combra.cs.rutgers.edu

425/525
Brain Inspired Computing

Konstantinos P. Michmizos

Computational Brain Lab

Computer Science | Rutgers University | NJ, USA

Lecture 1 | Course Overview | Tuesday January 22nd 2019

Disclaimer

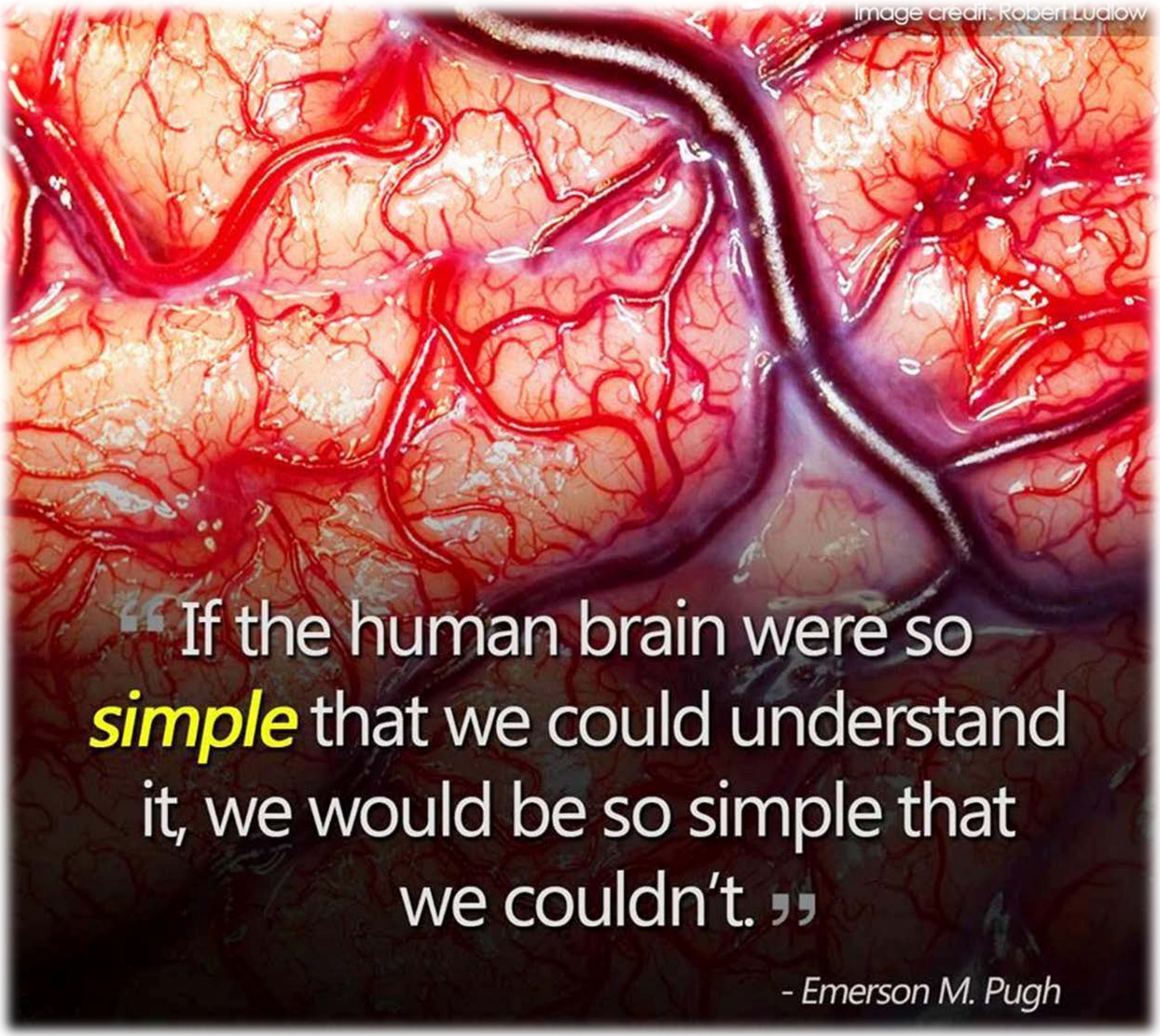
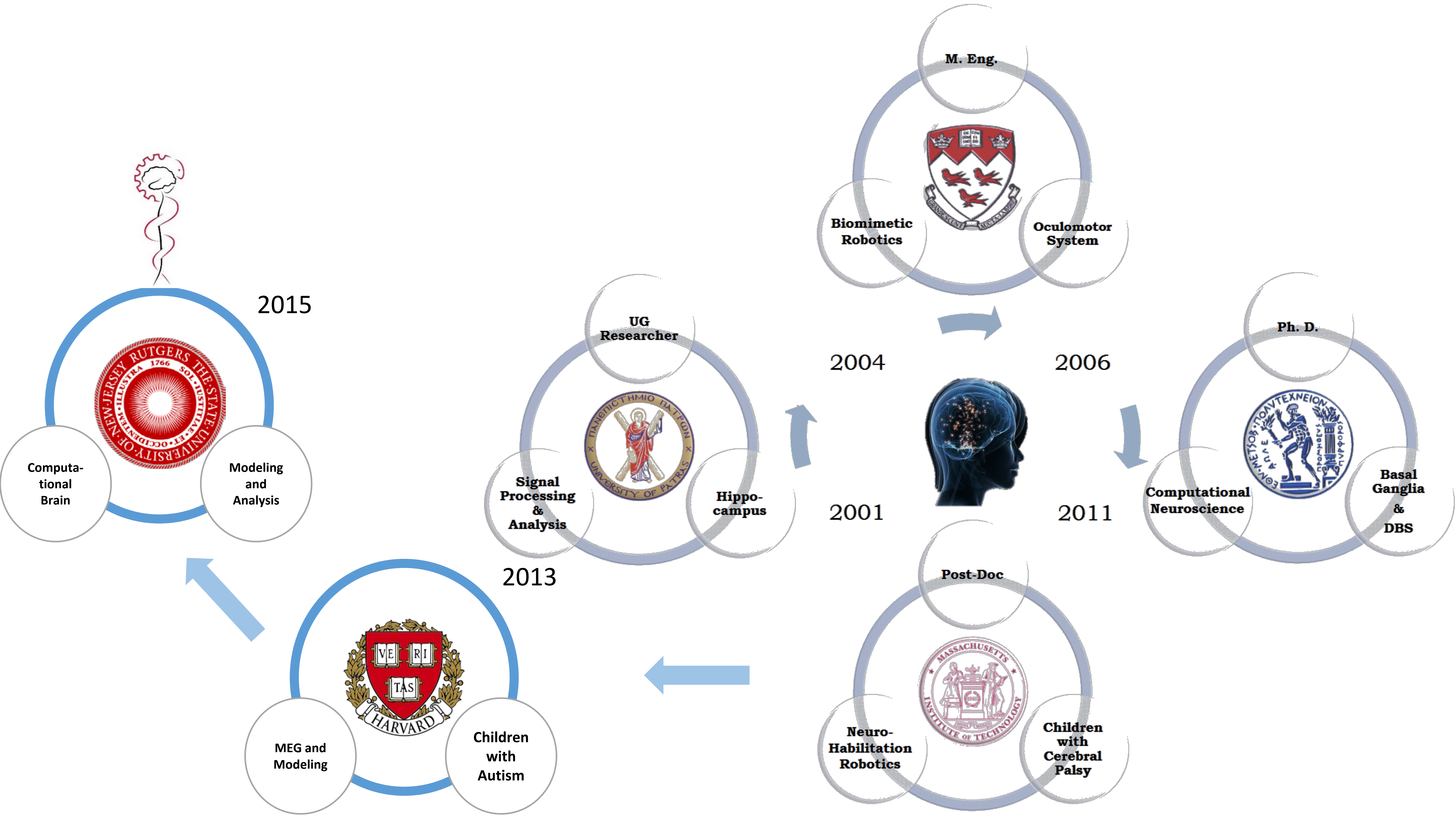


Image credit: Robert Ludlow
"If the human brain were so simple that we could understand it, we would be so simple that we couldn't."
- Emerson M. Pugh


M. Eng.
Biomimetic Robotics
Oculomotor System
2004
2006
Ph. D.
Computational Neuroscience
Basal Ganglia & DBS
UG Researcher
Signal Processing & Analysis
Hippo-campus
2001
2011
Post-Doc
Neuro-Habilitation Robotics
Children with Cerebral Palsy
2013
MEG and Modeling
Children with Autism
2015
Computa-tional Brain
Modeling and Analysis

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When?	Tue and Thu 1:40 PM - 3:00 PM
Where?	PH - 115
Who?	KPM – 2 TA’s – 1 grader

How to reach me

- Office Hours

Thu: 3.00 – 4.30 pm (actually open 24/7)

- e-mail: konstantinos.michmizos@cs.rutgers.edu

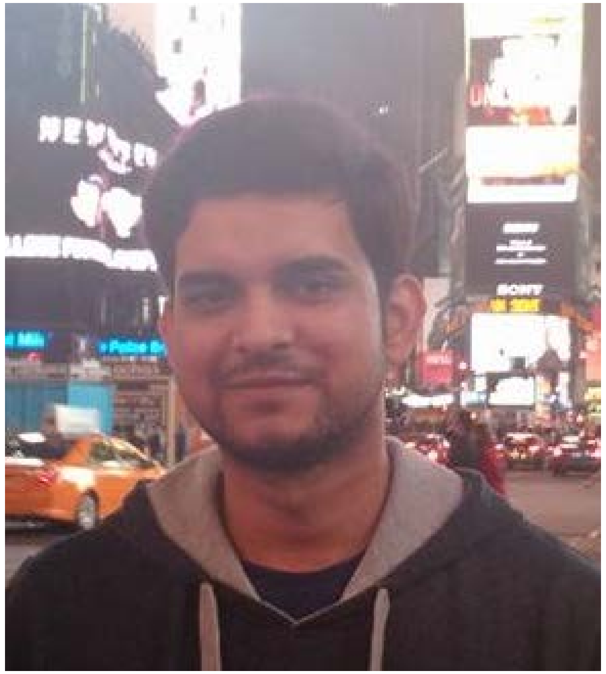
(if no response within 12 hours, **send a follow up email**)

- Office: CBIM Room # 04

(arrange an appropriate time slot before you come)

Who

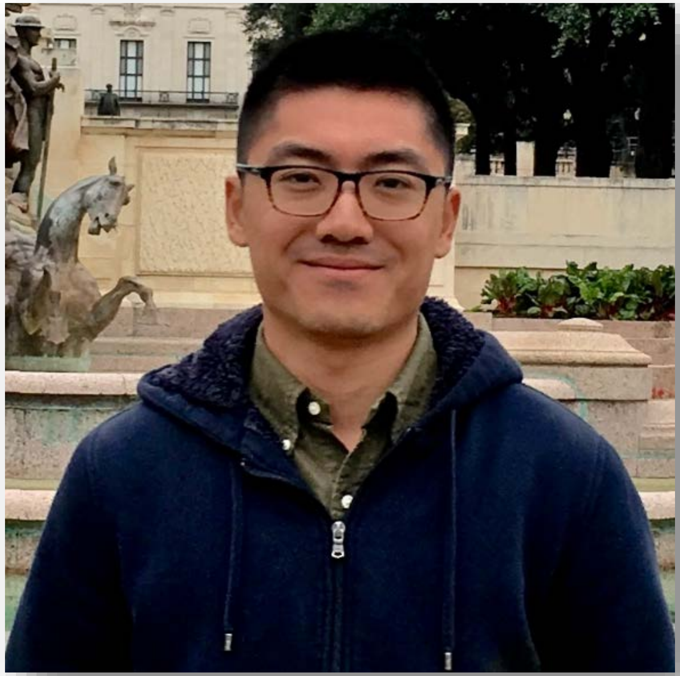
TA



Neelesh Kumar, MSc, PhDc

nk525@cs.rutgers.edu

TA



Guangzhi Tang, MSc, PhDc

tangguangzhi.cs@gmail.com

Who

Our Grader

- Why?
- What?
- How?

Why

2025 and beyond:
Two types of jobs

- Type A: You **instruct** a computer what to do
- Type B: You **are instructed by** a computer what to do

Allen Institute for Brain Science

Christof Koch

The Allen Institute for Brain Science (AIBS) started in 2003.

Aims. The AIBS seeks to understand the biological and biophysical properties of a speck (roughly 1 mm^3) of the most complex piece of highly excitable matter in the known universe: cerebral cortex. We are engaged in three large, interrelated projects. (i) Periodic Table of Cell

(HBP) started in 2013.

Aims. The original emphasis of the HBP was on simulations and modeling of the brains of mice and humans, based on a detailed neurobiological knowledge of the different parts of the brain. This required the development of multidimensional neuroinformatics databases, which is central to HBP. Complementary aspects of cellular systems and cognitive neuroscience are included that should serve as a background for simulations and modeling. In addition there are infrastructure platforms for high performance computing (to allow very large simulations), medical informatics, neuromorphic engineering and robotics. During the first 30 months the focus has shifted somewhat to emphasize the infrastructure development of six separate platforms.

Achievements. The major thrust of the HBP is to emphasize the need to use simulation since a great number of interacting processes take place in parallel. The six different platforms for neuroinformatics, simulation, high performance computing, medical informatics, neuromorphic engineering and robotics are a major resource for the research community.

Measuring 10–15 year impact. The impact of the HBP will depend entirely on what critical new insights into brain function will have been obtained and how useful the different infrastructure platforms are for the broader neuroscience community as well as HBP researchers.

Challenges. The different brain initiatives complement each other in many respects. What is critical is that these initiatives interact openly to facilitate progress in the understanding of brain function and to avoid competition. My personal feeling is that collaboration between the different projects will come naturally, particularly if encouraged, and that a coordinating

Efforts to address reproducibility, data availability and resource sharing. The neuroinformatics platform of HBP is critical in this respect, and its goal is to facilitate data availability and data sharing and to provide curated information to HBP and the neuroscience community.

China Brain Project

Nancy Ip and Mu-ming Poo

The China Brain Project is expected to start in late 2016 or early 2017.

Goals. The China Brain Project will support three research areas in a 'one body, two wings' framework. The central body of the project will be the study of the neural basis of cognitive functions, with two wings addressing two translational aspects of brain science. The first

Christof Koch
Allen Institute

2003

Miri Polachek
Israel Brain Technologies (IBT)

2011

Sten Grillner
Human Brain

2013

Walter Korosh
Brain Res. thr'

2013

Hideyuki Okan
Brain Map. by

2014

Nancy Ip & M
China Brain P

2017

China Brain Project

Nancy Ip and Mu-ming Poo

The China Brain Project is expected to start in late 2016 or early 2017.

Goals. The China Brain Project will support three research areas in a 'one body, two wings' framework. The central body of the project will be the study of the neural basis of cognitive functions, with two wings addressing two translational aspects of brain science. The first is to improve and develop diagnoses and therapies for major brain disorders, with emphasis on early diagnosis and early intervention. The second is to develop brain–machine intelligence technologies, including brain–machine interfaces, and brain-inspired computing methods and devices. This framework reflects the consensus reached after many meetings among neuroscientists, clinicians and intelligence technologists over the past two years.

Why CS challenges

1 GB/s

- Volume of data
  - The amount of data we have produced within 100 years, we are producing it every 10 to 20 minutes today
  - In the next 10 years, we will produce the same amount of data in 5 seconds
- Speed of processing the data
  - Real-time applications

Systems can no longer digest this information

We need help – in form of algorithms, architecture, theory

Why

Robots

Fast communication

Rigid bodies

Transmission speed: 100,000,000 m/s

Bandwidth:
~ 100 Hz (electromagnetics)
~ 1,000 Hz (electrohydraulics)

Humans

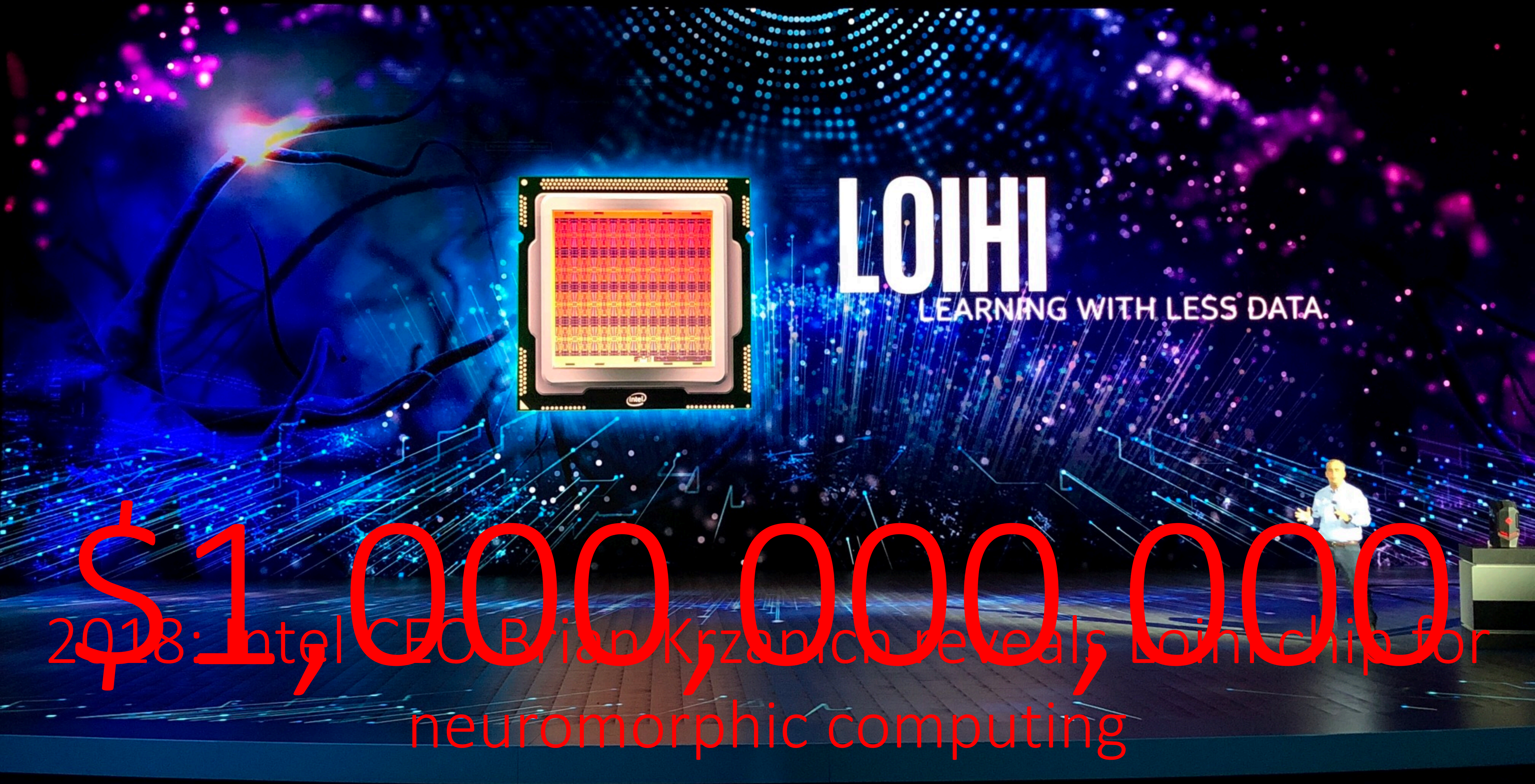
Slow neurons, slow muscles, noisy sensors

200 degrees of freedom

Transmission speed: 100 m/s (neuron)

Bandwidth:
~ 3 Hz (muscle)

Is this science fiction?



$1,000,000,000

2018: Intel CEO Brian Krzanich reveals Loihi chip for neuromorphic computing


IBM
IBM13K
00031
Neurosynaptic
System
4¹⁶

vicarious

Fei – Fei Li
Associate Professor
Computer Science
Stanford University

"Vicarious is bringing us all closer to a future where computers perceive, imagine, and reason just like humans."

Peter Thiel

"The technology that Vicarious is developing has the potential to improve all lives and revolutionize every industry."

Dustin Moskovitz

brain CORPORATION

QUALCOMM®

Brain Corporation applies expertise in machine learning and computer vision to create intelligent systems capable of functioning autonomously in complex human environments.

We're building brains for robots, and turning today's manually-operated machines into tomorrow's autonomous solutions.

IBM

Epic Shift to Low-Power Supercomputers

Dharmendra Modha, IBM Fellow

"The architecture can solve a wide class of problems from vision, audition, and multi-sensory fusion, and has the potential to revolutionize the computer industry by integrating brain-like capability into devices where computation is constrained by power and speed."

— Dharmendra Modha, IBM Fellow

Read Dr. Modha's SyNAPSE article, here.

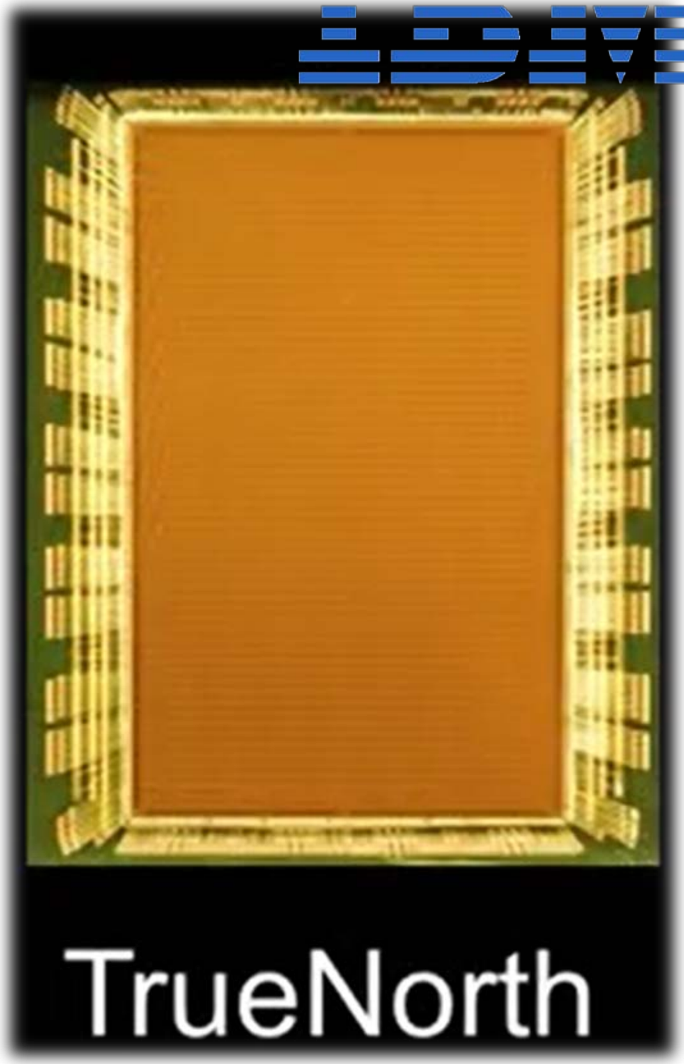
What

Towards a non Von-Neumann architecture

Brain-inspired vs. human engineered architecture

- No clocks
- Event driven
- Fault tolerant

- No C-code, or Java or Python or …
- Instead: spiking neural network



What

Relevant Courses in CS Departments

The University of Texas at Austin
Computer Science

CS 378 The Computational Brain

Carnegie Mellon University
School of Computer Science

CS 874 Machine Learning from Neural Cortical Circuits

EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE
SCHOOL OF COMPUTER AND COMMUNICATION SCIENCES

Neuronal Dynamics: Computational neuroscience of single neurons

Computer Science & Engineering
UNIVERSITY of WASHINGTON

CSE 490I Neurobotics
CSE 528 Computational Neuroscience
CSE 529 Neural Control Of Movement:
A Computational Perspective

Relevant Courses – The MIT perspective

MIT CSAIL

Massachusetts Institute of Technology

brain+cognitive sciences · McGOVERN INSTITUTE · THE PICOWER INSTITUTE FOR LEARNING AND MEMORY

9.523	Aspects of a Computation Theory of Intelligence	Poggio, Ullman
9.014	Quantitative Methods and Computational Models in Neurosciences	Jazayeri, Zysman
9.660J	Computational Cognitive Science	Tenenbaum

- Earl K. Miller
- Josh Tenenbaum
- Emery Brown
- Jean-Jacques Slotine

LIS LEARNING & INTELLIGENT SYSTEMS

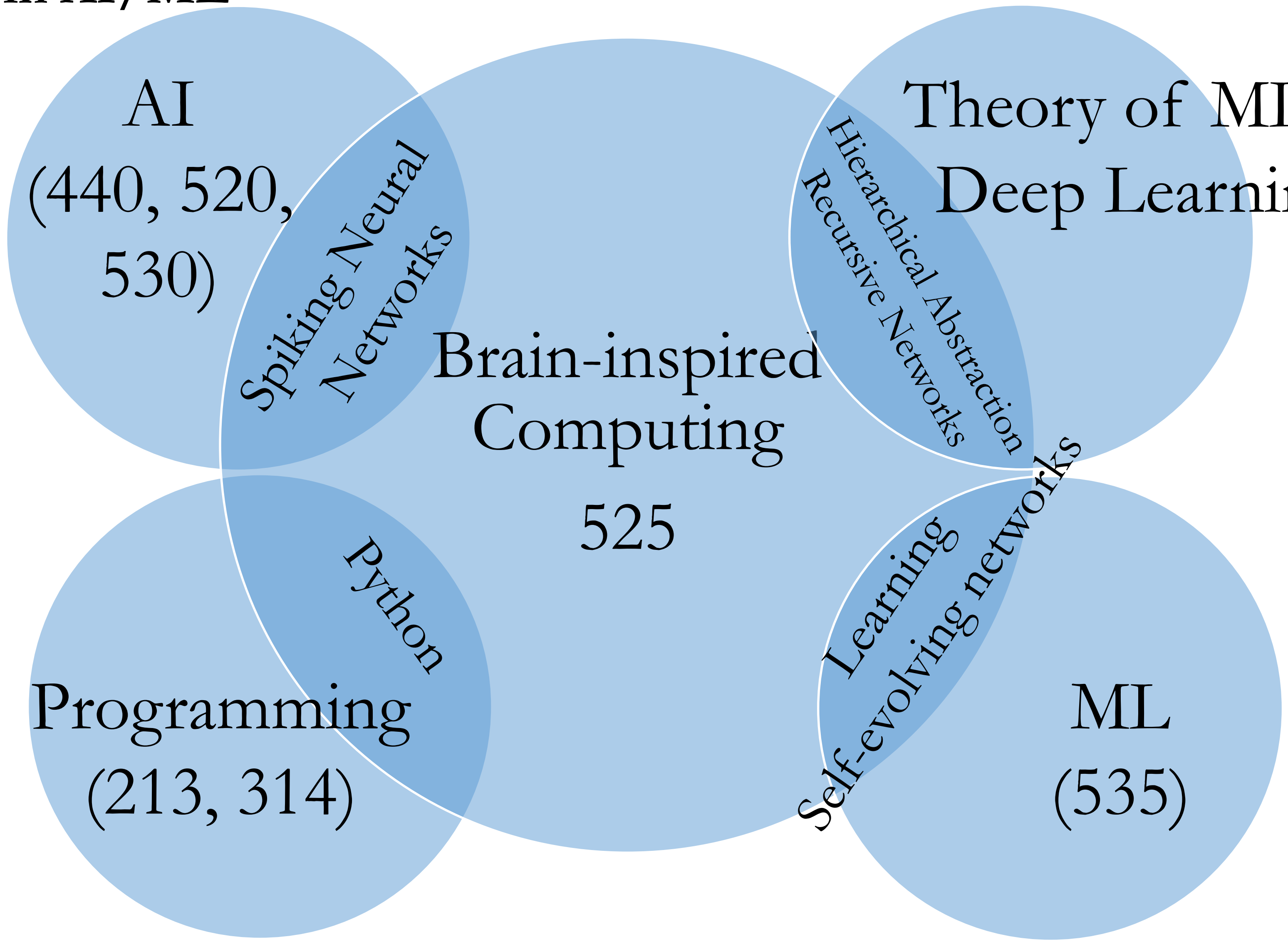
Center for Biological & Computational Learning

Computational Cognitive Science Group

More: https://bcs.mit.edu/academic-program/graduate/course-offerings

“This class has moved me to **take more classes in AI/ML next semester.**”

“…helped me in understanding **deep neural nets** better.”



“Wonderful course that allows us to participate in real world applications of **programming.**”

“This class really is a **nice mix of Neuroscience, Computer Science, and AI/ML.**”

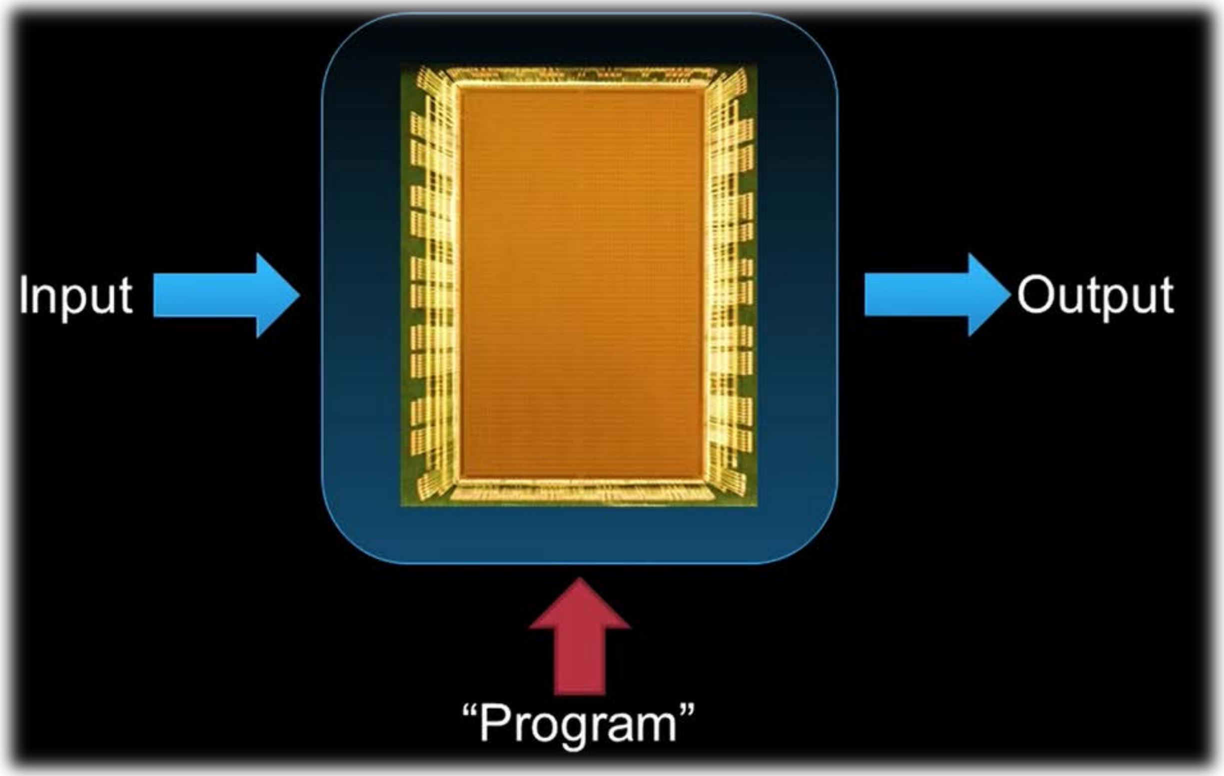
Course Goals

- To explore how computation in the human brain can be effectively modeled* across different levels of abstraction (from a single neuron to brain systems)
- To introduce a computational formalization of brain function based on the Spiking Neural Networks –SNNs (the 3rd generation of ANNs)
- To employ SNNs and solve a CS problem in a term-wide project

* **abstracted away**

What

Course Overview



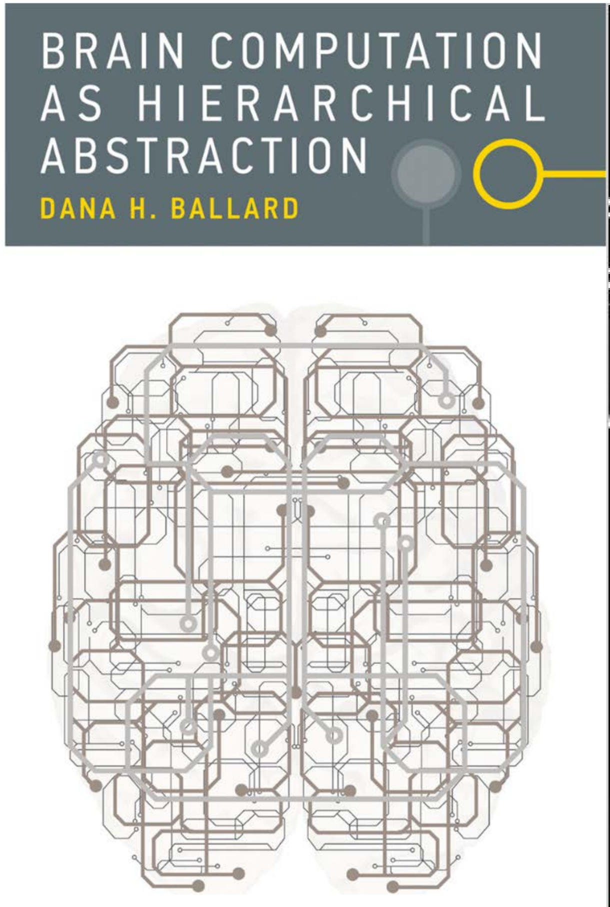
To describe computational models of

intelligent behavior

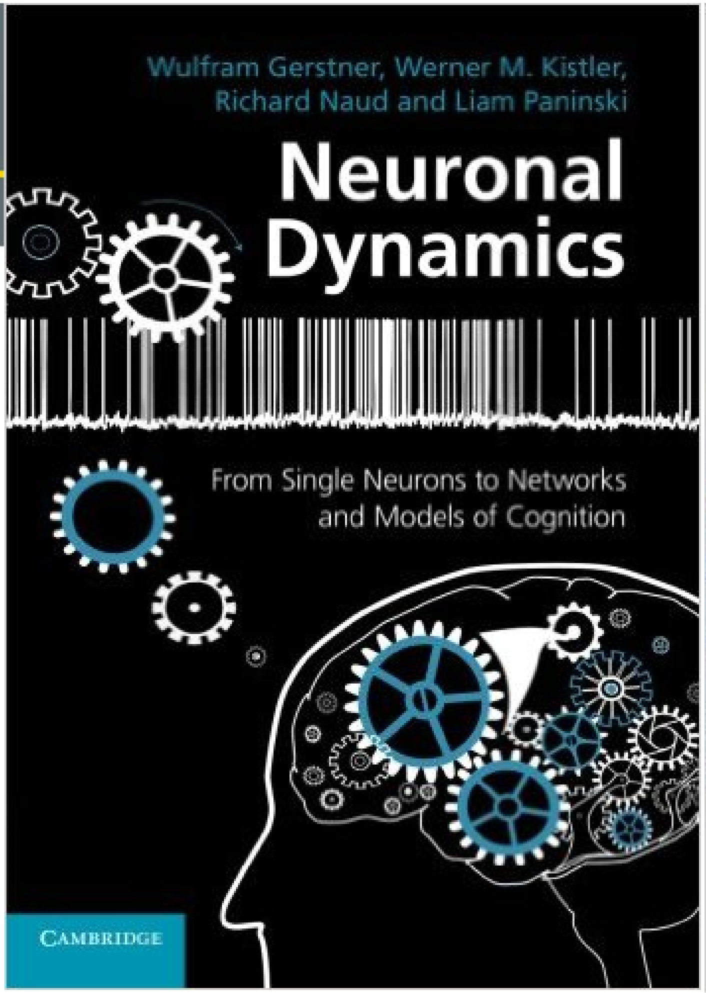
and how they relate to brain function

- Brain-Inspired
- Brain-derived

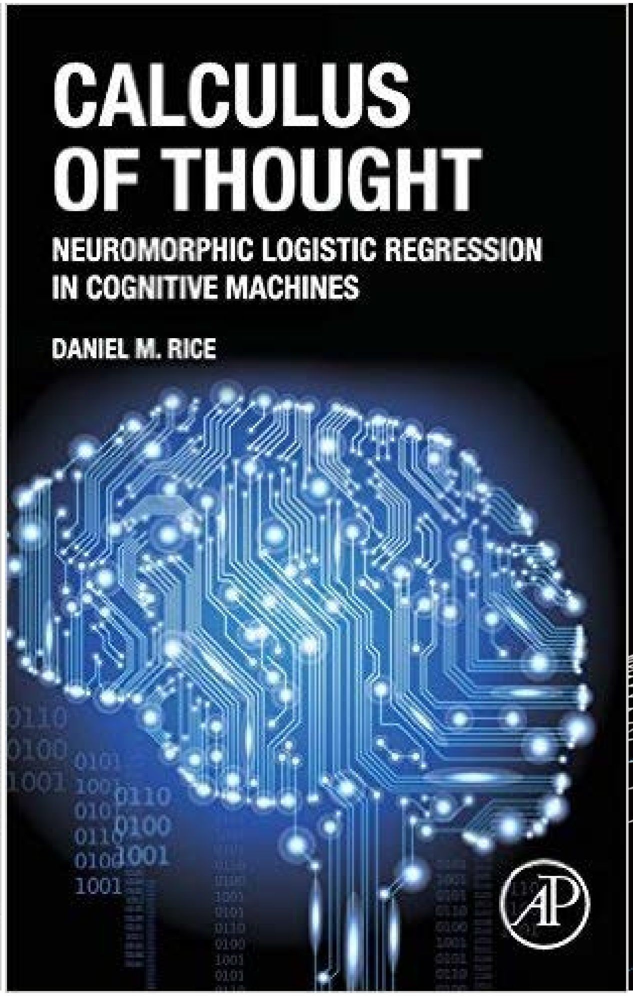
Textbooks



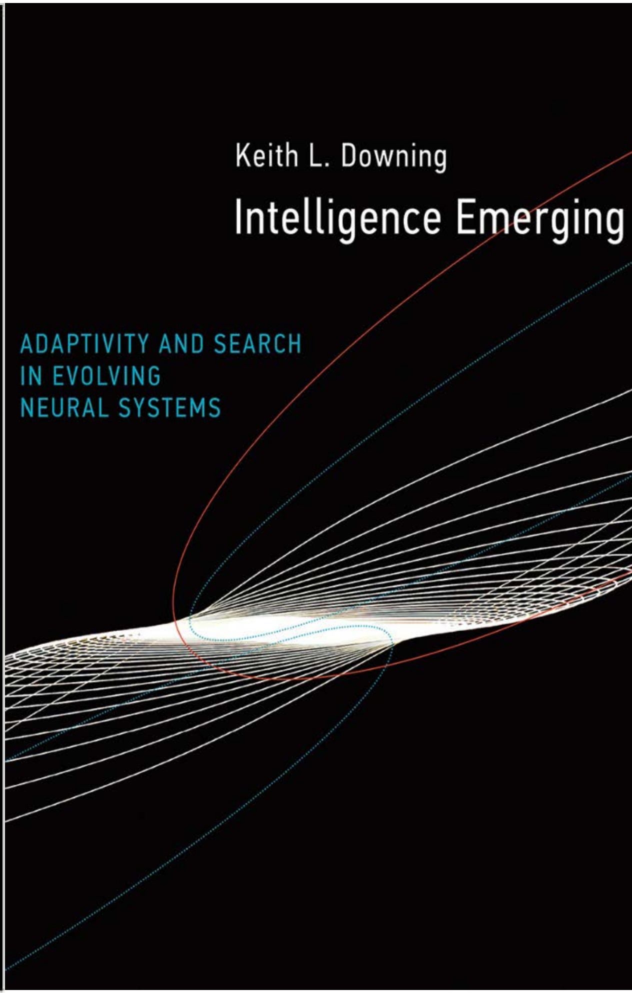
MIT Press
February 2015



Cambridge University Press
September 2014



Academic Press - Elsevier
October 2013



MIT Press
May 2015

What

Course Syllabus

Brain Science

Biophysics of Brain Computation

Computational Modeling

Neurons as Spike Processing Machines

Neuroinspired AI

Integrating Neurons into SNNs

- **[Week 01]** Overview of Brain Computation Handouts
- **[Week 02]** Macro-Scale: Vision, Movement, Memory, Learning and Cognition Handouts
- **[Week 03]** Micro- and Meso- Scales: Biological Neurons and Networks Handouts
- **[Week 04]** Biophysically realistic Neuron Models Handouts + Downing Ch. 6
- **[Week 05]** Phenomenological Neuron Models Gerstner Ch. 4
- **[Week 06]** Probabilistic neuron models Gerstner Ch. 10
- **[Week 07]** Evolving Neuronal Populations Downing Ch. 12
- **[Week 08]** Brain as an optimization machine Sterling – Chs. 13/14
- **[Week 09]** Learning via synaptic tuning Downing – Ch. 10
- **[Week 10]** Memory and Attractor Dynamics Gerstner – Ch. 17
- **[Weeks 11-12]** Students' presentations
- **[Week 13]** Building functional SNNs Abbott Nature Neuroscience, 2015; Eliasmith Science, 2013
- **[Week 14]** Synaptic Plasticity and Learning in SNNs Gerstner – Chs. 19/20
- **[Week 15]** Computational elements of decision making, emotions and consciousness Ballard – Chs. 9/10/11

Pitch talk

- What is the computational problem?
- Why is it interesting and important?
- Why is it hard? What has been done up to now
- Where/Why have previous approaches failed?
- What are the key components of your neuro-inspired approach?
- What model/simulation environments will be used to validate your approach?

Course Material

- Lecture notes (available as 4-page handouts)
- Research papers (suggested and/or assigned)
- Other material (e.g., please check **Instructions to Authors**)

This course **will use sakai**

How?

Course Structure (old)

- 24 lectures (1 h 20 min, each)
- A pitch talk on the term-project
- A term project on SNN
- A 20 min paper presentation per student/team (the most influential paper for their term project)
- A draft term-paper
- A final term-paper

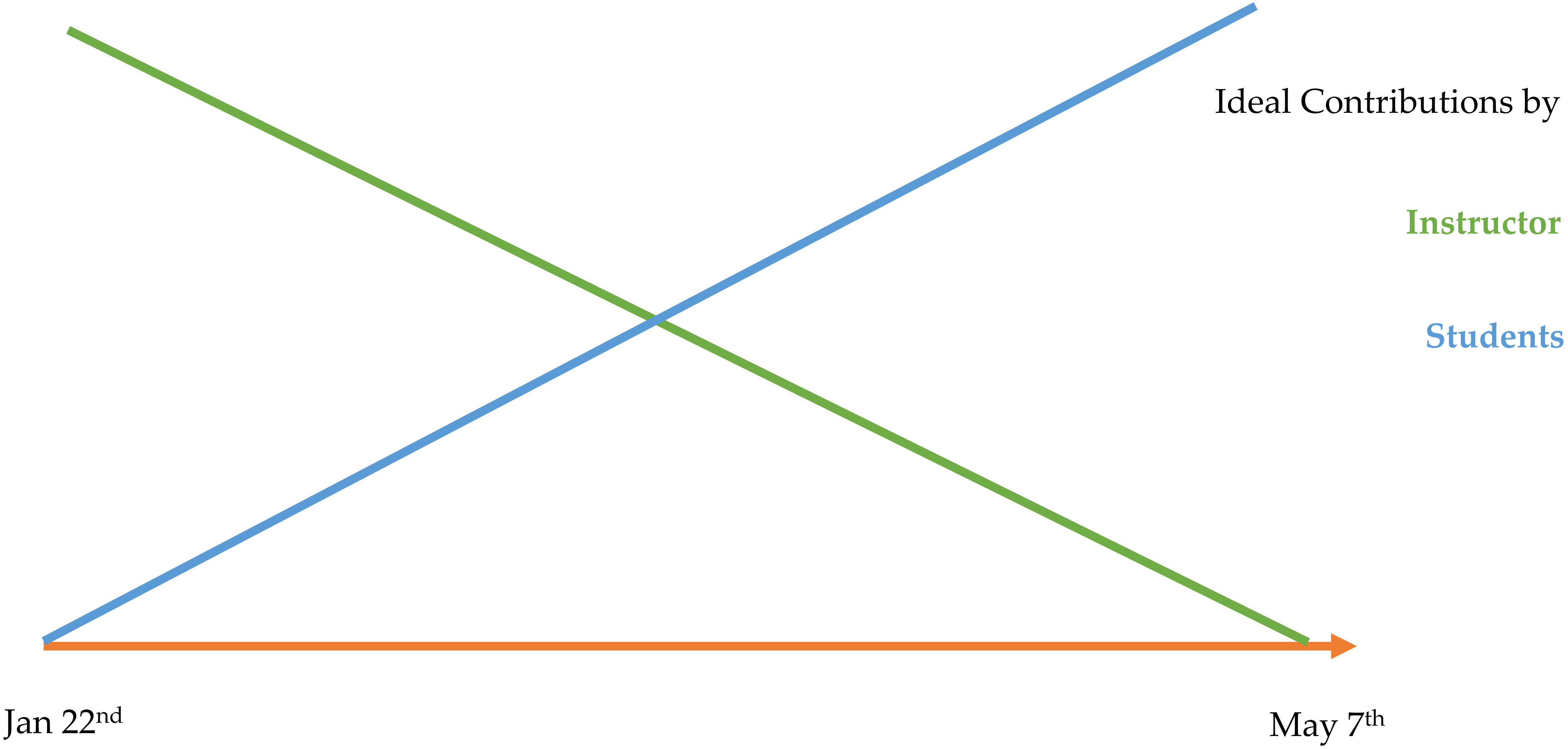
How?

Course Structure (new)

- 24 lectures (1h 05 min, each)
- Quiz or Paper presentation (15 min)
- A term project on SNN
- 2 assignments to prepare you for the term project
- A final term-paper

How?

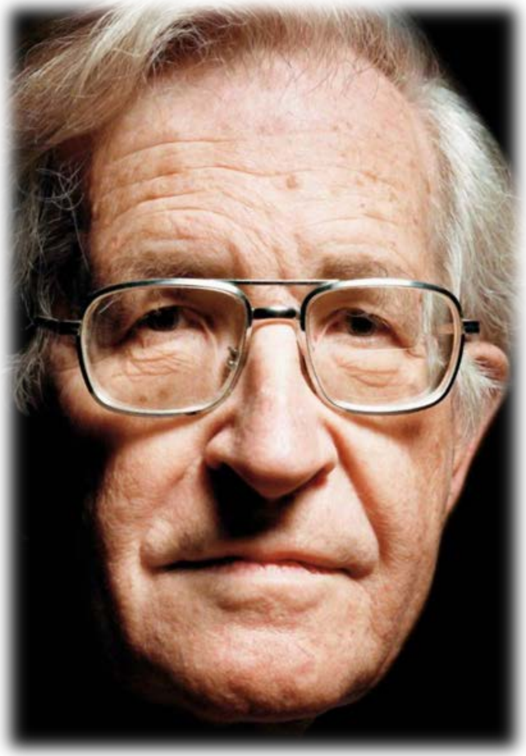
Course Structure



The importance of doing a term-project

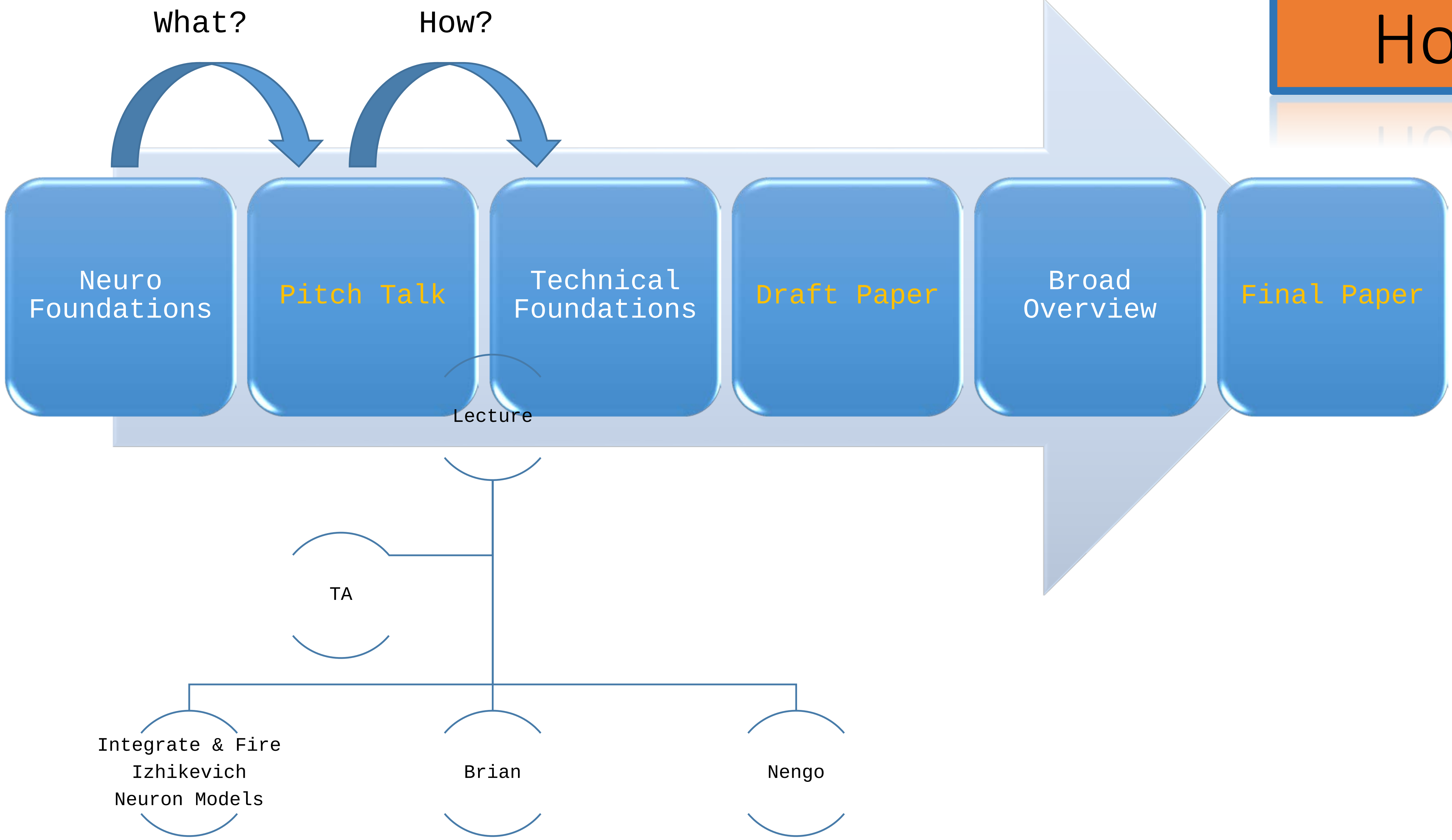
"... it's not important what we cover in the class, it's important what *you* discover.

To be truly educated from this point of view means to be in a position to ***inquire*** and to ***create*** on the basis of the resources available to you which you've come to appreciate and comprehend. To know ***where*** to look, to know ***how*** to formulate serious questions, to question a standard doctrine if that's appropriate, **to *find your own way***, to shape the questions that are worth pursuing, and to develop the path to pursue them. That means knowing, understanding many things but also, ... to know where to look, how to look, how to question, how to challenge, ***how to proceed independently***..."

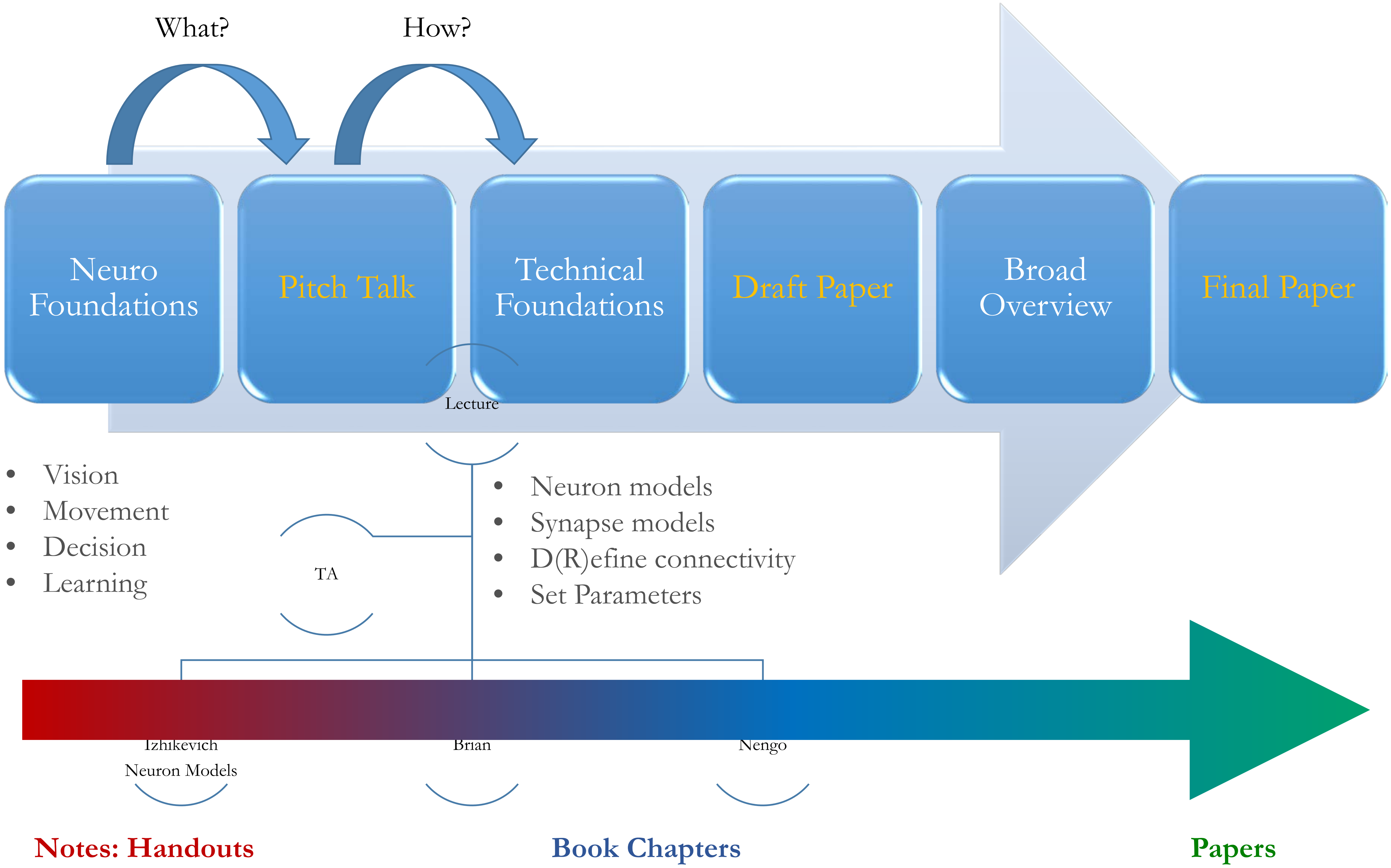


Noam Chomsky, MIT

How?



What?
How?
Neuro Foundations
Pitch Talk
Technical Foundations
Draft Paper
Broad Overview
Final Paper
Lecture
TA
Integrate & Fire
Izhikevich
Neuron Models
Brian
Nengo


What?
How?
Neuro Foundations
Pitch Talk
Technical Foundations
Draft Paper
Broad Overview
Final Paper
Lecture
• Vision
• Movement
• Decision
• Learning
TA
• Neuron models
• Synapse models
• D(R)efine connectivity
• Set Parameters
Izhikevich Neuron Models
Brian
Nengo
Notes: Handouts
Book Chapters
Papers

Lecture structure

- I will introduce new material ~ 1 hour
  - A 15min quiz will follow
  - A paper presentation/discussion will follow
- We will introduce ~ 4 papers per month
  - Papers will be presented by teams of 3 students
  - Each team will have 15 minutes to present the paper
  - This way we will cover ~ 12 papers!
    - *As much as a PhD student covers in a semester - or two ...*

Grading Policy

How?

- Term – paper Proposal/Pitch Talk = **10%** (Week of Feb 4)
  - The 10 best ideas will be presented in class – Feb 12/14

- 2 assignments = **20%**
  - **To help you implement an SNN**

the first is due on: Feb 19
the second is due on: March 12

Both will be announced 2 weeks before the deadline

Assignments submitted by a person (not by a team)

Helping each other is highly encouraged – plagiarizing is not

- Quizzes = **30%**

- Term paper = **40%**

- *** Paper presentation = **10%** **(12 slots – 15 min presentation)**

How?

Paper Presentations

- For extra 10%, you get to present a paper
- The paper will **be assigned**
  - But feel free to propose one to present
  - Each week ~2 new papers will be posted
  - The papers will support the current lecture (+/- 1 lecture)

Why present a paper?

Course Participation

How?

- … is highly encouraged

- Do not use your laptops – or cellphones
  - To check your Facebook page
    - Or your friends' Facebook page
      - Or any kind of Facebook page
        - Or any webpage page unrelated to the course
          - It is just not worth it
- In the past: you would be graded for Q&A
- From now on: you will be remembered* for Q&A
  - 4 MS students successfully did their MS These in the Lab
    - All 4 of them took an earlier version of this course
    - 2 of them are continuing towards their PhD in the Lab
    - These are your two TA's for this semester

You will be **remembered** for Q&A

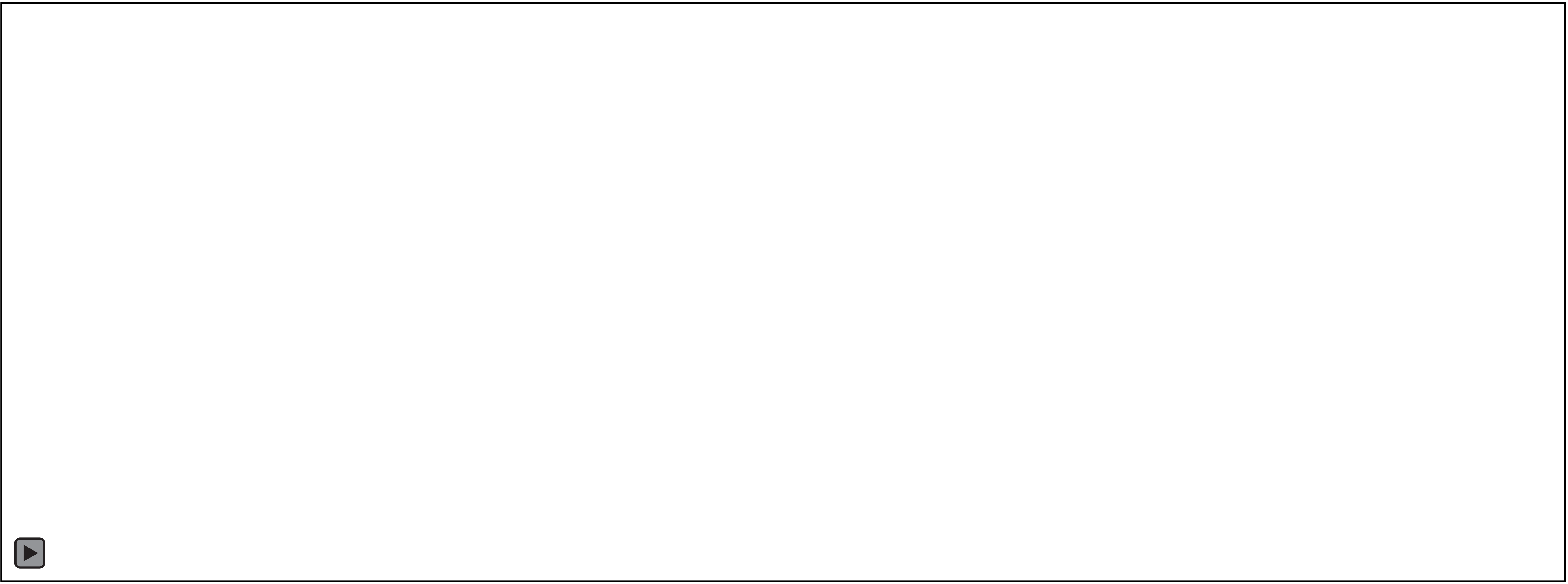
Leo Kozachkov

- UG student who took BIC in SP '16
- Did *really well* on the term-project

    (with Kevin Feigelis)

- They both did summer research in the Lab
- Leo continued as an RA in the Lab for 1 more year
    - We published 2+3 papers together
- Leo is now a PhD student at MIT


Modular Task Learning in an Embodied Two-Dimensional Visual Environment
Stimulus
representation
Neurons
read-out
Behavior
visual representation
FLOWER SNIFFIN



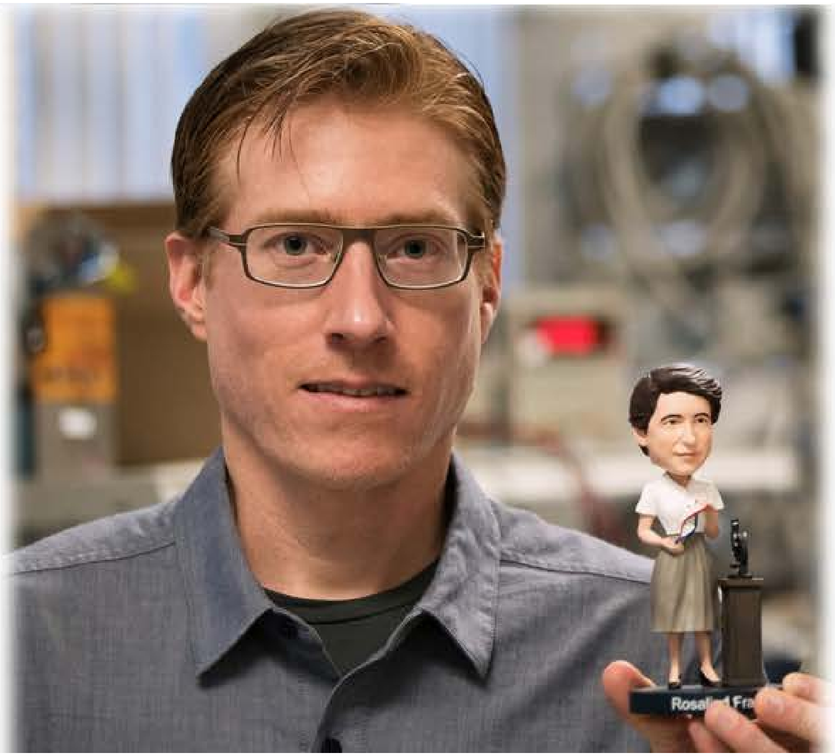
2nd Annual

CS Conference

Jan 31 | 12 noon

Fiber Optics Auditorium

Busch Campus



12.00 Lunch

Social Time

13.00 Keynote Talk

Mike Davies

Director, Neuromorphic Computing Lab | Intel Labs

14.00 Panel Discussion

Towards Intelligence Science: From Brain-inspired to Brain-interactive AI

Mike Davies
Intel

Brian McLaughlin
Philosophy | RuCCS

Dimitri Metaxas
Computer Science

Steven Silverstein
RWJ Medical School

15.00 Poster Session and Awards Ceremony

Discuss posters of over **60** Graduate and Undergraduate students in CS

contact Konstantinos.Michmizos@cs.rutgers.edu for more information

Next Thursday - No class

Attend the CS Conference --- and get 5%

HOW? Send an email to Neelesh with a title "CS_Conference_Registration" to register - NOW