

## **Breakout Session 6: Track B**

# **Retinal Circuitry - Improving AI Readiness of Existing Retinal Connectomes**

Dr. James Anderson

*Senior Software Design Engineer, University of Utah - Moran Eye Center*

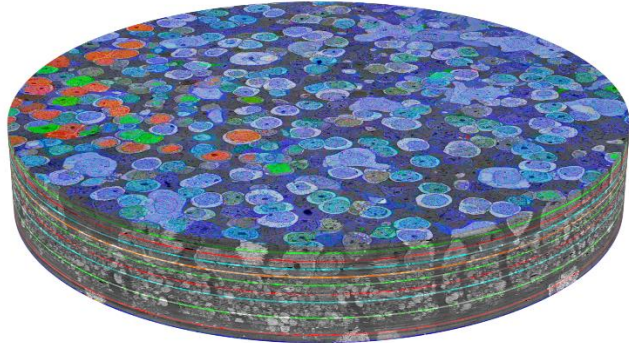
# Retinal Circuitry - Improving AI Readiness of Existing Retinal Connectomes

Presenter: James Anderson

PI: Bryan Jones

NOT-OD-22-67

Volume Construction

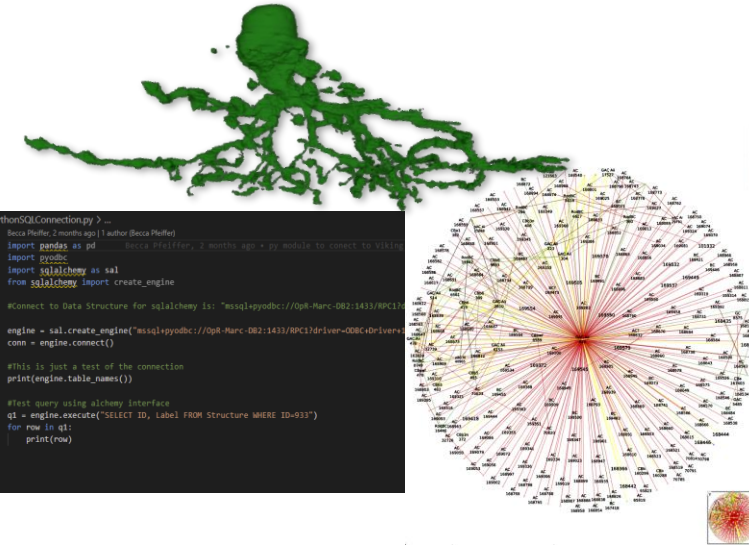


- ssTEM (70-90nm sections)
- 2.18nm/px resolution
- Interleaved small molecule labeling

Viking Annotation Environment

Column N.	Default V.	Data Type	Len.	Null.	Ident.	Descrpt.
ID		bigint	8	No	<input checked="" type="checkbox"/>	
ParentID		bigint	8	No	<input type="checkbox"/>	Structure which we belong to
Z		bigint	8	No	<input type="checkbox"/>	
Closed	00	bit	1	No	<input type="checkbox"/>	Defines whether vertices form a c...
Version	timestamp	timestamp	8	No	<input type="checkbox"/>	An image centered on X,Y,Z which...
Overlay	view	enum	-1	Yes	<input type="checkbox"/>	
Terminal	00	bit	1	No	<input type="checkbox"/>	Set to true if the location is the e...
OffEdge	00	bit	1	No	<input type="checkbox"/>	This bit is set if the structure bel...
TypeCode	00	enum	2	No	<input type="checkbox"/>	0 = Point, 1 = Circle, 2 = Ellipse, 3...
LastModif...	datetime	datetime	8	No	<input type="checkbox"/>	Date the location was last modified
Created	datetime	datetime	8	No	<input type="checkbox"/>	Date the location was created
Username	varchar	varchar	16	No	<input type="checkbox"/>	Last username to modify the row
MemoDescr...	text	text	-1	No	<input type="checkbox"/>	
VolumeId	bigint	bigint	8	No	<input type="checkbox"/>	
X	float	float	8	No	<input type="checkbox"/>	
Volume	float	float	8	No	<input type="checkbox"/>	Width used for line annotation ty...
Width	float	float	8	No	<input type="checkbox"/>	Radius, calculated column needs...
Radius	float	float	8	No	<input type="checkbox"/>	

Analysis



```
pythonSQLConnection.py >
1 import pandas as pd
2 import pyodbc
3 import sqlalchemy as sa
4 from sqlalchemy import create_engine
5
6 #Connect to Data Structure for sqlalchemy is: "msqlpyodbc://Opk-Marc-082:1433/RPC1"
7
8 engine = sa.create_engine("msqlpyodbc://Opk-Marc-082:1433/RPC1Driver=ODBC+Driver+
9 conn = engine.connect()
10
11 #this is just a test of the connection
12 print(engine.table_names())
13
14 #test query using alchemy interface
15 q1 = engine.execute("SELECT ID, Label FROM Structure WHERE ID=93")
16 for row in q1:
17     print(row)
```

RC1

Rabbit retinal connectome  
 Status: Open  
 Database Annotations: ~1.3 million

RC2

Mouse retinal connectome  
 Status: Active  
 Database Annotations: ~500k

RC3

Primate (Macaque) retinal connectome  
 Status: Captured  
 Database Annotations: N/A

RPC1

Pathoconnectome from 10mo rabbit model of  
 Retinitis Pigmentosa (Phase 1 retinal  
 degeneration)  
 Status: Open  
 Database Annotations: ~280k

RPC2

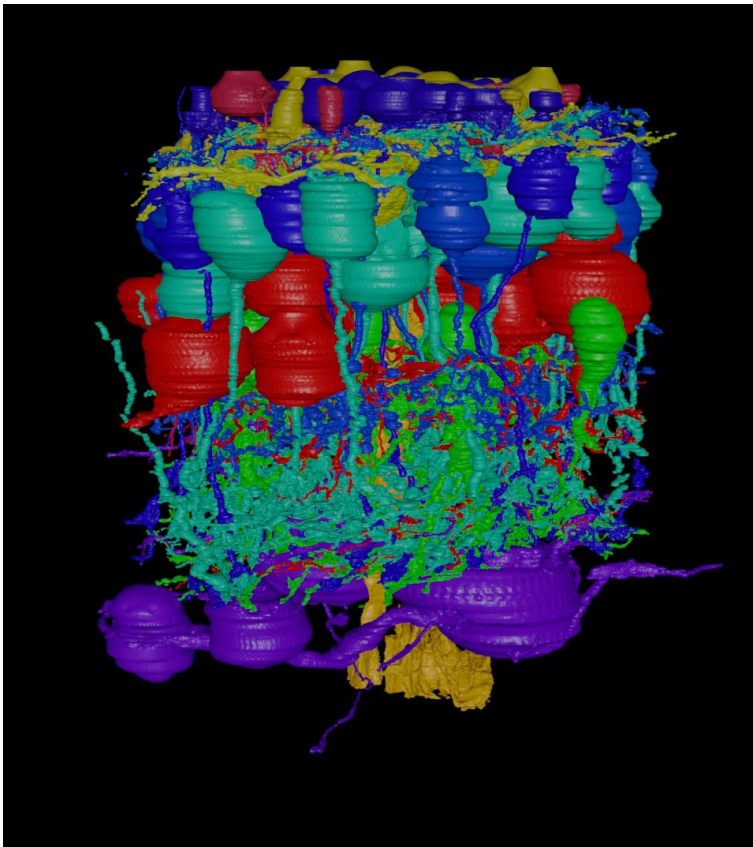
Pathoconnectome from 2yo rabbit model of  
 Retinitis Pigmentosa (Phase 2 retinal  
 degeneration)  
 Status: Active  
 Database Annotations: ~100k

RPC3

Pathoconnectome from 4yo rabbit  
 model of Retinitis Pigmentosa (Phase 3  
 retinal degeneration)  
 Status: Captured  
 Database Annotations: N/A

## Database Features:

- SQL reduces development cost and maintenance. Very mature tools.
- Flexible addition of new structures
- Geometry columns encode annotations. Spatial queries within SQL. Enables encoding any geometric shape.
- Hierarchy describes relationships of biological structures (Parent=Cell, Child=Subcellular structures)
- Size, shape, and position are encoded in every annotation
- Morphology and connectivity are encoded in separate but relatable graphs. Allowing efficient querying.



## Morphology

Column N...	Default V...	Data Type	Len...	Nulla...	Iden...	Descript...
ID		bigint	8	No	<input checked="" type="checkbox"/>	
ParentID		bigint	8	No	<input type="checkbox"/>	Structure which we belong to
Z		bigint	8	No	<input type="checkbox"/>	
Closed	((0))	bit	1	No	<input type="checkbox"/>	Defines whether Vertices form a c...
Version		timestamp	8	No	<input type="checkbox"/>	
Overlay		varbinary(MAX)	-1	Yes	<input type="checkbox"/>	An image centered on X,Y,Z which...
Tags		xml	-1	Yes	<input type="checkbox"/>	
Terminal	((0))	bit	1	No	<input type="checkbox"/>	Set to true if this location is the e...
OffEdge	((0))	bit	1	No	<input type="checkbox"/>	This bit is set if the structure leav...
TypeCode	((1))	smallint	2	No	<input type="checkbox"/>	0 = Point, 1 = Circle, 2=Ellipse, 3 ...
LastModif...	(getutcda...	datetime	8	No	<input type="checkbox"/>	Date the location was last modified
Created	(getutcda...	datetime	8	No	<input type="checkbox"/>	Date the location was created
Username	(N^)	nchar(16)	16	No	<input type="checkbox"/>	Last username to modify the row
MosaicSh...		geometry	-1	No	<input type="checkbox"/>	
VolumeSh...		geometry	-1	No	<input type="checkbox"/>	
X				No	<input type="checkbox"/>	
Y				No	<input type="checkbox"/>	
VolumeX				No	<input type="checkbox"/>	
VolumeY				No	<input type="checkbox"/>	
Width		float	8	Yes	<input type="checkbox"/>	Width used for line annotation ty...
Radius				No	<input type="checkbox"/>	Radius, calculated column neede...

Column N...	Default V...	Data Ty...	Len...	Nulla...	Iden...	Descript...
A		bigint	8	No	<input type="checkbox"/>	The co...
B		bigint	8	No	<input type="checkbox"/>	
Username	(N^)	nchar(...)	16	No	<input type="checkbox"/>	Last us...
Created	(getutcda...	datet...	8	No	<input type="checkbox"/>	Row Cr...

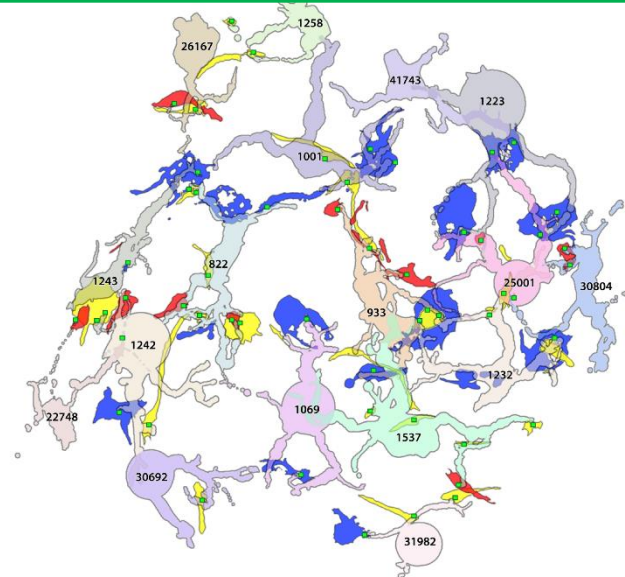
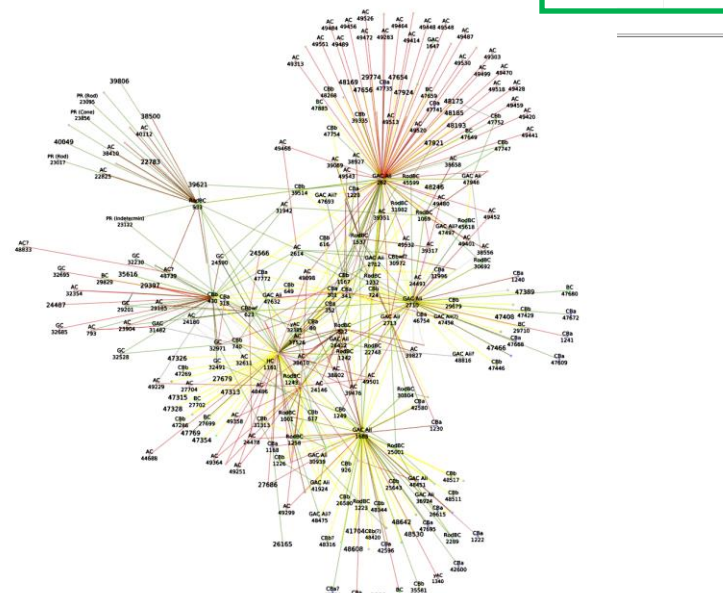
Column N...	Default V...	Data Type	Len...	Nulla...	Iden...
ID		bigint	8	No	<input checked="" type="checkbox"/>
ParentID		bigint	8	Yes	<input type="checkbox"/>
Name		nchar(128)	128	No	<input type="checkbox"/>
Notes		nvarchar(M...	-1	Yes	<input type="checkbox"/>
MarkupTy...	(NPoint)	nchar(16)	16	No	<input type="checkbox"/>
Tags		xml	-1	Yes	<input type="checkbox"/>
StructureT...		xml	-1	Yes	<input type="checkbox"/>
Abstract	((0))	bit	1	No	<input type="checkbox"/>
Color	(XXXXXXXX)	int	4	No	<input type="checkbox"/>
Version		timestamp	8	No	<input type="checkbox"/>
Code	(NNo Co...	nchar(16)	16	No	<input type="checkbox"/>
HotKey	(\0)	char(1)	1	No	<input type="checkbox"/>
Username	(N^)	nchar(16)	16	No	<input type="checkbox"/>
LastModif...	(getutcda...	datetime	8	No	<input type="checkbox"/>
Created	(getutcda...	datetime	8	No	<input type="checkbox"/>

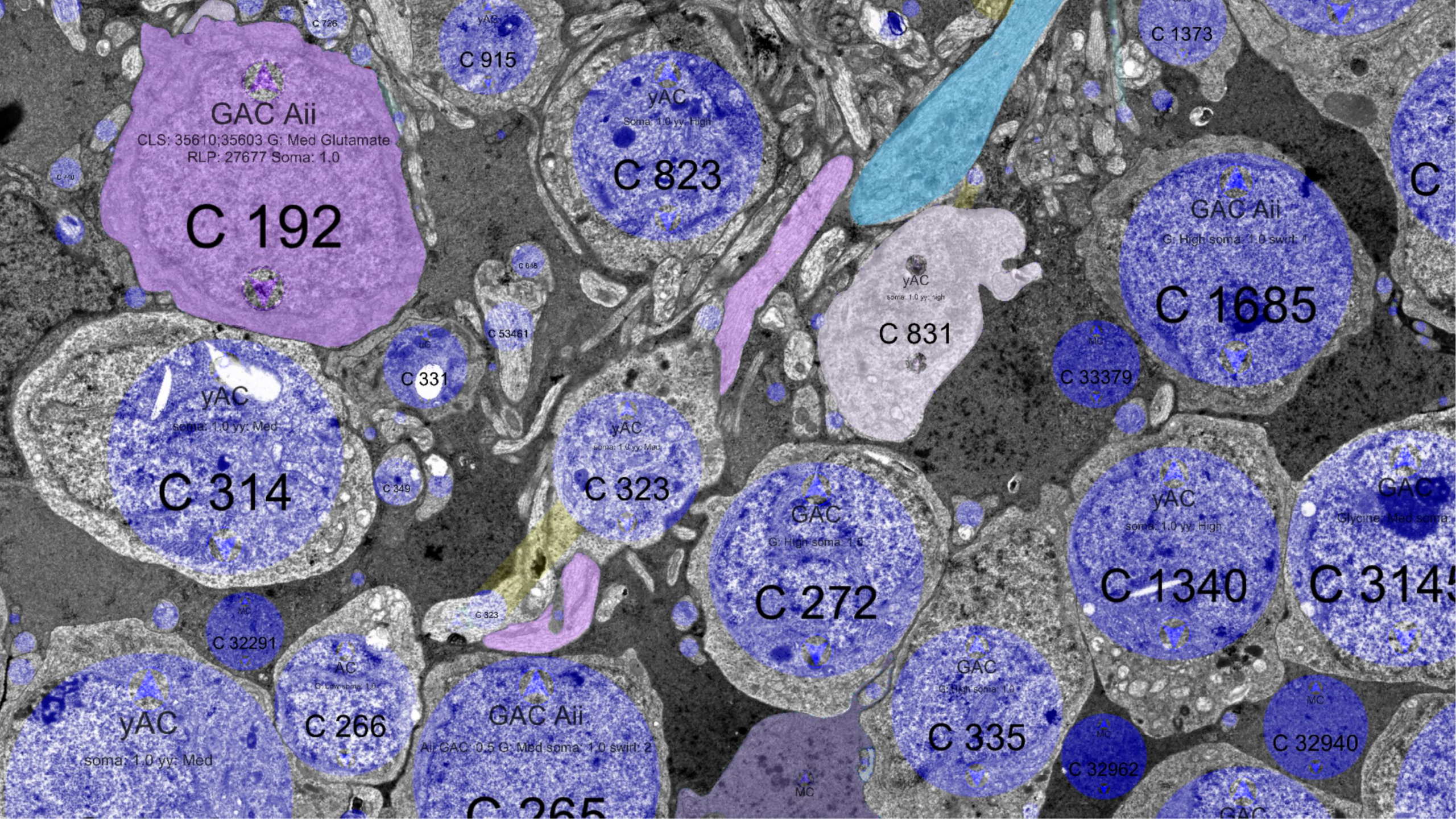
## Connectivity

Column Name	Default Va...	Data Ty...	Len...	Nulla...	Iden...	Descript...
ID		bigint	8	No	<input checked="" type="checkbox"/>	
TypeID		bigint	8	No	<input type="checkbox"/>	
Notes		nvarch...	-1	Yes	<input type="checkbox"/>	
Verified	((0))	bit	1	No	<input type="checkbox"/>	
Tags		xml	-1	Yes	<input type="checkbox"/>	Strings ...
Confidence	((0.5))	float	8	No	<input type="checkbox"/>	How ce...
Version		time...	8	No	<input type="checkbox"/>	Record...
ParentID		bigint	8	Yes	<input type="checkbox"/>	If the st...
Created	(getutcda...	dateti...	8	No	<input type="checkbox"/>	Date th...
Label		varcha...	64	Yes	<input type="checkbox"/>	Additio...
Username	(N^)	nchar(...)	16	No	<input type="checkbox"/>	Last us...
LastModified	(getutcda...	dateti...	8	No	<input type="checkbox"/>	

Column N...	Default V...	Data Ty...	Len...	Nulla...	Iden...	Descript...
SourceID		bigint	8	No	<input type="checkbox"/>	
TargetID		bigint	8	No	<input type="checkbox"/>	
Bidirectio...	((0))	bit	1	No	<input type="checkbox"/>	
Tags		xml	-1	Yes	<input type="checkbox"/>	
Username	(N^)	nchar(...)	16	No	<input type="checkbox"/>	Last us...
Created	(getutcda...	dateti...	8	No	<input type="checkbox"/>	Row Cr...
LastModif...	(getutcda...	dateti...	8	No	<input type="checkbox"/>	

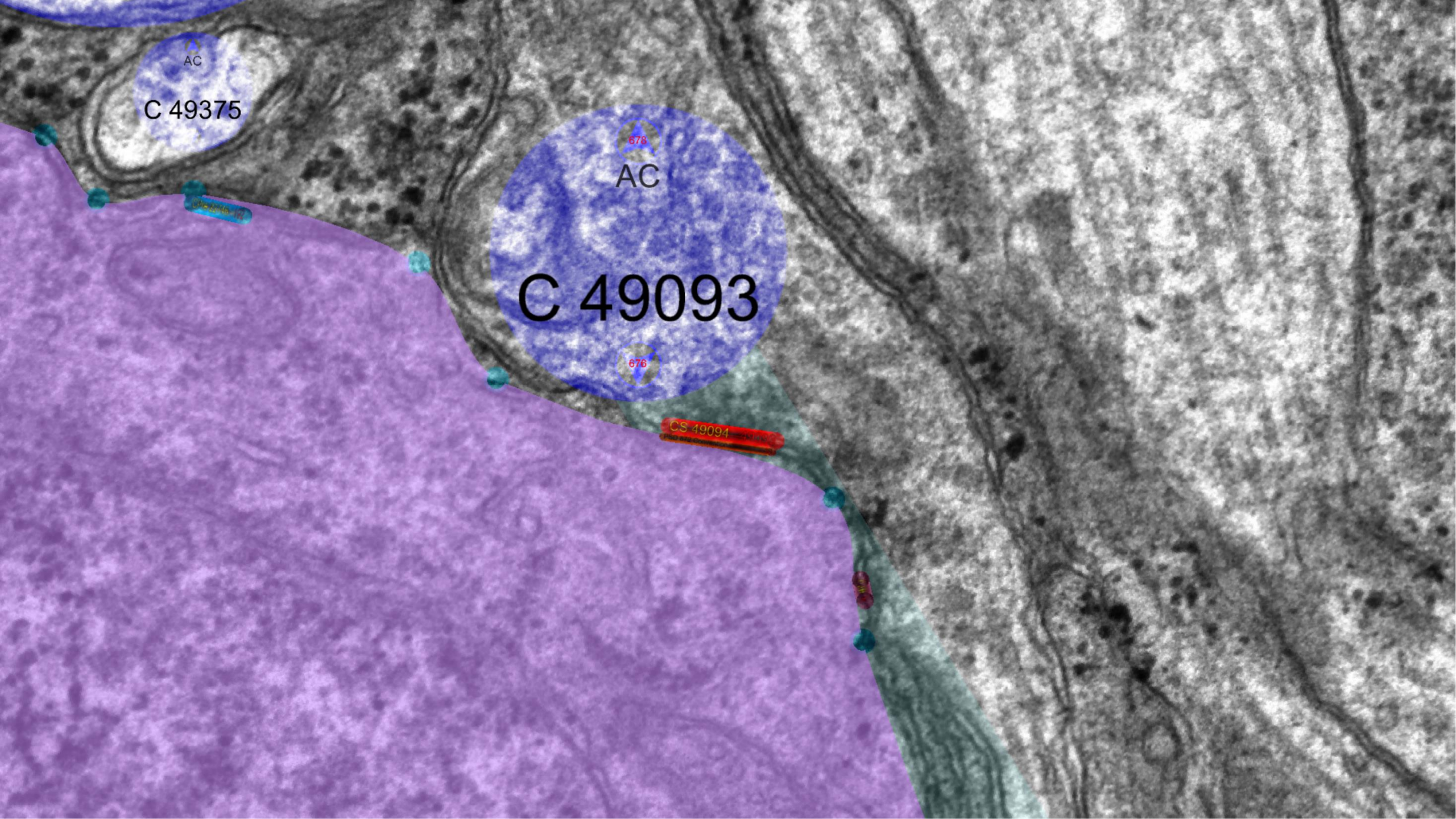




C 726  
yAC  
C 915  
Soma: 1.0 yy: High  
C 823  
C 1373  
GAC Aii  
CLS: 35610;35603 G: Med Glutamate  
RLP: 27677 Soma: 1.0  
C 192  
C 1685  
G: High soma: 1.0 swirl: 1  
yAC  
soma: 1.0 yy: high  
C 831  
C 33379  
MC

yAC  
soma: 1.0 yy: Med  
C 314  
C 331  
C 53461  
C 648  
C 349  
yAC  
soma: 1.0 yy: Med  
C 323  
GAC  
G: High soma: 1.0  
C 272  
C 1340  
yAC  
soma: 1.0 yy: High  
GAC  
Glycine: Med soma:

MC  
C 32291  
AC  
G: Low soma: 1.0  
C 266  
yAC  
soma: 1.0 yy: Med  
GAC Aii  
Aii GAC: 0.5 G: Med soma: 1.0 swirl: 2  
C 265  
MC  
C 335  
GAC  
G: High soma: 1.0  
C 32962  
MC  
C 32940  
GAC



AC

C 49375

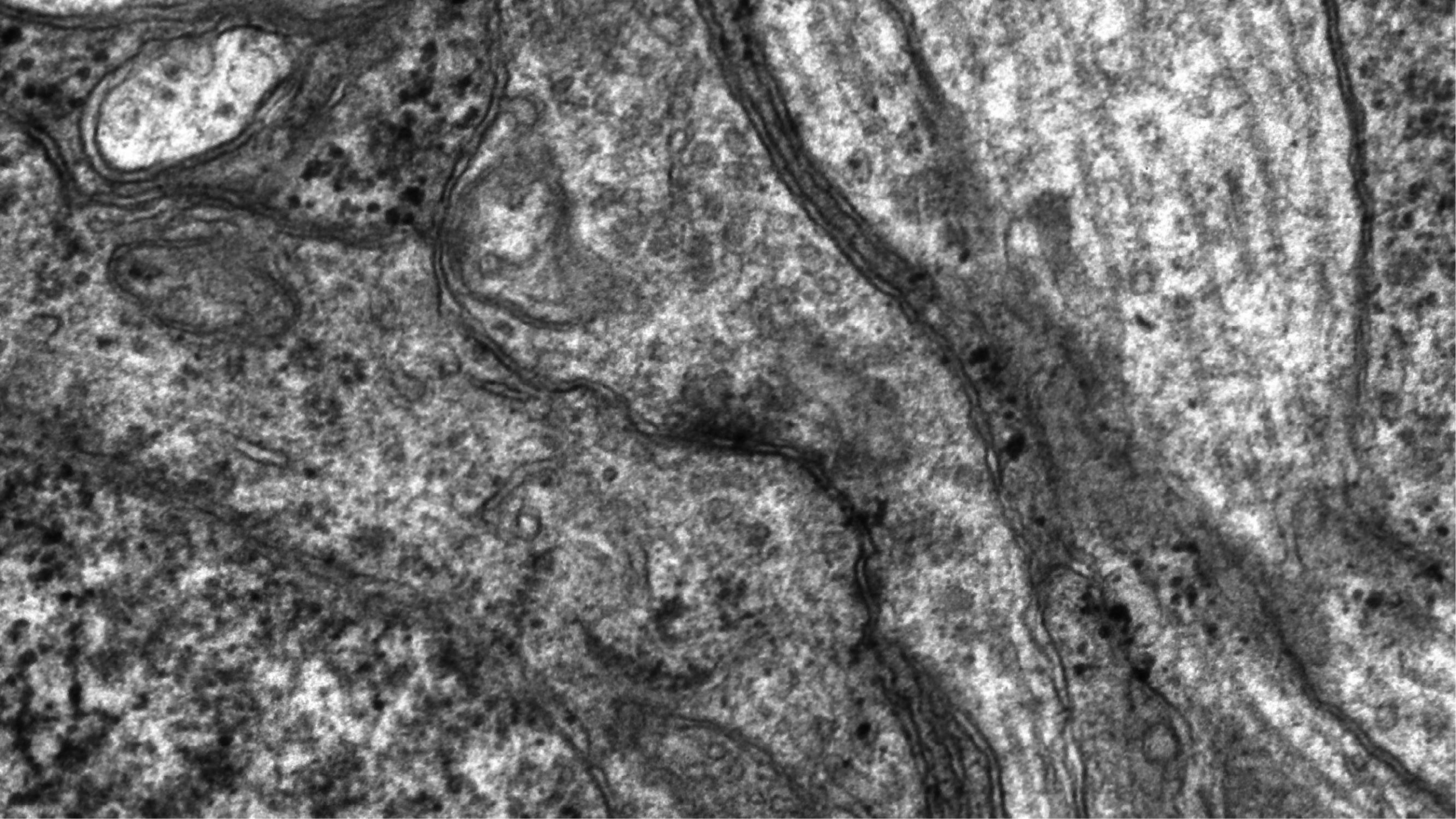
678

AC

C 49093

676

CS 49094



# Data Sharing

**Primary Goal:** Make it simple for collaborators to access our combined annotation and image data to create machine learning algorithms to augment volume annotation efforts.

## Annotations:

- OData works great for sharing annotations:
  - <http://websvc1.connectomes.utah.edu/RC1/OData/>
- Queryable, Readable directly into a Browser, Spreadsheet, or programming API
- Spatial data is plain text Open Geospatial Consortium format. Libraries exist to interpret it

## Images:

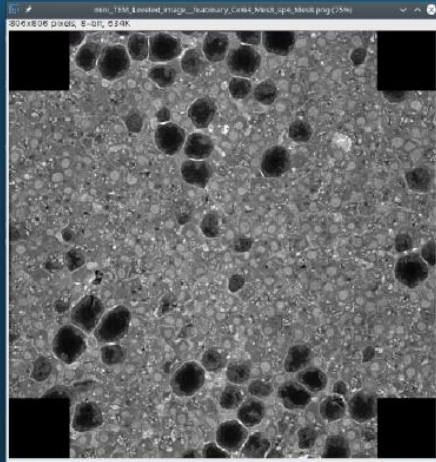
- The goal is to ease accessibility for the image processing lab.
- Viking uses client GPU to perform transforms. Moving processing from client to server simplifies the client experience.
- Real-time transformation has been an advantage for adjusting volume registration during annotation phase.
- Attempts to share images:
  - 1<sup>st</sup> Approach : Client exports region-of-interest to disk
  - 2<sup>nd</sup> Approach : Cached RC1 volume available via HTTP, ex: [http://storage1.connectomes.utah.edu/RC1VolumeRegisteredV2/RC1/234/Tiles/001/X160\\_Y049.png](http://storage1.connectomes.utah.edu/RC1VolumeRegisteredV2/RC1/234/Tiles/001/X160_Y049.png)
  - 3<sup>rd</sup> Approach : Web API (Stopped at prototype due to performance issues)
  - 4<sup>th</sup> Approach : A stack of numpy arrays, either shipped in the mail or a long download



# Progress Towards Goal: CuPy proof-of-concept

## Python tests - self registration

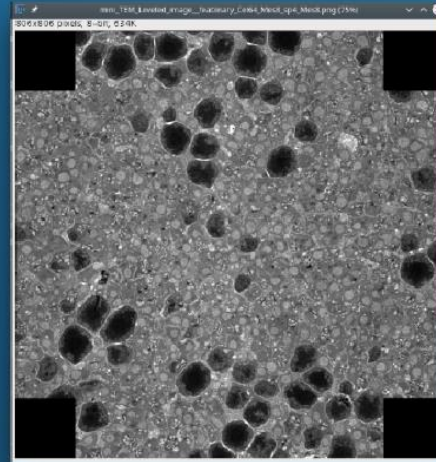
mini\_TEM  
806x806 pixels



Self-image  
registration



Peak: (0,0)  
Angle: 0



mini\_TEM  
806x806 pixels

Angle search range:

- Fast: [-2, 0, 2]
- Brute: (-178, 178)

Methods:

- Single thread
- Multi-thread
- GPU

```
✓ Test Results 7 min 37 sec
  ✓ test_SliceToSliceBrute 7 min 37 sec
    ✓ TestStosBruteToSameImage 7 min 37 sec
      ✓ testSameTEMImageFast_GPU (Make sure the same image aligns to itself 1 sec 522 ms)
      ✓ testSameTEMImageFast_MultiThread (Make sure the same image aligns t 3 sec 186 ms)
      ✓ testSameTEMImageFast_SingleThread (Make sure the same image aligns 6 sec 327 ms)
      ✓ testSameTEMImage_GPU (Make sure the same image aligns to itself wit 6 sec 955 ms)
      ✓ testSameTEMImage_MultiThread (Make sure the same image aligns to it 1 min 41 sec)
      ✓ testSameTEMImage_SingleThread (Make sure the same image aligns to 15 min 38 sec)
```

Clement Vachet

Registration requirements:

- FFT
- Random Number Generation
- Image Labeling
- Arithmetic
- Convolution

Assembly Requirements:

- Delaunay triangulation
- Texture mapping

Registration Speed

GPU	< 7 sec
Multi-core	101 sec

GPU is 14x faster at  
Registration!

# Progress Towards Goal: GPU Implementation with CuPy



CuPy

CuPy is a NumPy/SciPy open-source array library for GPU-accelerated computing with Python

Transforms	single CPU	multi CPU	partial GPU	full GPU
Rigid_NoRotation	✓	✓		✓
Rigid	✓	✓		✓
Centered Similary	✓	✓		✓
MeshWithRBFFallback	✓	✓	✓	
GridWithRBFFallback	✓	✓	✓	

Implementation for assembly transforms

**Note:** some transform components (e.g. triangulation) haven't yet been implemented in CuPy

- CuPy lacked the LinearNDInterpolator function necessary for a full GPU implementation.
- The function was [pulled into the next CuPy release](#) two weeks ago
- Our CuPy version will be fully implemented upon next official cupy release

# Progress Towards Goal: Tile Assembly

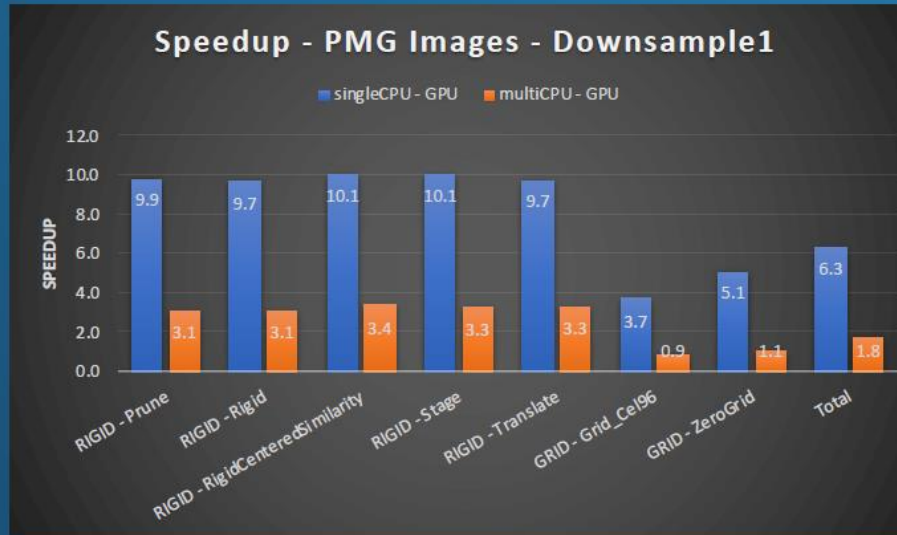
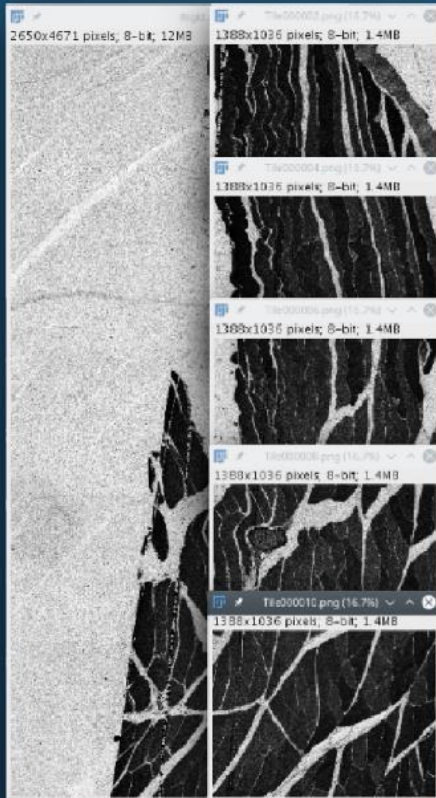
## PMG files

- 10 image tiles - 7 mosaic transforms

```
Grid_Cel96_Mes8_sp4_Mes8_Thr0.5.mosaic
Prune_Thr1.0.mosaic
RigidCenteredSimilarity.mosaic
Rigid.mosaic
Stage.mosaic
Translate_Max0.5.mosaic
ZeroGrid.mosaic
```

Image tiles:  
- 1388x1036 pixels

Full image:  
- 2650x4671 pixels



- Ignore the blue bar results.
- Yellow multi-core comparison ran on an 8-core desktop system.
- Beyond missing LinearNDInterpolate I suspect moving memory between CPU and GPU is a significant time cost. Most likely optimizable.

# Progress and Ongoing Efforts

## Tools

- Every critical path now utilizes CuPy (with the one exception discussed). Passes unit tests.
- Have support to export a stack of full resolution numpy files
- Waiting for next cupy version to fully test with GPU at scale

## Docker Distribution

- Docker is simple to deploy and gives us easy access to our university high-performance computing center. This provides easier access to the command-line tool that can export registered volumes and will allow clients to run the Web Service locally for performance.
- All but one tool required to take images from capture to a 3D numpy array now run in a single docker image.
- We have contracted Kitware to port the remaining legacy C++ ITK-based tool to a web image to complete the docker image.

## Web Service

- In progress.
- GPU performance determines if we revisit the original on-the-fly web service prototype or rely upon pre-generated images.

## Legacy Data

- Original registered RC1 images available via HTTP are being copied into a stack of numpy arrays.
- RC1 raw data is now compatible with the latest code. Going from imported data to a registered volume is a great stress test for the new GPU code.

## MarcLab for Connectomics:

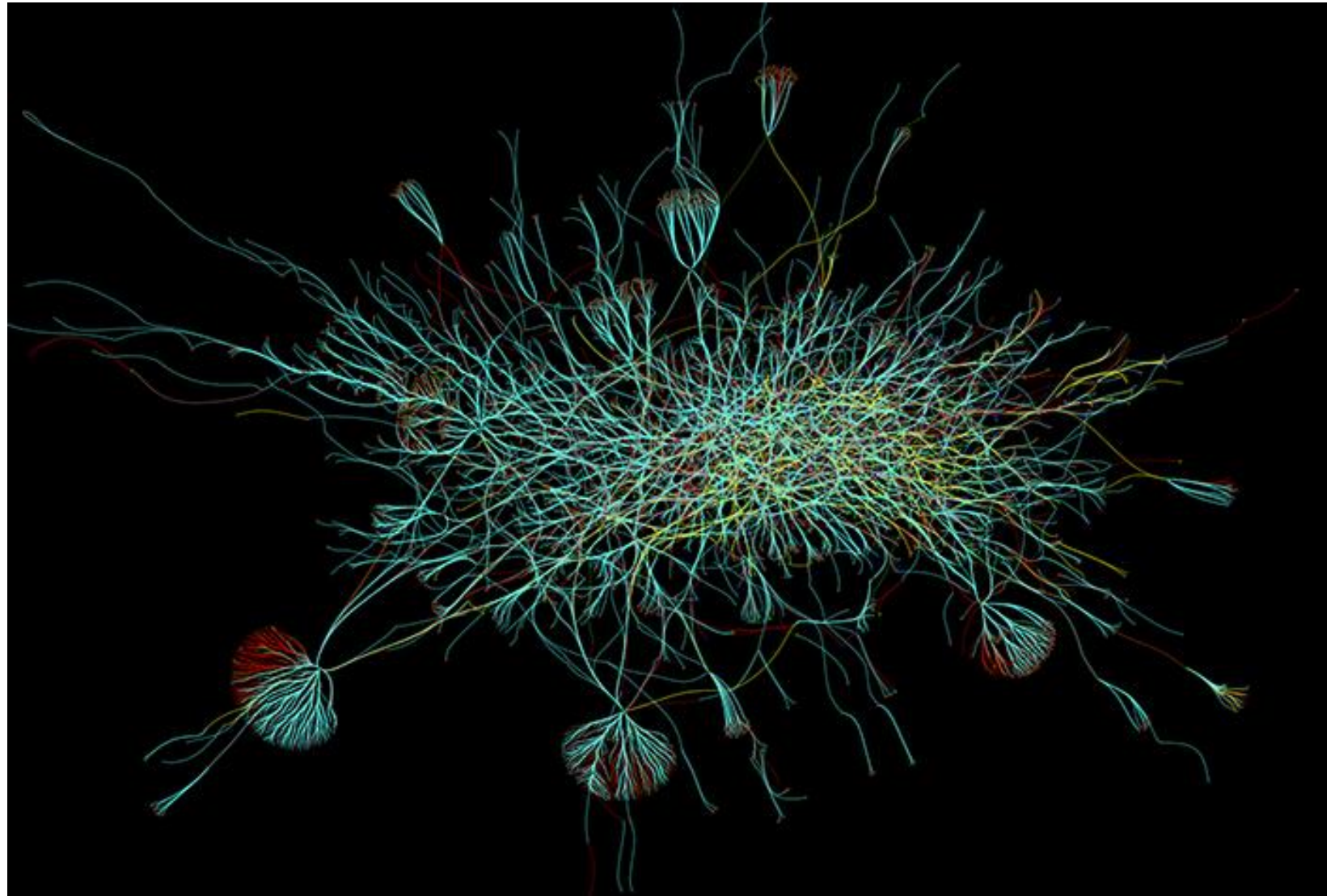
Bryan W. Jones (Director)  
James Anderson  
Rebecca Pfeiffer  
Crystal Sigulinsky  
Megan Croom  
Jia Hui Yang  
Matt Berardy  
Selena Wirthlin  
Taylor Otterness

## Collaborators:

Clement Vachet (*Scientific  
Computing Institute, University of Utah*)  
KitWare

## Unmet CuPy Contributor:

Edgar Andrés Margffoy Tuay  
(LinearNDInterpolator Author)



NEI EY015128  
NSF NeuroNex2 Grant (2014862)  
NEI EY14800 Vision Core  
Research to Prevent Blindness CDA  
Unrestricted Grant from Gabe Newell