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425/525

Brain Inspired Computing

Konstantinos P. Michmizos

Computational Brain Lab

Computer Science | Rutgers University | NJ, USA





Disclaimer

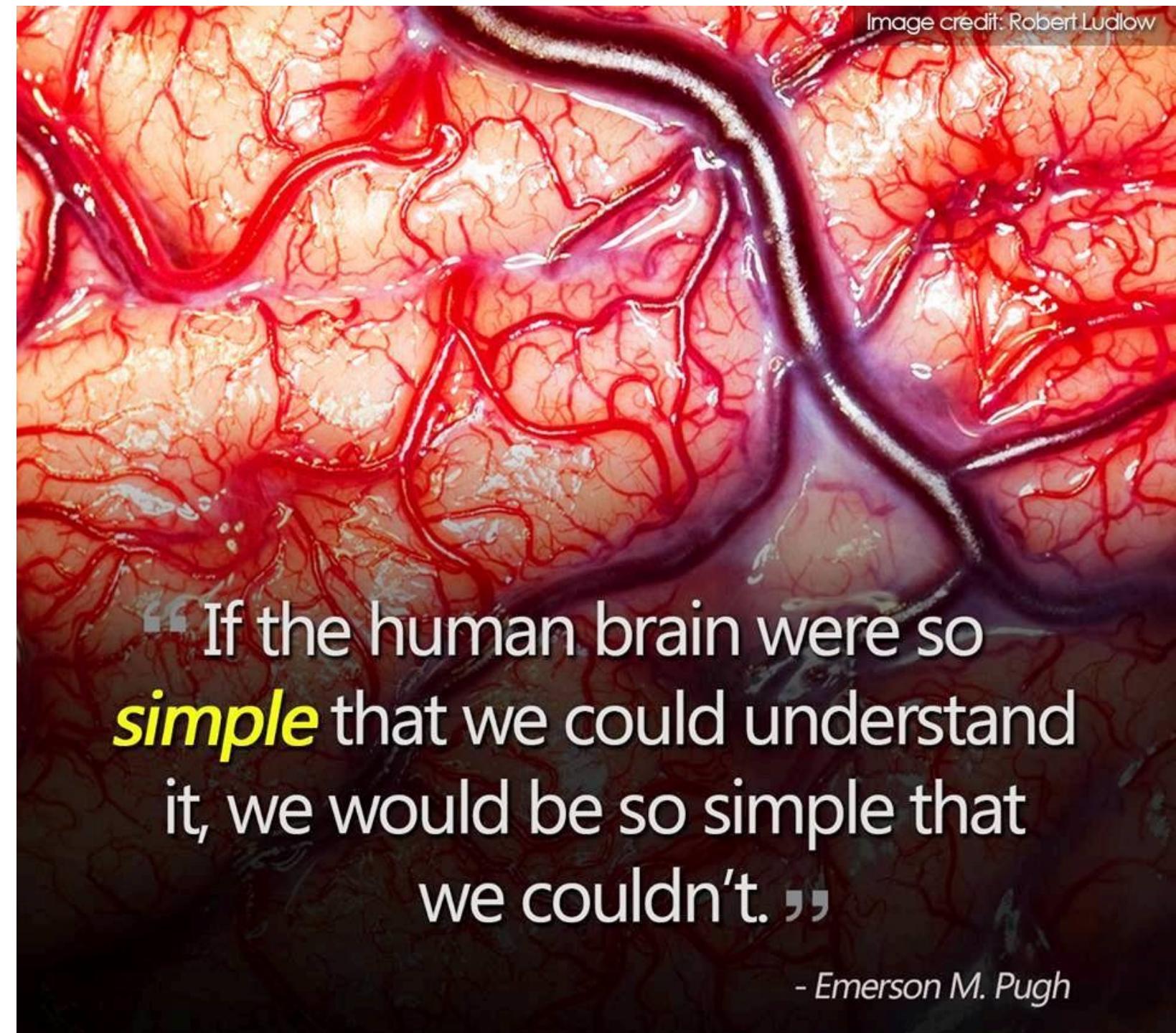
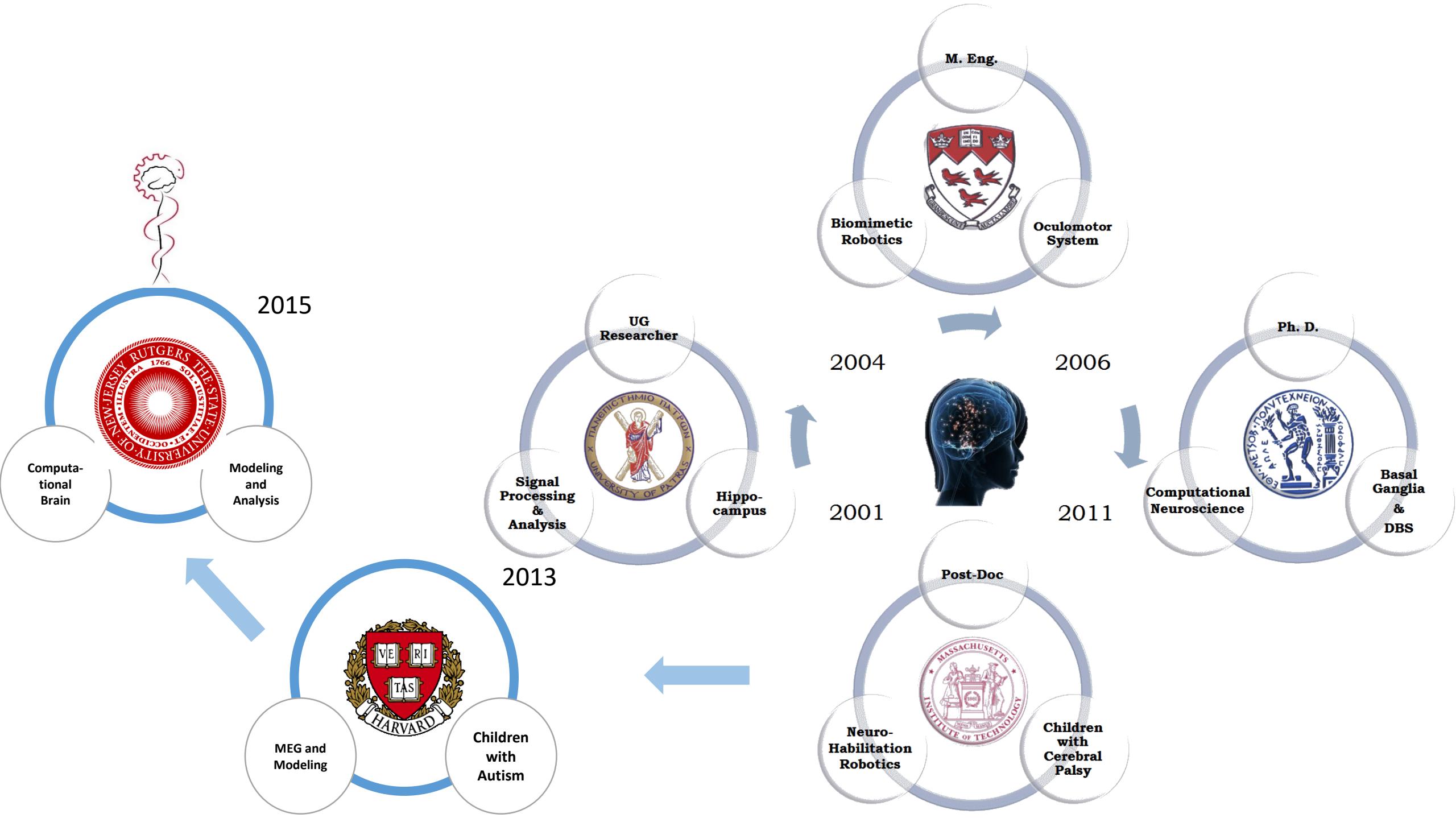


Image credit: Robert Ludlow

If the human brain were so **simple** that we could understand it, we would be so simple that we couldn't. , ,

- Emerson M. Pugh





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Brain Inspired Computing with Michmizos

Has anyone taken this class with him? I have sent out spn request for it but wanted to know how tough this class is supposed to be and how it is structured. It does sound very interesting but I wanna know how much of a workload it is. Any information would be highly appreciated. Thanks!

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moosypooper 1 point · 1 month ago



It's a fascinating class and he's a great teacher in that he really cares about your learning and will absolutely help you - IF you take the initiative. It's very much a grad class, and you're expected to do your own research and above all else, pace yourself.



good4y0u  1 point · 1 month ago



This class is fantastic. It taught me a ton in retrospect. Honestly it's the best machine learning crash course.

He said in the beginning of the class that if you show up he will give you a B. But if you put in work you can get an A .

Honestly he actually made me like the class and I showed up because it was actually good . The man does some cool research and you get to see some of it explained . Really a win/ win class.



When?

Tue and Thu

1:40 PM - 3:00 PM

Where?

PH - 115

Who?

KPM – 3 TA's



How to reach me

- Office Hours

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



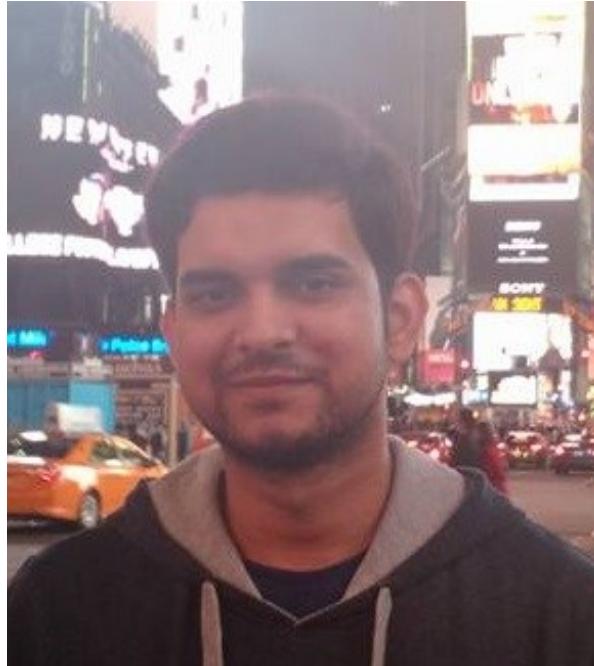
- e-mail: konstantinos.michmizos@cs.rutgers.edu
(if no response within 12 hours, [send a follow up email](#))
- Office: CBIM Room # 04
(arrange an appropriate time slot before you come)

Who



TAs

Who



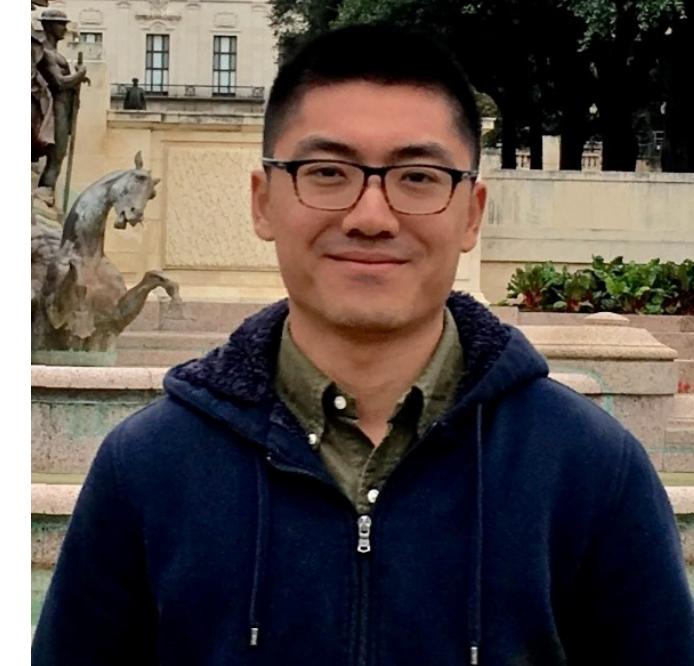
Neelesh Kumar, MSc, PhDc

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Vladimir Ivanov, PhDc

vai9@scarletmail.rutgers.edu



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gt235@cs.rutgers.edu



- 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) was started in 2003.

Aims. The AIBS seeks to understand the biological and biophysical properties of a speck (roughly 1 mm³) 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

concerned
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he brain in
ience asked
d to ques-
about their
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'foresee in
bsites may

not needed.
including
ves are, of
reaction.

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

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

(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

effort is needed. This includes the need to share resources and to coordinate the different projects. The ultimate goal is to create a sustainable research environment that will benefit all parties involved.

1118

VOLUME 19 | NUMBER 9 | SEPTEMBER 2016 NATURE NEUROSCIENCE

OLBOX
avi Foundation
NDATION
for all editorial content



2003

Christof Koch
Allen Institute



2011

Miri Polacheck
Israel Brain Technologies (IBT)



2013

Sten Grillner
Human Brain Project



2013

Walter Koroshetz
Brain Res. thr'



2014

Hideyuki Okamoto
Brain Map. by



2017

Nancy Ip & Mu-ming Poo
China Brain Project

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

Why CS challenges



- 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

Humans

Robots

Fast communication

Rigid bodies

Transmission speed: 100,000,000 m/s

Bandwidth:

- ~ 100 Hz (electromagnetics)
- ~ 1,000 Hz (electrohydraulics)



Slow neurons, slow muscles, noisy sensors

200 degrees of freedom

Transmission speed: 100 m/s (neuron)

Bandwidth:

- ~ 3 Hz (muscle)

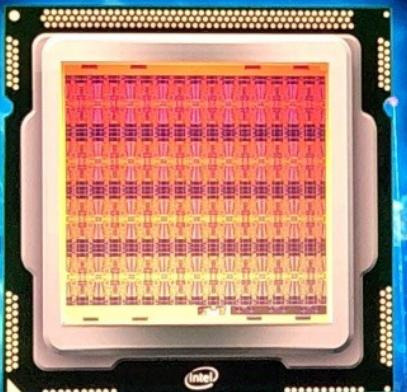


Is this science
fiction?



\$1,000,000,000

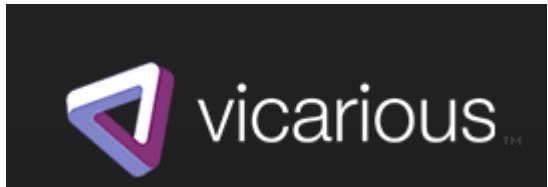
2018: Intel CEO Brian Krzanich reveals Loihi chip for neuromorphic computing



LOIHI

LEARNING WITH LESS DATA





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

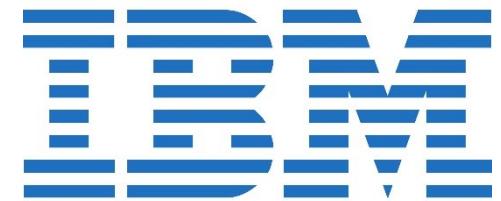
"The technology that Vicarious is developing has the potential to improve all lives and revolutionize every industry."

Dustin Moskovitz

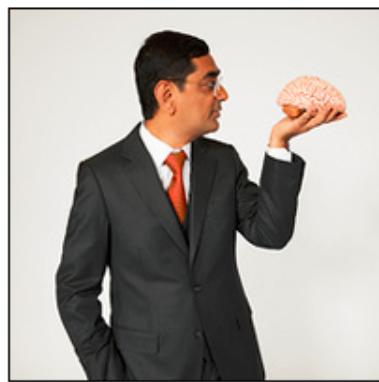


Brain Corporation applies expertise in machine learning and computer vision to create intelligent systems capable of functioning autonomously in complex human environments.

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



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](#).

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



Relevant Courses in CS Departments



SCHOOL OF COMPUTER AND COMMUNICATION SCIENCES



CS 378 The Computational Brain

CS 874 Machine Learning from Neural Cortical Circuits

Neuronal Dynamics: Computational neuroscience of single neurons

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

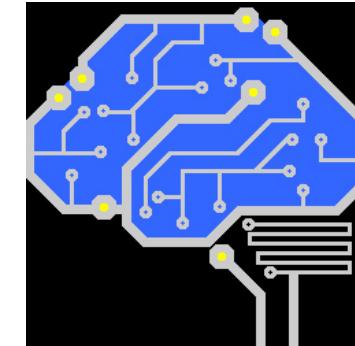


Relevant Courses – The MIT perspective



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

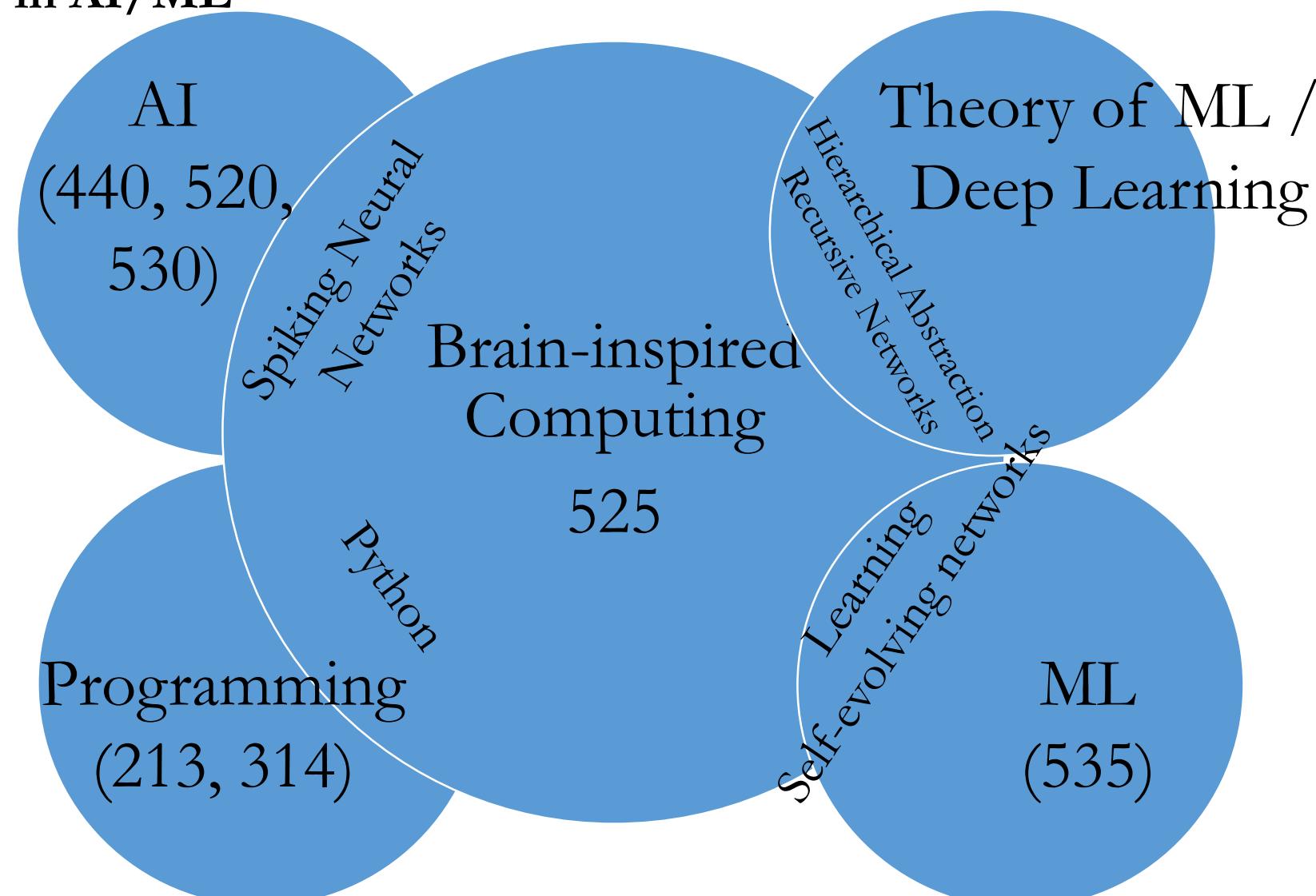


Computational
Cognitive Science Group

Center for Biological & Computational Learning

“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**.”

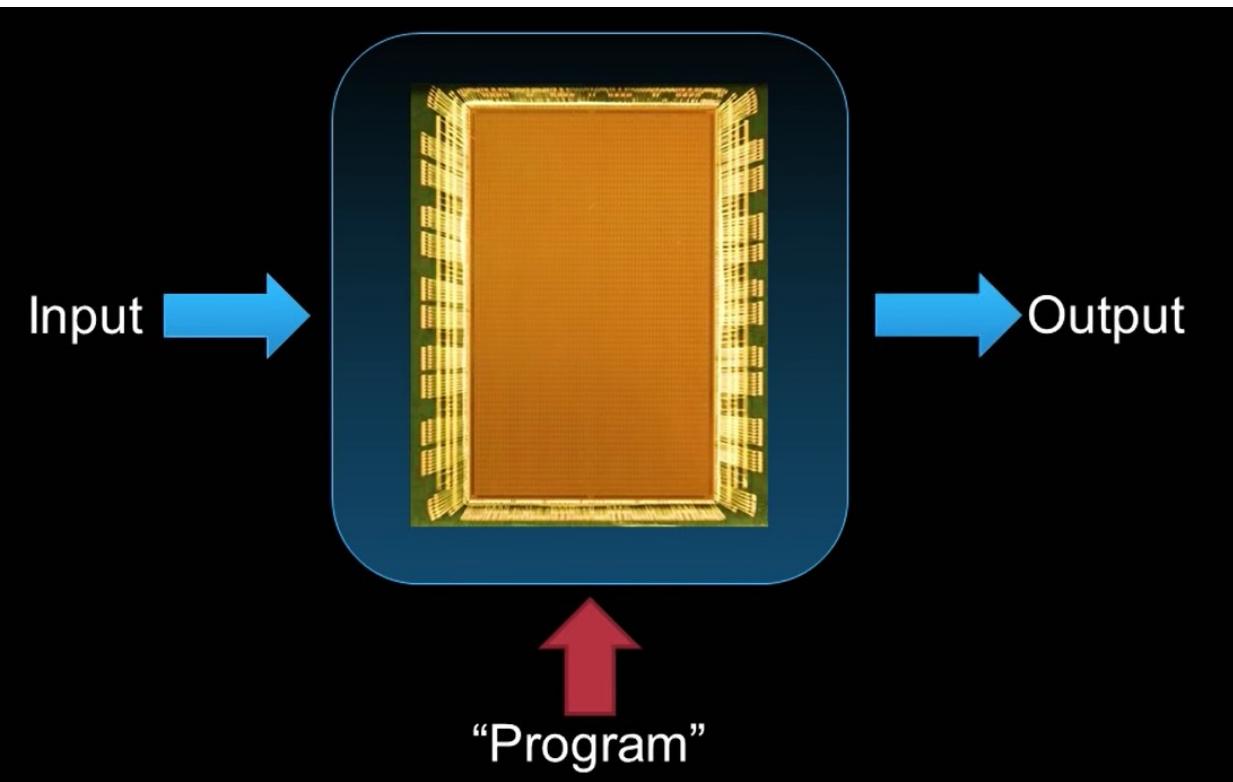
“This class really is a **nice mix of Neuroscience, Computer Science, and AI/ML**.”

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

Course Overview



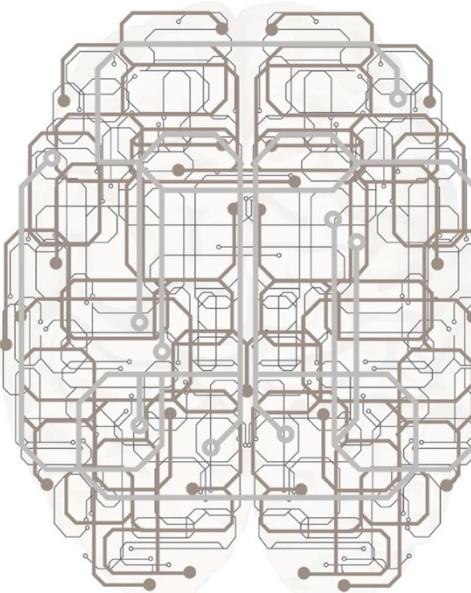
To describe computational models of
intelligent behavior
and how they relate to brain function

- Brain-Inspired
- Brain-derived

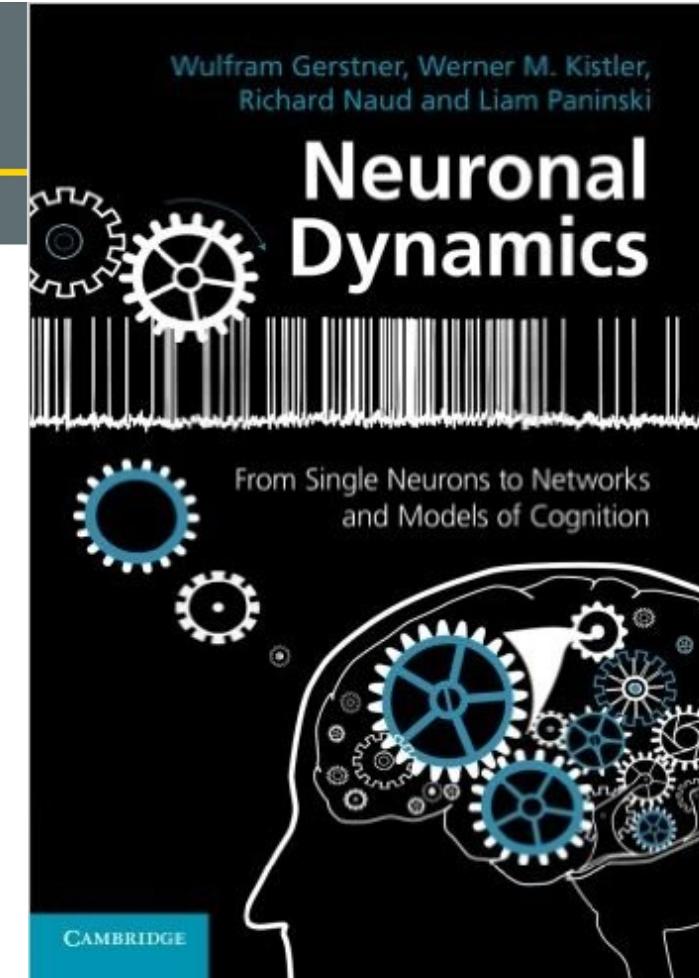
What

Textbooks

BRAIN COMPUTATION
AS HIERARCHICAL
ABSTRACTION
DANA H. BALLARD



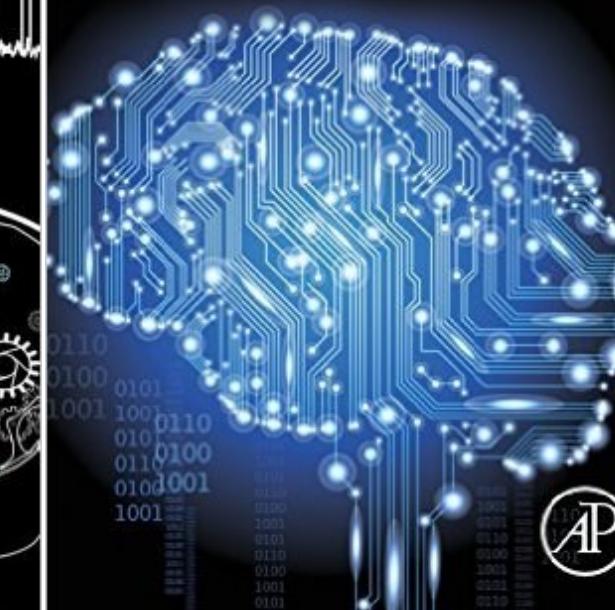
MIT Press
February 2015



Cambridge University Press
September 2014

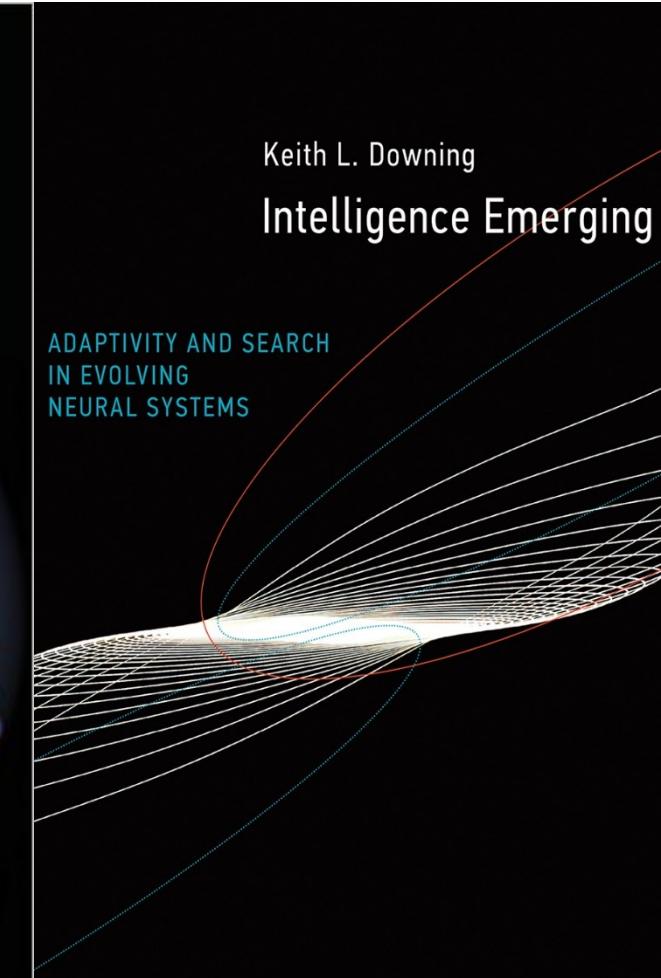
**CALCULUS
OF THOUGHT**
NEUROMORPHIC LOGISTIC REGRESSION
IN COGNITIVE MACHINES

DANIEL M. RICE



Academic Press - Elsevier
October 2013

ADAPTIVITY AND SEARCH
IN EVOLVING
NEURAL SYSTEMS



MIT Press
May 2015



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**

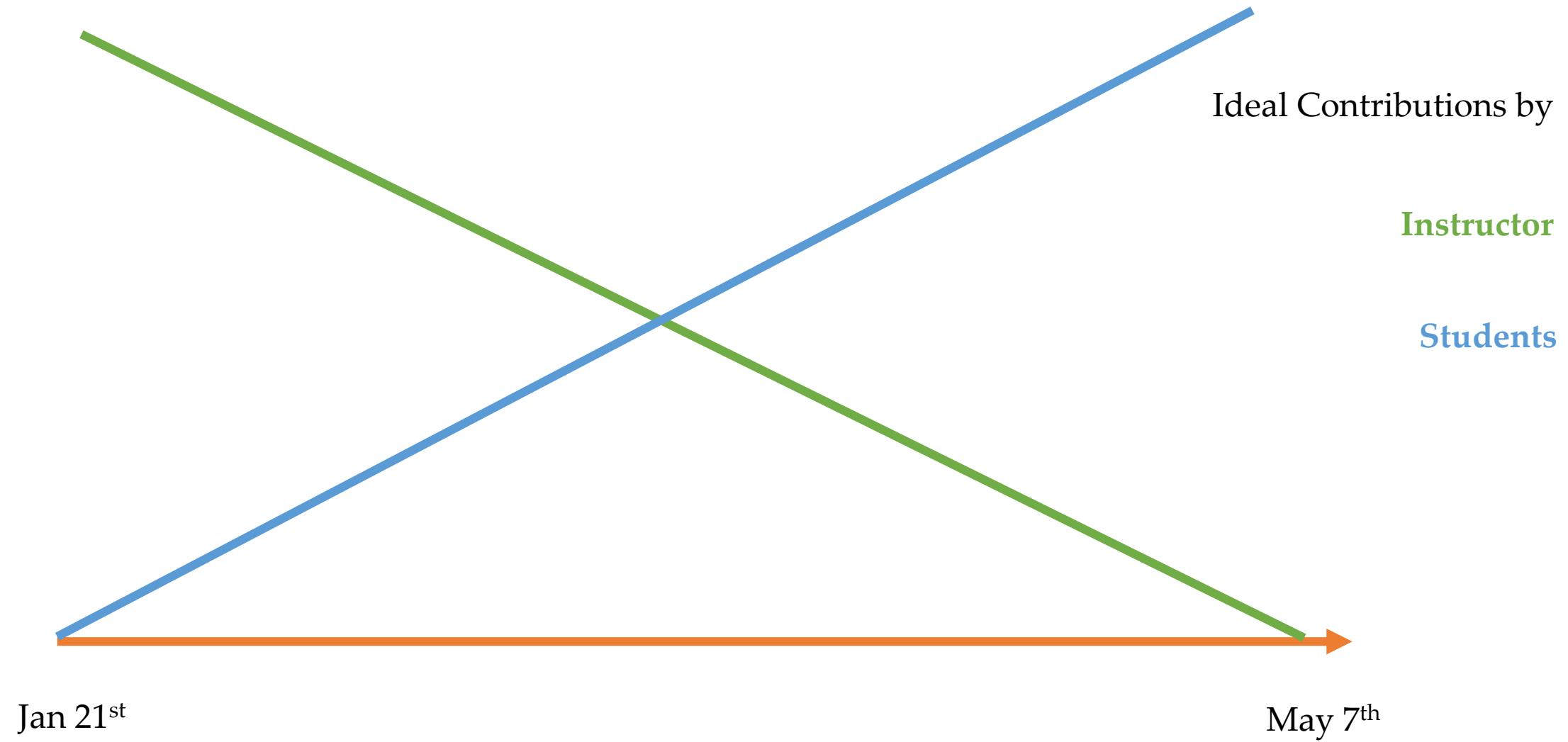
Course Structure (back to roots)

- 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



Why present
a paper?
Why a project?

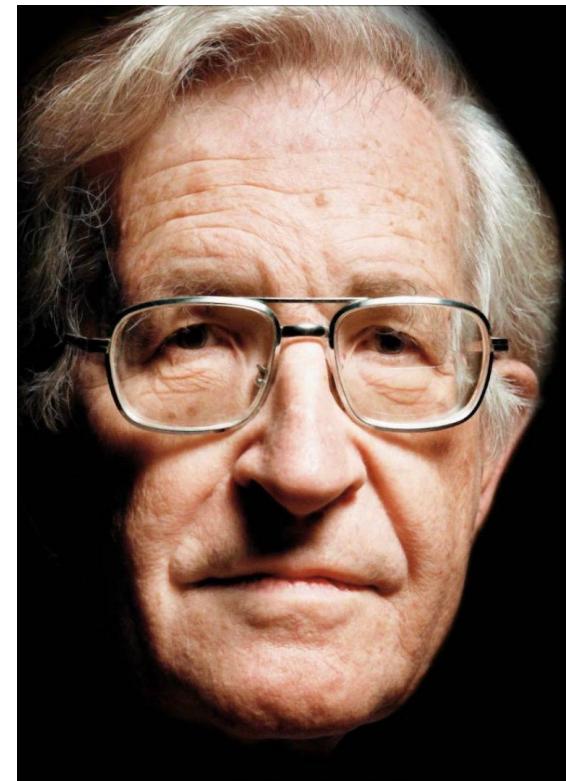




The importance of doing a term-project

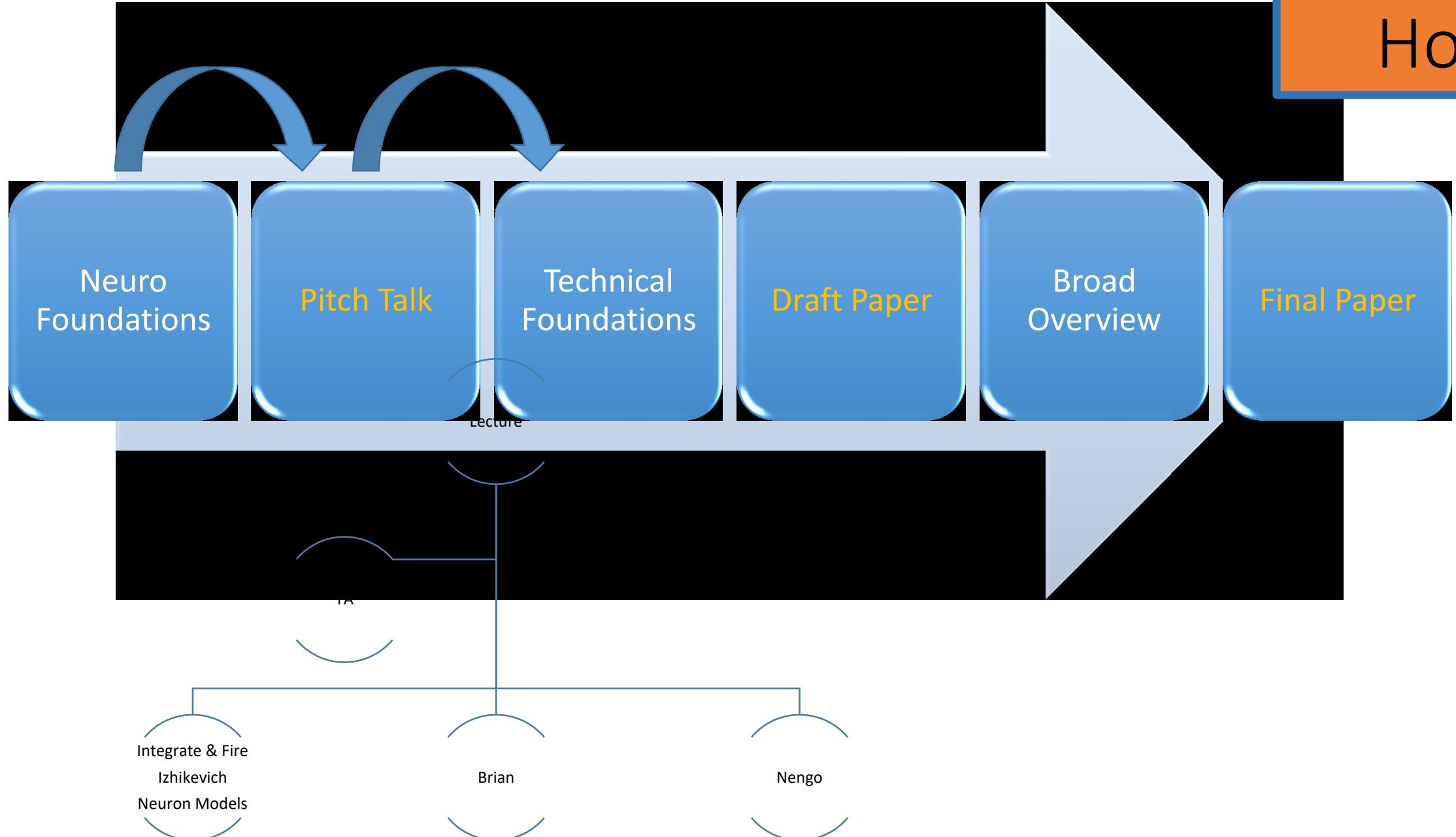
"... it's not important what we cover in the class, it's important what *you* discover.

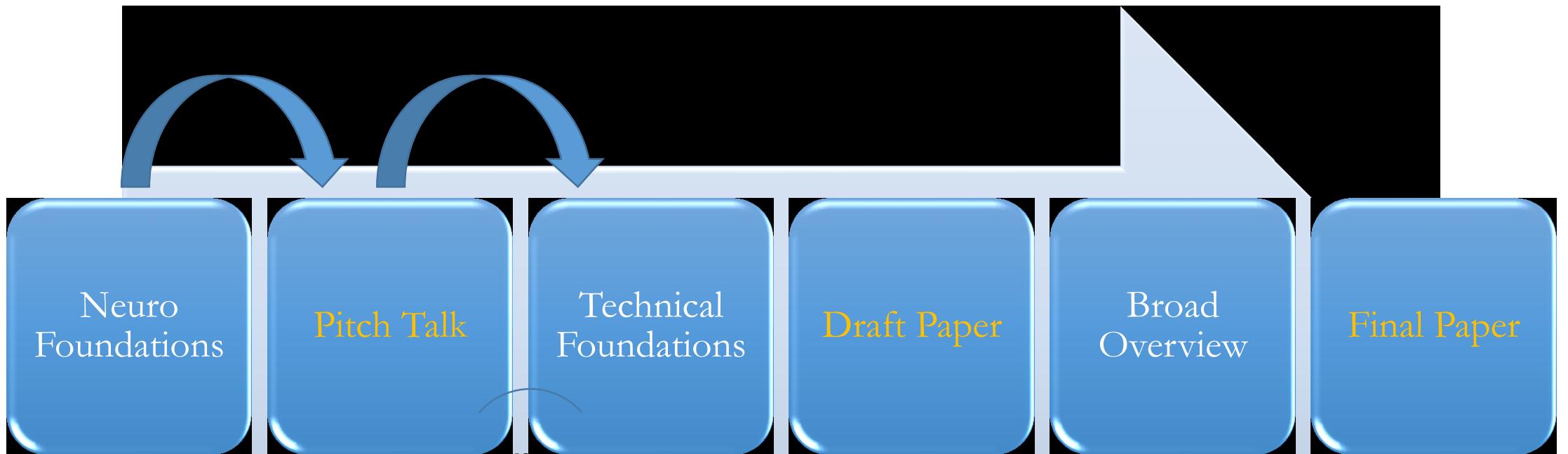
To be truly educated from this point of view means to be in a position to *inquire* and to *create* on the basis of the resources available to you which you've come to appreciate and comprehend. To know *where* to look, to know *how* to formulate serious questions, to question a standard doctrine if 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...*"



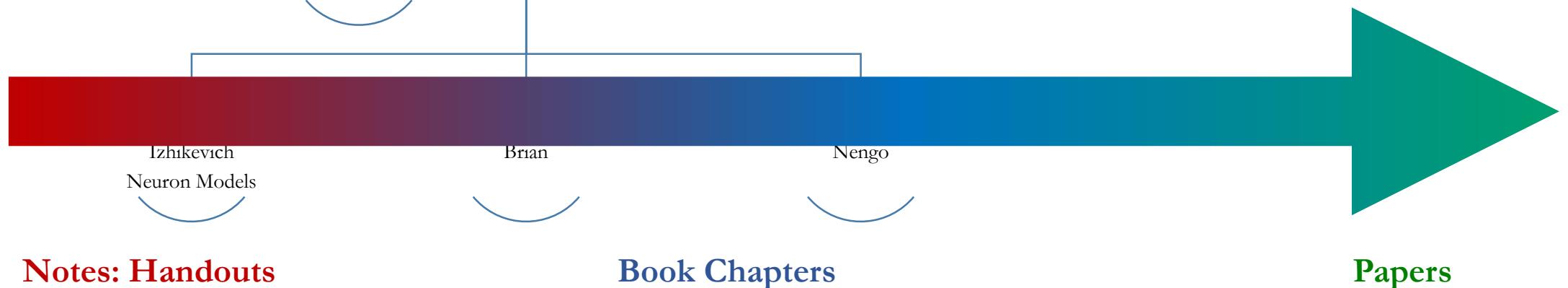
Noam Chomsky, MIT

How?





- Vision
 - Movement
 - Decision
 - Learning
- Neuron models
 - Synapse models
 - D(R)efine connectivity
 - Set Parameters



Lecture structure

- I will introduce new material ~ 1 hour
 - Sometimes, a 15min quiz will follow for extra credits
 - 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

- 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 20**

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

- Paper Presentation = **20%**
- Term paper = **50%**
- *** Paper presentation = **10%**

How?

Pop-up Quizzes

- For **extra 20%**, you get to present a paper

Course Participation

- ... 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