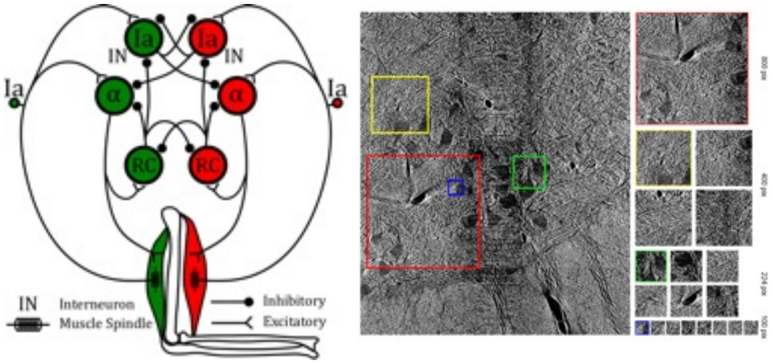
AUGUST 5, 2022

ATPESC 2022 – DINNER TALK

PEEK INSIDE THE FELINE SPINAL CORD WITH X-RAYS AND MACHINE LEARNING SUPERPOWERS



MARTA GARCIA MARTINEZ
Principal Project Specialist – Computational Science
Computational Science Division

Machine Learning for Neurobiology

- Electrical stimulation of the **spinal cord** has become an accepted therapeutic tool. Its most successful approach is in **pain management**, where 30,000 patients per year have electrodes implanted epidurally. With respect to spinal cord injury, the approach has been much less successful and has remained at a research state. We believe that this is due to a lack of a detailed stimulation map able to predict the effect of spinal cord electrical stimulation on the underlying motor circuits. In order to construct this stimulation map, a model based on the 3D structure of the spinal cord internal network needs to be built.
- In this talk I will present how we are using high powered **X-Ray tomography** at the Advanced Photon Source (APS) to image, at 1 μm resolution, sections of feline spinal cord and how we used **deep learning techniques** to train a convolutional neural network with the images obtained at the APS to detect somas (**neural cell bodies**) that will help us build this model.

"INGREDIENTS"

Image: Monika Grabkowska (unsplash)

Hardware (HW)

APS for imaging

Supercomputers

- *Bebop* *(LCRC)*
- *Cooley* *(ALCF)*

…

Software (SW)

Python

Petrel

Pytorch

MATLAB

tomopy

Globus

custom scripts

…

Funding
($ / node-hours / beamtime)

NAISE

NIH

DOE

APS beamtime

LCRC allocations

ALCF DD

…

People

Matthieu, Marta, Nicole, Tiberiu, Rafael, Josh, Vincent, Mike, Jeff, CJ, Vandana, Randy, Bobby …

KEYWORDS

In this talk you will hear these words

lumbar region L4-5-6

stimulation map

Advanced Photon Source (APS)

imaging

experiments

simulations

spinal cord

staining

tomography

feline

Ia

X-ray

microCT

Renshaw cells (RC)

motoneuron (MN)

Canonical Motor Microcircuit (CMM)

THE ONE WITH THE INSTITUTIONS

COLLABORATIVE EFFORT – INSTITUTIONS

Northwestern University

Northwestern Medicine
Feinberg School of Medicine

NAISE
Northwestern University
Argonne National Laboratory
Institute of Science and Engineering

Argonne NATIONAL LABORATORY

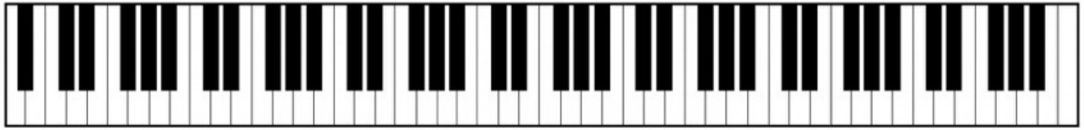
Argonne Leadership Computing Facility

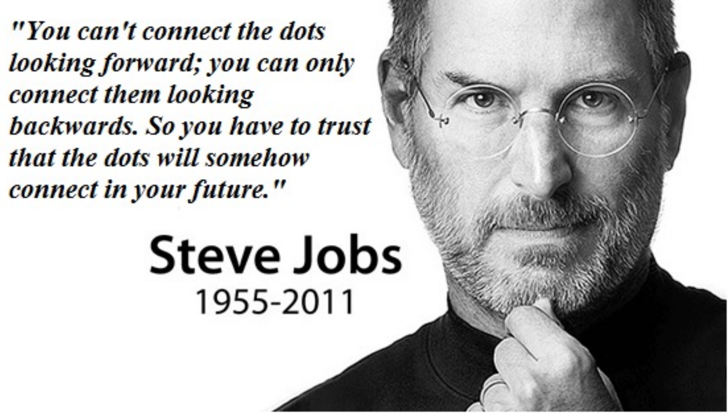
LABORATORY COMPUTING RESOURCE CENTER

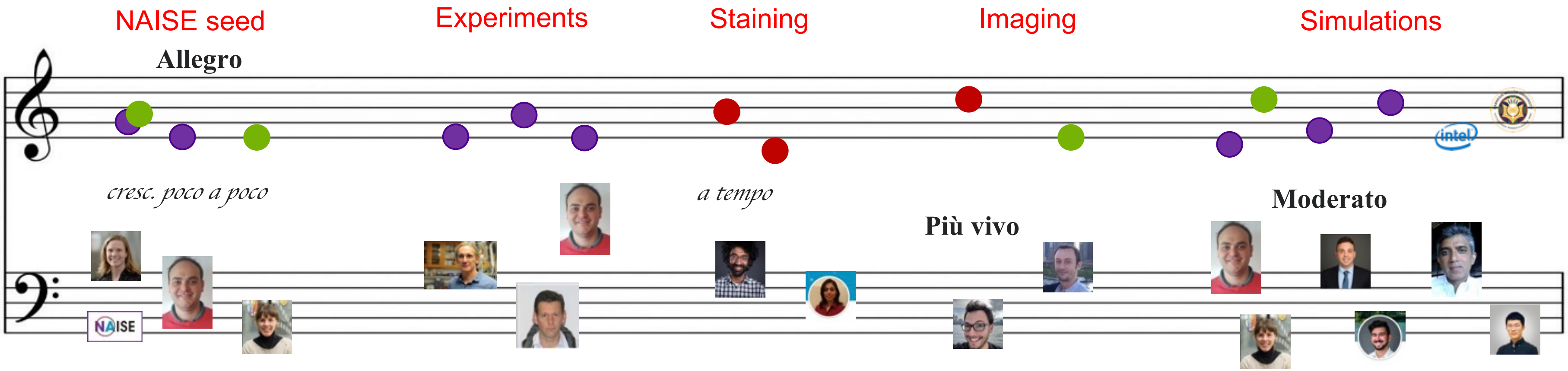
THE UNIVERSITY OF CHICAGO

CONNECT THE DOTS

The Spinal Cord Song







THE ONE WITH THE SPINAL CORD

THE SPINAL CORD

- The spinal cord is a cylindrical shaped bundle of nerve fibers that is connected to the brain at the brain stem.
- The spinal cord runs down the center of the protective spinal column extending from the neck to the lower back.
- The brain and spinal cord are the major components of the central nervous system (CNS).
- The CNS is the processing center for the nervous system, receiving information from and sending information to the peripheral nervous system.


Illustration of spinal cord cross-section. PIXOLOGICSTUDIO/Science Photo Library/Getty Images

Types of Cells

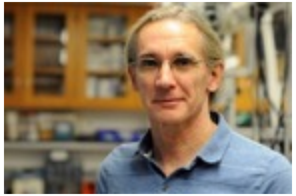
There are **two types of cells** in the peripheral nervous system. These cells carry information to (sensory nervous cells) and from (motor nervous cells) the CNS.

- Cells of the **sensory nervous system** send information to the CNS from internal organs or from external stimuli.
- **Motor nervous system** cells carry information from the CNS to organs, muscles, and glands.

Web: ThoughtCo.
https://www.thoughtco.com/the-spinal-cord-373189

Nógrádi, Antal. "Anatomy and Physiology of the Spinal Cord." *Current Neurology and Neuroscience Reports.*, U.S. National Library of Medicine, www.ncbi.nlm.nih.gov/books/NBK6229/.

"Spinal Cord Injury: Hope Through Research." *National Institute of Neurological Disorders and Stroke*, U.S. Department of Health and Human Services, www.ninds.nih.gov/Disorders/Patient-Caregiver-Education/Hope-Through-Research/Spinal-Cord-Injury-Hope-Through-Research.



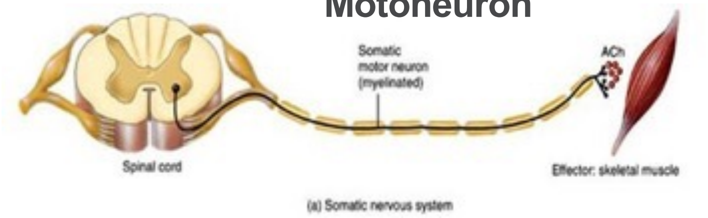
THE HECKMAN LABORATORY & SPINAL CORD RESEARCH

Northwestern Medicine
Feinberg School of Medicine

The basic element for motor control is the **motor unit**. A motor unit consists of a motoneuron in the ventral portion of the spinal cord, its axon that travels in the appropriate nerves, and the set of muscle fibers the axon innervates in its target muscle. The Heckman lab studies the motor unit and the spinal circuits that help generate motor unit firing patterns in both normal and pathological states. We are particularly interested in amplification of synaptic input by voltage-sensitive conductances in dendrites of spinal motoneurons and interneurons.

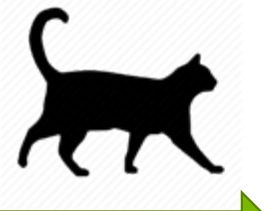
Motoneuron

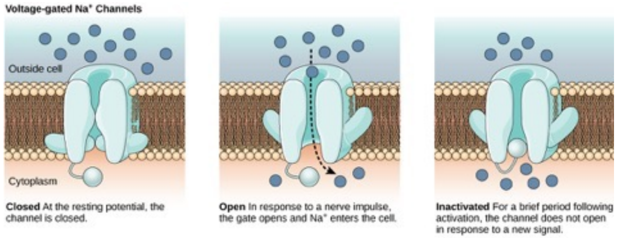
Johnson, M. D., Kajtaz, E., Cain, C. M., & Heckman, C. J. (2013). Motoneuron intrinsic properties, but not their receptive fields, recover in chronic spinal injury. ***The Journal of Neuroscience***, *33*(48), 18806–18813.



Motor Control

Johnson, M. D., Hyngstrom, a. S., Manuel, M., & Heckman, C. J. (2012). Push-Pull Control of Motor Output. ***Journal of Neuroscience***, *32*(13), 4592–4599.

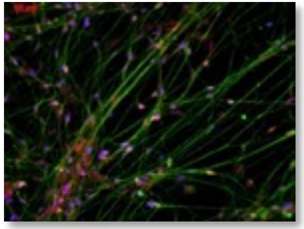




https://cnx.org/contents/cs_Pb-GW@5/How-Neurons-Communicate

Powers, R. K., & Heckman, C. J. (2017). Synaptic control of the shape of the motoneuron pool input-output function. ***Journal of Neurophysiology***, jn.00850.2016.

Spinal Circuits



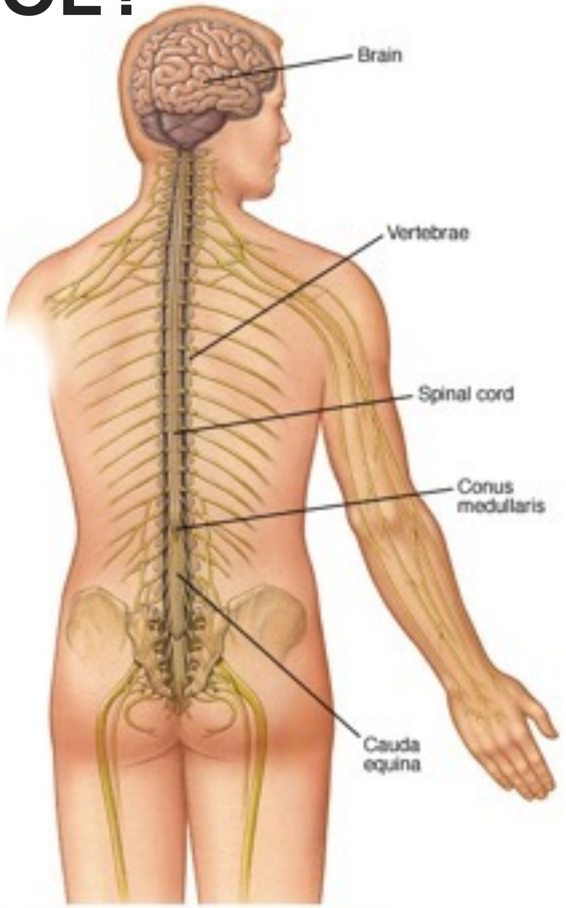
Hyngstrom, A. S., Johnson, M. D., Miller, J. F., & Heckman, C. J. (2007). Intrinsic electrical properties of spinal motoneurons vary with joint angle. ***Nature Neuroscience***, *10*(3), 363–369.

WHAT EXPERIMENTAL PROTOCOL?

Map of the spinal cord motorpools

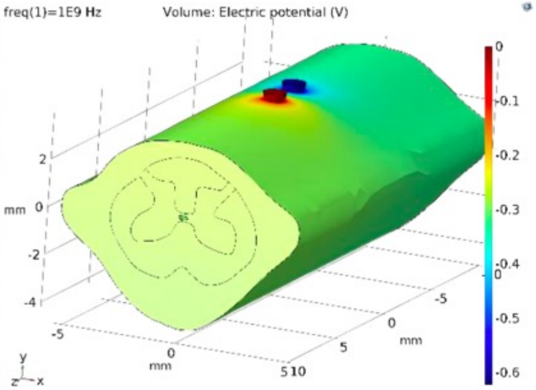
The idea
If you stimulate the spinal cord at a certain location you should be able to see that muscle turn on.

Objective
Build a map of how to stimulate the spinal cord to create functional motion.



SPINAL CORD STIMULATOR

Specific objective



Left image shows a typical spinal cord stimulator. These stimulators are therapeutically used to provide analgesic relief to patients.

Central image shows a finite element electromagnetic model of a feline spinal cord surrounded by a cerebral spinal fluid layer. A bipolar electrode is shown on top and the electric field they generated are shown in color. The ultimate goal of this proposal is to predict the neural activity of the spinal circuits within the spinal cord given the stimulation provided by the bipolar electrode.

Right image Human Spine Blueprint. This is a detailed blueprint of a human spine showing the side view with different regions and vertebrae labeled. (wetcake/Getty Image)

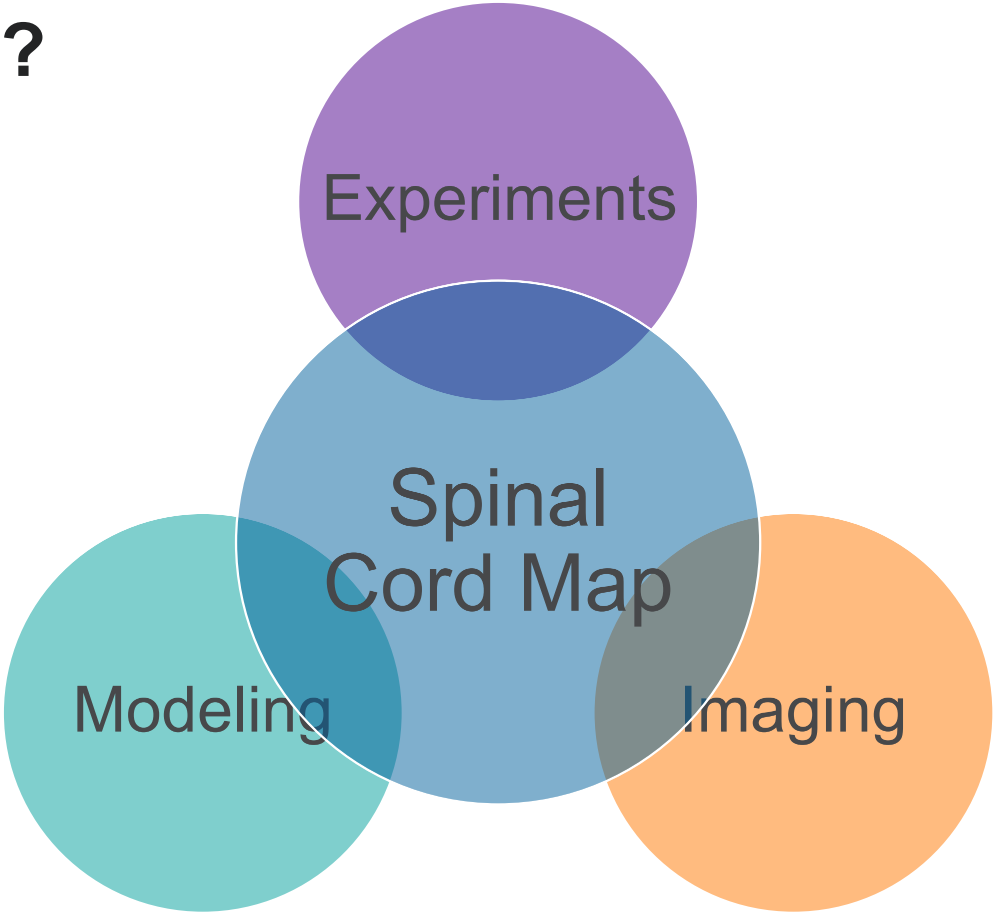
WOULD IT BE USEFUL?

- Well established market for pain
  - 30,000 implants/year
  - 1.8 Billion USD
  - 50% do not work
  - No placebo studies
  - Hard to measure

- SCI Autonomic system: bladder control, blood pressure, etc.

- SCI Motor system: believe to be best model as it is can be measured in animal models easily.

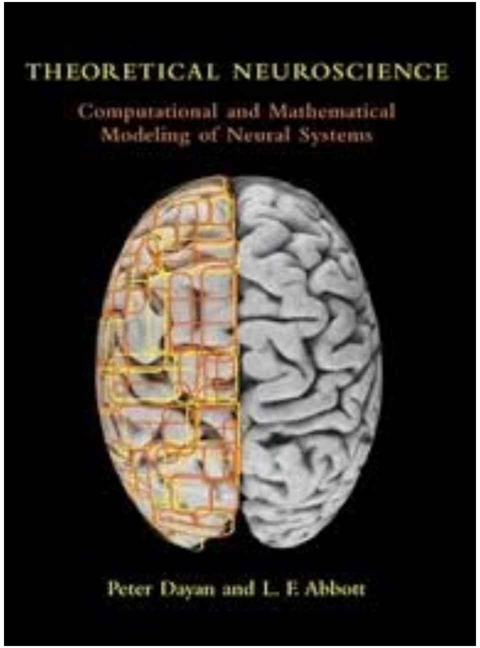
SCI = Spinal Cord Injury



THE ONE WITH THE NEURONS

THEORETICAL NEUROSCIENCE

1. Neural Encoding I: Firing Rates and Spike Statistics



1.1 Introduction

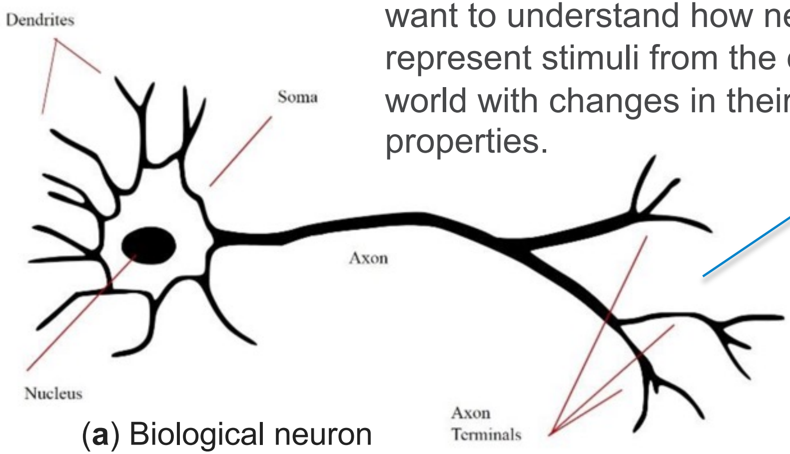
*Neurons are remarkable among the cells of the body in their ability to propagate signals rapidly over large distances. They do this by generating characteristic electrical pulses called **action potentials** or, more simply, **spikes** that can travel down nerve fibers.*

Neurons represent and transmit information by firing sequences of spikes in various temporal patterns.

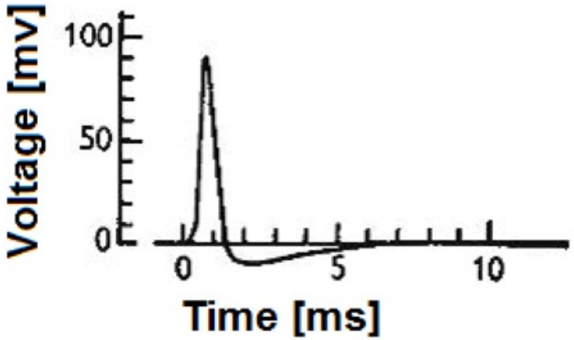
*The study of **neural coding** involves measuring and characterizing how stimulus attributes, such as light or sound intensity, or **motor actions**, such as the direction of an arm movement, are represented by action potentials.*

NEURONS

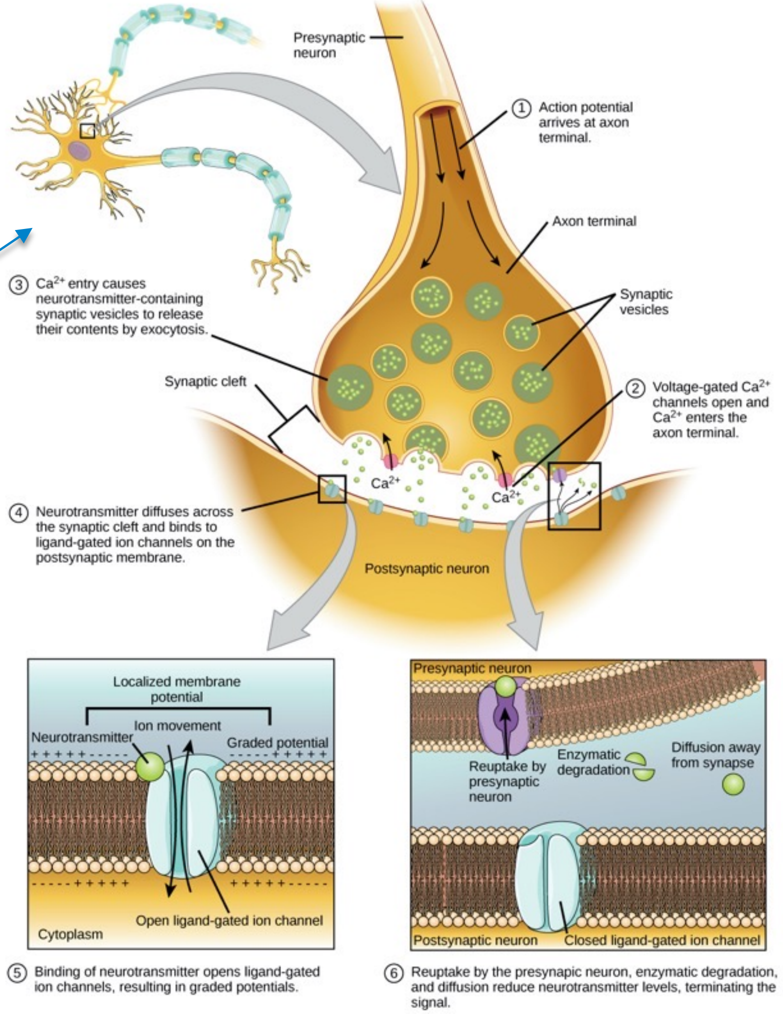
Neuroscientists are interested in knowing what neurons are doing. More specifically, researchers want to understand how neurons represent stimuli from the outside world with changes in their firing properties.



(**a**) Biological neuron

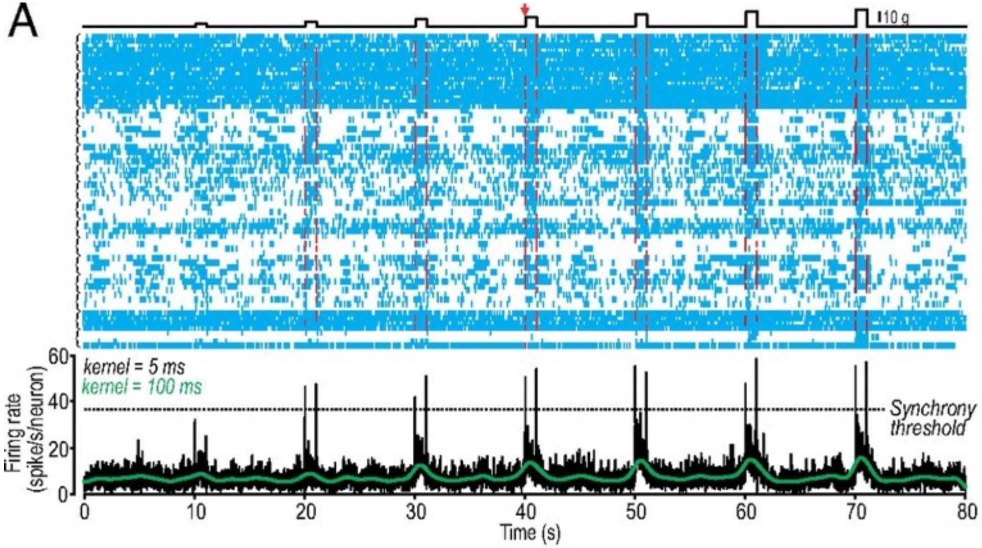


(**b**) Action potential voltage spike



https://cnx.org/contents/cs_Pb-GW@5/How-Neurons-Communicate

EXAMPLE WITH SOUND



Differentially synchronized spiking enables multiplexed neural coding
Milad Lankarany, Dhekra Al-Basha, Stéphanie Ratté, and Steven A. Prescott
PNAS May 14, 2019 116 (20) 10097-10102

Fig 1

Neurons in primary somatosensory (S1) cortex use spike timing and rate to encode different tactile stimulus features.

(A) Rasters from 17 neurons, four trials each, during tactile simulation (Top). FRH was calculated using a narrow (σ = 5 ms; black) or broad (σ = 100 ms; green) Gaussian kernel. Black FRH was thresholded to distinguish synchronous (red) from asynchronous (blue) spikes. Arrow highlights 10 g stimulus.

HOW MANY NEURONS ARE IN THE SPINAL CORD?

ABSTRACT: In the cynomolgus **monkey spinal cord**, the isotropic fractionator and stereology yielded **206–275 million cells**, of which 13.3–25.1% were neurons (28–69 million). Stereological estimates yielded 21.1% endothelial cells and 65.5% glial cells (glia-neuron ratio of 4.9–5.6).

In **human spinal cords**, the isotropic fractionator and stereology generated estimates of **1.5–1.7 billion cells** and 197–222 million neurons (13.4% neurons, 12.2% endothelial cells, 74.8% glial cells), and a glia-neuron ratio of 5.6–7.1, with estimates of neuron numbers in the human spinal cord based on morphological criteria.

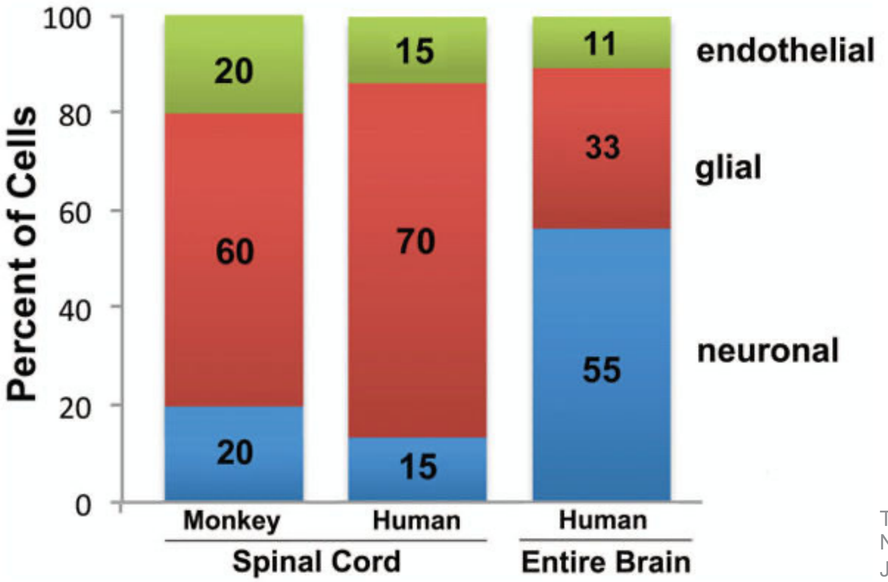


Fig. 5.
Cellular composition of the spinal cord in cynomolgus monkey and human compared with the composition in an entire human brain, showing the relative percentage of **neurons** (blue), **glial cells** (red) and **endothelial cells** (green), based on the data obtained in the current study.

Approximate percentages are indicated on the columns. The bar for the entire human brain adds to 99%, not 100%, due to rounding.

The cellular composition in the spinal cord differed considerably from that in the entire brain, and was most similar to the composition found in the brainstem ("rest of brain").

The Cellular Composition and Glia-Neuron Ratio in the Spinal Cord of a Human and a Nonhuman Primate: Comparison With Other Species and Brain Regions.
Jami Bahney & Christopher von Bartheld. November 2017 *The Anatomical Record Advances in Integrative Anatomy and Evolutionary* Biology 301(4) DOI: 10.1002/ar.23728

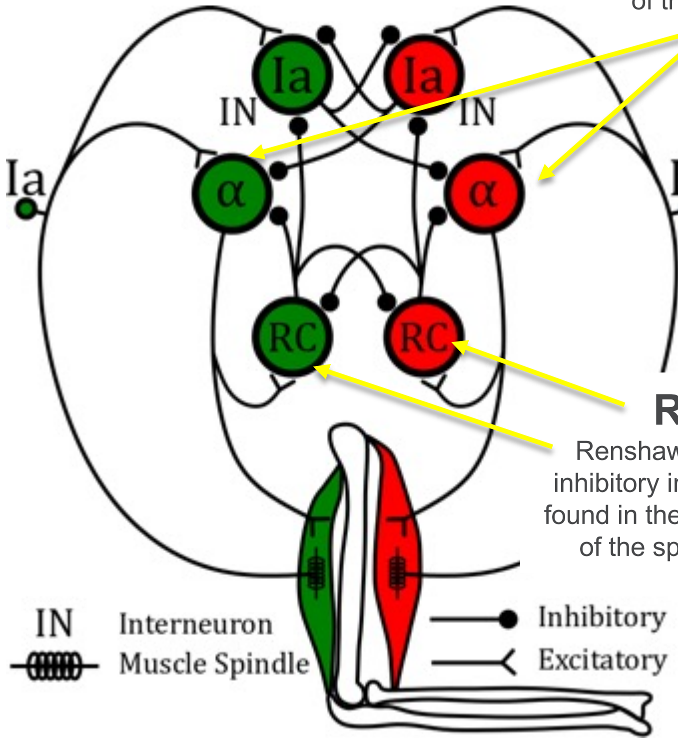
CANONICAL MOTOR MICROCIRCUIT (CMM)

Model choice

- **Fundamental**: Basis for locomotion (reciprocal inhibition),
- **Understandable:** Large background of its structure (motorpools location),
- **Accessible**: Highest sensitivity to activation by DES are almost certainly the Ia axons arising in muscle spindles (large diam fiber).
- **Generalizable**: Circuit is repeated throughout the spinal cord.

α

Main controller of the muscles

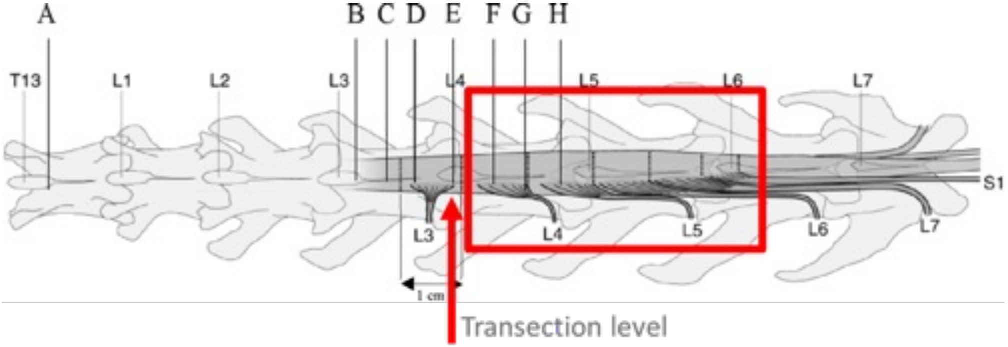


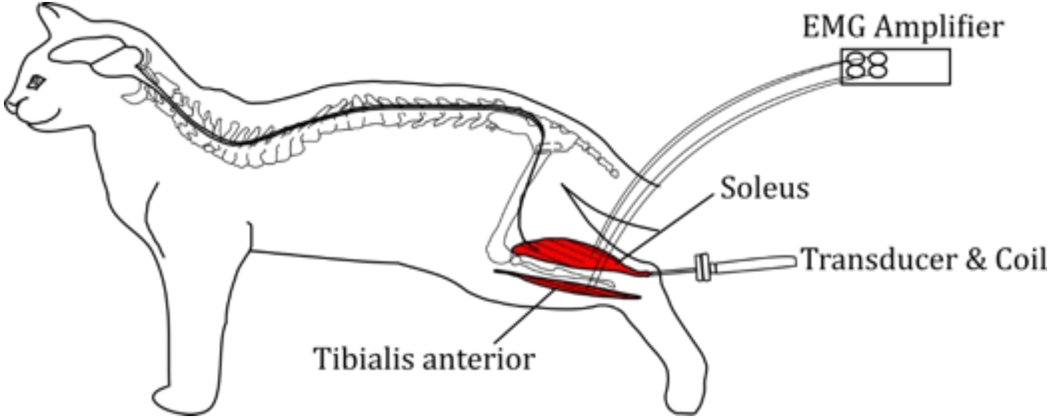
RC

Renshaw cells are inhibitory interneurons found in the gray matter of the spinal cord.

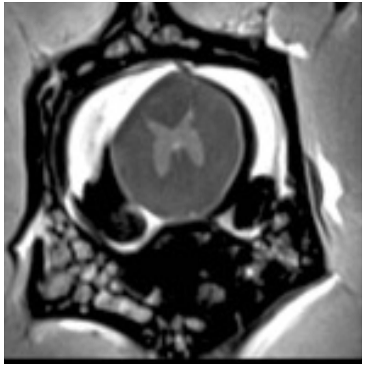
THE ONE WITH THE EXPERIMENTS

GENERAL MOTORPOOL MAP OF THE LUMBAR REGION





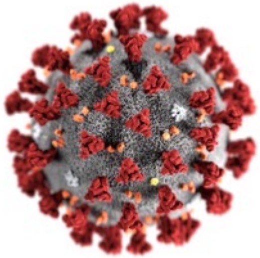
SPINAL CORD SAMPLES



7T MRI Image of Cat Lumbar Spinal Cord

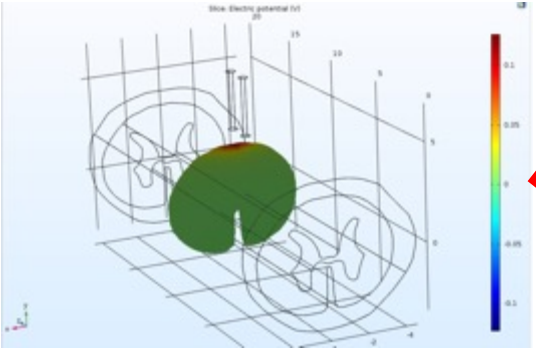
- All post-mortem feline spinal cord tissues were collected at the Feinberg School of Medicine (NU) by collaborator Matthieu K. Chardon
- This study was conducted following NU protocols for experiments and tissue sample extraction.

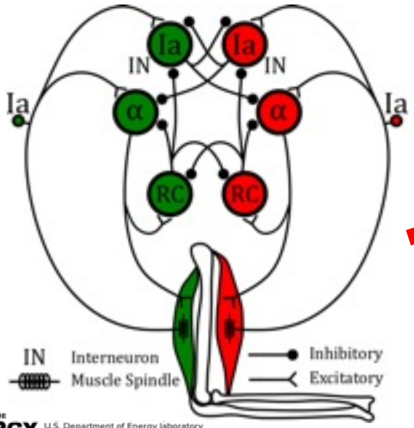
COVID-19 → Labs closed

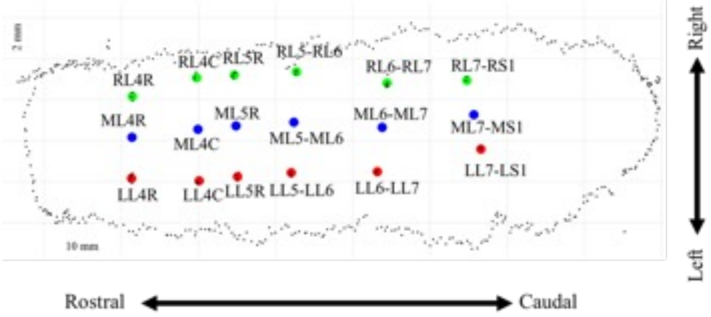


FINAL GOAL

To use imaging and to computational neuroscience to predict where we should stimulate and come up with paradigms to control the muscles in an effective way.





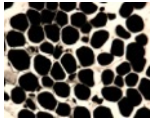


THE ONE WITH THE STAINING

Staining

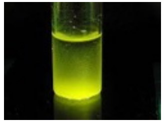
SPINAL CORD TISSUE SAMPLES STAINED

The tissue samples are stained with **heavy metals** including multiple rounds of **osmium tetroxide** followed by **uranyl acetate** and **lead**.



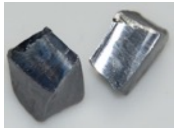
OsO_4

highly poisonous!

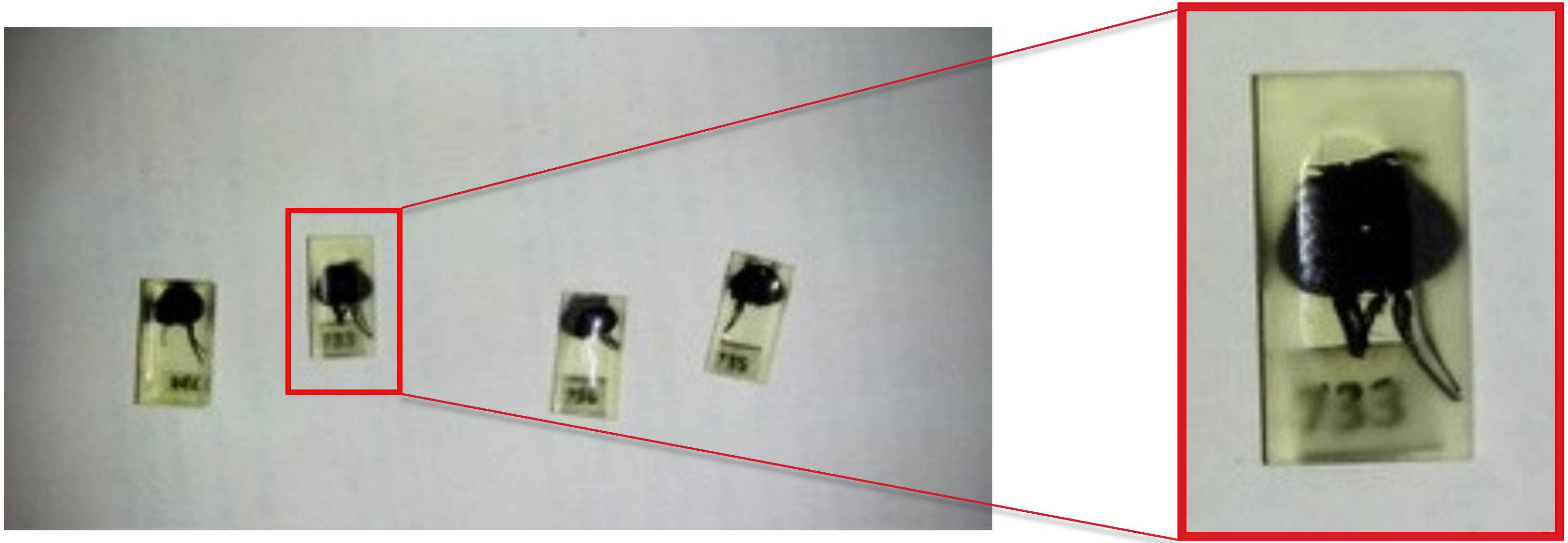


UA

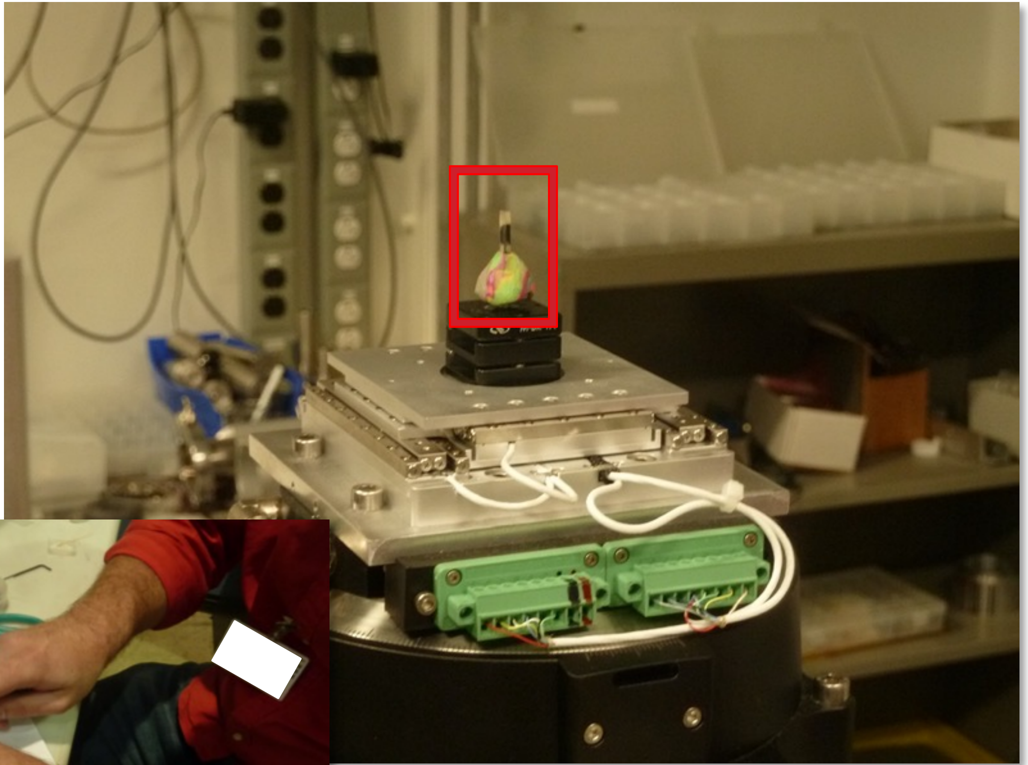
$\{[UO_2(CH_3CO_2)_2H_2O)]H_2O\}_n$



Pb



SAMPLE CHANGES



Cut the sample to get a “carrot” or cylindrical shape

THE ONE WITH THE IMAGING “TOOLS”

X-ray microtomography (µCT)

Technique provides mesoscale anatomy, of neurons, glial cells and vasculature, at an isometric resolution of ~1µm^3 using large tissue samples (1-2 mm thickness)

APS-U in the news!!

Advanced Photon Source Upgrade

*In the almost **25 years** since the Advanced Photon Source (APS), a U.S. Department of Energy (DOE) Office of Science User Facility*

*As the APS readies to undergo an **$815 million** upgrade that will, as early as late-2023, enable science at a completely new and unprecedented scale,*

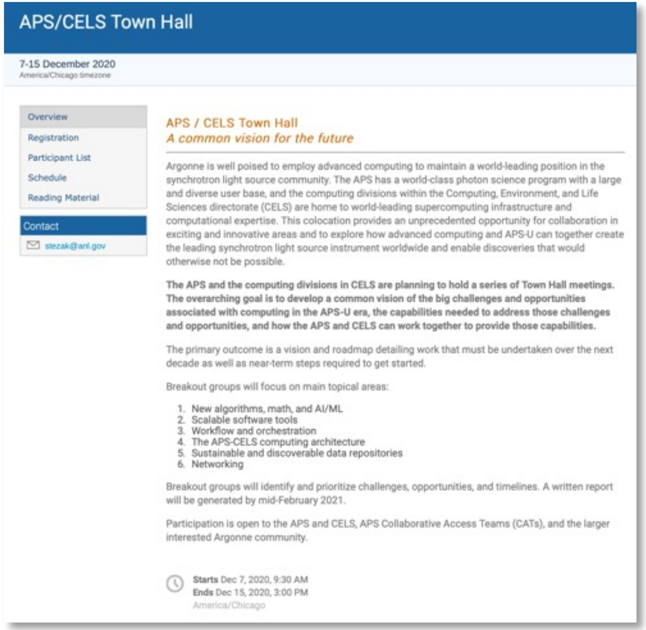
*More than **5,000 researchers** from around the world conduct experiments at the APS **every year***

> *"The APS Upgrade will allow us to conduct new experiments that we can barely even imagine right now. It will be transformational." — Jonathan Lang, the APS X-ray Science Division (XSD) director*

*"We want to ensure the APS is relevant **for another 25 years**," Lang said.*

https://www.aps.anl.gov/APS-Upgrade
https://www.anl.gov/article/advanced-photon-source-upgrade-will-transform-the-world-of-scientific-research

APS/CELS Town Halls



APS/CELS Town Hall

7-15 December 2020
America/Chicago timezone

Overview
Registration
Participant List
Schedule
Reading Material

Contact
stezak@anl.gov

APS / CELS Town Hall
A common vision for the future

Argonne is well poised to employ advanced computing to maintain a world-leading position in the synchrotron light source community. The APS has a world-class photon science program with a large and diverse user base, and the computing divisions within the Computing, Environment, and Life Sciences directorate (CELS) are home to world-leading supercomputing infrastructure and computational expertise. This colocation provides an unprecedented opportunity for collaboration in exciting and innovative areas and to explore how advanced computing and APS-U can together create the leading synchrotron light source instrument worldwide and enable discoveries that would otherwise not be possible.

The APS and the computing divisions in CELS are planning to hold a series of Town Hall meetings. The overarching goal is to develop a common vision of the big challenges and opportunities associated with computing in the APS-U era, the capabilities needed to address those challenges and opportunities, and how the APS and CELS can work together to provide those capabilities.

The primary outcome is a vision and roadmap detailing work that must be undertaken over the next decade as well as near-term steps required to get started.

Breakout groups will focus on main topical areas:

1. New algorithms, math, and AI/ML
2. Scalable software tools
3. Workflow and orchestration
4. The APS-CELS computing architecture
5. Sustainable and discoverable data repositories
6. Networking

Breakout groups will identify and prioritize challenges, opportunities, and timelines. A written report will be generated by mid-February 2021.

Participation is open to the APS and CELS, APS Collaborative Access Teams (CATs), and the larger interested Argonne community.

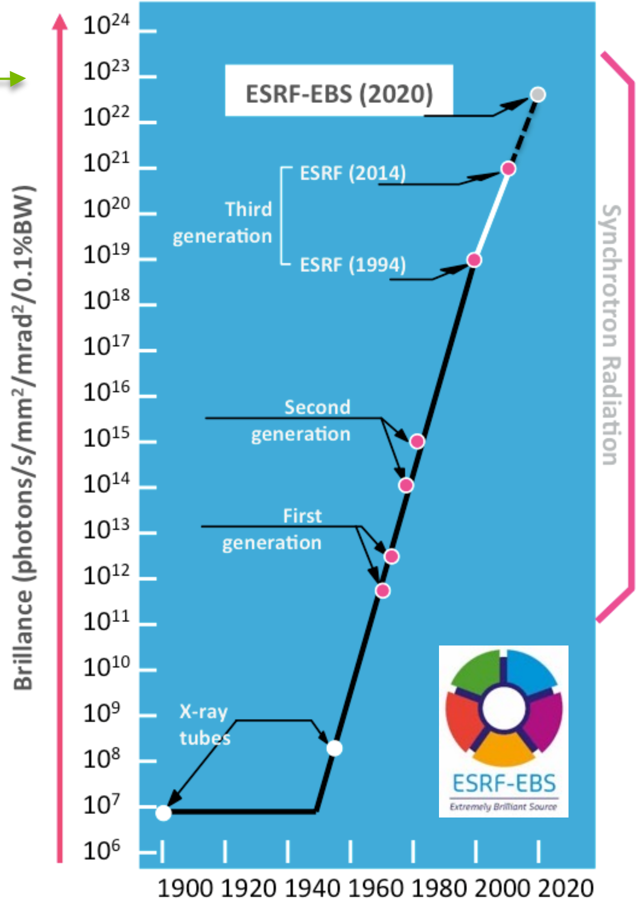
Starts Dec 7, 2020, 9:30 AM
Ends Dec 15, 2020, 3:00 PM
America/Chicago

The upgraded APS will be able to generate **X-rays up to 500 times brighter** than those created by the current APS.

IMAGING "TOOLS"

High Energy Synchrotrons

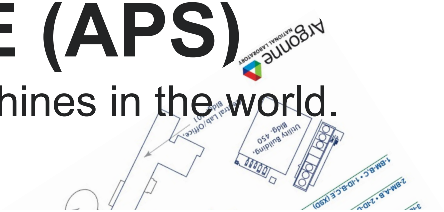
Name	Location	City / Country	Generation
ESRF		Grenoble (FRANCE)	4th gen 2021
APS	ANL	Lemont (USA)	4th gen ~2023
Spring-8		Sayo (JAPAN)	
NSLS	BNL	Upton (USA)	
Diamond II	DLS	Oxford (UK)	4th gen ~2025
PETRA IV	DESY	Hamburg (GERMANY)	
SOLEIL		Paris (FRANCE)	
SSRF		Shanghai (CHINA)	

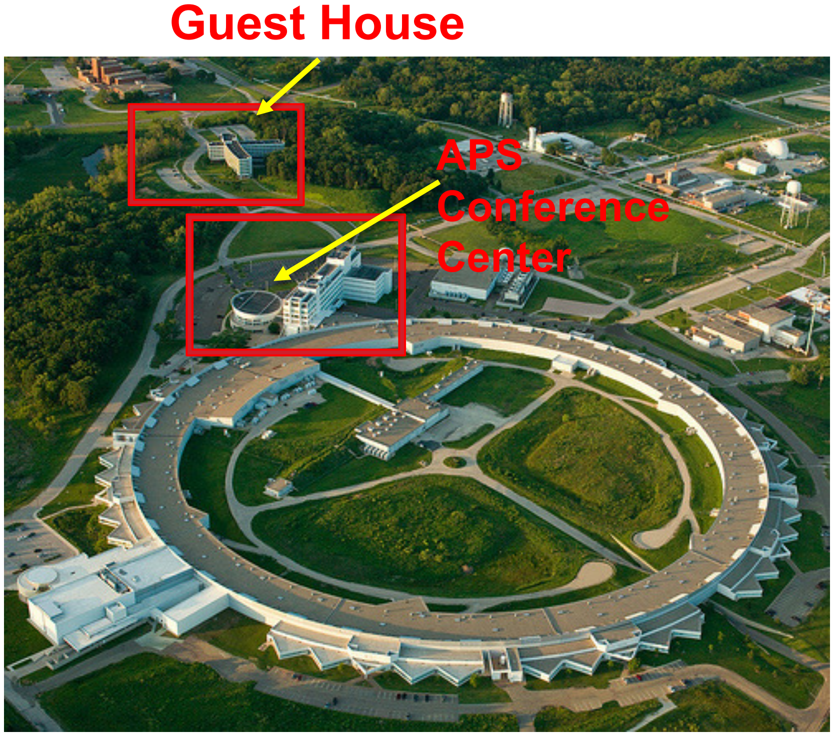


https://www.esrf.fr/home/UsersAndScience/Accelerators.html

ADVANCED PHOTON SOURCE (APS)

The APS is one of the most technologically complex machines in the world.





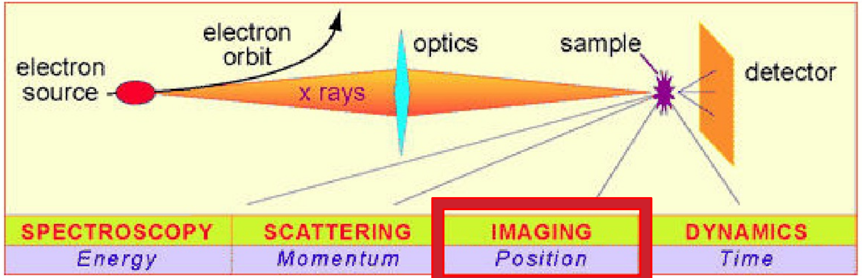
Aerial View APS

This premier national research facility provides **ultra-bright**, **high-energy X-ray beams** that enable the collection of data in unprecedented detail and in amazingly short time frames.

Electrons are accelerated to over 99 percent of the speed of light around its **ring**, which is the **size of a baseball stadium**.

More than 5,700 scientists come to the APS each year from academia, industry, medical schools, and other research institutions to conduct experiments that promise new discoveries in nearly every scientific discipline.

ADVANCED PHOTON SOURCE (APS)



Spectroscopy

Spectroscopy is used to study the energies of particles that are emitted or absorbed by samples that are exposed to the light-source beam and is commonly used to determine the characteristics of chemical bonding and electron motion.

Scattering

Scattering makes use of the patterns of light produced when x-rays are deflected by the closely spaced lattice of atoms in solids and is commonly used to determine the structures of crystals and large molecules such as proteins.

Imaging

Imaging techniques use the light-source beam to obtain pictures with fine spatial resolution of the samples under study and are used in diverse research areas such as cell biology, lithography, infrared microscopy, radiology, and x-ray tomography.

Inside View from above the beamlines

https://www.aps.anl.gov/Beamlines/Research-Techniques

APS BEAMLINES

https://www.aps.anl.gov/Beamlines

Beamline	Disciplines	Techniques	Energy Range	Access	Operator	Status
2-BM-A,B	• Physics • Life Sciences • GeoScience • Materials Science	• Tomography • Phase contrast imaging	• 10-170 keV • 11-35 keV	• On-site	XSD	●
2-ID-D	• Life Sciences • Materials Science • Environmental Science	• Microfluorescence • Micro x-ray absorption fine structure • Nano-imaging • Ptychography	• 5-30 keV	• On-site	XSD	●
2-ID-E	• Life Sciences • Environmental Science • Materials Science	• Microfluorescence • Tomography	• 5-20 keV • keV	• On-site	XSD	●
...						
32-ID-B,C	• Materials Science • Life Sciences • GeoScience	• Phase contrast imaging • Radiography • Transmission x-ray microscopy • Tomography	• 7-40 keV	• On-site	XSD	●

2-BM-A,B • 2-ID-D • 2-ID-E (XSD)

32-ID-B,C (XSD)

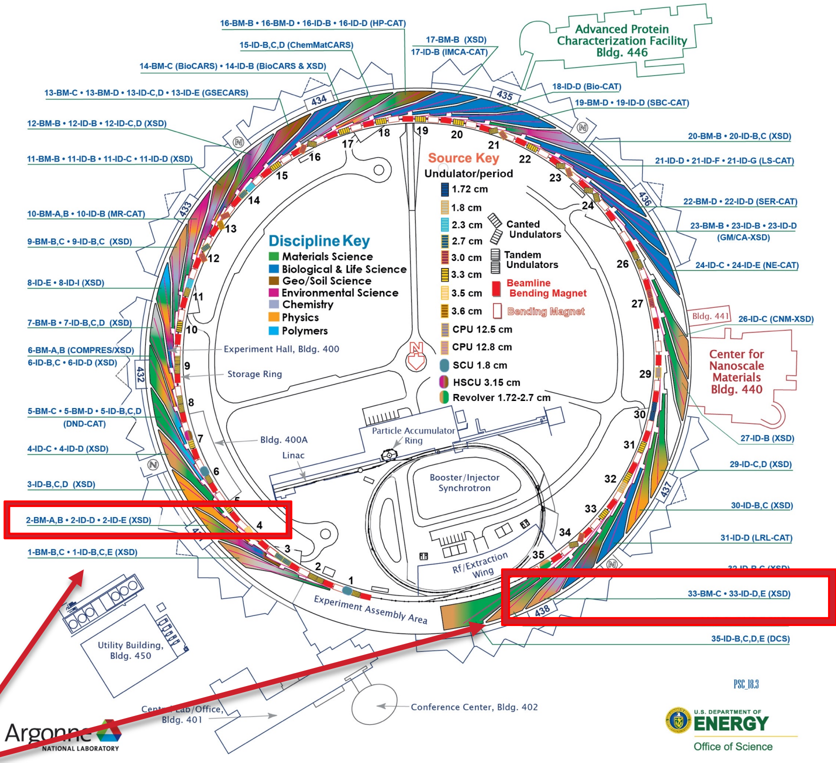
ARGONNE NATIONAL LABORATORY 400-AREA FACILITIES

ADVANCED PHOTON SOURCE

(Beamlines, Disciplines, and Source Configuration)

ADVANCED PROTEIN CHARACTERIZATION FACILITY

CENTER FOR NANOSCALE MATERIALS



TOMOGRAPHY

XSD-IMG: 2-BM-A,B

Welcome to 2-BM-A,B

The sector 2 bending magnet beamline is fully dedicated to microtomography with capability to perform large field of view (20x2 mm^2) fast 2D phase contrast imaging for slow dynamic phenomena studies (0.1m/s). The applications of this beamline range from life science [1], geoscience [2, 3], physics [4], material science and engineering [5, 6], and paleontology [7]. The flexibility of switching setups and capabilities of developing on-demand accessory experimental techniques make this beamline versatile in tomography applications.

Beamline Specs

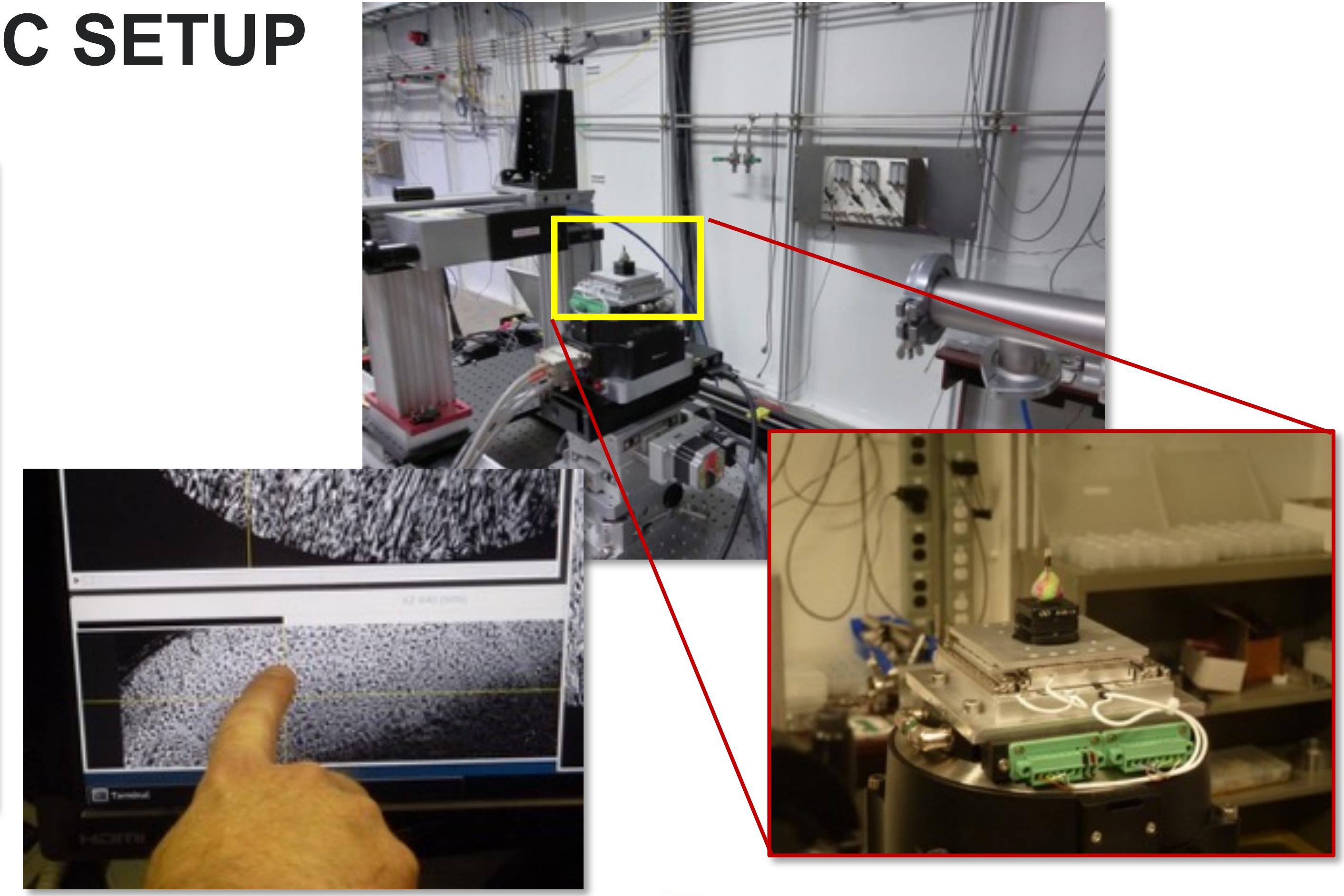
Source	Bending Magnet
Energy Range	11-35 keV
Beam Size	25mm x 4mm
Energy Resolution (ΔE/E)	1 x 1012 @17 keV

Types of tomography [edit]

Name	Source of data	Abbreviation	Year of introduction
Aerial tomography	Electromagnetic radiation	AT	2020
Atom probe tomography	Atom probe	APT	
Computed tomography imaging spectrometer[2]	Visible light spectral imaging	CTIS	
Computed tomography of chemiluminescence[3][4][5]	Chemiluminescence Flames	CTC	2009
Confocal microscopy (Laser scanning confocal microscopy)	Laser scanning confocal microscopy	LSCM	
Cryogenic electron tomography	Cryogenic transmission electron microscopy	CryoET	
Electrical capacitance tomography	Electrical capacitance	ECT	1988[6]
Electrical capacitance volume tomography	Electrical capacitance	ECVT	
Electrical resistivity tomography	Electrical resistivity	ERT	
Electrical impedance tomography	Electrical impedance	EIT	1984
Electron tomography	Transmission electron microscopy	ET	1968[7][8]
Focal plane tomography	X-ray		1930s
Functional magnetic resonance imaging	Magnetic resonance	fMRI	1992
Hydraulic tomography	fluid flow	HT	2000
Infrared microtomographic imaging[9]	Mid-infrared		2013
Laser Ablation Tomography	Laser Ablation & Fluorescent Microscopy	LAT	2013
Magnetic induction tomography	Magnetic induction	MIT	
Magnetic particle imaging	Superparamagnetism	MPI	2005
Magnetic resonance imaging or nuclear magnetic resonance tomography	Nuclear magnetic moment	MRI or MRT	
Muon tomography	Muon		
Microwave tomography[10]	Microwave (1-10 GHz electromagnetic radiation)		
Neutron tomography	Neutron		
Ocean acoustic tomography	Sonar	OAT	
Optical coherence tomography	Interferometry	OCT	
Optical diffusion tomography	Absorption of light	ODT	
Optical projection tomography	Optical microscope	OPT	
Photoacoustic imaging in biomedicine	Photoacoustic spectroscopy	PAT	
Positron emission tomography	Positron emission	PET	
Positron emission tomography - computed tomography	Positron emission & X-ray	PET-CT	
Quantum tomography	Quantum state	QST	
Single photon emission computed tomography	Gamma ray	SPECT	
Seismic tomography	Seismic waves		
Terahertz tomography	Terahertz radiation	THz-CT	
Thermoacoustic imaging	Photoacoustic spectroscopy	TAT	
Ultrasound-modulated optical tomography	Ultrasound	UOT	
Ultrasound computer tomography	Ultrasound	USCT	
Ultrasound transmission tomography	Ultrasound		
X-ray computed tomography	X-ray	CT, CATScan	1971
X-ray microtomography	X-ray	microCT	
Zeeman-Doppler imaging	Zeeman effect		

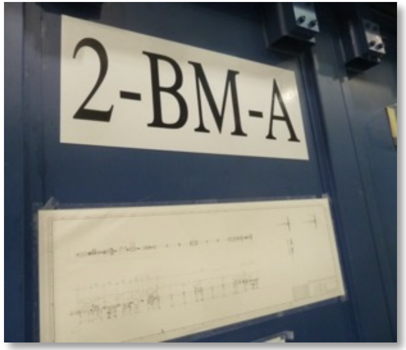
https://en.wikipedia.org/wiki/Tomography

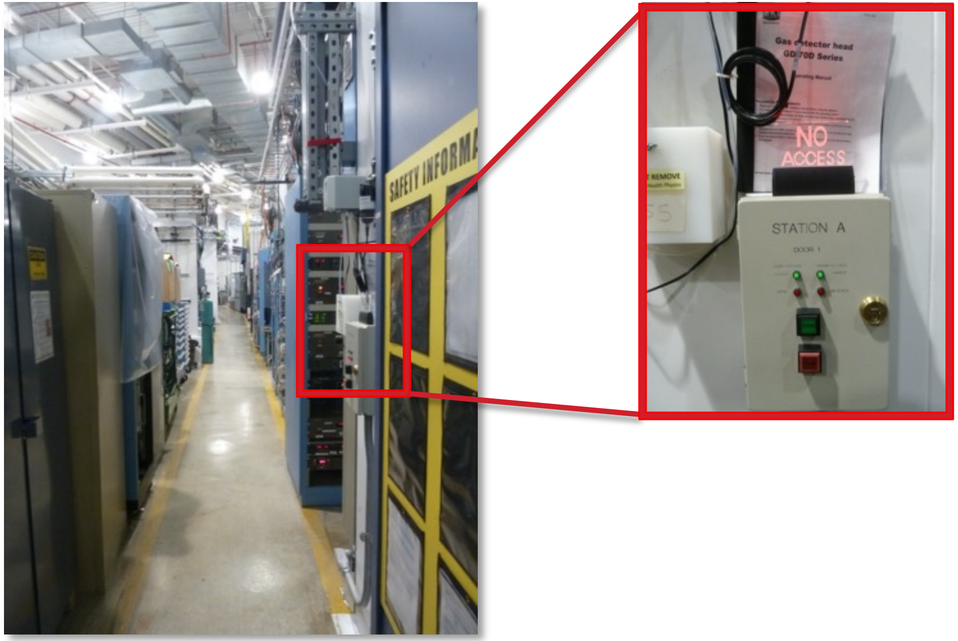
32-ID-C SETUP

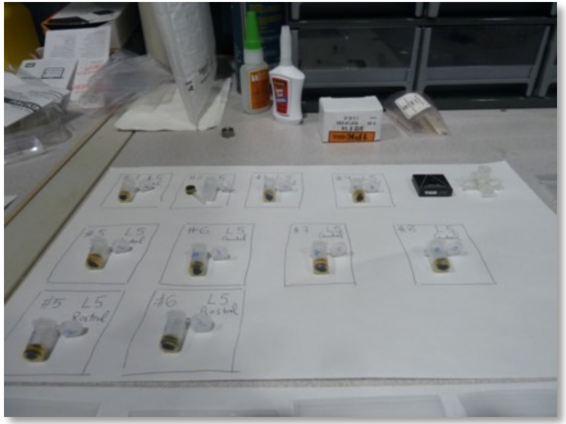


APS BEAMLINES

https://www.aps.anl.gov/Beamlines







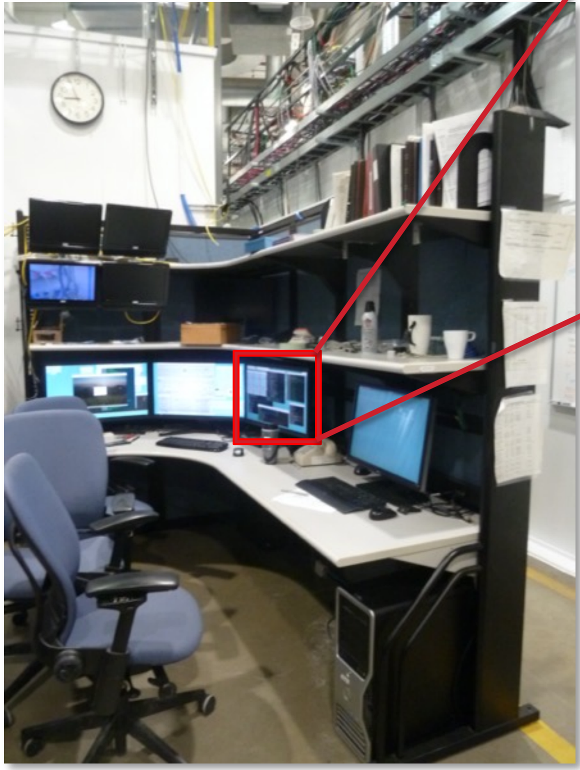
Samples

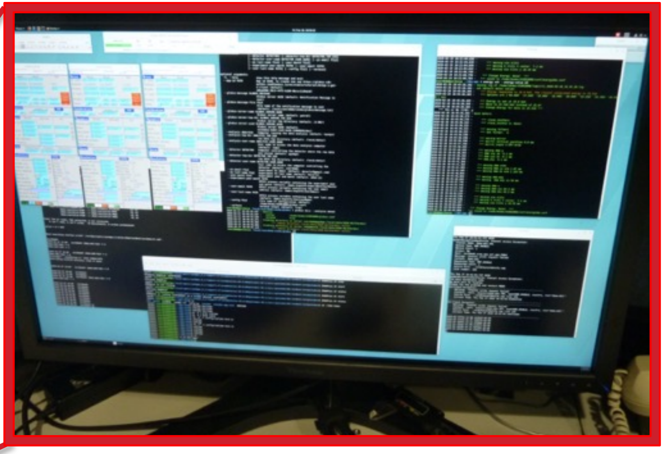
Inside Argonne | TMS - Training Profile

Course	Course Name	Status
APS101	APS Orientation	Completed
APS232	Sector 32 Orientation	Completed

A PEEK INSIDE APS

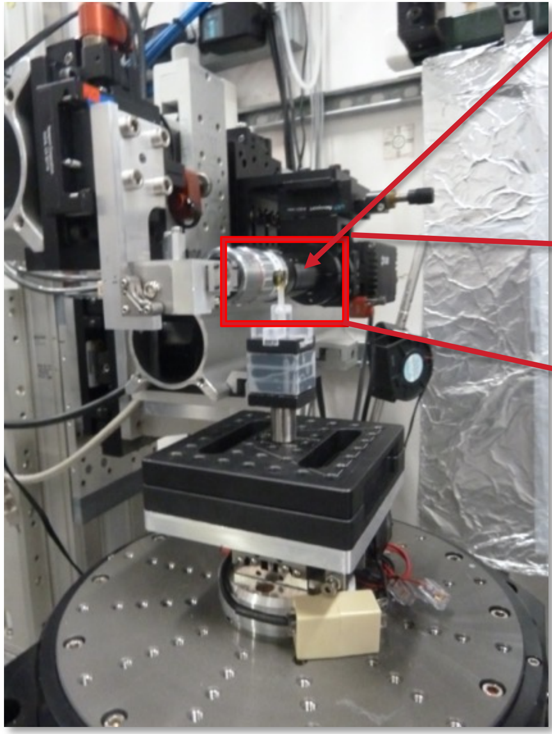
Beamline station

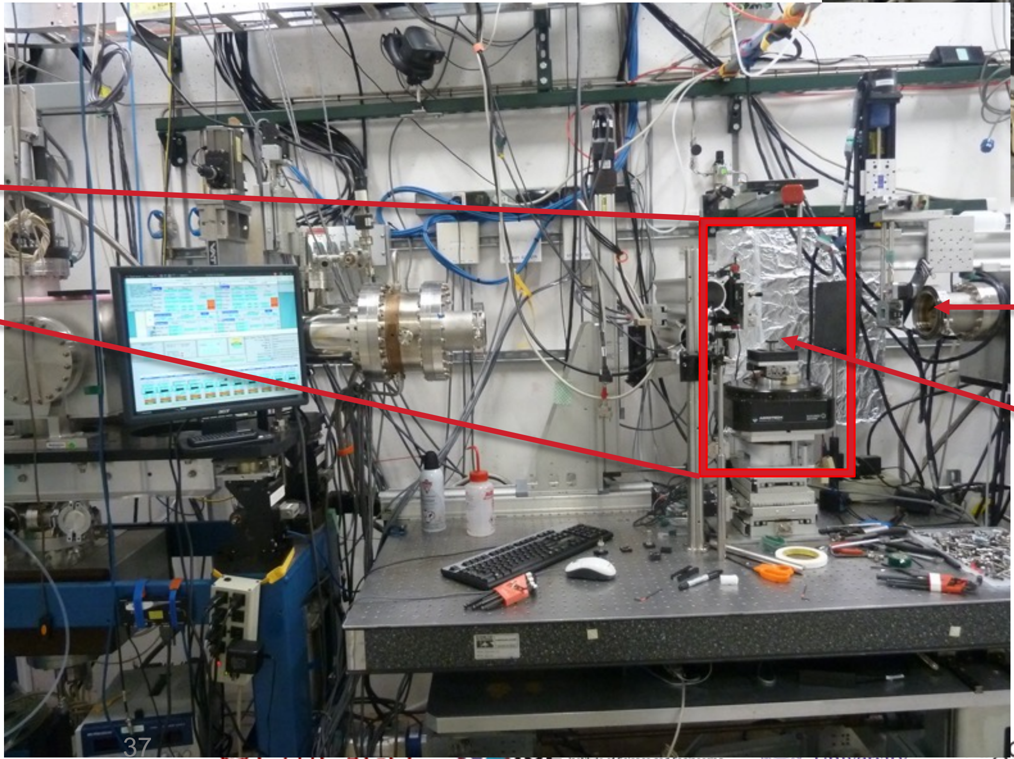




APS BEAMLINES

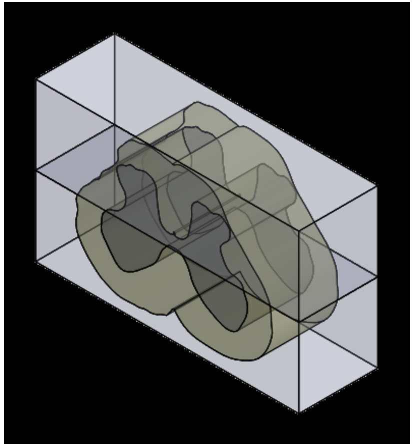
https://www.aps.anl.gov/Beamlines



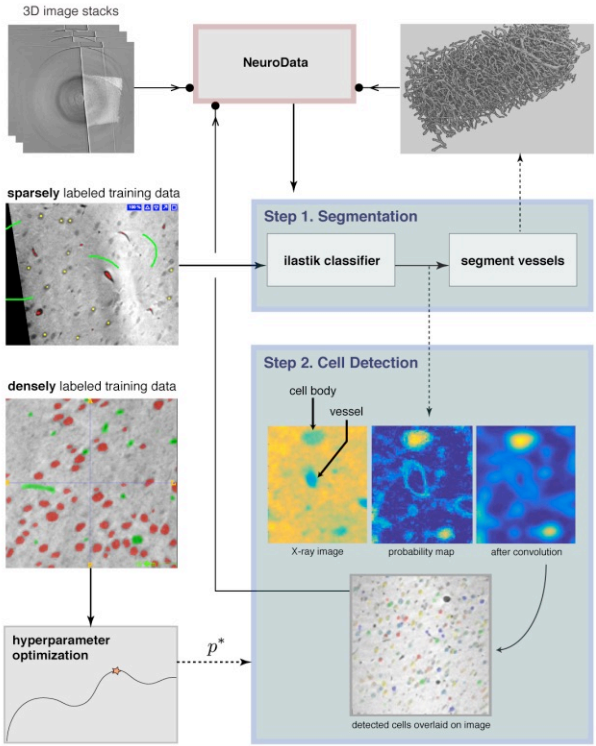


THE ONE WITH THE RECONSTRUCTION

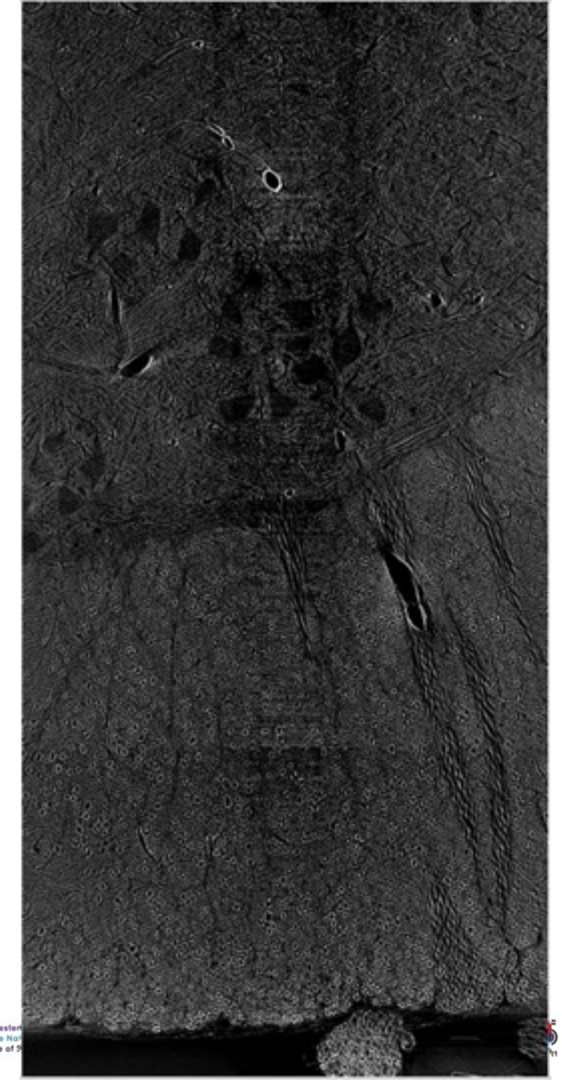
RECONSTRUCTION



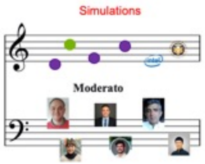
3D Reconstruction



Thanks to the collaboration with B. Kasthuri group at UChicago: Rafael Vescovi and Vandana Sampathkumar

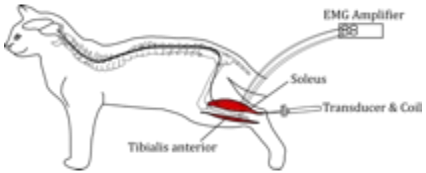


THE ONE WITH THE DEEP LEARNING



2019 NAISE SUMMER STUDENT: JOSHUA PRITZ

Feline Spinal Cord

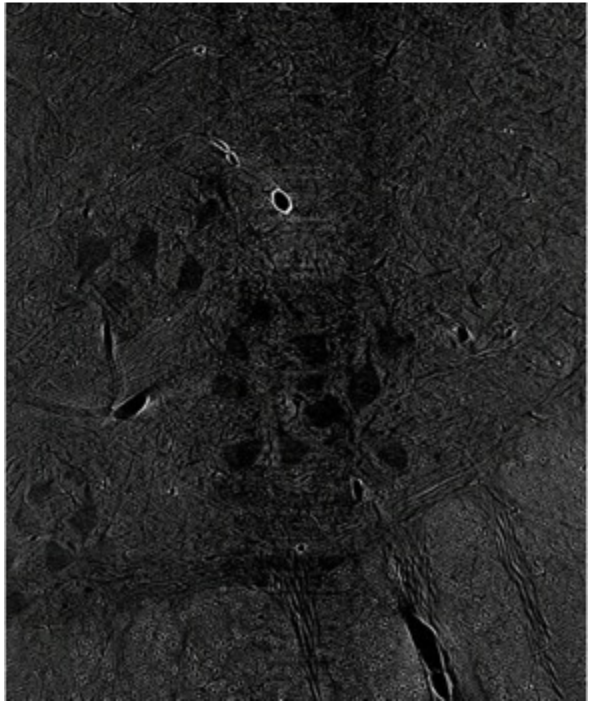


The Dataset

- Images of feline spinal cord obtained via X-ray microtomography
- Image corresponds to horizontal cross-section of spinal cord

Project Goals

- Aid in the 3D mapping of the feline spinal cord's relevant structures via image segmentation
- Develop Neural Network based segmentation approach to avoid time-consuming manual alternative
- Move machine learning program from MATLAB to Python
- Optimize resulting network with respect to segmentation metrics as well as computational resources



Images of Spinal Cord

MACHINE LEARNING AND SEMANTIC SEGMENTATION

Overview of Convolutional Neural Networks (CNNs)

- We employ the SegNet NN architecture to perform image segmentation
- Semantic segmentation is the process of assigning a **class label** to each pixel of an image
- Given an input image, a trained NN will return a predicted segmentation whose pixels can be classified as true positive, true negative, false positive, or false negative

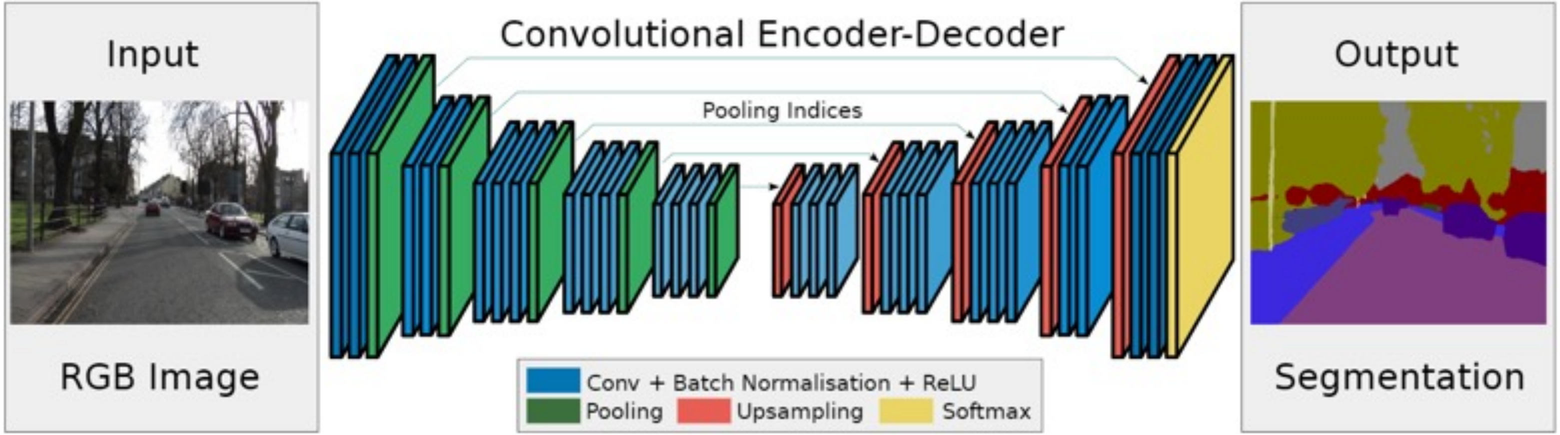


Illustration of SegNet Architecture

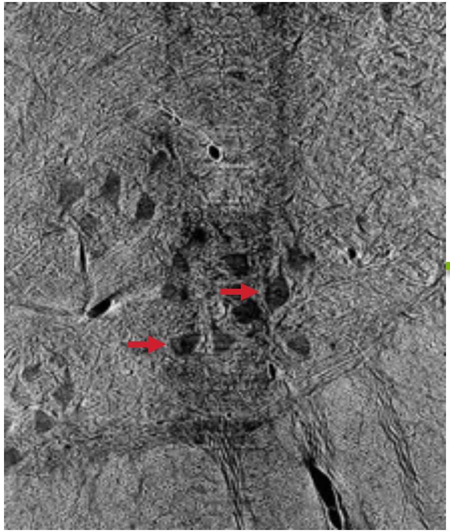
(2016) https://arxiv.org/pdf/1511.00561.pdf

IMAGE SEGMENTATION

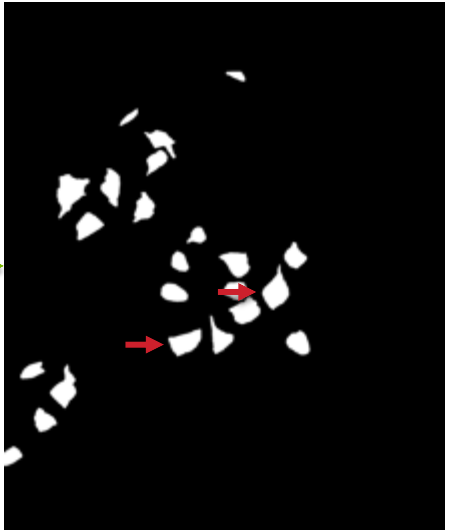
Goals and Related Metrics

- **Step 1**: Train the network, manual annotation of somas.
- **Step 2**: Find metrics to track accuracy/correctness

what is correctness??



Raw Image (F0001)



Segmented Image
showing ground truth

Segmentation Metrics

$$Accuracy = \frac{Correctly\ Segmented\ Pixels}{Total\ Pixels}$$

$$= \frac{TP + TN}{TP + TN + FP + FN}$$

$$IoU = \frac{Target \cap Prediction}{Target \cup Prediction}$$

Intersection over Union

$$= \frac{TP}{TP + FP + FN}$$

$$BF1 \sim \frac{1}{|B_{ps}|} \sum_{z \in B_{ps}^{c}} \left[\left[d\left(z, B_{gt}^{c}\right) < \theta\right]\right]$$

COMPUTATIONAL RESOURCES

@ ANL

Bebop (LCRC)	www.lcrc.anl.gov/systems/resources/bebop/
Partition	BDWALL (Intel Broadwell)
CPU Type	Intel Xeon E5-2695v4
Cores per Node	36
Memory per Node	128GB DDR4

Cooley (ALCF)	www.alcf.anl.gov/support-center/cooley/cooley-system-overview
Architecture	Intel Haswell
GPU Type	NVIDIA Tesla K80
GPUs per Node	2
Memory per GPU	12GB RAM

- Initial training runs focused on reducing computational time and tuning hyperparameters
- Despite CPU based architecture, Bebop offers an approximate two-fold decrease in training time per epoch
- Also used initial training to determine upper bound on epochs needed for convergence

IMAGE SEGMENTATION CASES AND RESULTS

Training Hyperparameters and Image Datasets

Number of images
In choosing a number of images for our training set, we need balance whether or not enough data is present to affect meaningful training with oversampling of training data

Image size: Smaller images, which are randomly cropped from our full-sized dataset, require a fewer number of trainable weights and biases, thus exhibiting quicker convergence. Yet, such images can neglect the global characteristics of certain classes, resulting in poorer performance on full-sized images

Initial training images: **2300 x 1920** pixels

Images	Image Size: 100 pixels	224 pixels	400 pixels	800 pixels	Full
2000	■	■			
1000	■	■	■		
500		■	■	■	
250				■	
15					■

Hyperparameter	Value
Platform	Bebop
Epochs	40
Learning Rate	1.0×10^{-3}
Optimizer	SGD
Augmentation	TRUE
Class Balancing	TRUE
Training Batch Size	4
Validation Batch Size	1

RANDOM IMAGE CROPS

Smaller training images are created by sampling

- NN assigns a node to each pixel of an incoming image
- Number of training weights and biases directly related to the size of training images
- Smaller images leads to faster training convergence and allows more data to be obtained from full-sized images
- May result in poorer performance on full-sized test images

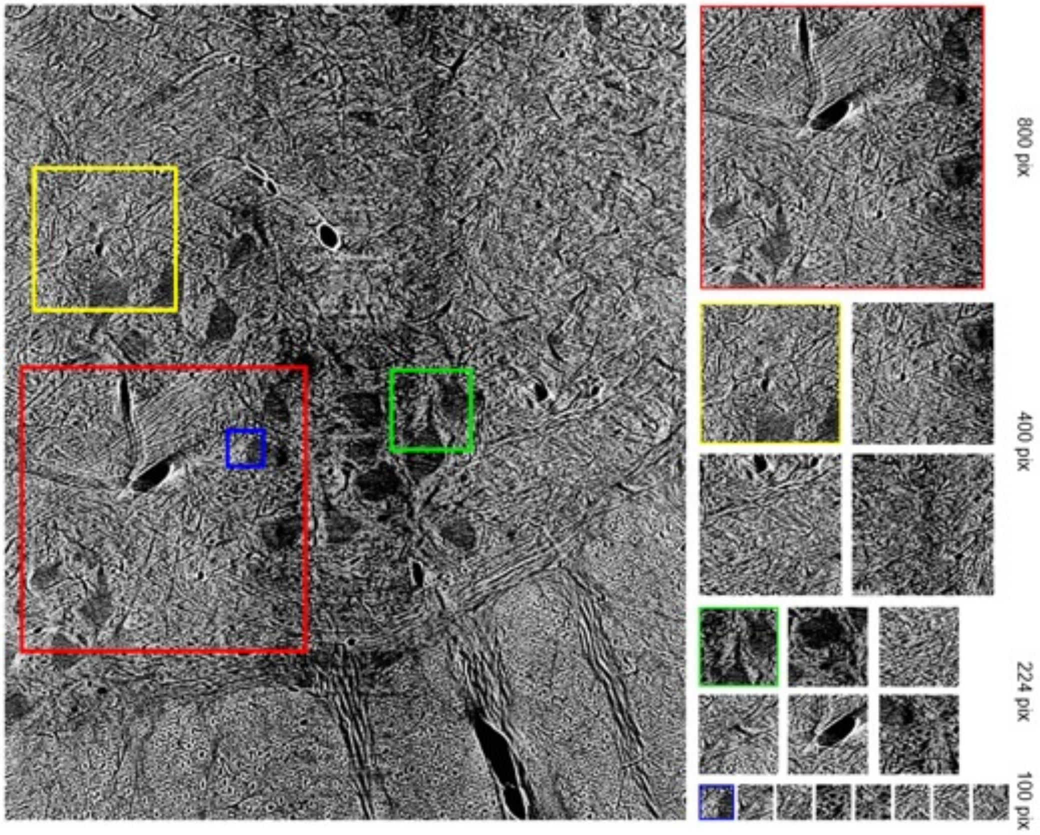


IMAGE SEGMENTATION RESULTS

Global and Soma Accuracy

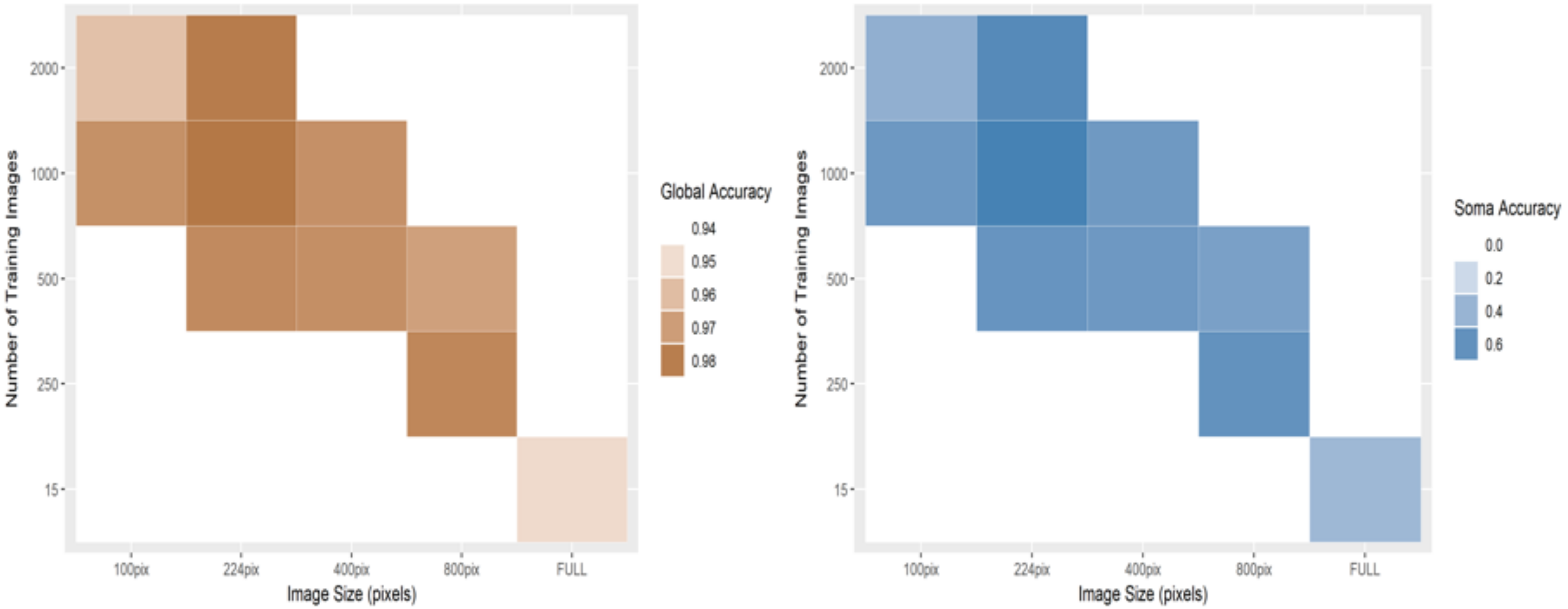
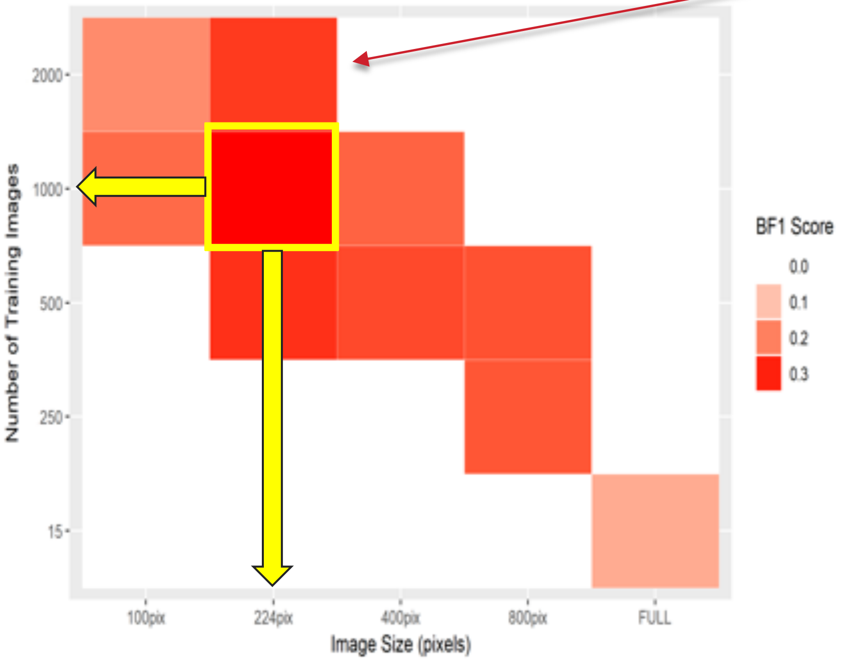
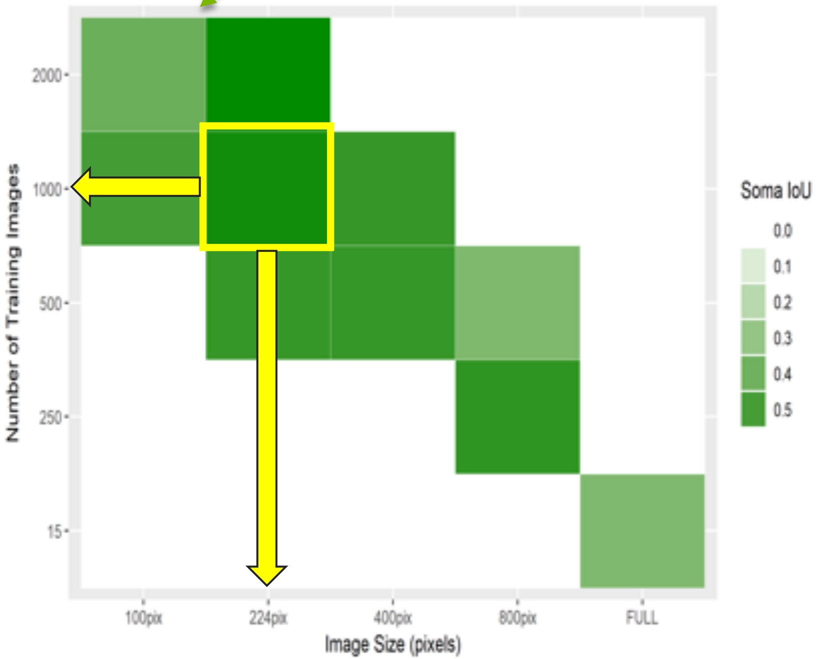


IMAGE SEGMENTATION RESULTS

BF1 Scores and Soma IoU

Oversampling occurs when network becomes over-adjusted to segment the training data and loses its transferability in the process (i.e. metrics go down with more images)





OUTPUT AND OVERLAYS

NN Trained Using Full-Sized Images

Test Metrics	
Soma IoU	35.79 %
BF1 Score	13.51 %

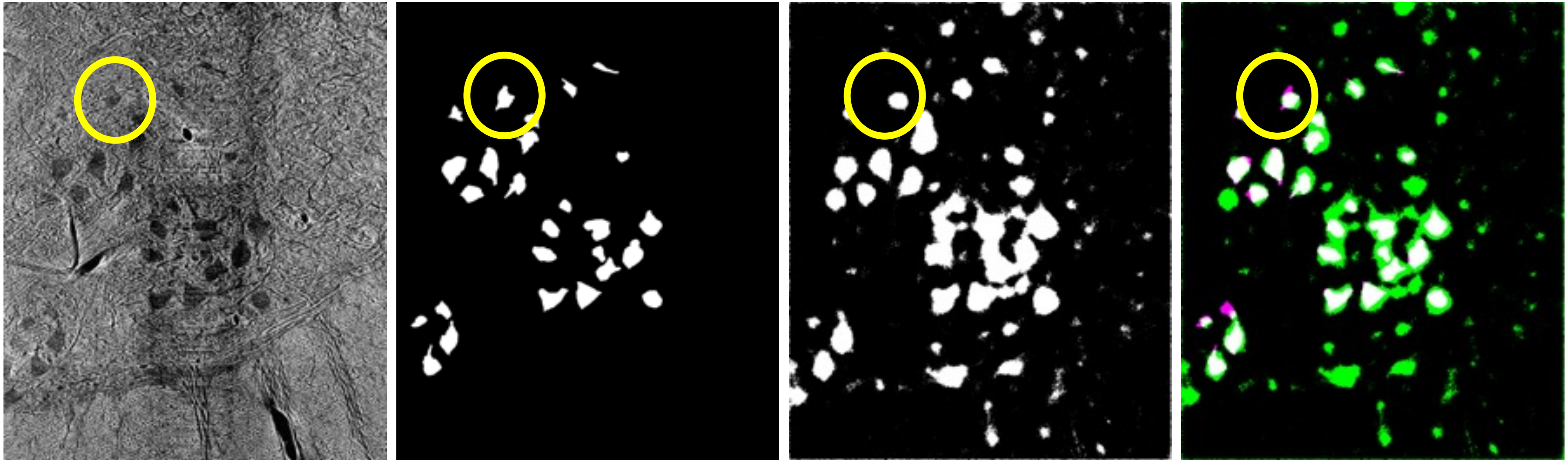


Image (F0010) | Ground Truth | NN Prediction | Overlay

True Positive (Soma)

True Negative (Background)

False Positive

False Negative

OUTPUT AND OVERLAYS

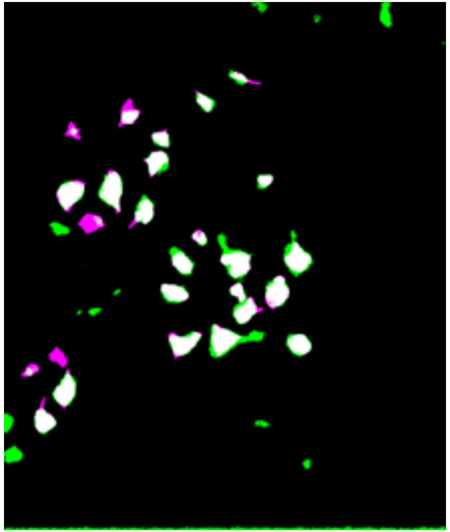
Best NN Trained Using 1000 Images, Size 224 pixels

Test Metrics	
Soma IoU	58.12 %
BF1 Score	30.99 %

Image (F0010)

Ground Truth

NN Prediction

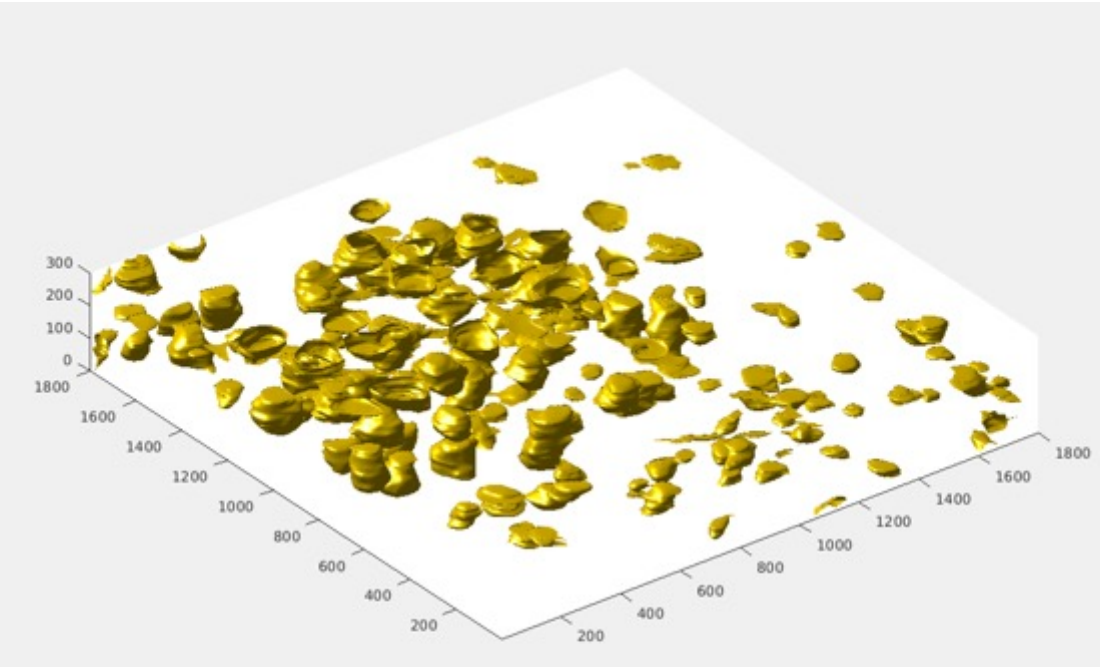


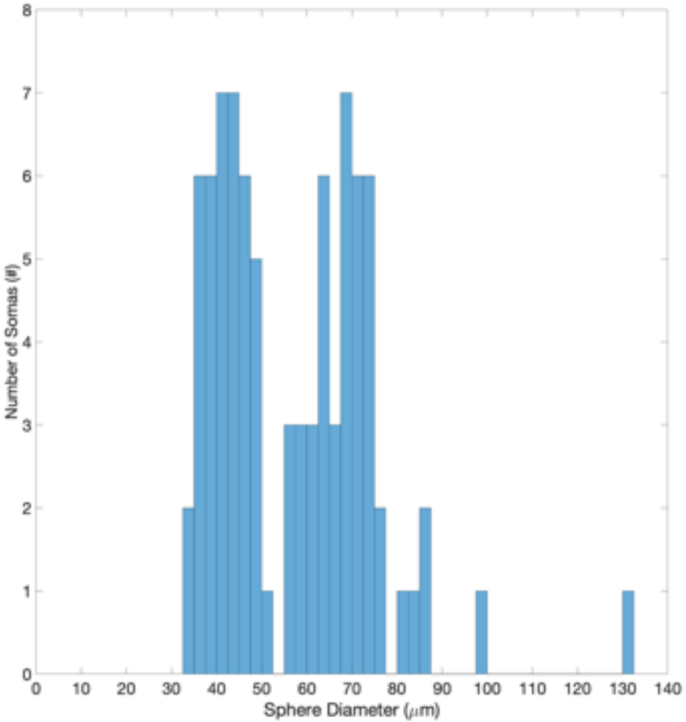
Overlay

True Positive (Soma) | True Negative (Background) | False Positive | False Negative

3D RECONSTRUCTION

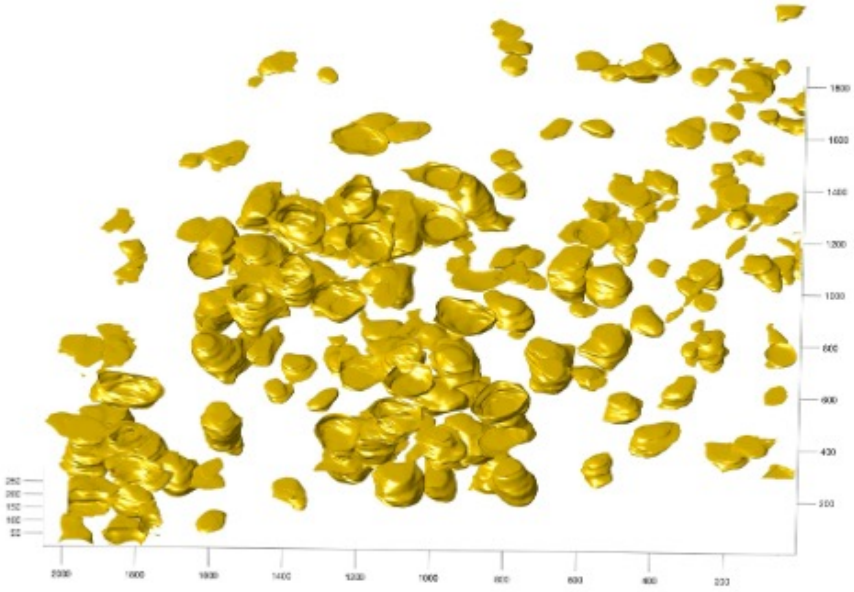
3D reconstruction from best NN results (T. Stan, NU)

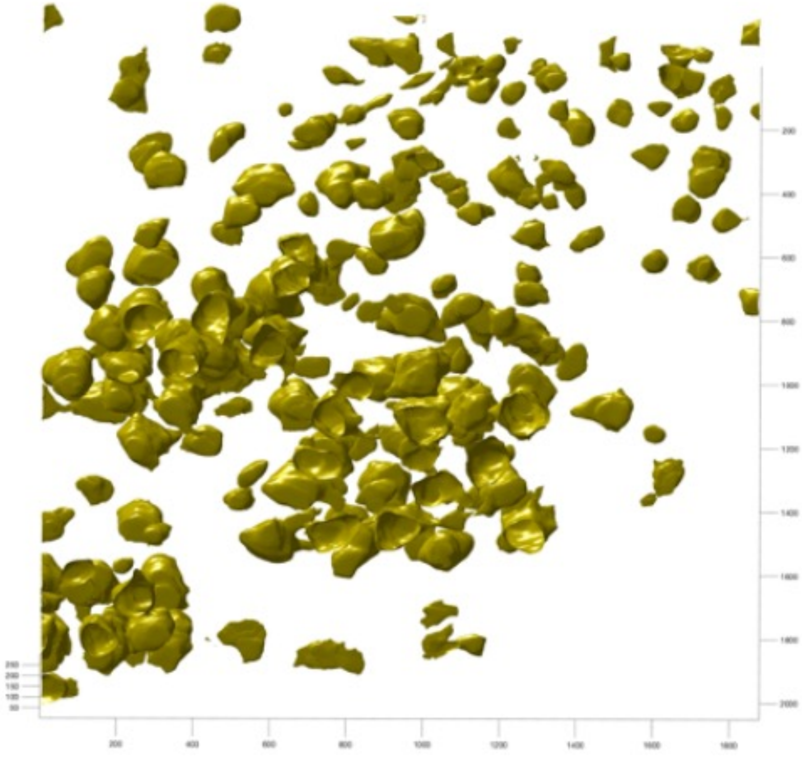




IMAGES

Courtesy: T. Stan (NU)





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ALCF
A DOE Office of Science User Facility

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LABORATORY COMPUTING RESOURCE CENTER

We gratefully acknowledge the computing resources provided on Bebop (and/or Blues), a high-performance computing cluster operated by the Laboratory Computing Resource Center at Argonne National Laboratory."

The Advanced Photon Source
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QUESTIONS?

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