Dynamics of Multifunction Brain Networks

ONR: Program Manager Dr. M. Shlesinger

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University of Chicago: **Howard Nusbaum (Psychology), Daniel Margoliash (Organismic Biology, Neuroscience)**

Postdocs: Sadique Sheik, Tristan Webb, Daniel Knudsen, Jordi Fonollosa, Arij Daou, Emre Necfti + 2 more in Fall, 2014

PhD students: Brenton Maisel, Paul Rozdeba, Uriel Morone, Jingxin Ye, Chris Knowlton, Justin Kiggins, and Michael Eldridge

Scientific Objective

Design of functional cognitive networks based on ideas about human brain structures and winnerless competition networks

1. Hubs and activity centers

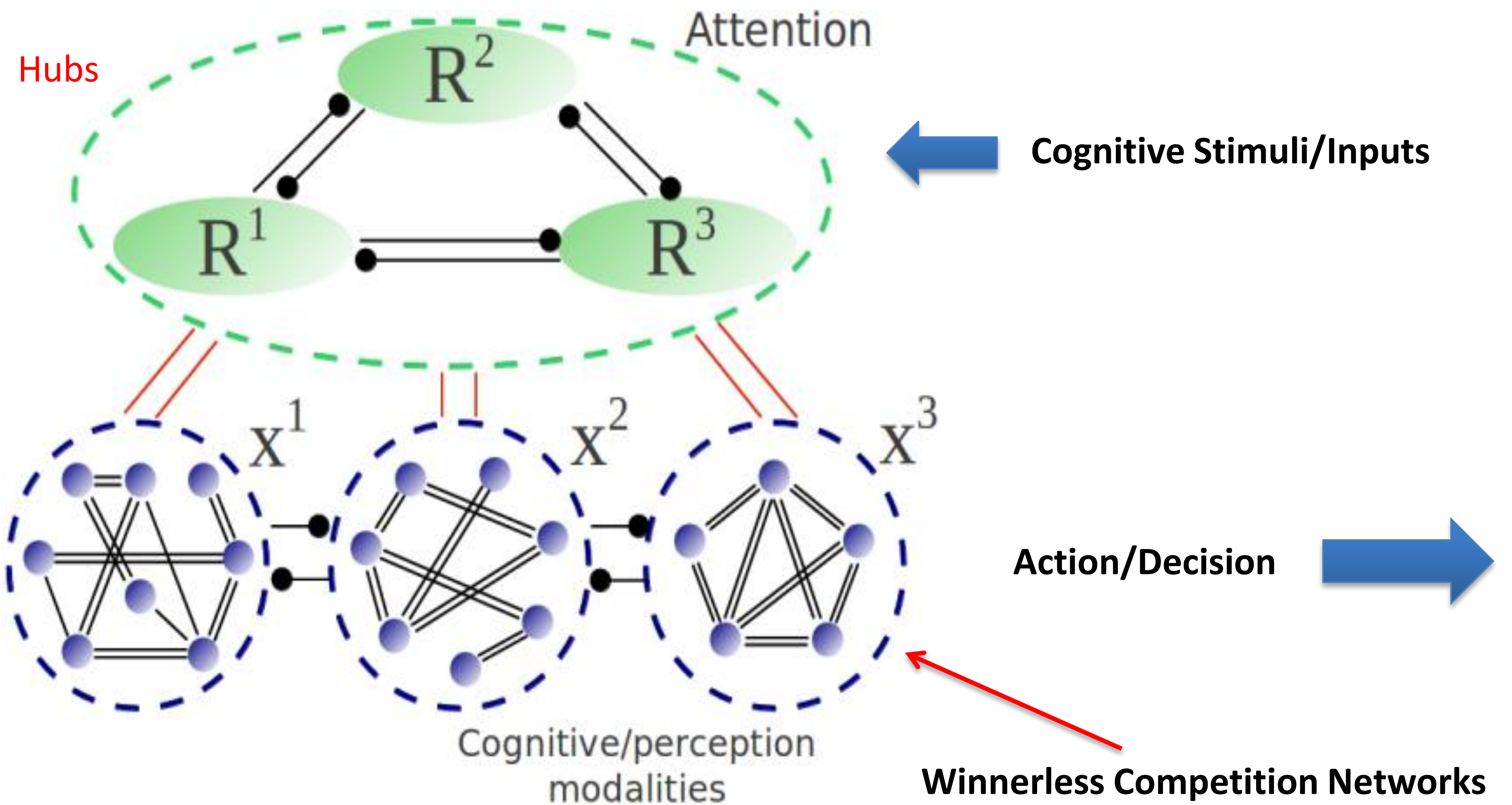
2. VLSI realizations of network design

3. Experiments to verify and validate network ideas

4. Determination of biophysical properties of functional networks of neurons from experiment, validation of models in 1. via experiments in 3.

Technical Approach

Hierarchy in the Mind: Input->Attention->Action

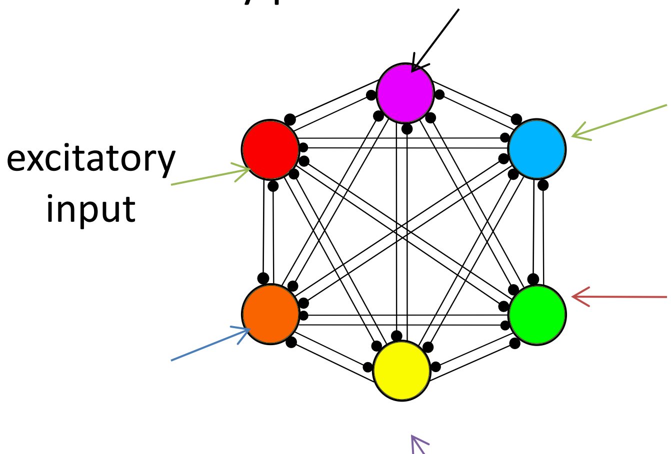


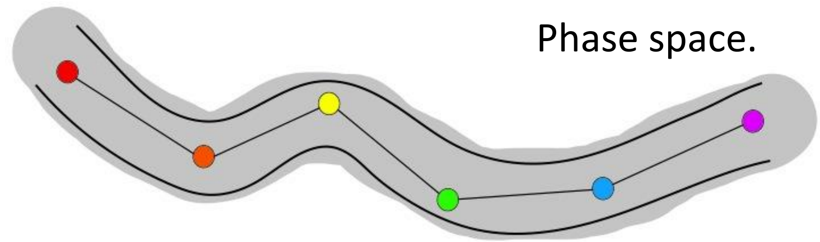
Architecture of the attention mode interaction in the case of three modality processing (X_i).

R^i represent attention resource modes corresponding to these modalities.

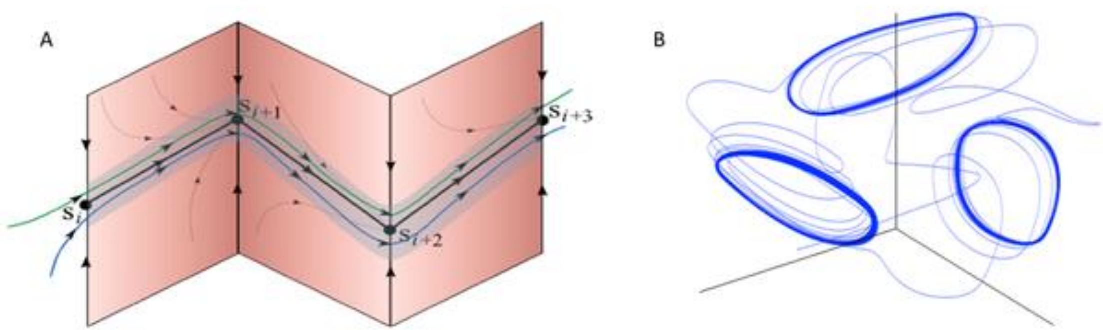
Sequential Working Memory

Attentional networks integrate many cortical and subcortical elements. They have to dynamically control mental processes to focus on specific events and make a decision. Although the resources of attentional processing are finite, it is necessary to simultaneously process several modalities





Chain of metastable states representing cognitive informational items in the state space. The system travels along a potential minimum path.

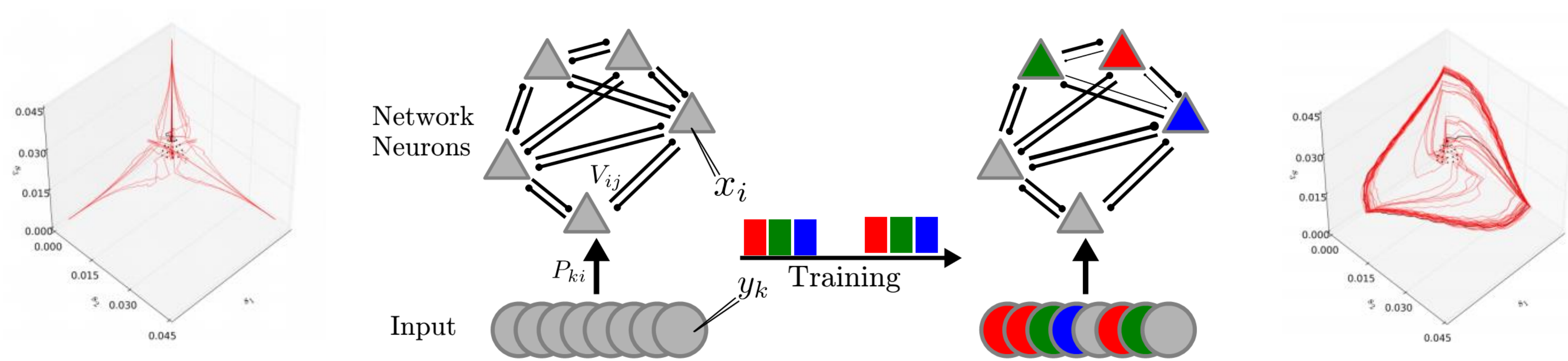


saddle fixed point saddle limit cycle

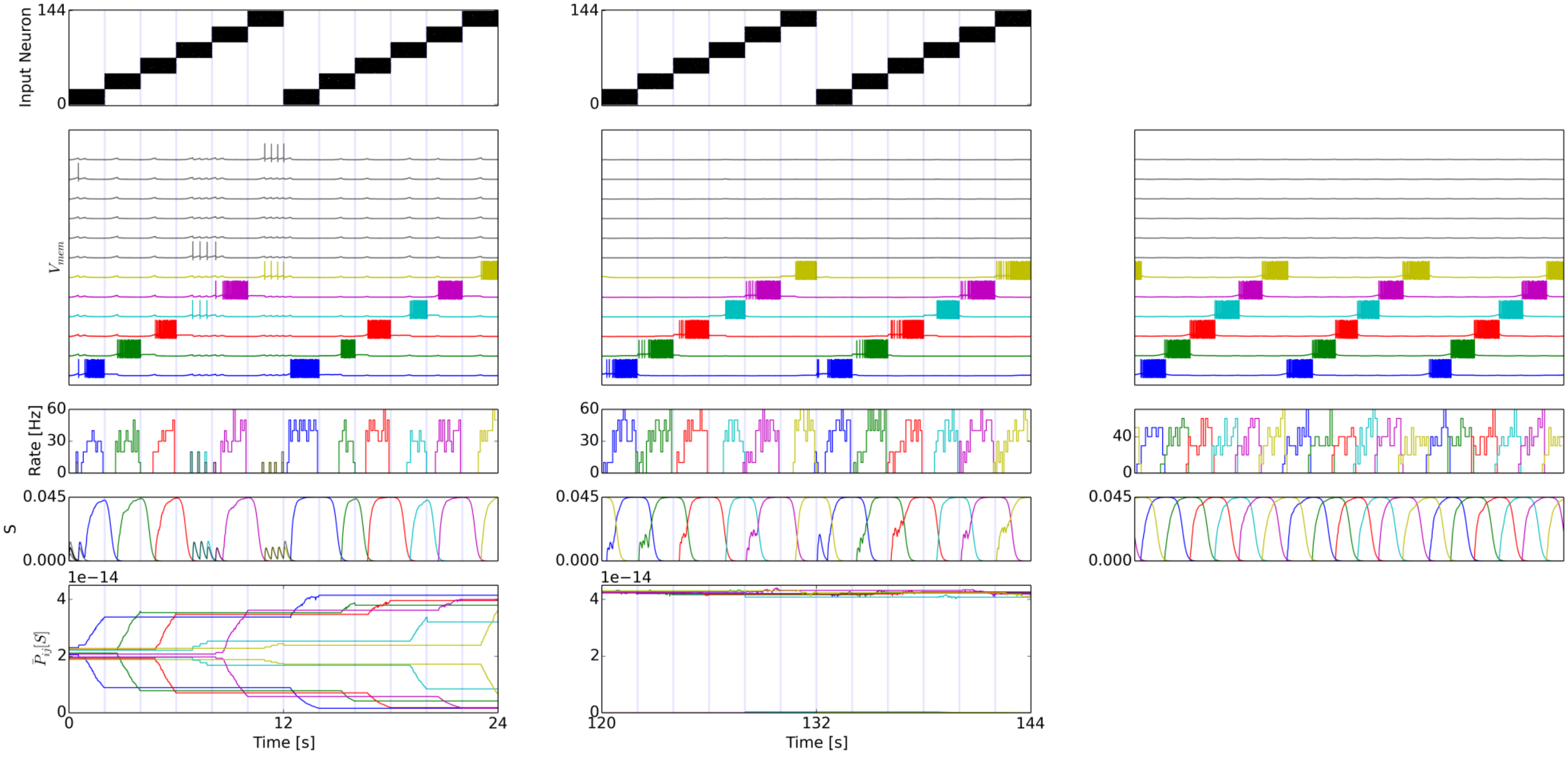
Sequence Learning and Sequence Recall

The network starts in a statistically homogeneous state. During training, sequences of patterns are presented, and the network associates a small subset of the neurons to each pattern.

Simultaneously, on a slower time scale, an asymmetric and bistable rule adjusts the weight of the inhibitory connections between the neurons to store the order of the patterns



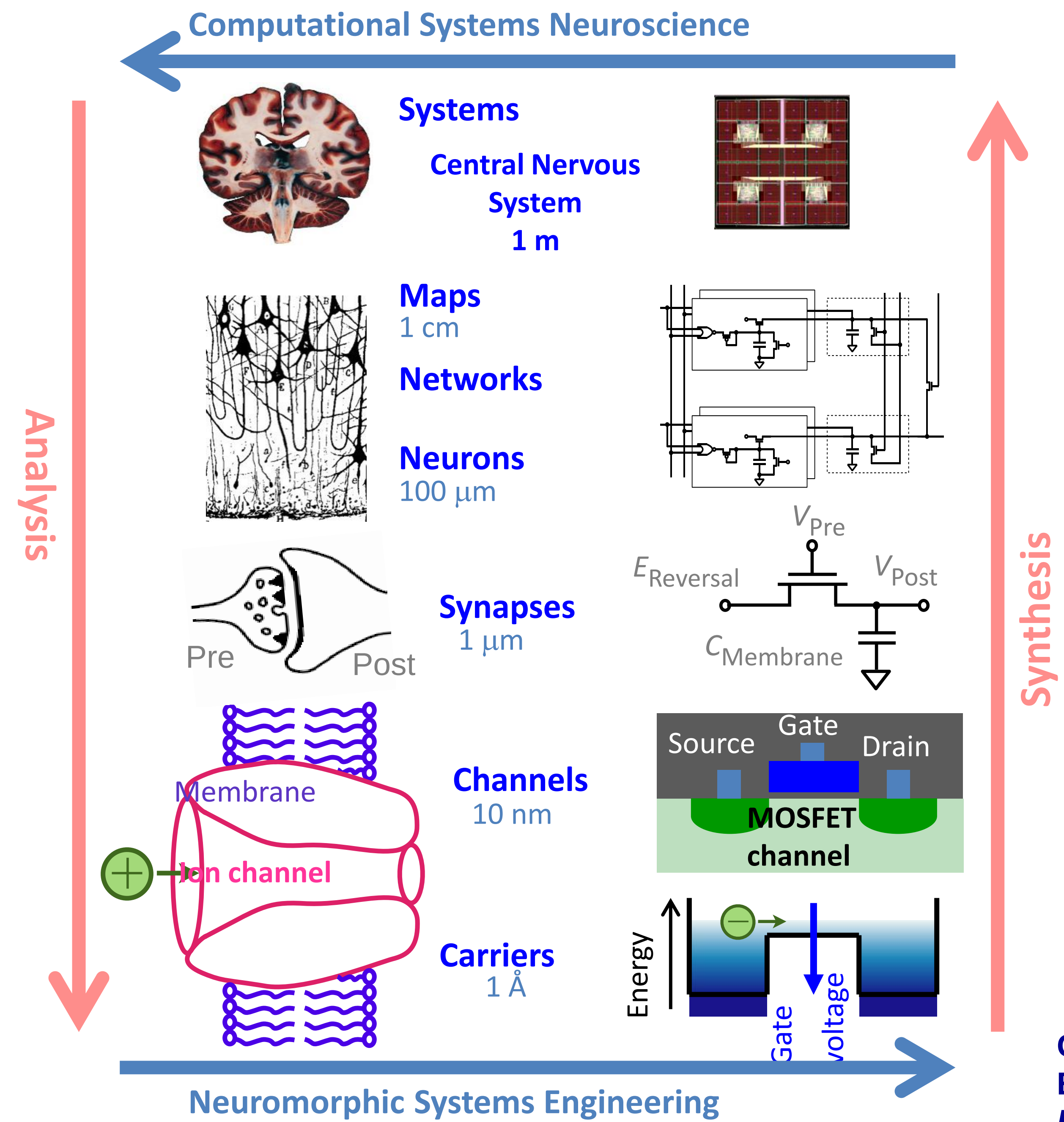
Sequence Learning and Sequence Recall



Inputs; network activity; individual membrane potentials synaptic states:

(left) before learning, **(center)** during learning,**(right)** after learning

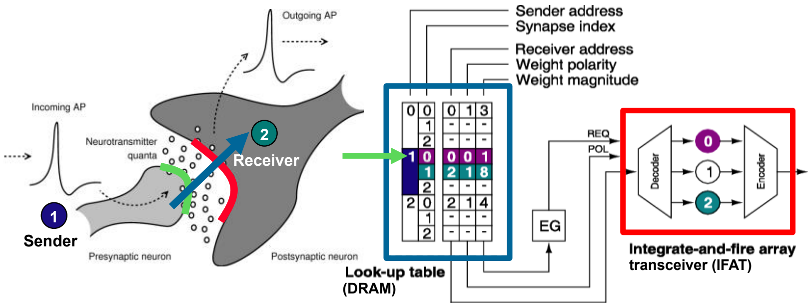
VLSI Neuron Devices

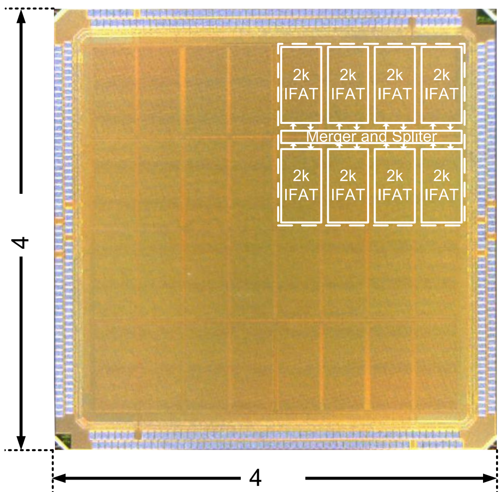


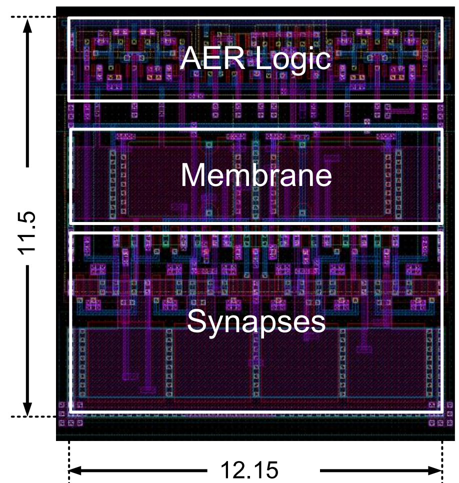
Multi-scale levels of investigation in analysis of the central nervous system and corresponding neuromorphic synthesis of highly efficient silicon cognitive devices.

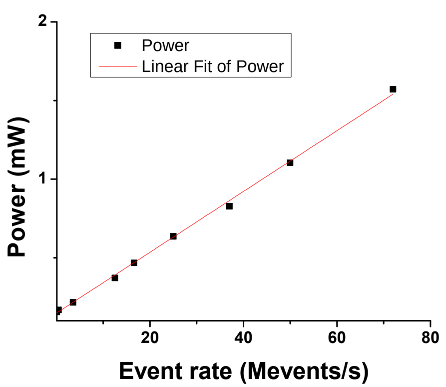
G. Cauwenberghs, "Reverse Engineering the Cognitive Brain," *PNAS*, 2013

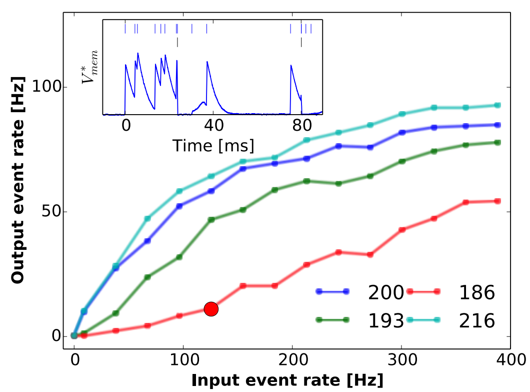
Large-Scale Reconfigurable Neuromorphic Computing







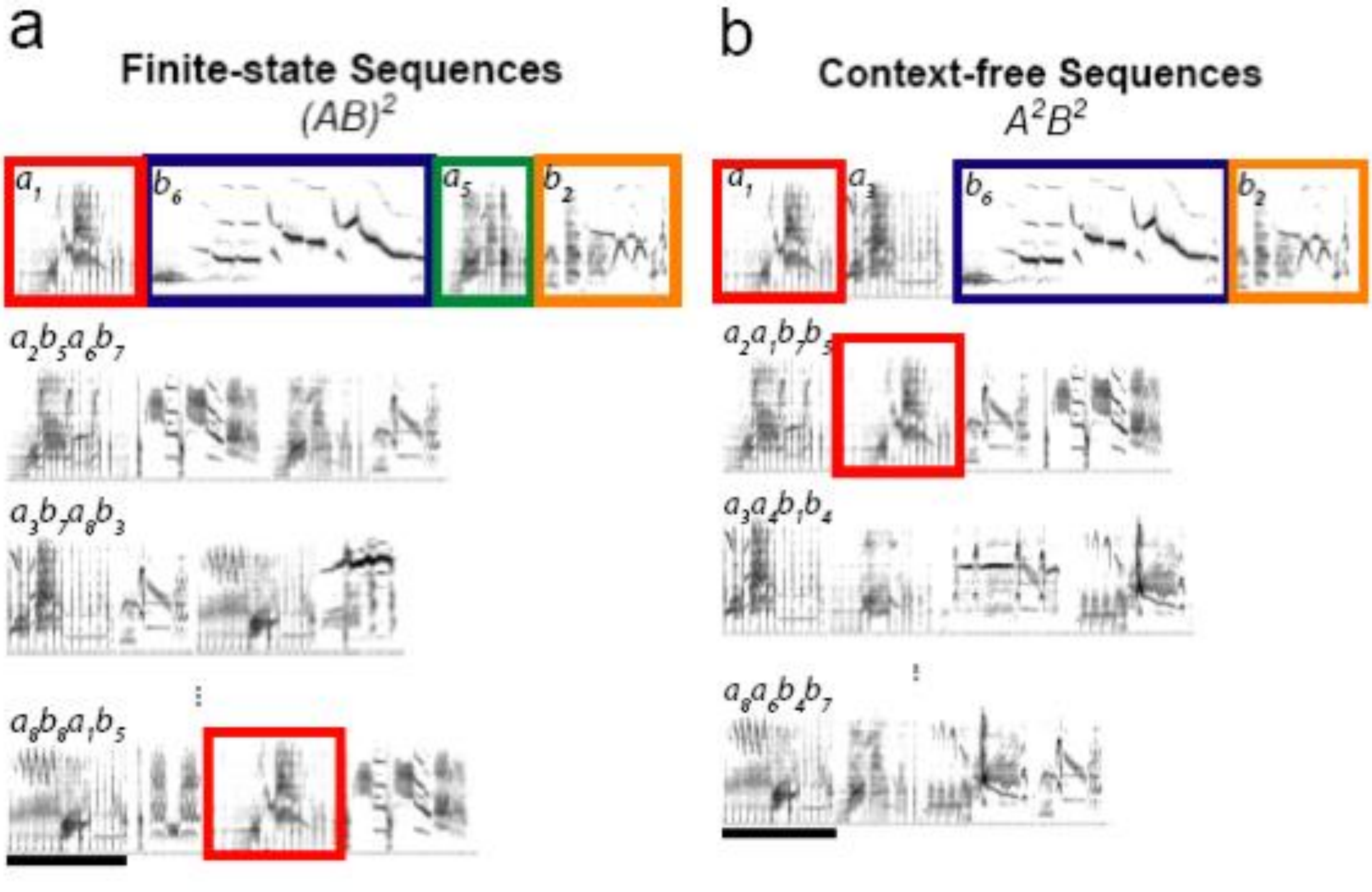




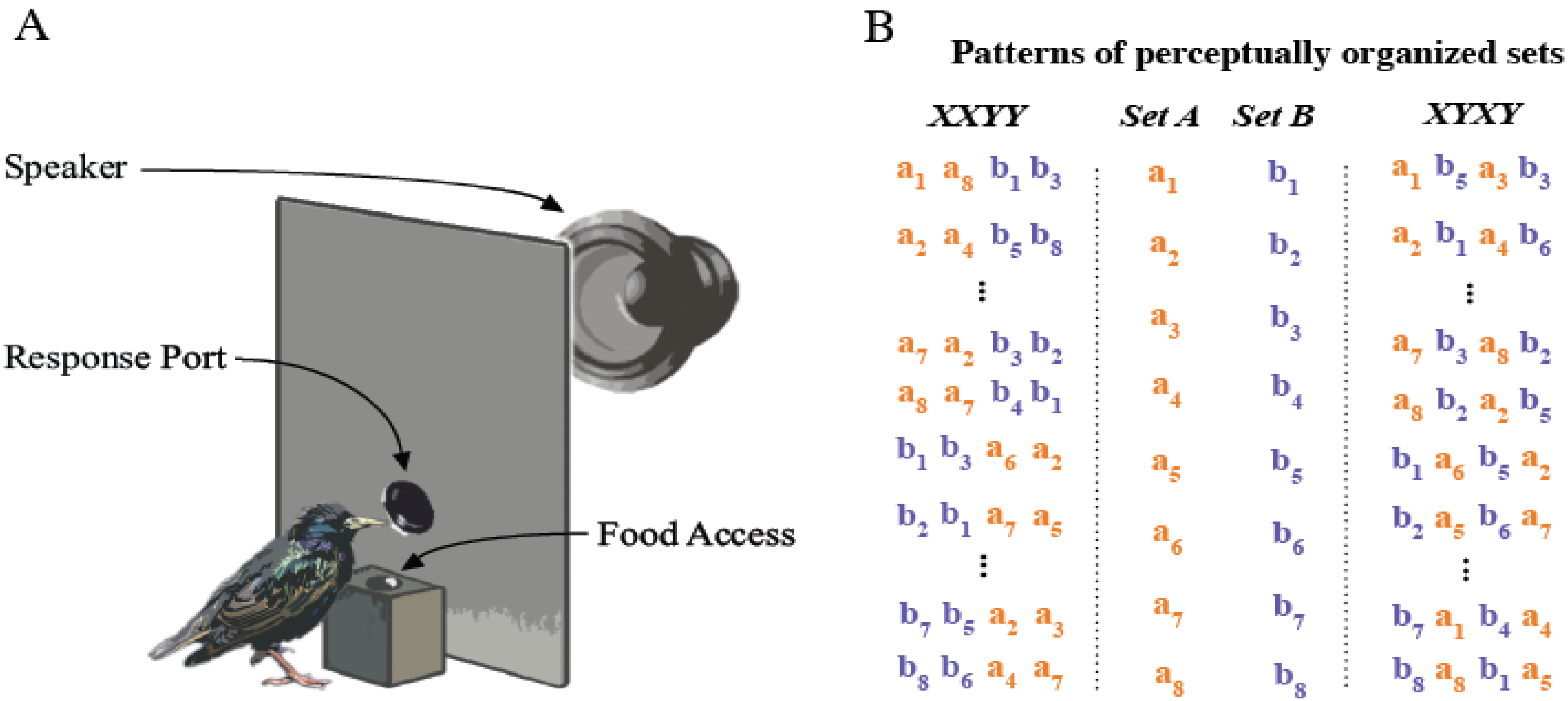
- Integrate-and-fire array transceiver (IFAT) as digitally programmable analog neural supercomputer
- Record large size: 65k two-compartment neurons with 65M reconfigurable conductance-based synapses
- Record low energy: 22 pJ per synaptic event
- Real-time at 73M spikes per second

J. Park *et al*, "A 65k-Neuron 73-Mevents/s 22-pJ/event Asynchronous Micro-Pipelined Integrate-and-Fire Array Transceiver", submitted, 2014.

Sequence Learning in Starlings



Example sequences of starling motifs


A
Speaker
Response Port
Food Access
B
Patterns of perceptually organized sets
XXYY
Set A
Set B
XYXY
a_1 a_8 b_1 b_3
a_2 a_4 b_5 b_8
⋮
a_7 a_2 b_3 b_2
a_8 a_7 b_4 b_1
b_1 b_3 a_6 a_2
b_2 b_1 a_7 a_5
⋮
b_7 b_5 a_2 a_3
b_8 b_6 a_4 a_7
a_1 a_2 a_3 a_4 a_5 a_6 a_7 a_8
b_1 b_2 b_3 b_4 b_5 b_6 b_7 b_8
a_1 b_5 a_3 b_3
a_2 b_1 a_4 b_6
⋮
a_7 b_3 a_8 b_2
a_8 b_2 a_2 b_5
b_1 a_6 b_5 a_2
b_2 a_5 b_6 a_7
⋮
b_7 a_1 b_4 a_4
b_8 a_8 b_1 a_5

Biophysical properties of functional networks of neurons from experiment

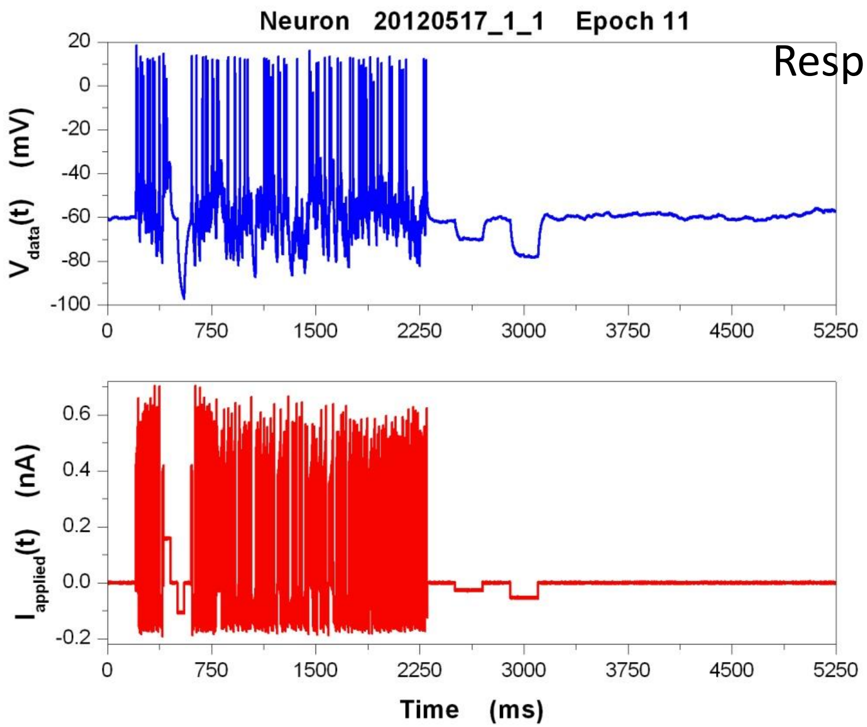
Experiments on individual neurons from a central nucleus of 50,000 neurons in the avian song system---*in vivo* as well as *in vitro*

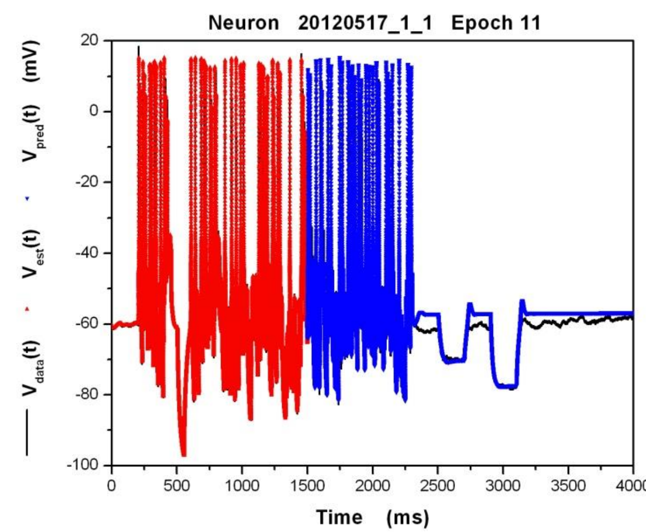
Well designed stimulating currents injected into isolated neurons and small networks. States and parameters of detailed biophysical models estimated using a statistical physics approach, and models validated by prediction:

Data: Stimulus Current Voltage Response

Estimated and Predicted Voltage

Response





New Direction:

Combine:

Laboratory Data Acquisition (Gentner) with VLSI neurochips (Cauwenberghs) and structured physics based model verification algorithms (Abarbanel) to determine network model validity and establish functional structure of networks---online and *in vivo*

Scientific challenges and advances

- Robust, reproducible operating functional circuits ("neural" circuits) for cognitive/attention modes
- Winnerless Competition—role of noise
- Accurate method for completing models from data and testing via prediction
- Dynamical data assimilation
- Develop reconfigurable VLSI implementations of models
- 4 "biophysical" neuron chip, 64,000 `neuron' chip produced and being tested. New biophysical chip being designed, fabricated, …

Scientific challenges and advances

- **Laboratory experiments on sequence learning in songbirds and humans**

- **Data being collected, models developed**

- **Online, real time data collection and analysis system for testing models of *in vivo* behavior in sequence learning and decision making**

- **Algorithms completed, tested offline, VLSI interface to algorithms and online data in development**

Technical challenge

- Cognitive “assistant”

Importance of topic

- Understanding of functional organization in decision making
- Methodology for transferring information from observations to accurate models of behavior; critical for complex systems
- Utilization to assist in rapid assessment, focused attention, and accurate determination of effective action

UCSD PROPOSAL BUDGET FORM

University of California - San Diego

Cumulative Budget

Cumulative Budget Period: From 12/1/12 Through 6/31/17

UCSD# 2012-0805

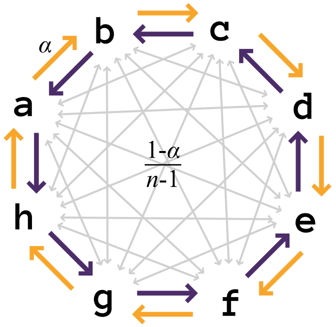
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Cumulative
Salaries	173,357	382,664	483,132	292,725	221,412	485,583	250,945	2,289,818
Fringe Benefits	22,088	50,361	71,641	46,239	31,306	70,259	35,914	327,808
Tuition Remission	3,732	36,954	40,644	39,744	4,968	49,176	48,080	223,298
Consultant(s)	-	-	-	-	-	-	-	-
Equipment	160,000	42,500	27,500	20,000	27,500	27,500	-	305,000
Supplies and Materials	13,000	39,000	39,000	26,000	13,000	39,000	26,000	195,000
Travel	7,000	41,000	64,823	35,661	7,794	67,466	34,559	258,303
Chicago Subaward	174,807	258,366	266,221	199,445	99,746	299,268	199,551	1,497,404
Berkeley Subaward	38,991	102,288	13,041	-	-	-	-	154,320
Other Expenses	4,684	17,464	19,795	13,405	7,047	19,724	12,426	94,545
Total Direct Costs	$ 597,659	$ 970,597	$ 1,025,797	$ 673,219	$ 412,773	$ 1,057,976	$ 607,475	$ 5,345,496
Total Indirect Costs	$ 134,515	$ 291,769	$ 373,115	$ 227,717	$ 154,307	$ 375,117	$ 197,914	$ 1,754,454
Total Costs Requested	$ 732,174	$ 1,262,366	$ 1,398,912	$ 900,936	$ 567,080	$ 1,433,093	$ 805,389	$ 7,099,950

	Base Period Total:	4,294,388	Option Period Total:	$ 2,805,562

MURI WINTER SCHOOL 2015

Dynamics of Multifunction Brain Networks

Organizers: Henry Abarbanel (UCSD), Timothy Gentner (UCSD), and Daniel Margoliash (Univ. Chicago)



15th Floor, Building 1, Village West, UC San Diego

January 7-9, 2015

Lecturers:

- **Tim Gardner** ***(Boston University)***
- **Gabriel Mindlin** ***(University of Buenos Aires)***
- **Marc Schmidt** ***(University of Pennsylvania)***
- **Michael Long** ***(New York University)***
- **Richard Mooney** ***(Duke University)***
- **Ofer Tchernichovski** ***(Hunter College)***

This is the third annual Winter School sponsored by the U.S. Office of Naval Research as part of its UCSD/Chicago MURI program in Dynamics of Multifunction Brain Networks.

This year's School presents a series of pedagogical and research oriented talks on the use of birdsong as a model system where theory and experiment can meet productively. It includes a series of educational presentations and a poster session.

The School is intended for all researchers, including advanced graduate students, interested in the general area of understanding functional nervous systems. Active participation during the School's lectures is strongly encouraged. All attendees are invited to submit abstracts for poster presentations. Selected contributed posters will be highlighted in an oral session.

Registration is required for attendance, but there is no fee for attending. A limited number of travel awards are available for exceptionally qualified graduate students and postdocs, who should apply to and have their supervisor send a letter of reference to muri.winter.school@gmail.com. Please visit us online to register and for details regarding the schedule and poster abstract submission:

http://biocircuits.ucsd.edu/special/winterschool2015/