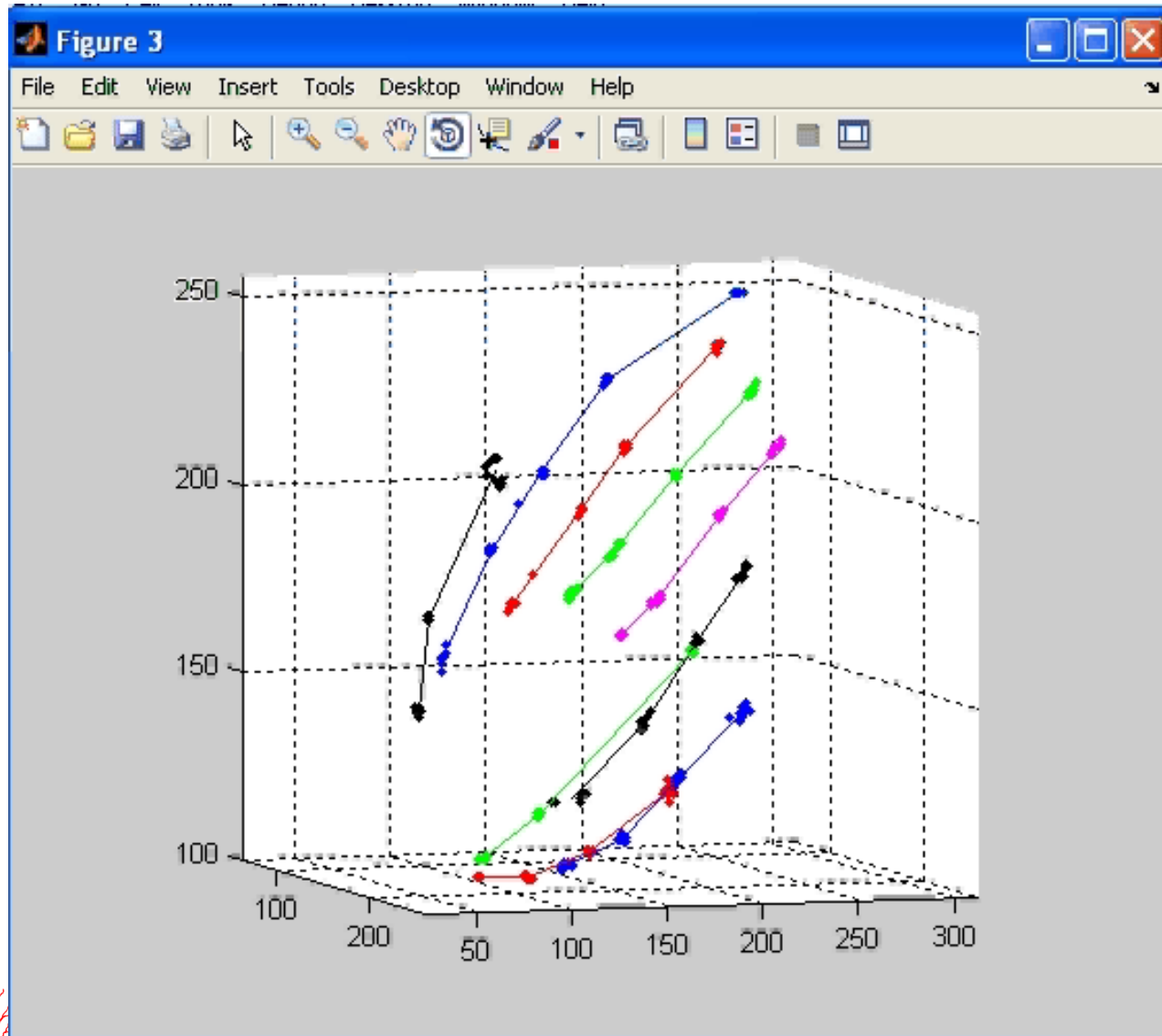


1 Transmitter, a Neck,
2 Broadband Receivers

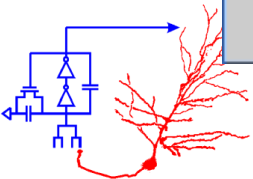
Can transmit in different directions (neck & sidelobes)
Uses multidimensional spatial cues for localization
Envelope of waveform encoded logarithmically



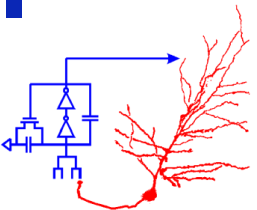
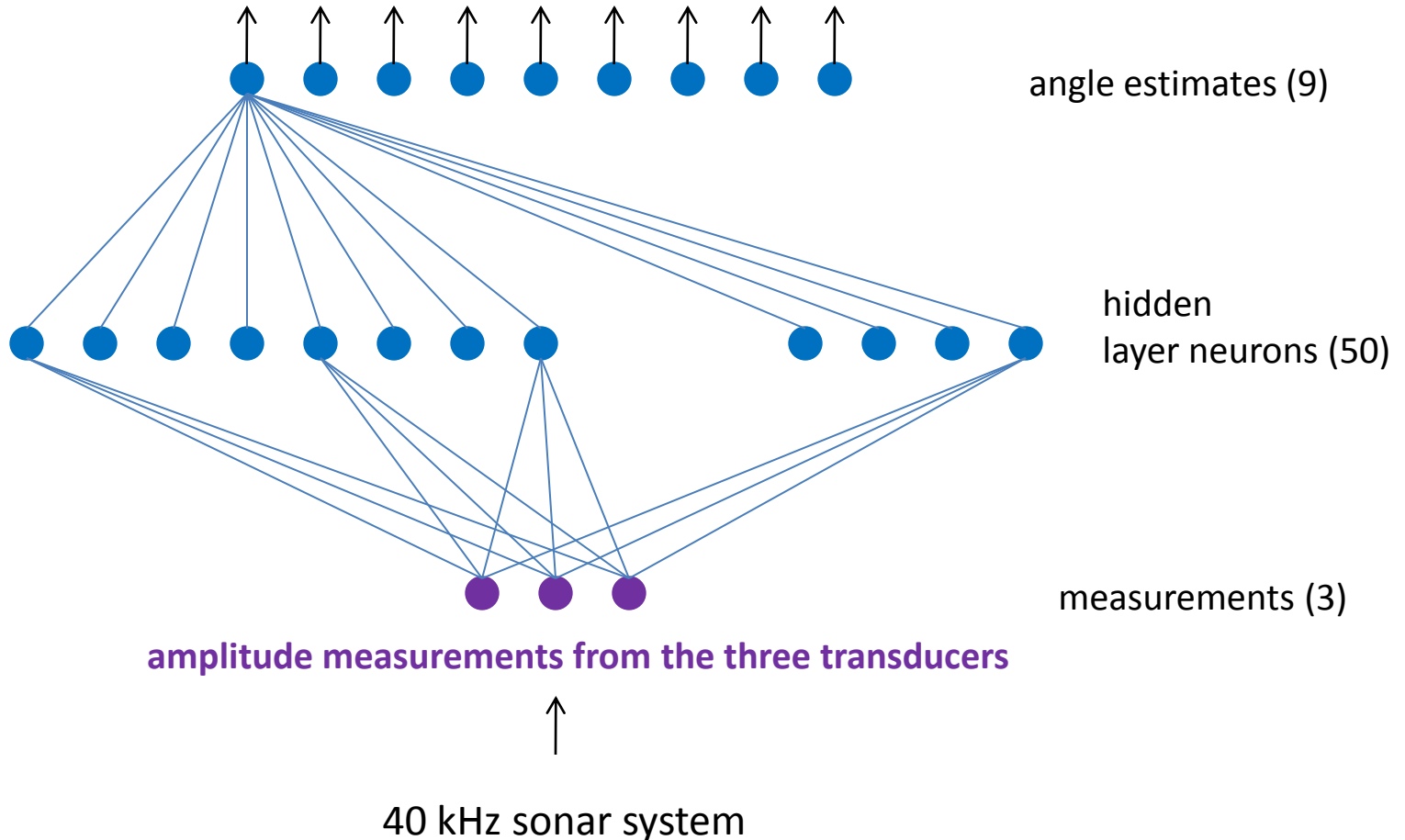
Echoes from different azimuthal directions lie in different subspaces (colors).



Clusters along each line represent sample echoes from different **distances**.



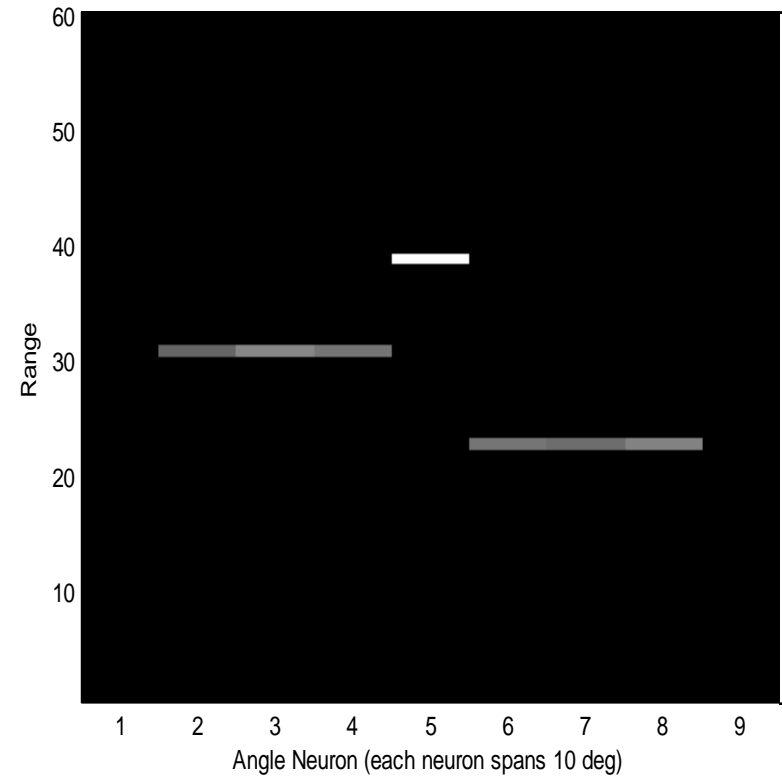
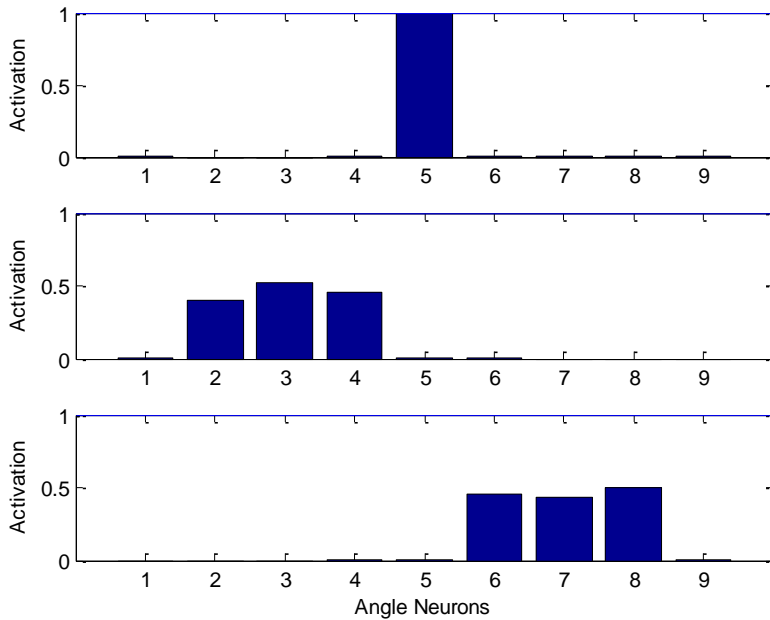
Using a simple supervised-learning neural network,
echoes can be rapidly classified (after training).



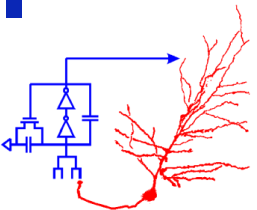


In this example, nine (9) angles were trained for poles at different ranges. Angle neuron responses for the three echoes are shown.

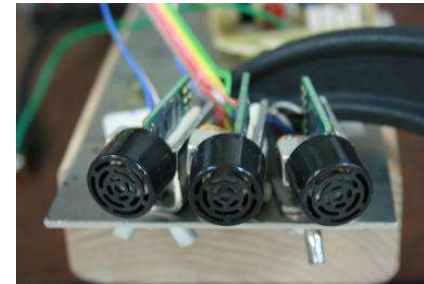
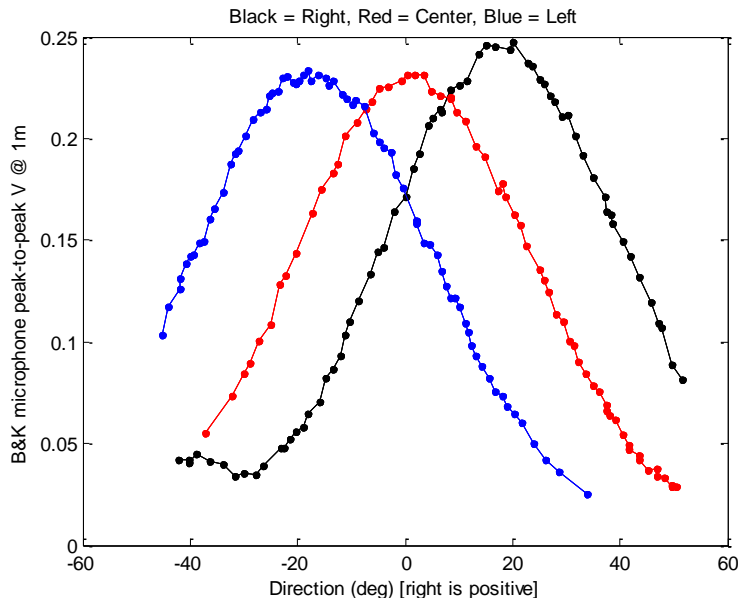
The spread in the neuron field activation acts like an unnormalized likelihood distribution.



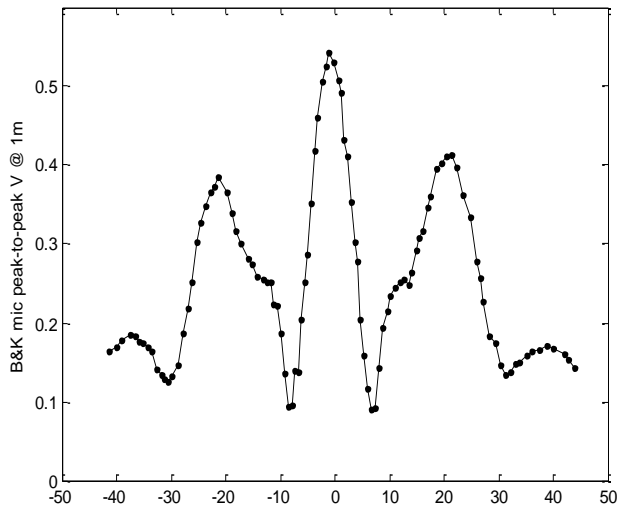
Something about active perception and steering the beam



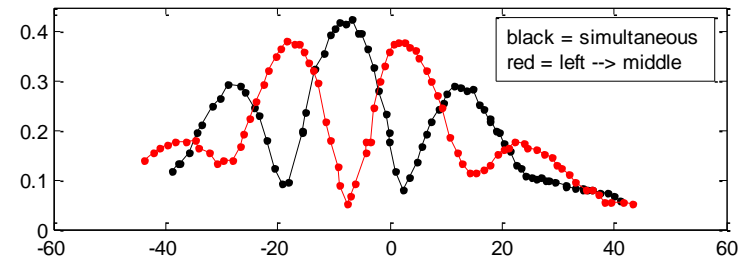
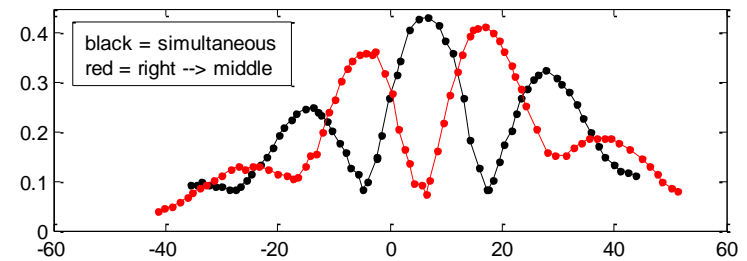
Coordinated triggering of the three transmitters can produce different spatial transmission patterns.



single transmitter patterns

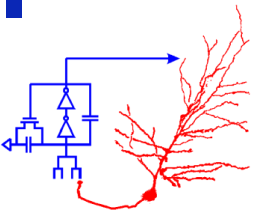


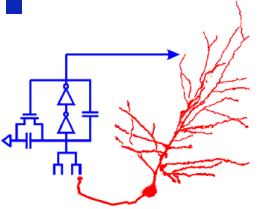
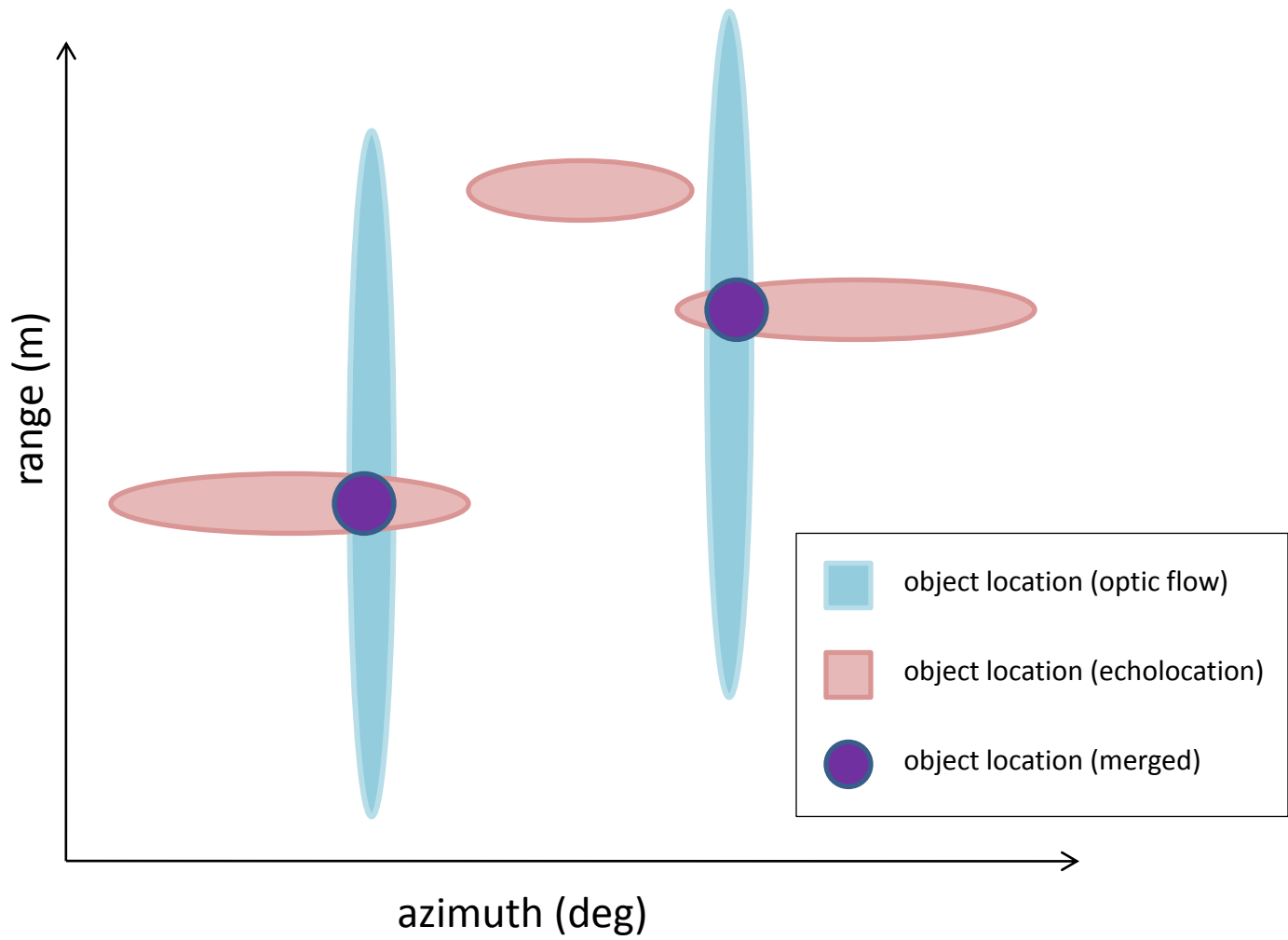
all three: using phase delays



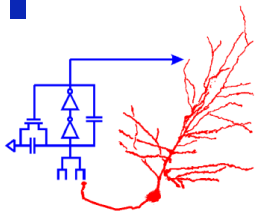
pairs: (top) R & M, (bottom) L & M

Merging Sonar & Vision

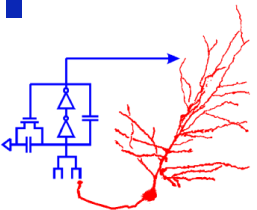
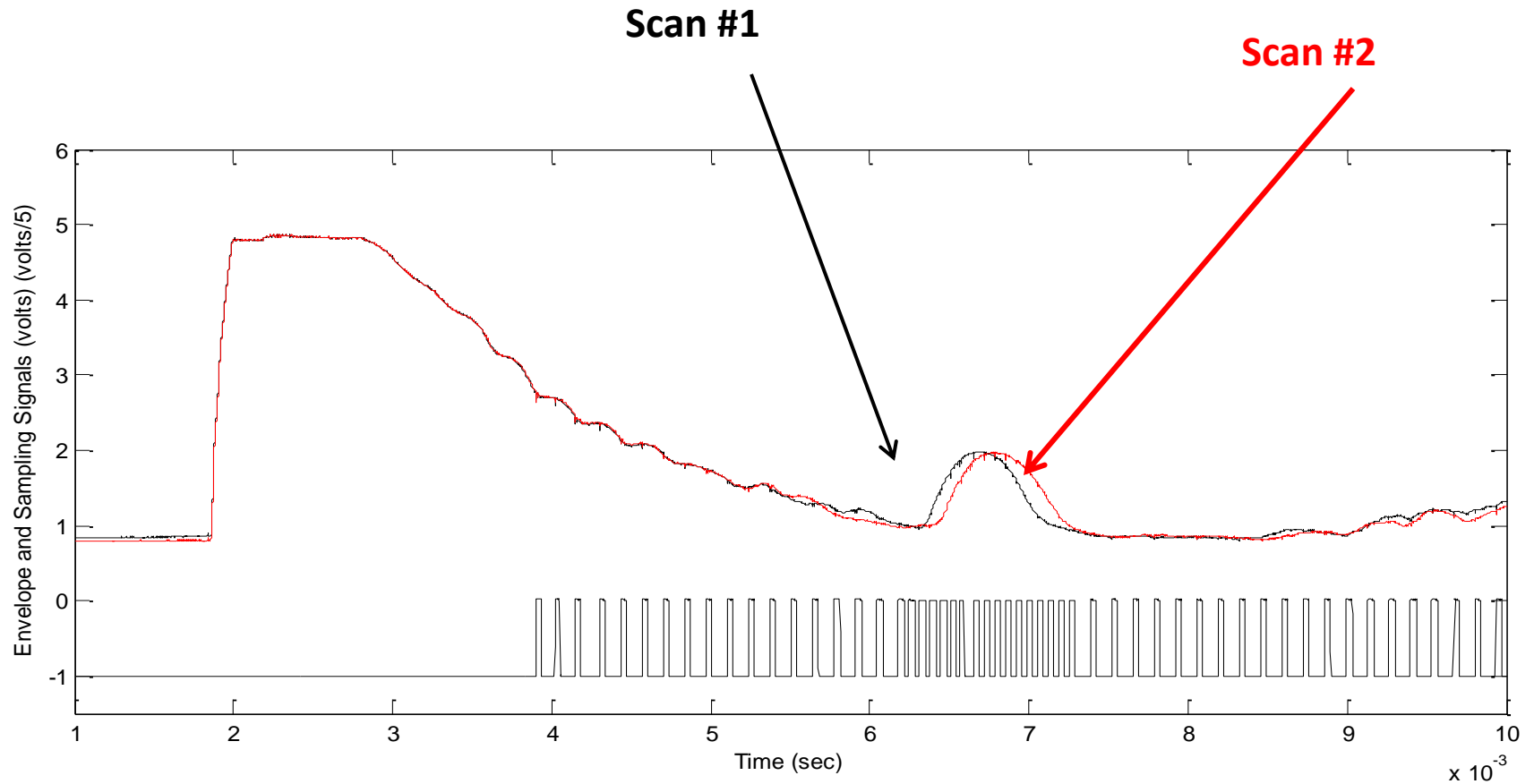




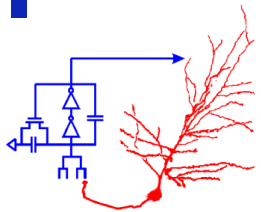
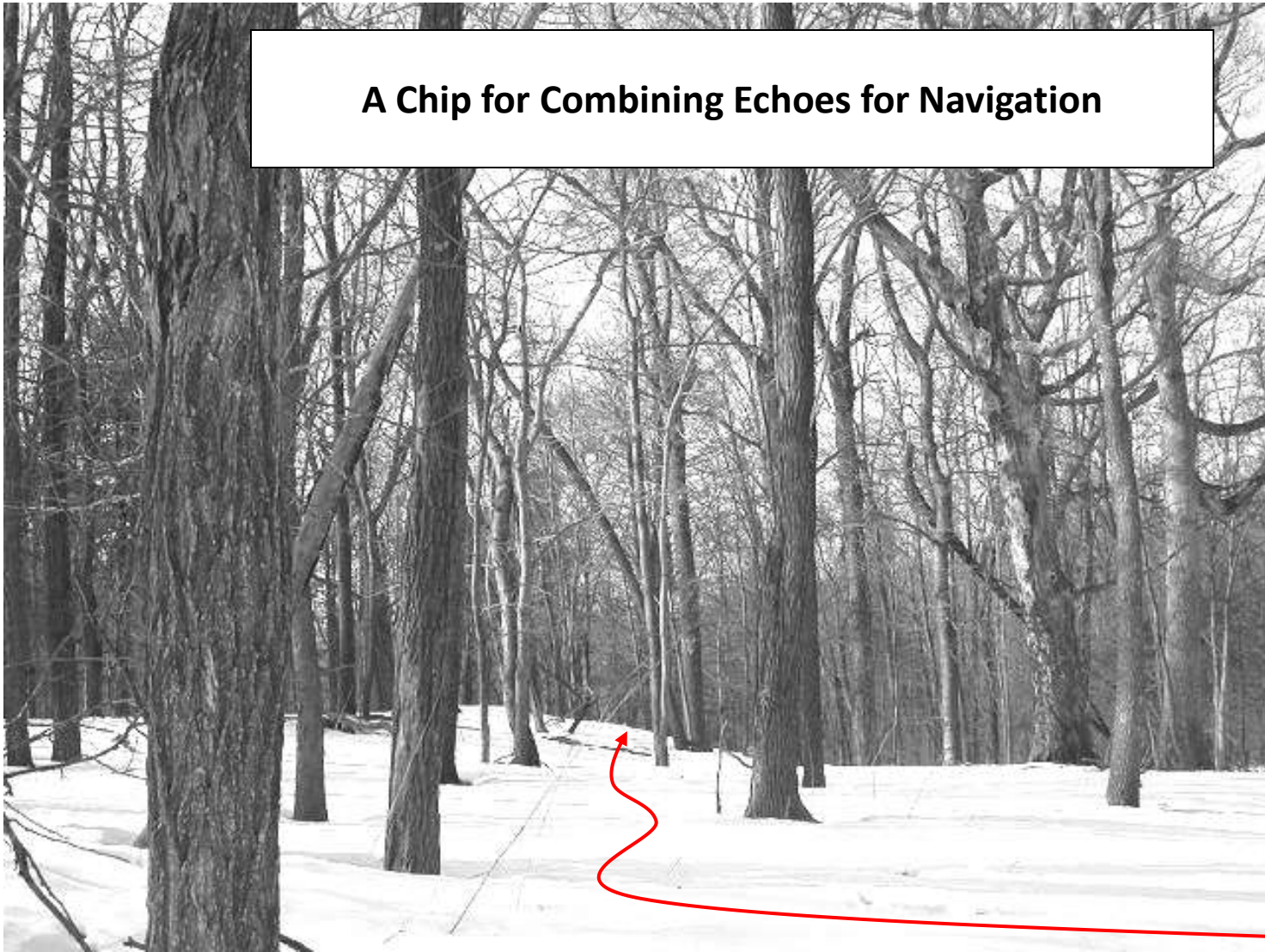
Attention can be used to guide the measurement of velocities for station-keeping



The use of variable temporal resolution allows for more detailed velocity measurements.



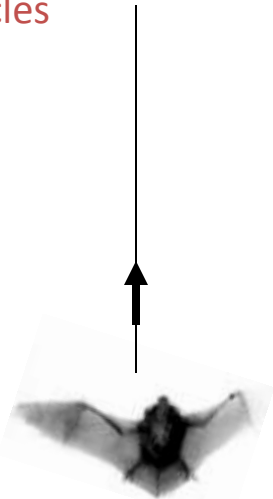
A Chip for Combining Echoes for Navigation



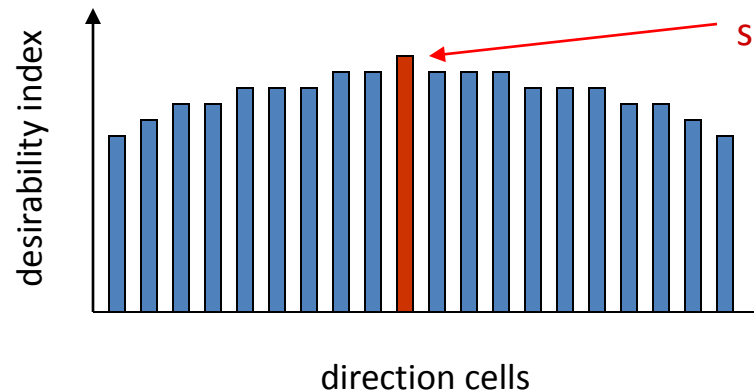
Collision Avoidance and the “Openspace” Algorithm

- Sonar echoes only indicate places where the robot should **not** go.
- The robot should be able to initially turn **towards** some obstacles in order to steer towards more desirable directions
- Tightly packed obstacles should “appear” to be one large obstacle.

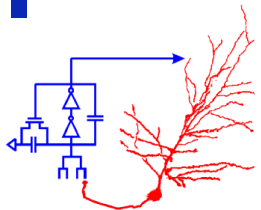
no obstacles



background activity (goal steering)



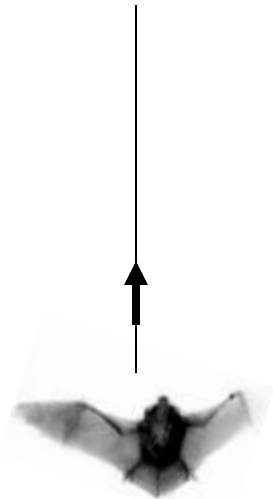
winner-take-all selects the max



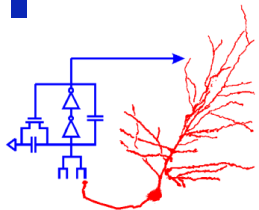
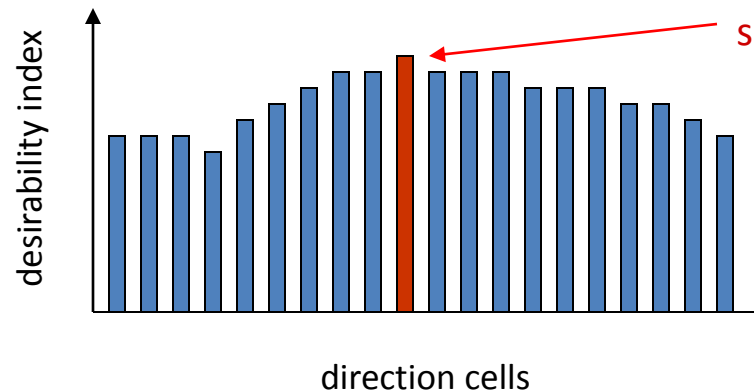
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obstacle far & to the side



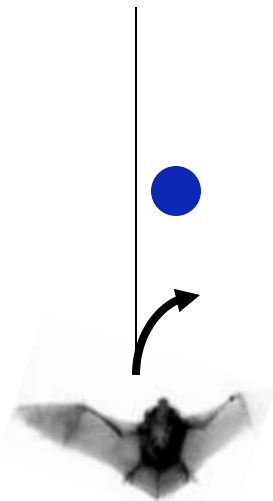
goal steering + target inhibition



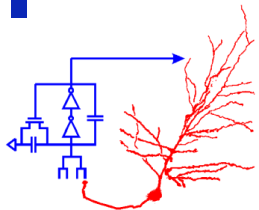
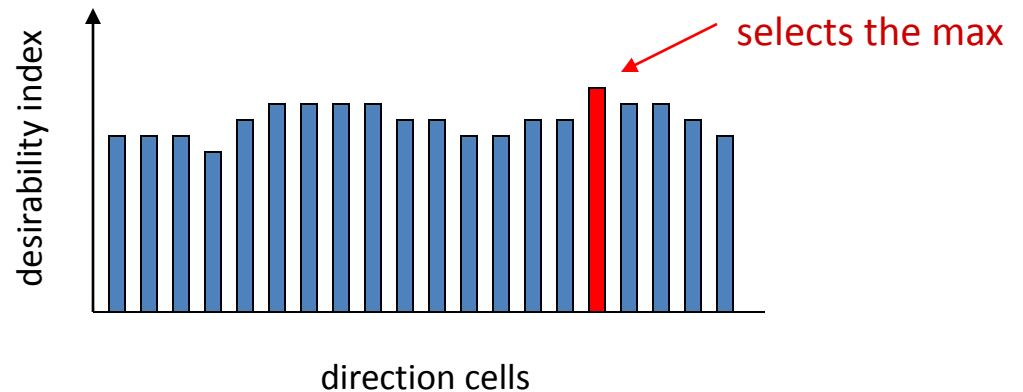
Collision Avoidance and the “Openspace” Algorithm

- Sonar echoes only indicate places where the robot should **not** go.
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- Tightly packed obstacles should “appear” to be one large obstacle.

additional obstacle close & central

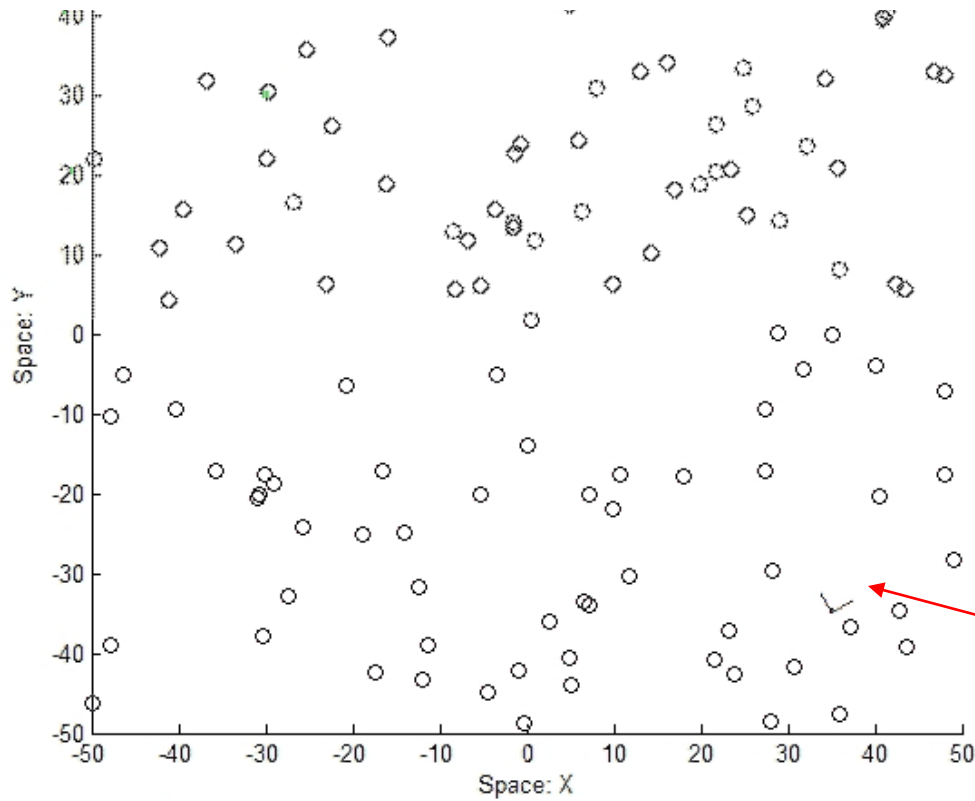


goal steering + target inhibition



MATLAB Simulation

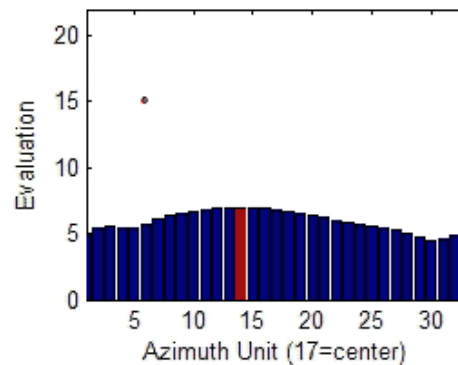
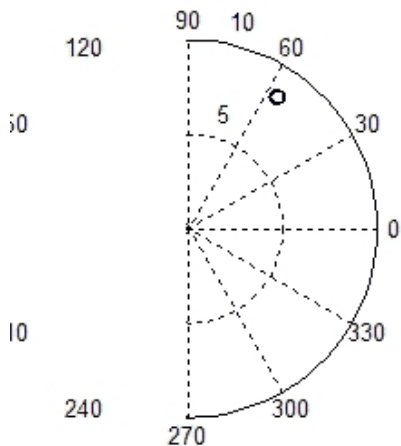
A “forest” of
obstacles
(top view)



Constant
velocity
(only steering)

robot starts here

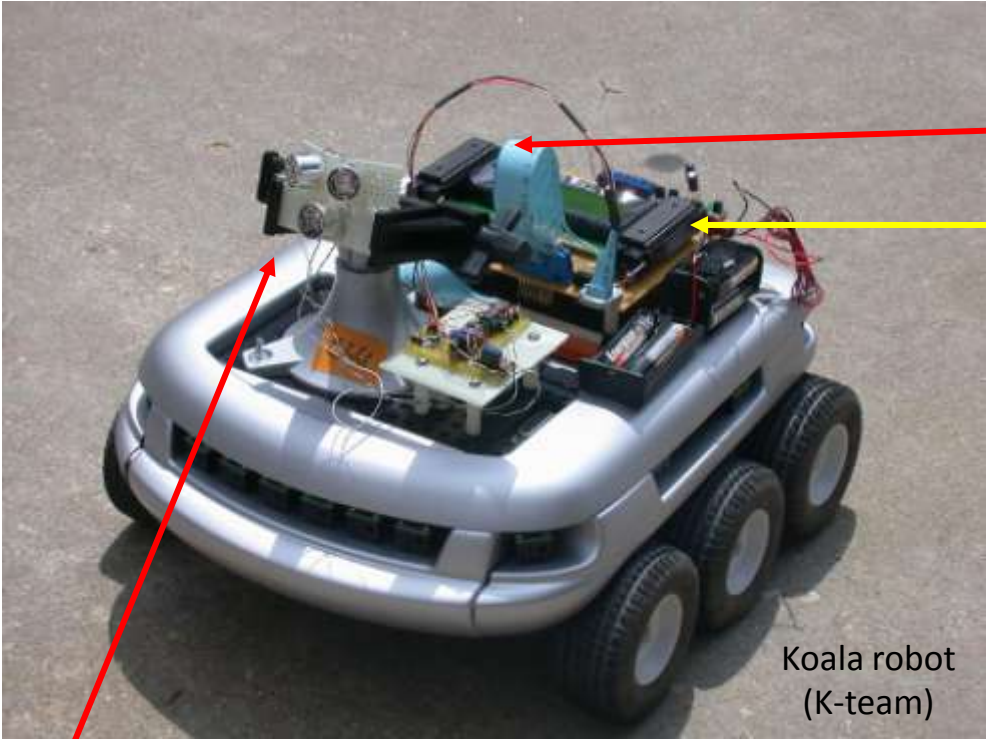
travel direction
bat's view
of obstacle field



desirability
index vs. direction

(red dot
indicates
goal direction)

Software Implementation on Robot

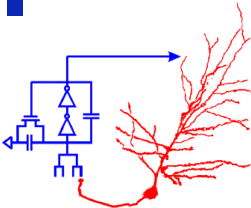


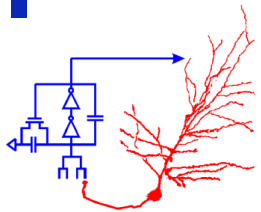
“openspace” algorithm

azimuth & range algorithm

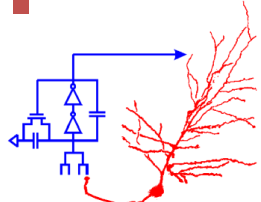
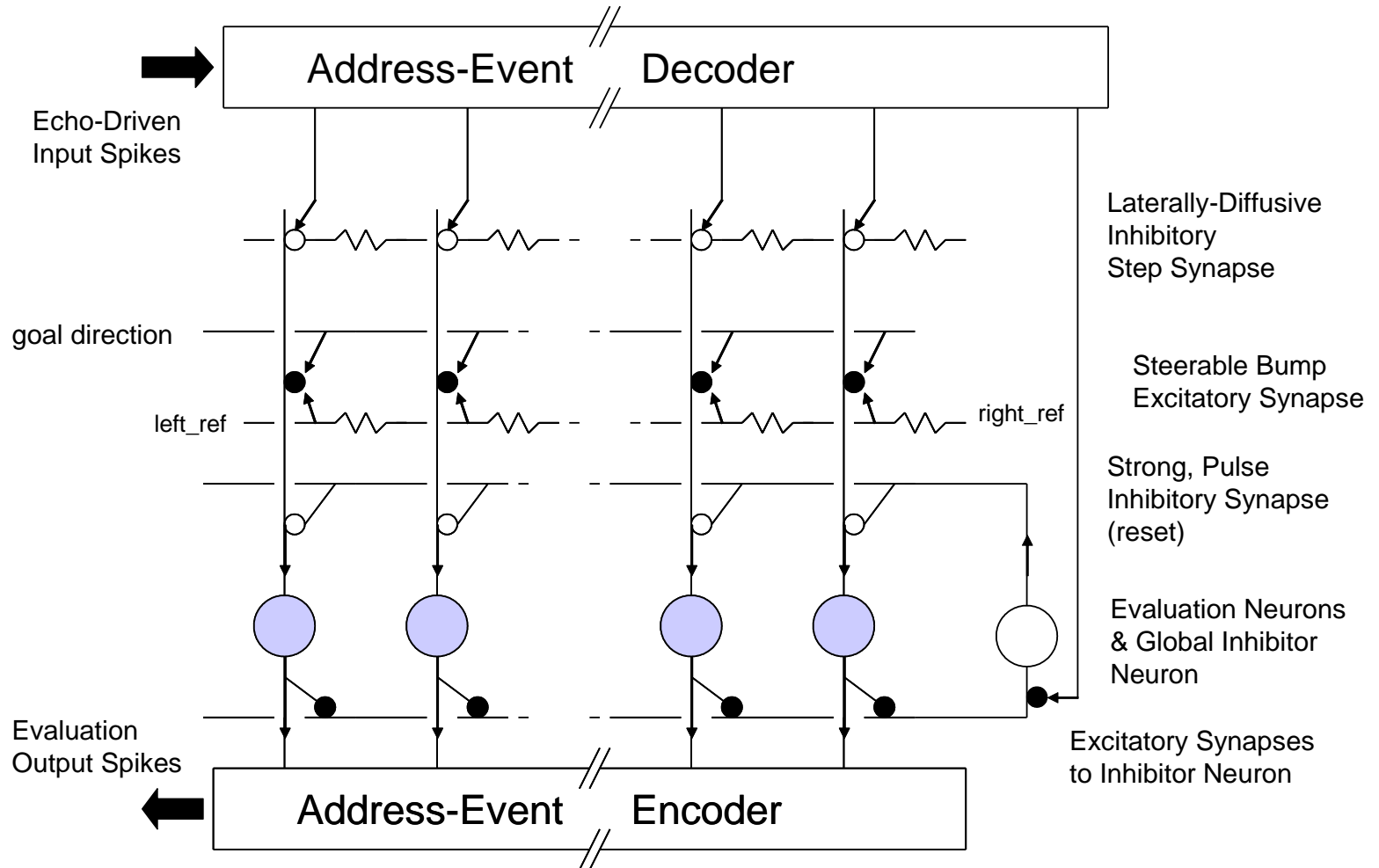
Koala robot (K-team)

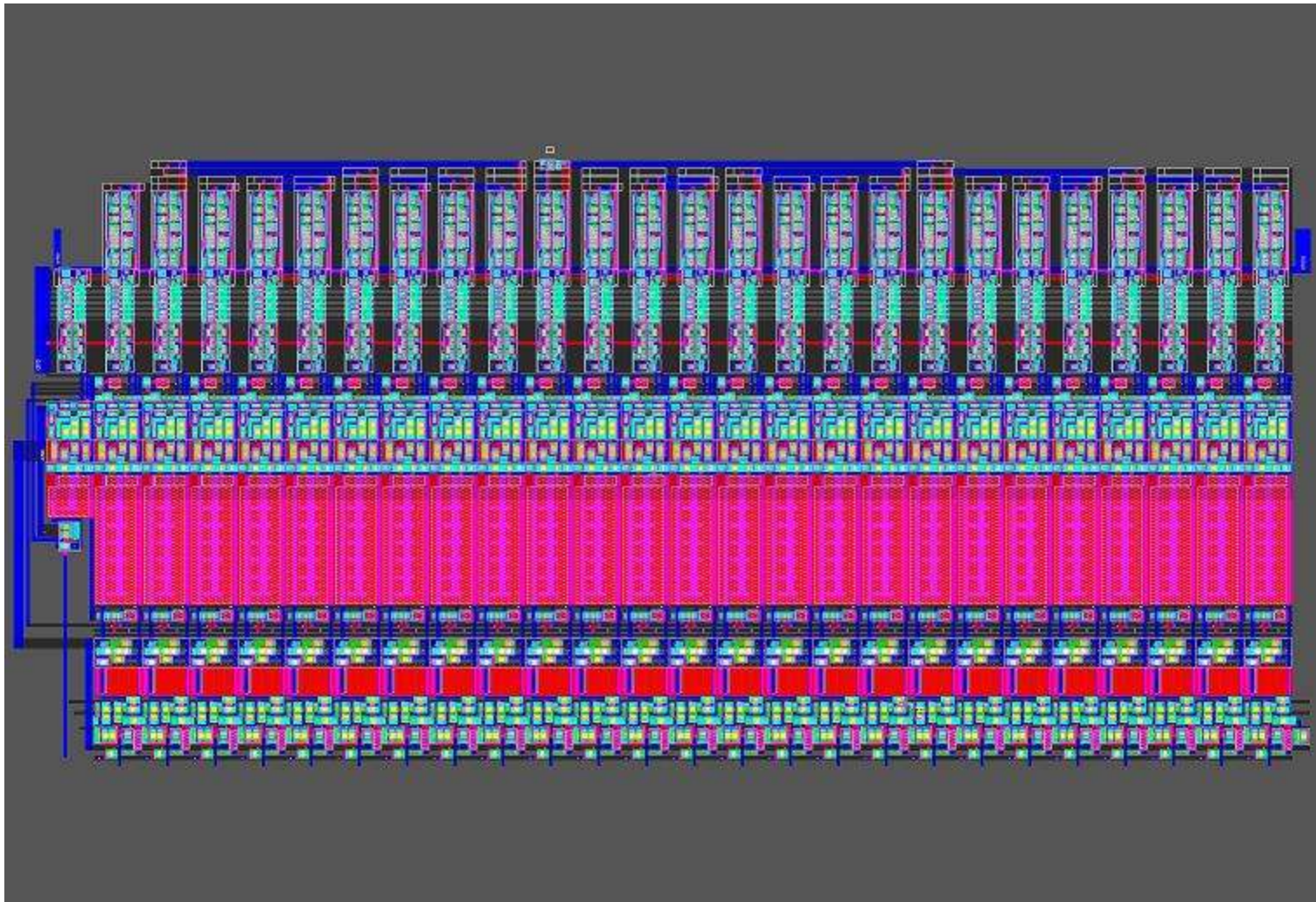
binaural sonar head



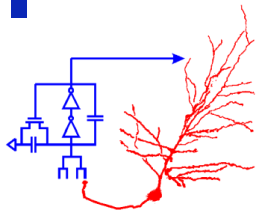


Chip Block Diagram



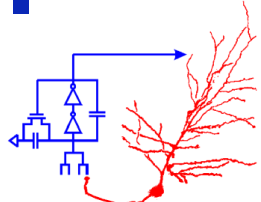
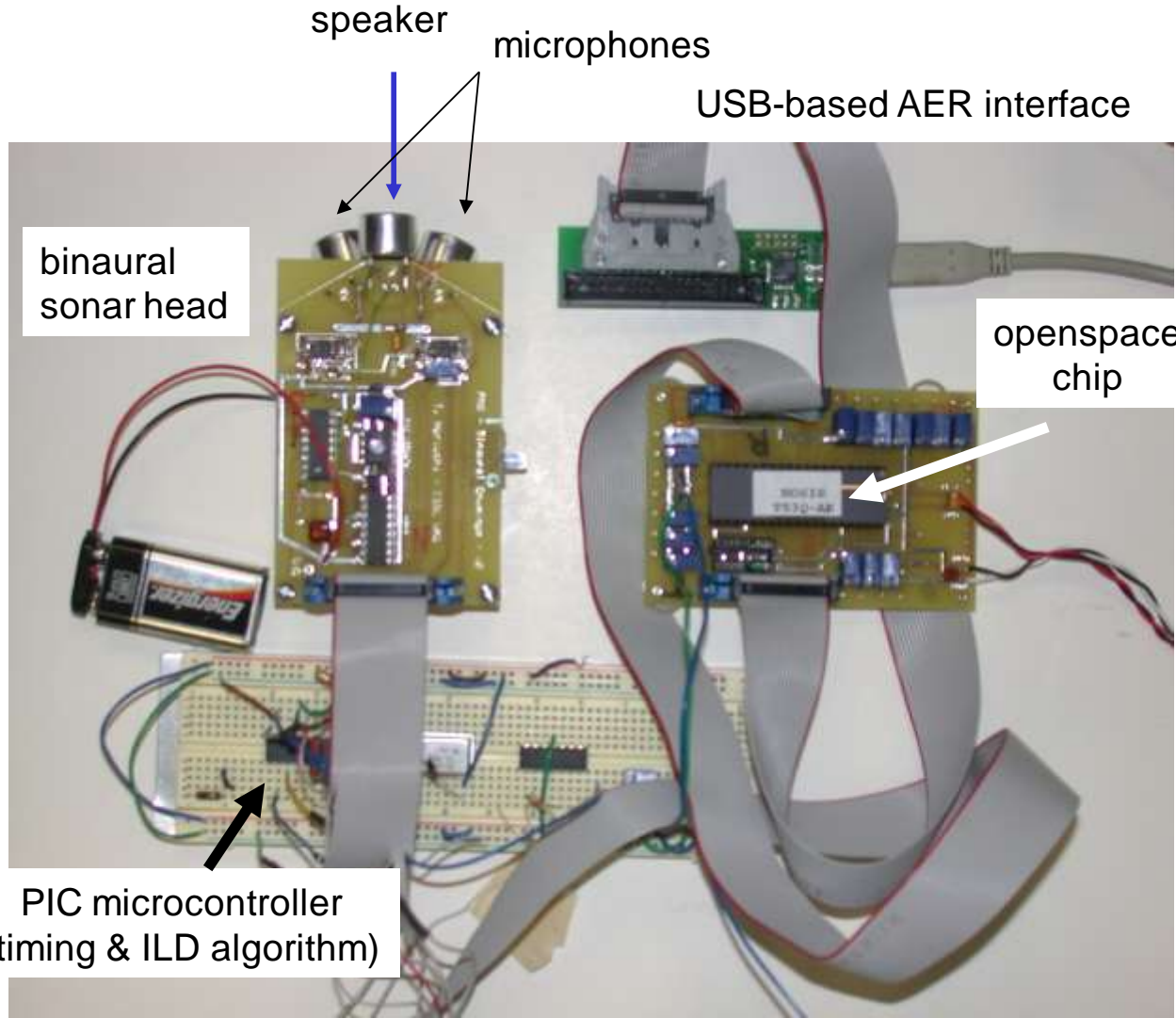


'openspace1' chip – 26 spiking neurons (AER interface)

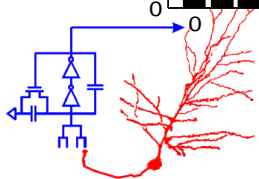
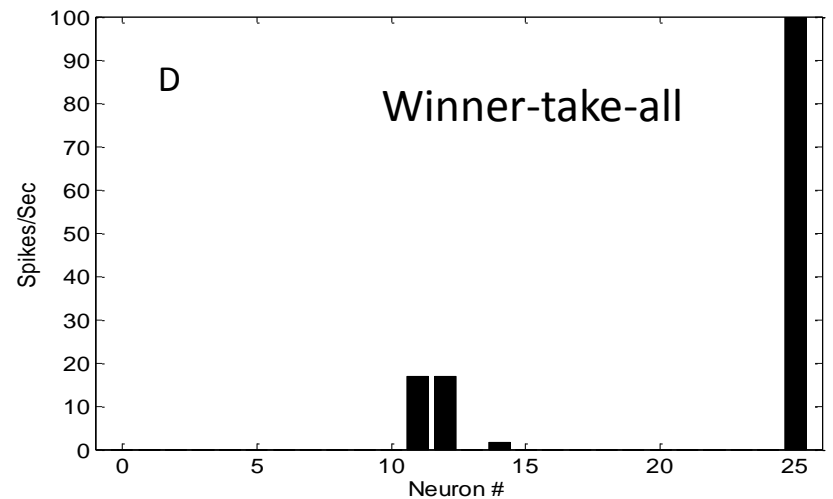
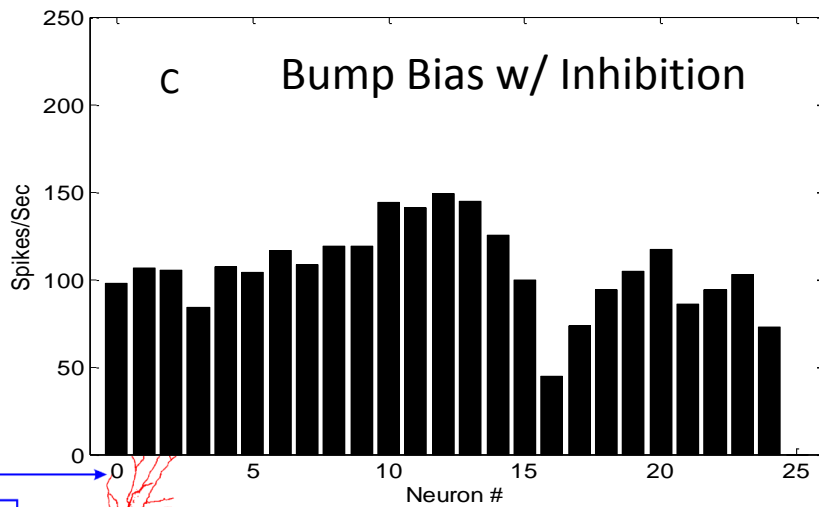
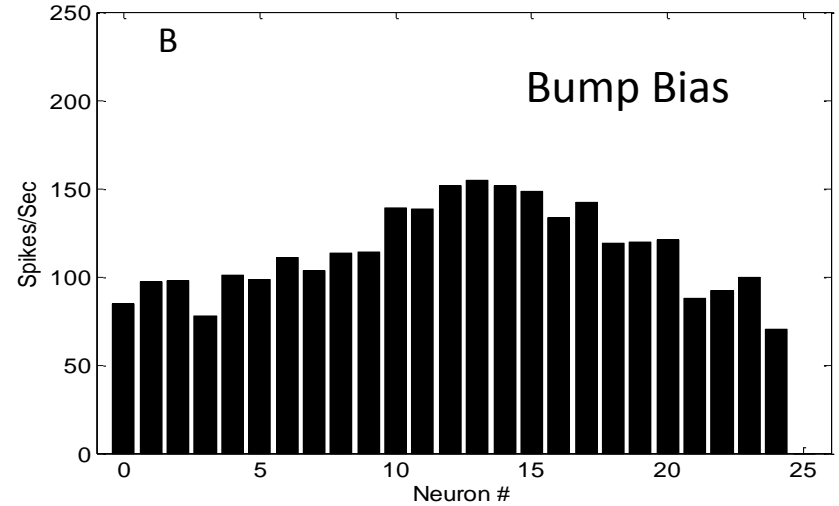
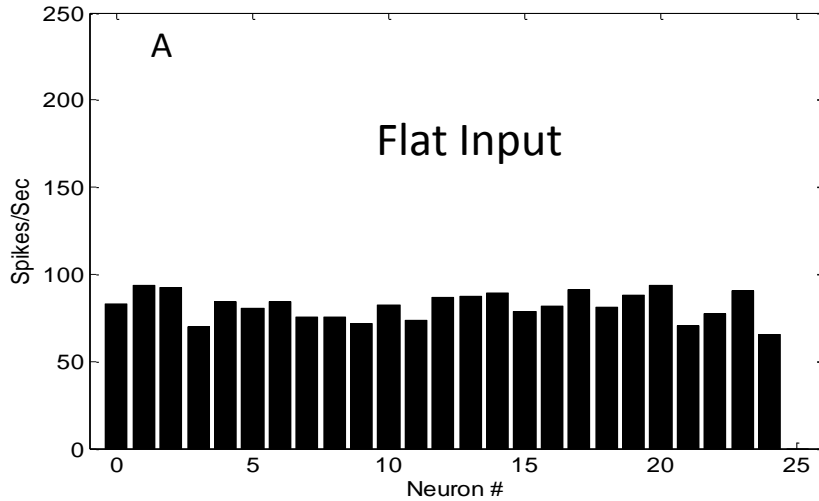


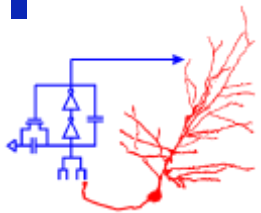
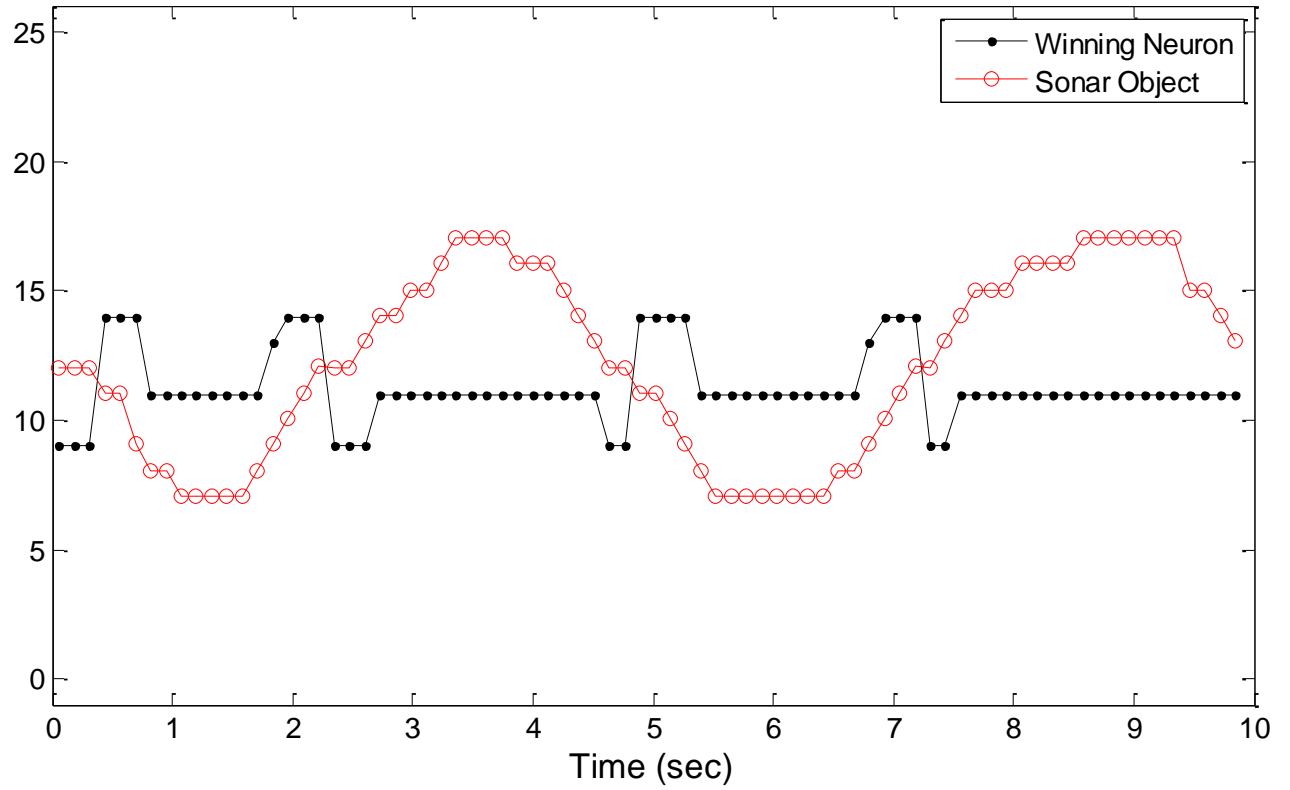
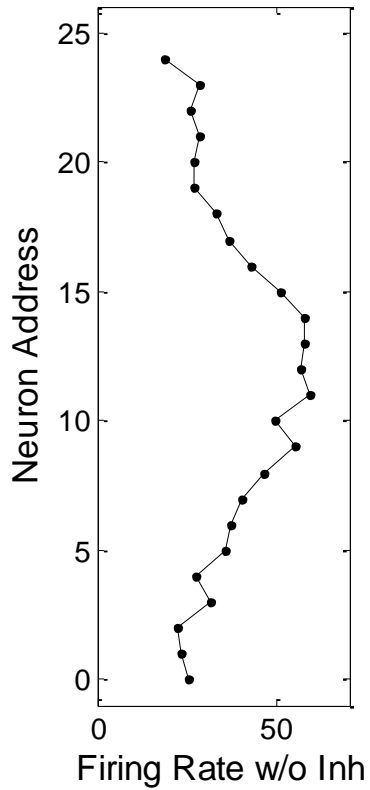
T. Horiuchi (ISCAS'06, May 24, 2006)



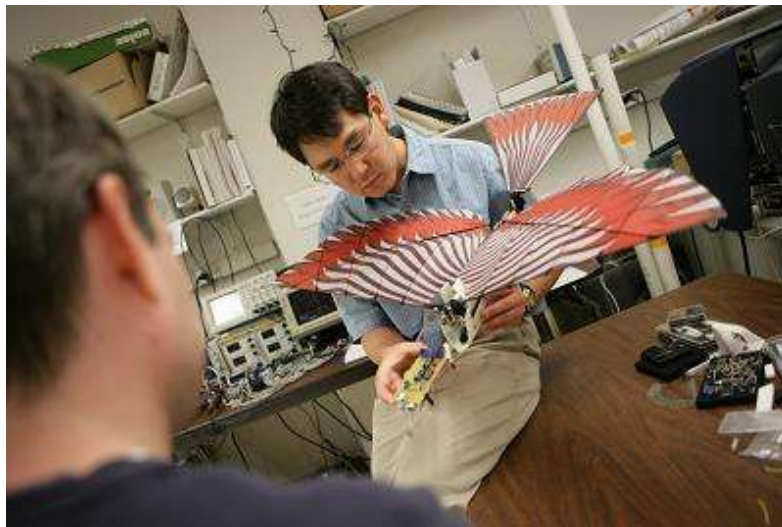
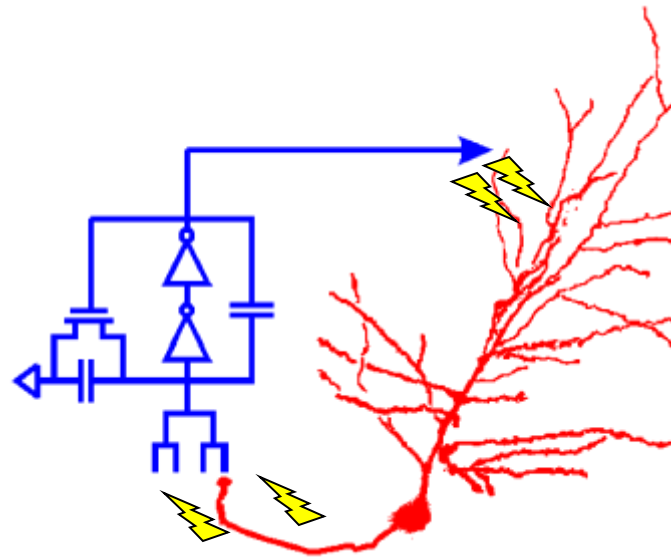


Mean Rate Operation





Computational
Sensorimotor
Systems
Laboratory



<http://www.isr.umd.edu/~timmer>

This work was supported by:

AFOSR (FA95500410130, FA95500710446)

NIH (R01 MH56366)

NIH/NIBIB (CRCNS 1R01EB004750)

NSF (CAREER: CCF0347573)



DEPARTMENT OF
**ELECTRICAL &
COMPUTER ENGINEERING**

Telluride Neuromorphic Engr. Workshop

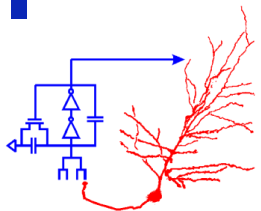
Integration onto a Flying Vehicle



E-flite Blade CX



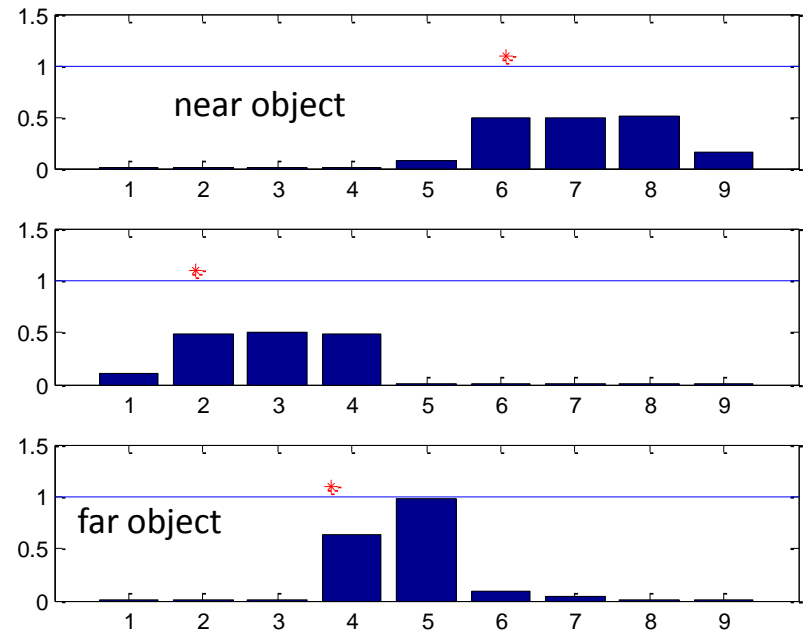
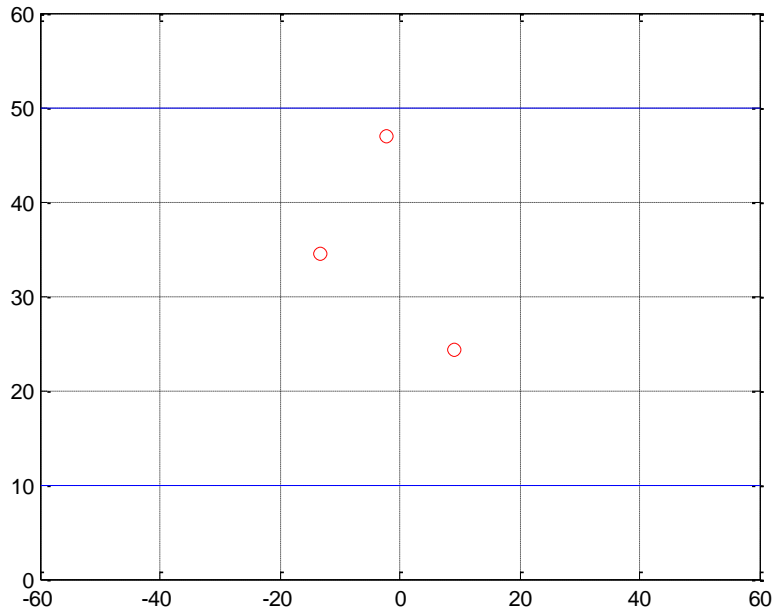
Slow Hawk RC Ornithopter





Example: Population Estimates of Position

For each of the three objects, the neurons in the output layer respond to indicate the relative fit to the learned categories (from training data). The red dot represents the weighted mean location.



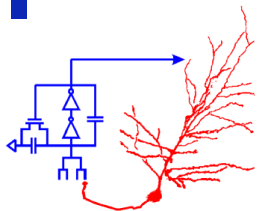
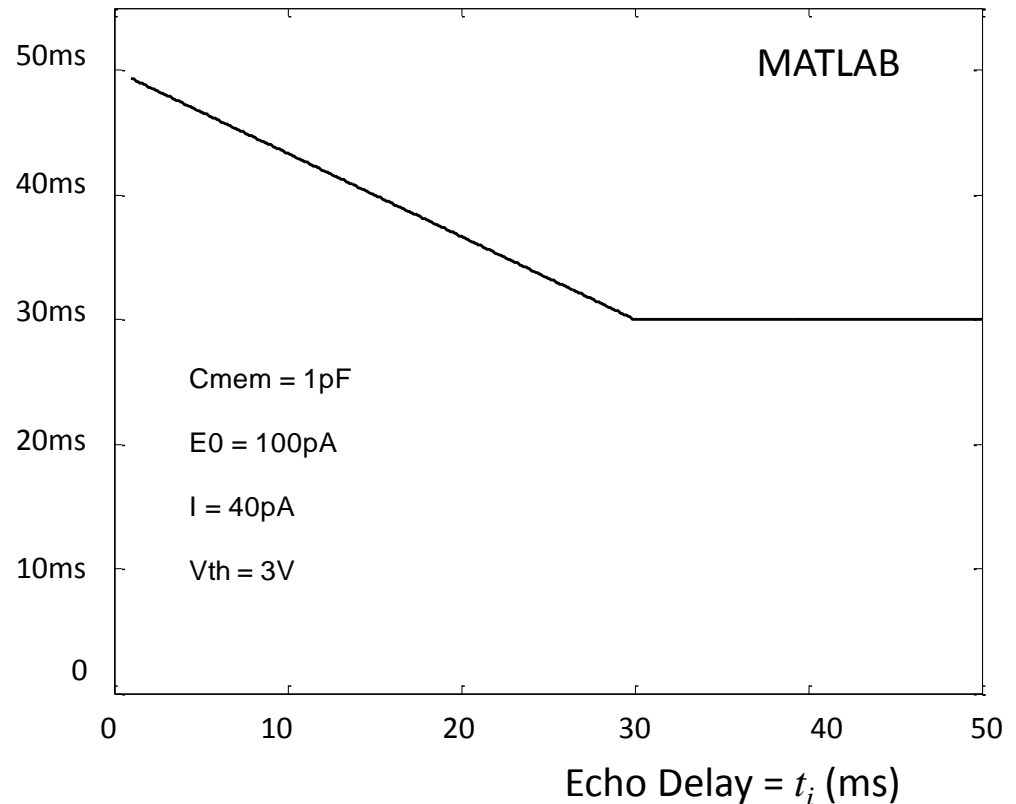
For a neuron with a membrane capacitance C_{mem} , a spike threshold V_{thresh} , that receives a constant excitatory bias current E_o and a step-inhibition current at time t_i , the latency of the spike, T , is given by:

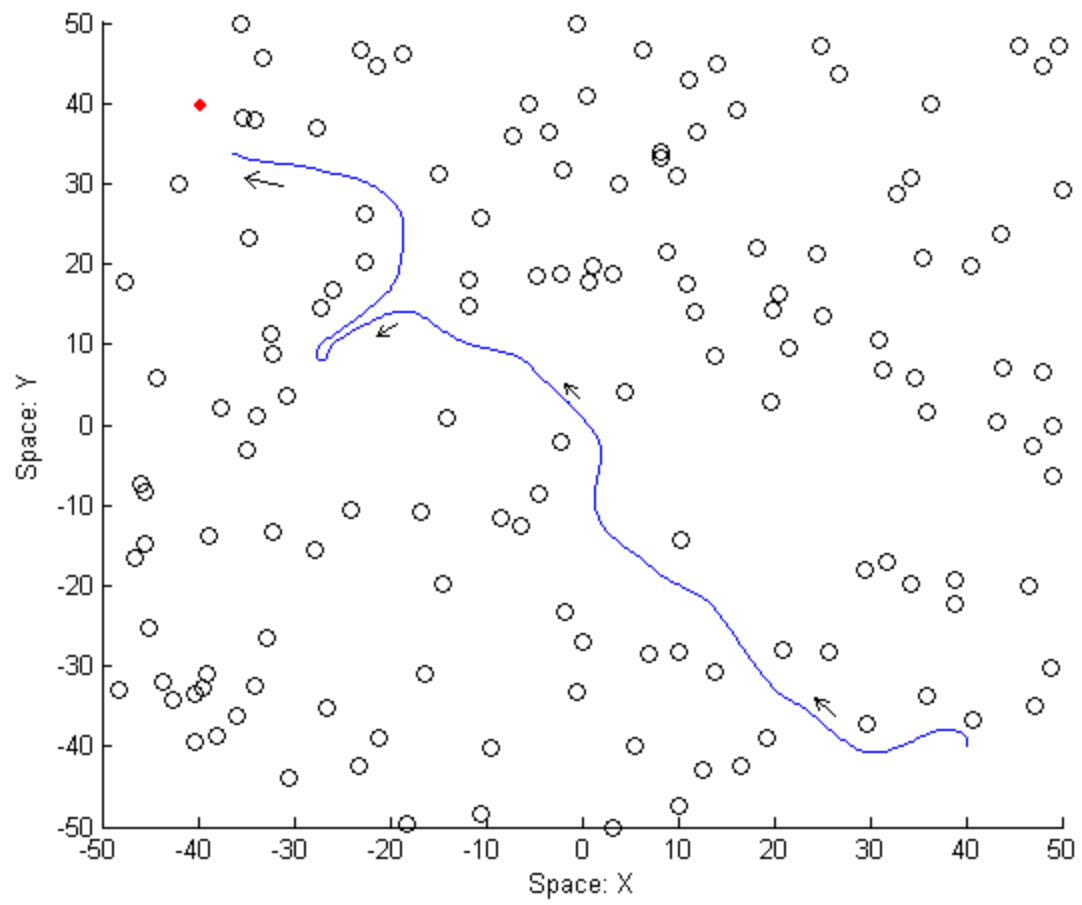
We assume that $E_o > I$

$$T_{latency} = \frac{C_{mem} V_{thresh} - I \cdot t_i}{E_o - I}$$

and that $t_i < \frac{C_{mem} \cdot V_{thresh}}{E_o}$

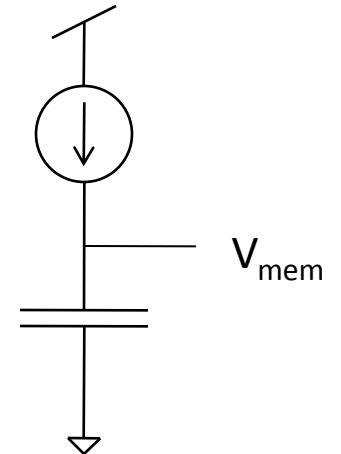
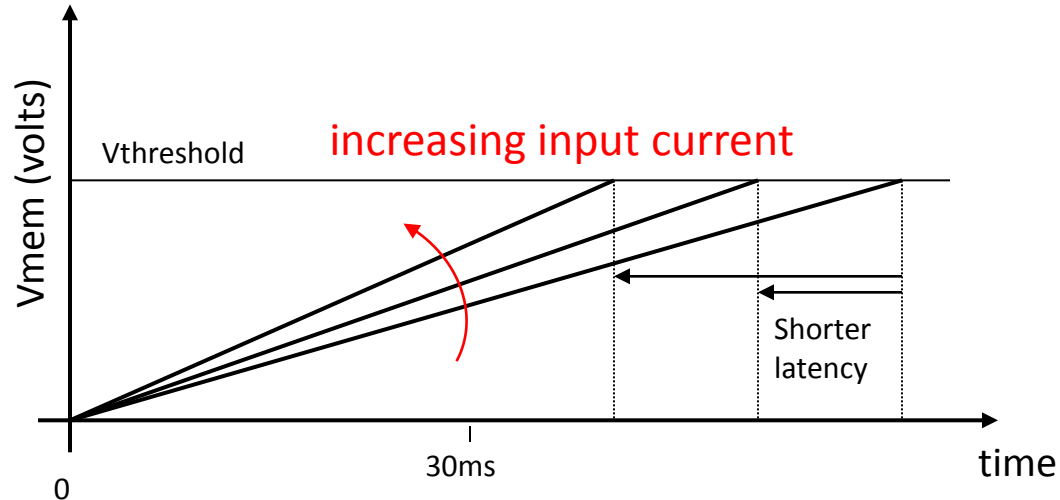
Spike Latency (ms)



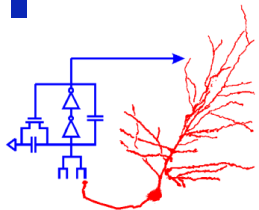


A Spike Timing-based Implementation

time of sonar pulse

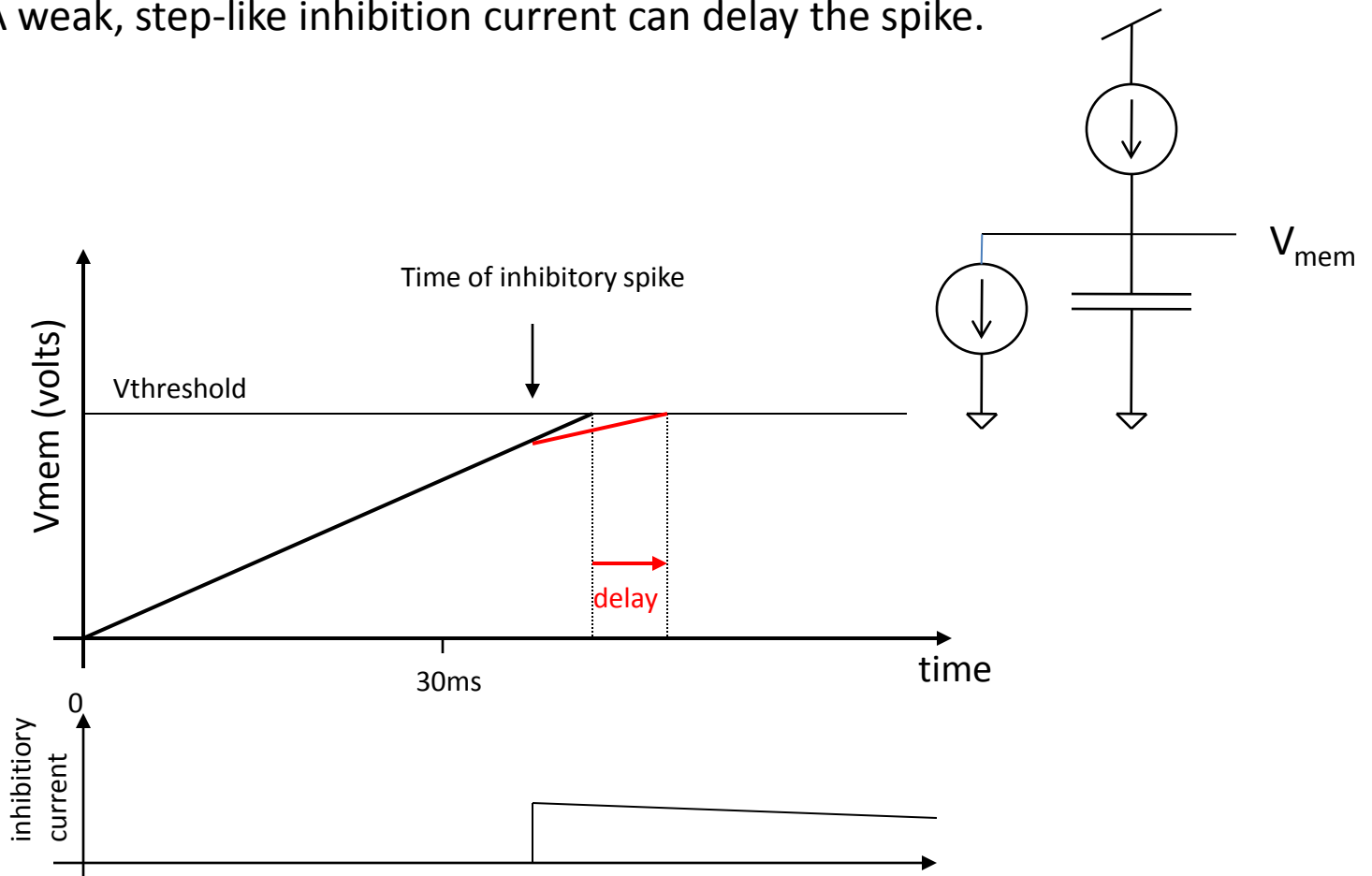


- In an array of neurons, the neuron with the largest input wins.
- Using inhibitory feedback, a time-domain WTA* can be made.

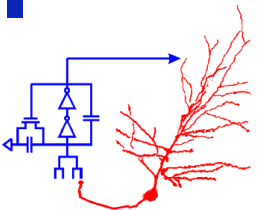


*Abrahamsen, Hafliger, and Lande, "A time domain winner-take-all network of integrate-and-fire neurons" (ISCAS 2004)

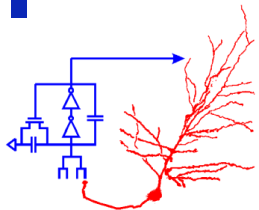
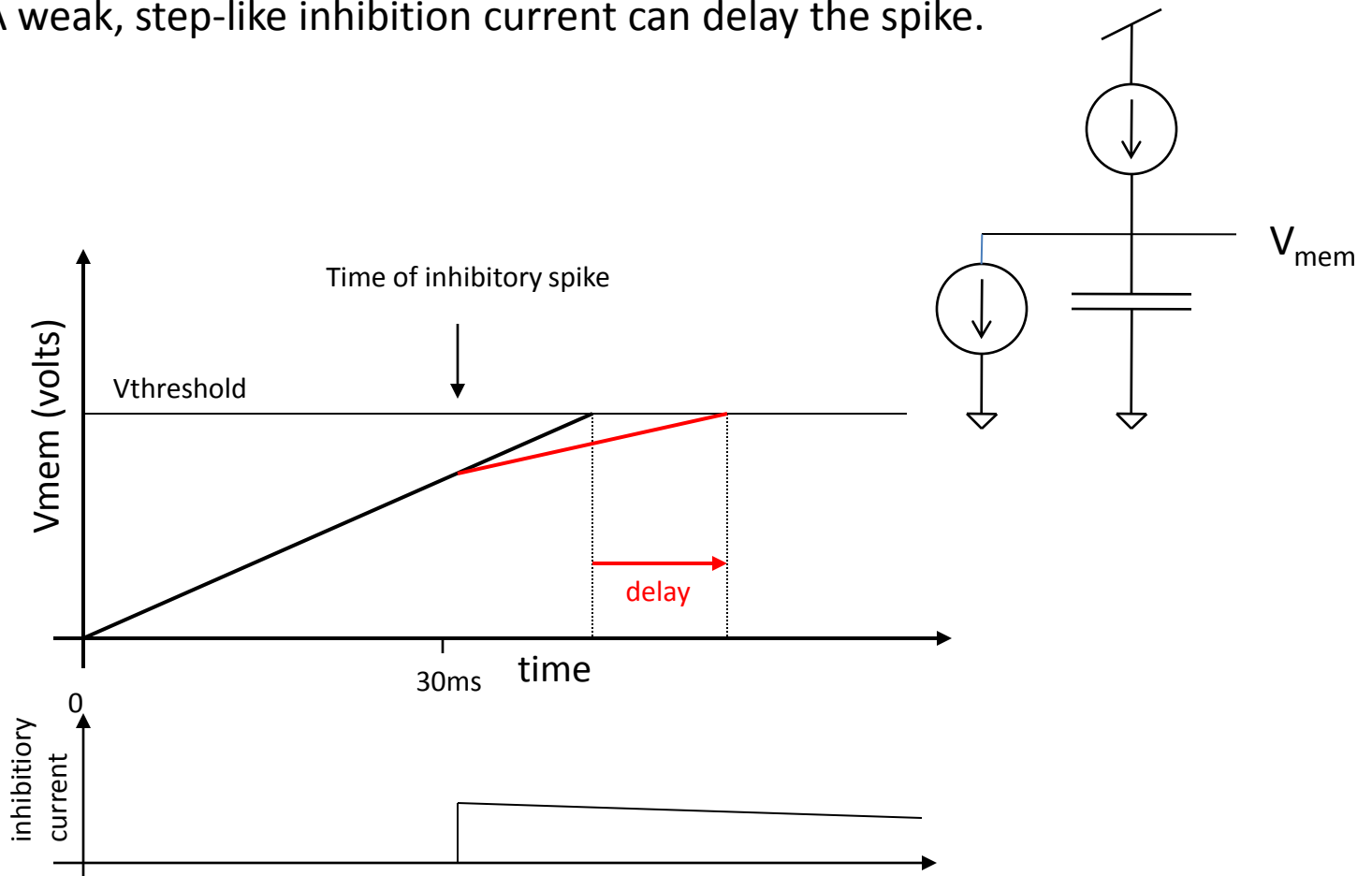
A weak, step-like inhibition current can delay the spike.



- Maass, W., *Pulsed Neural Networks*, 1998;
- Ravinuthala, V. and Harris, J., "Time-based-Arithmetic Using Step-Functions", ISCAS 2004

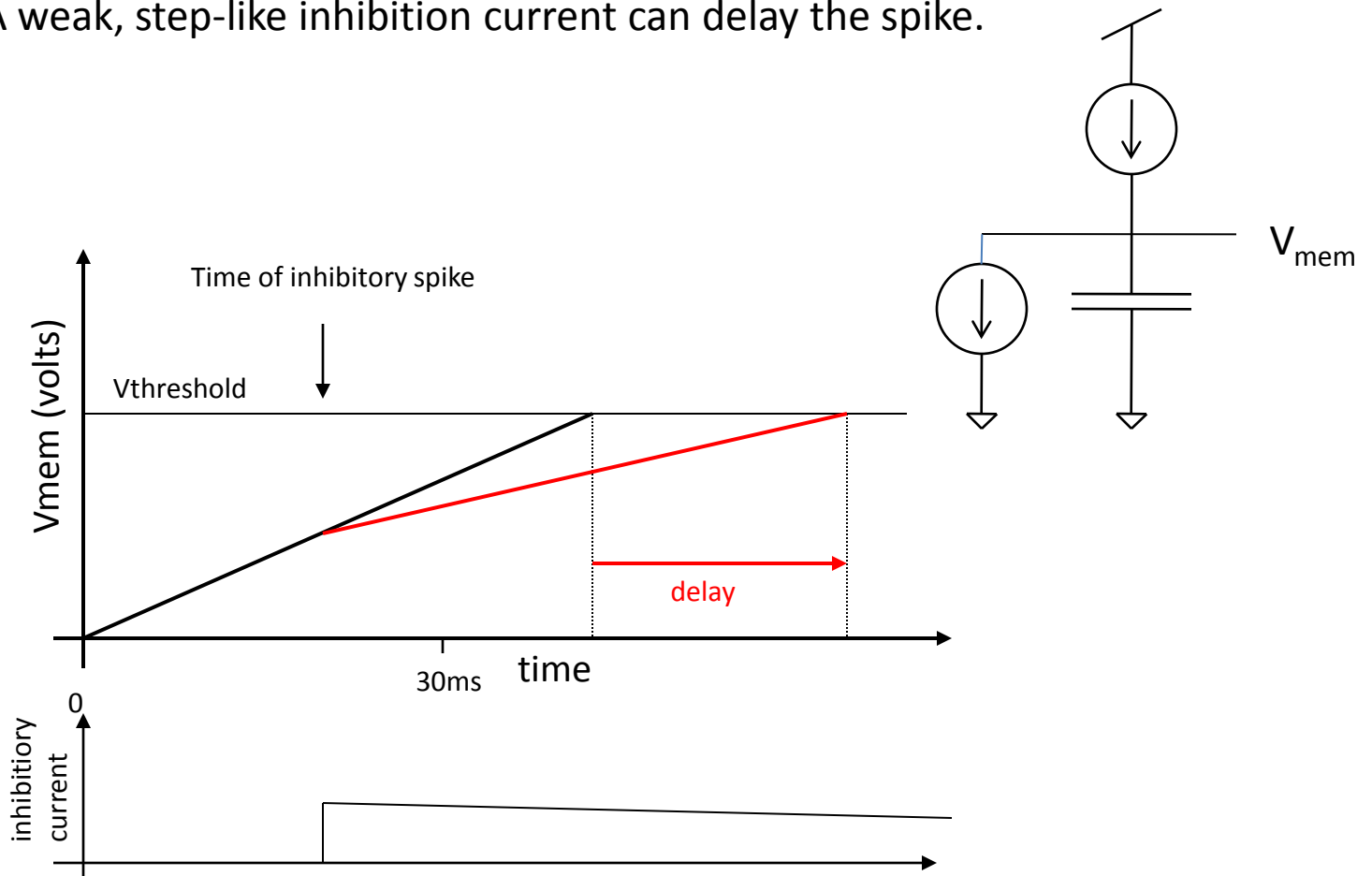


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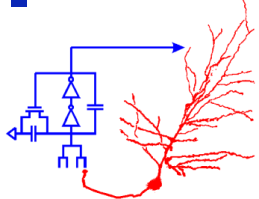


- Maass, W., *Pulsed Neural Networks*, 1998;
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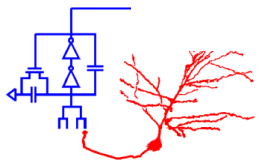
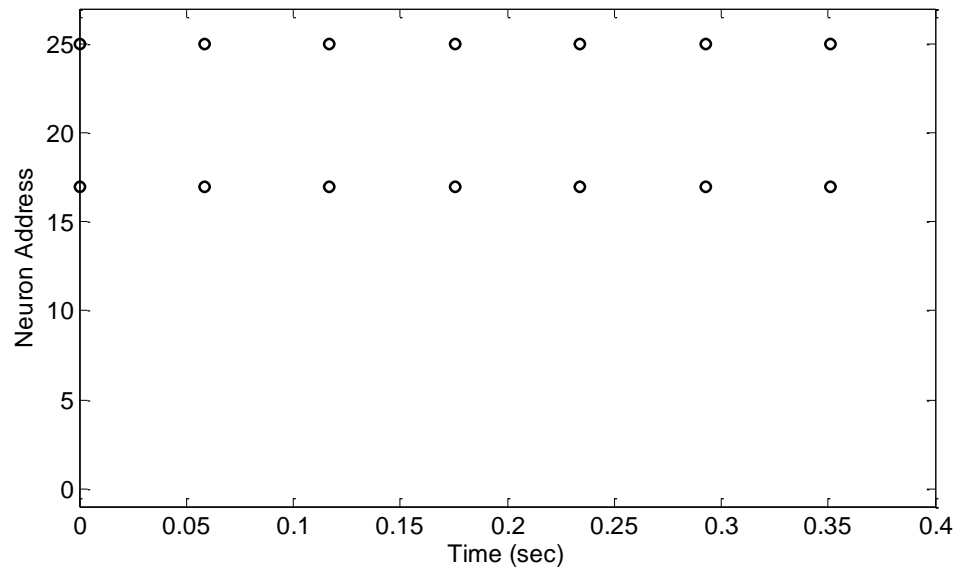
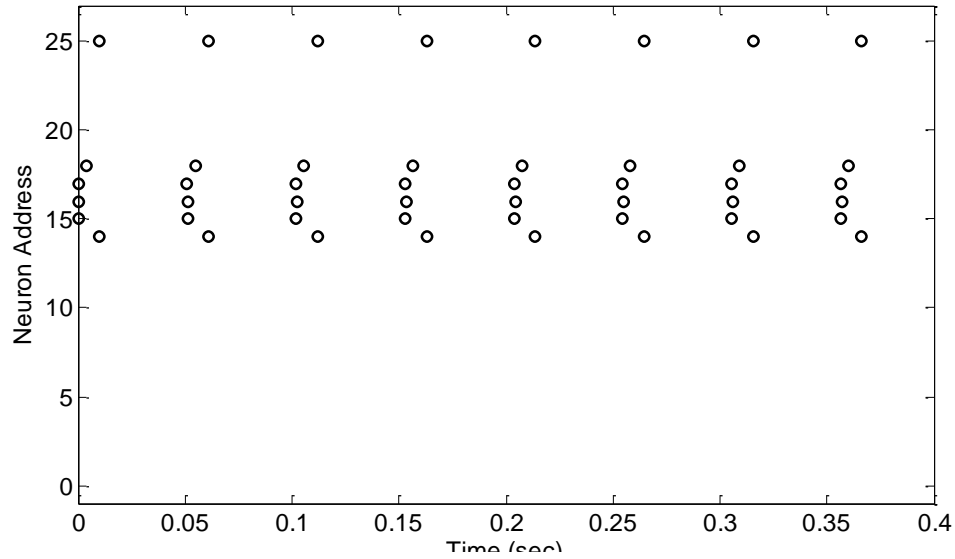


If this inhibition is triggered by a sonar echo, **closer objects “inhibit” more than far objects.**



- Maass, W., *Pulsed Neural Networks*, 1998;
- Ravinuthala, V. and Harris, J., “Time-based-Arithmetic Using Step-Functions”, ISCAS 2004

Temporal WTA



The Depth and Spread of Inhibition Increases with Proximity

