[Advertised] Stereo Pseudo-3D Rendering for Web-based Display of Scientific Volumetric Data

IAMCS Workshop: Visualization in Biomedical Computation

February 24, 2011

Yoonsuck Choe
Brain Networks Laboratory
Department of Computer Science and Engineering
Texas A&M University

Joint work with: L. C. Abbott, J. Keyser, B. McCormick, D. Han, J. Kwon, D. Mayerich, D, E. Miller, J. R. Chung, C. Sung.

[Actual] New Visualization Challenges for High-Volume, High-Resolution Brain Connectomics Data

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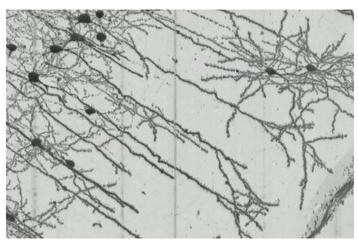
Long-Term Goal of the BNL

C57BL/6 mouse
http://mouseatlas.org

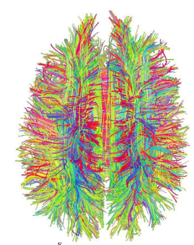
Mouse brain
http://nervenet.org

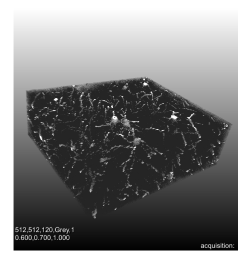


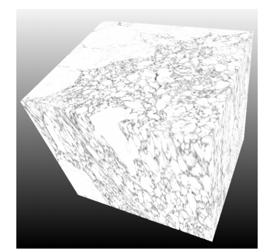
Brain circuits (Mouse cortex)

- Image and reconstruct the **mouse connectome** at a sub-micrometer resolution.
  - **connectome** = full connection matrix of the brain.
- **Understand brain function**: Structure $\longrightarrow$ function.

Background: Connectomics



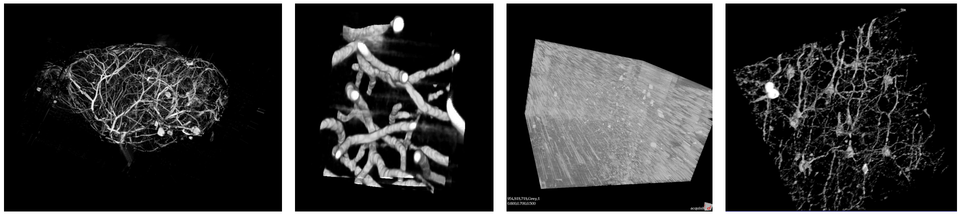




Imaging:	Diffusion Tensor Imaging	Light Microscopy	Electron Microscopy
Scale:	$\sim$ 10 cm cube Human brain	$\sim$ 1 cm cube Mouse brain	$\sim$ 100 μm cube Several neurons
Resolution:	$\sim$ 1 mm cube	$\sim$ 1 μm cube	$\sim$ 10 nm cube
Time:	hours	weeks	year
	Hagmann et al. (2007)	Mayerich et al. (2008)	Denk and Horstmann (2004)

- Study of the connectome, the full connection matrix of the brain (Sporns et al. 2005).

Motivation and Research Issues



Vasculature	Vasculature	Neurons	Neurons
Whole brain: 1 cm cube	∼50 µm cube	Whole brain: 1 cm cube	∼200 µm cube

- Very large 3D volumes of biological data (TBs).
- Very high resolution.
- Details are too fine to be visible at the scale of the whole volume.

→ Innovative visualization methods are needed

Overview

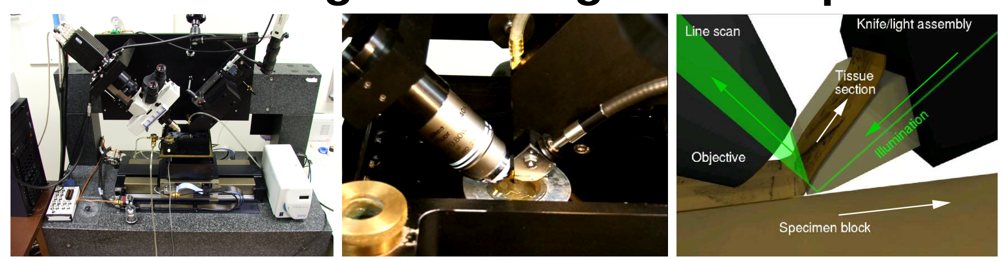
1. Instrument: Knife-Edge Scanning Microscope
2. Data: Mouse brain data
3. Visualization

Part I

The Instrument: Knife-Edge Scanning Microscope

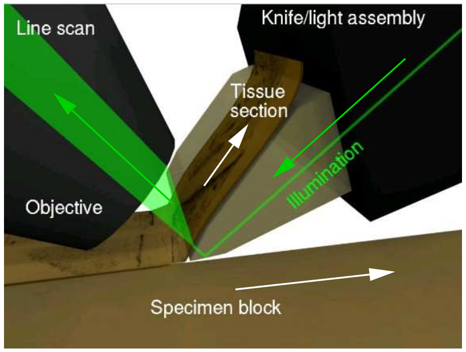
Mayerich et al. (2008); McCormick (2004)

The Instrument: Knife-Edge Scanning Microscope



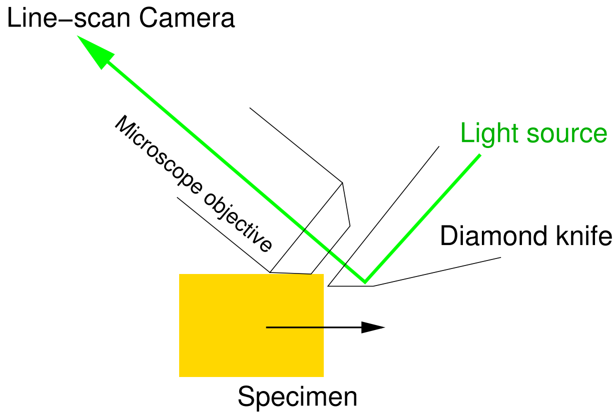
- Physical sectioning, as opposed to optical sectioning.
- Light microscopy, bright-field imaging (fluorescence in the works).
- Stains: Golgi (neuron morphology), Nissl (soma), India ink (vasculature). (Fluorescence imaging in the works.)
- 0.6 µm × 0.7 µm × 1 µm voxel resolution.
- Custom software for control, image capture (Kwon et al. 2008).

Operational Principles of the KESM



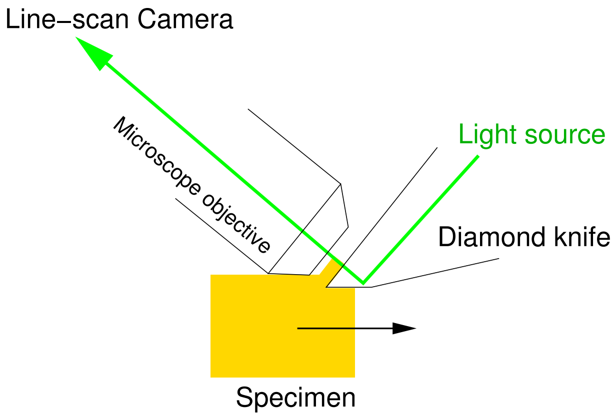
- Image while cutting (line-scan at the tip of the knife).
- Back-illumination through the diamond knife.
- Tissue thickness: 1 µm (or possibly less).

KESM Imaging



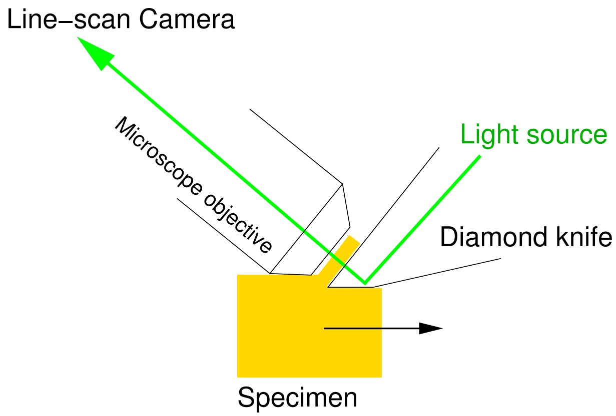
Brain specimen is embedded in plastic block.

KESM Imaging



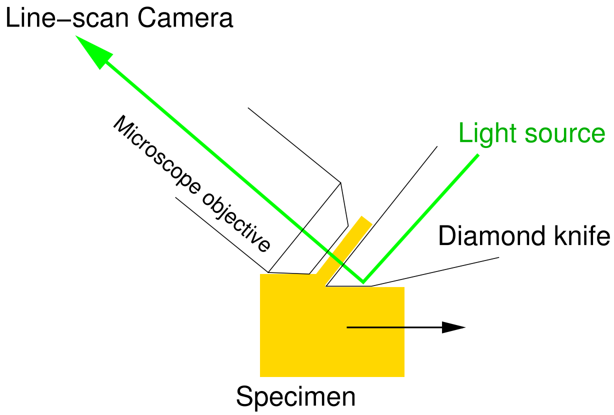
Plastic block is moved toward the knife.

KESM Imaging



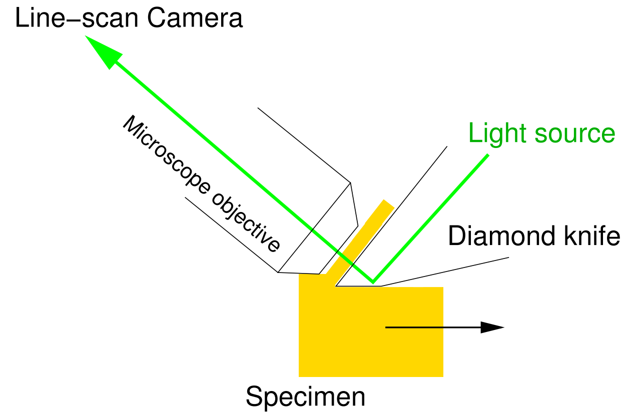
Thin tissue slides over knife and gets imaged.

KESM Imaging



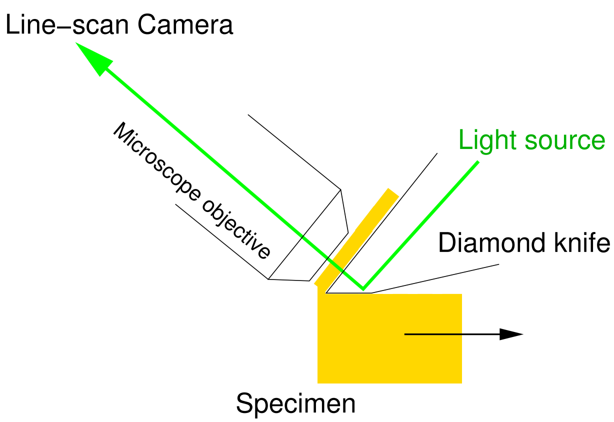
Successive line scan constructs a long image.

KESM Imaging



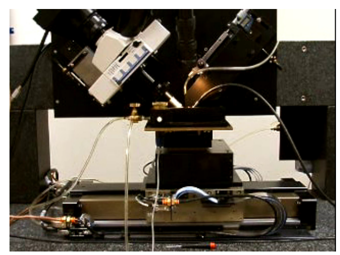
One sweep results in a $\sim 4,000 \times 12,000$ image ($\sim$ 48 MB).

KESM Imaging

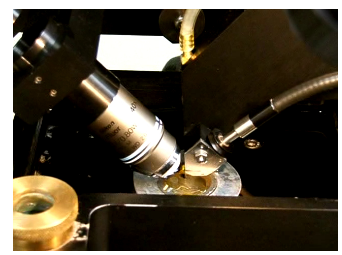


One brain results in $\sim 25,000$ to $40,000$ images.

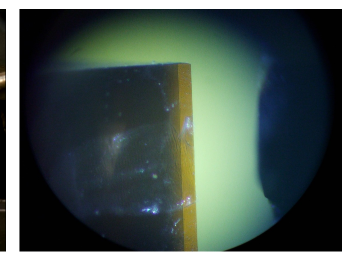
KESM [Movies]



Macro view



Close-up



Observation port

- Movies showing the KESM in action.

Related 3D Microscopy

Physical sectioning:

- Array Tomography (Micheva and Smith 2007)
- ATLUM (Hayworth 2008)
- SBF-SEM (Denk and Horstmann 2004)

Hybrid: Ablation + confocal

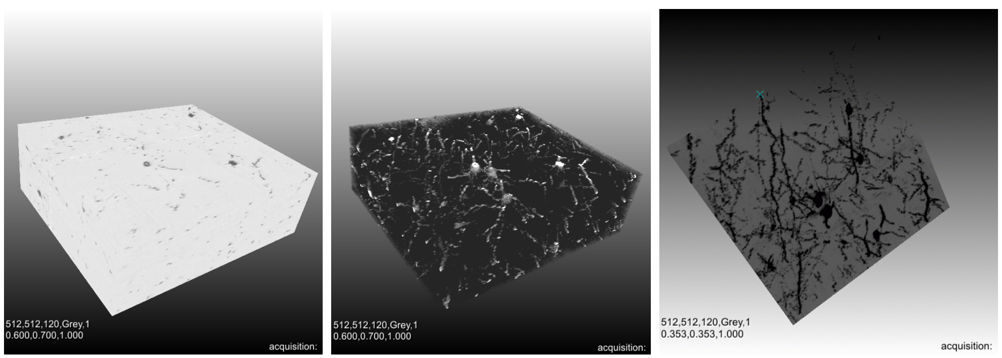
- All-Optical Histology (Tsai et al. 2003)

Part II

The Data

Abbott (2008); Choe et al. (2009, 2010)

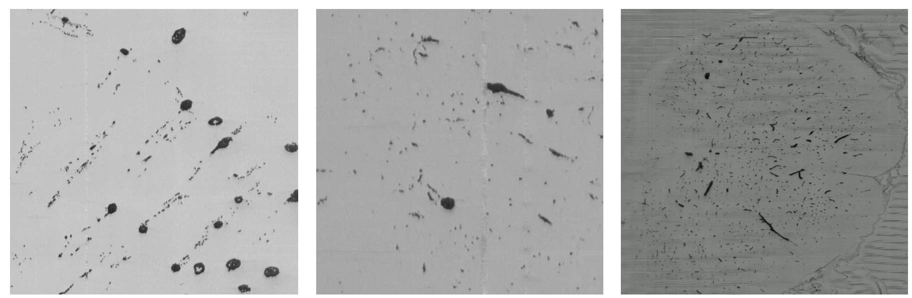
KESM Data



300 μm × 350 μm × 120 μm block

- Basically a huge 3D stack made up of 2D images.
- Details such as dendritic spines can be observed.

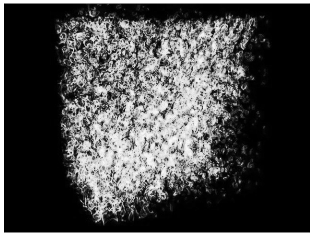
KESM Data [Movies]



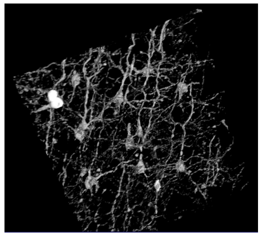
Cerebellum (Golgi) | Cortex (Golgi) | Spinal cord (India ink)

- Flythrough of 3D stack: Looks like a movie in 2D.

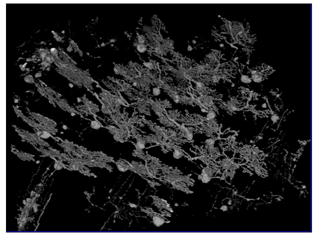
KESM: Volume Vis. [Movies]



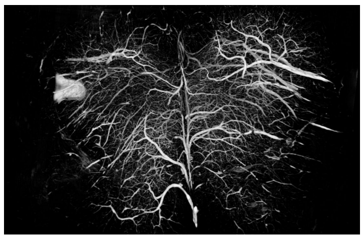
Nissl (Cortex)



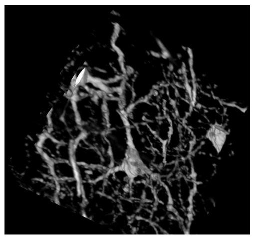
Golgi (Cortex)



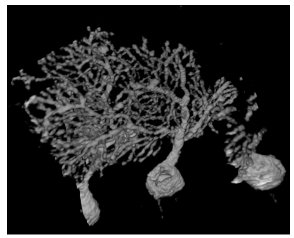
Golgi (Cerebellum)



India ink (Spinal cord)

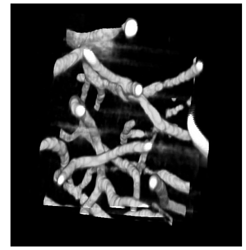


Golgi (Pyramidal cell)

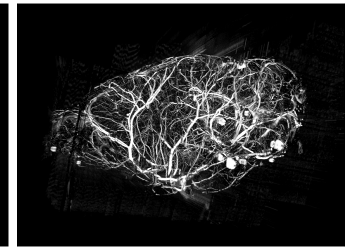


Golgi (Purkinje cell)

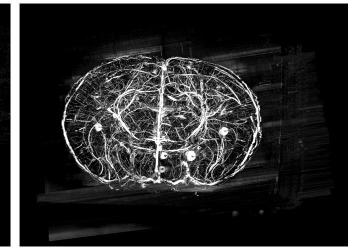
KESM: Whole Brain [Movies]



Close-up



Sagittal



Coronal

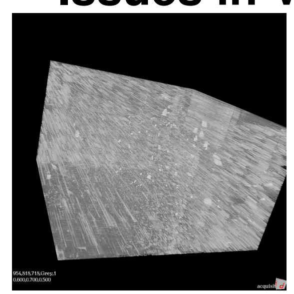
- Vascular network in the mouse brain stained with India ink.
- Whole brain at 0.6 μm $\times$ 0.7 μm $\times$ 1.0 μm resolution.

Part III

Visualization

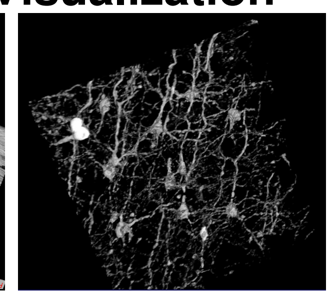
Eng and Choe (2008); Choe et al. (2011)

Issues in Visualization



Neurons

Whole brain: 1 cm cube



Neurons

$\sim$200 μm cube

- Very large volume ($\sim$ 24,000 $\times$ 12,000 $\times$ 5,500 $\approx$ 2 TB)
- Fine detail (typical fibers $\sim$ 1 to 2 μm diameter).
- We want a **global perspective**, but **preserve fine detail**.

Two Approaches

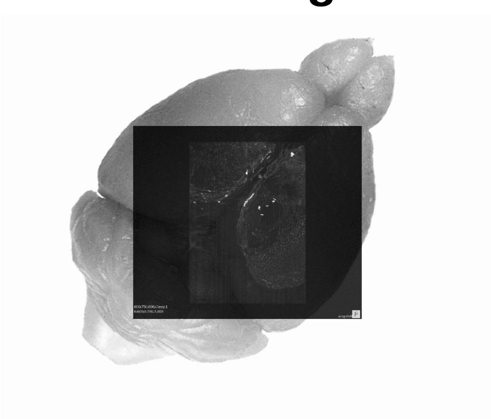
1. Thin slab fly-through:
   - View the whole volume, but only show a thin slab.
   - Interactively move around the slab perpendicular to one sectioning plane.
   - More of a visualization know-how than an algorithm.
2. Web-based rendering using image overlays:
   - Google Map-like interface (multi-scale tiling).
   - Transparent image overlays for 3D.
   - Pseudo-stereo by offsetted overlays.

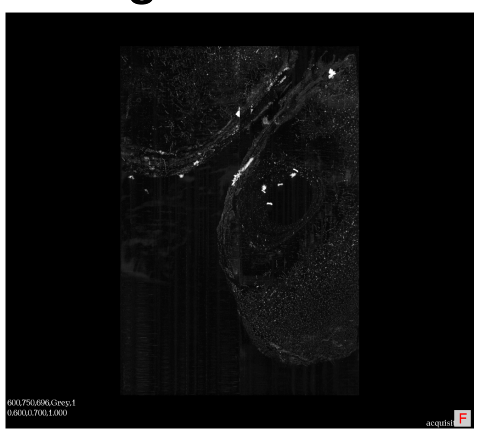
Part III.1

Visualization

Thin-Slab Visualization

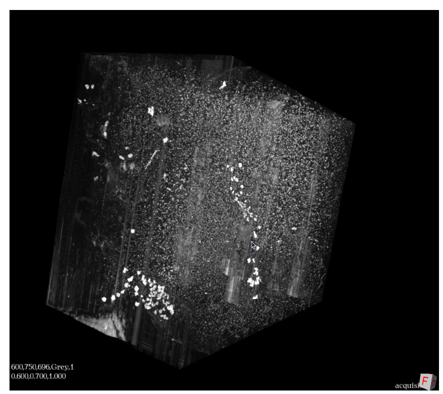
Getting Oriented: Golgi Brain



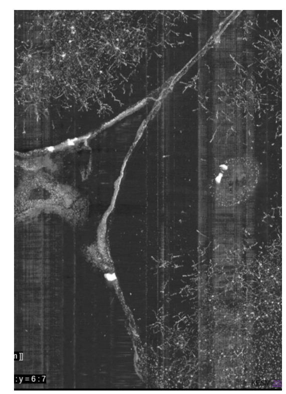


- Partial view of the whole-brain Golgi data set (horizontal section, seen from above).
- Data block width = 2.88 mm. Horizontal section.

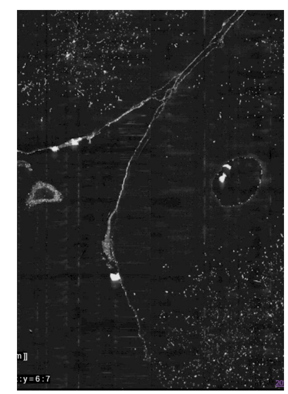
Whole Block Reveals Little



Whole Block



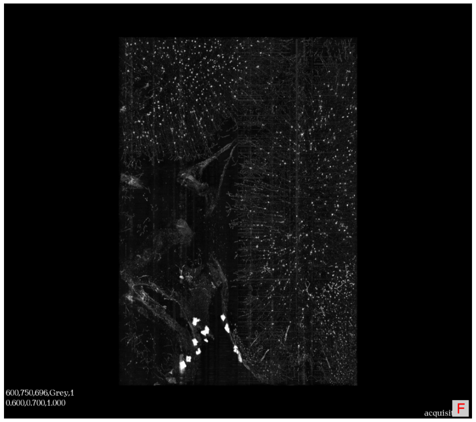
100 μm-thick slab

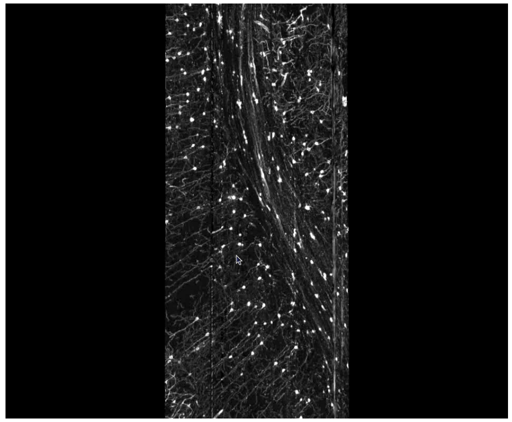


Single layer

- Looking at entire block is not informative.
- Nor is looking at a single layer.

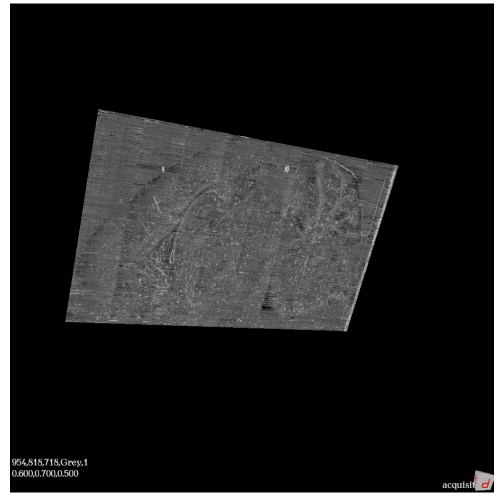
Thin-Slab Visualization [1/2]



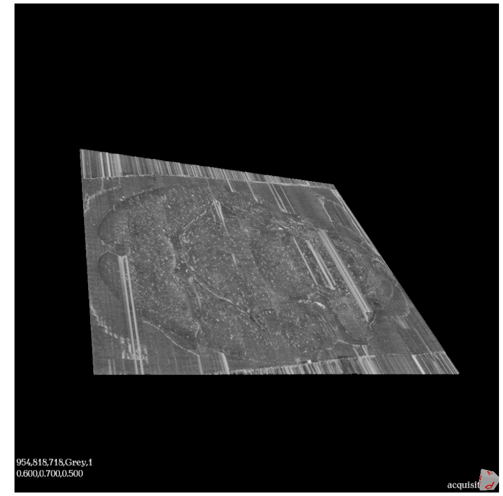


- Flying through ∼100 µm-thick slabs reveals intricate detail.

Thin-Slab Visualization [2/2]



Sagittal



Horizontal

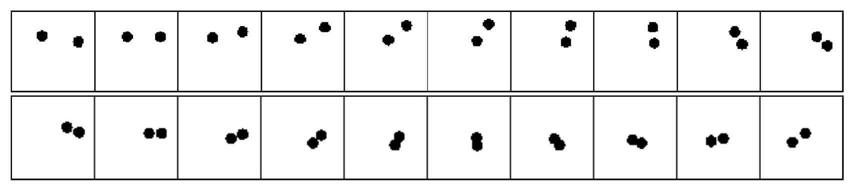
- Thin-slab visualization of new full-brain Golgi data.

Part III.2

Visualization

Web-Based Rendering Using Image Overlays

Visualizing an Image Stack

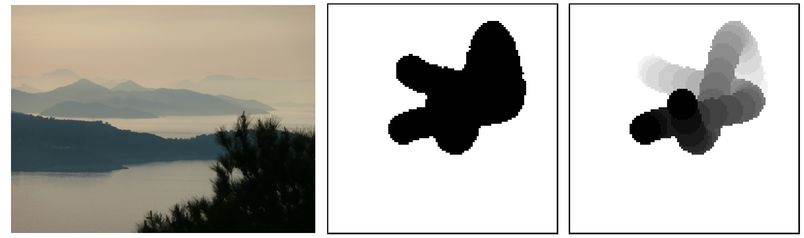


- Again, single images convey little information.
- Looking at the images as a movie does not help either.
- Looking at the whole set at once does not either.
- Try that for a 2 TB image stack!

Goals and Requirements

- Goal 1: Visualization in 3D
- Goal 2: Broad dissemination:
  - No high-end hardware.
  - No custom application.
  - Platform independence.
  - Runs in a standard web browser without plugins.

Approach: Overlay w/ Dist. Attenuation

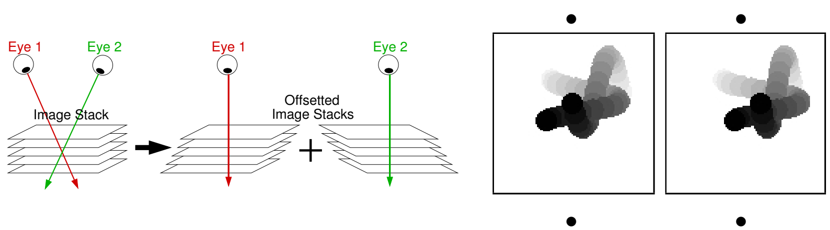


Off the coast of Dubrovnik, Croatia (The inspiration) | MIP | Distance Attenuation

How to visualize an image stack? (Eng and Choe 2008)

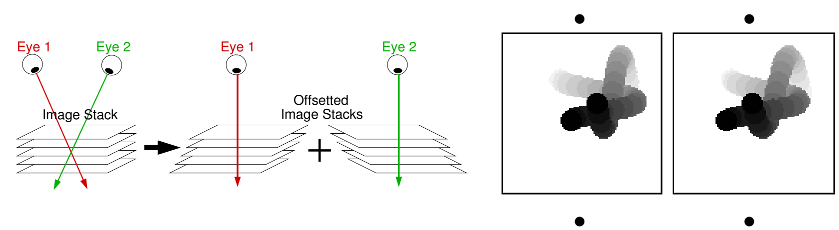
- We can overlay the images in HTML, using CSS.
- Simple overlay (MIP) is not good.
- We need distance attenuation (haze effect).

Approach: Pseudo-3D Rendering



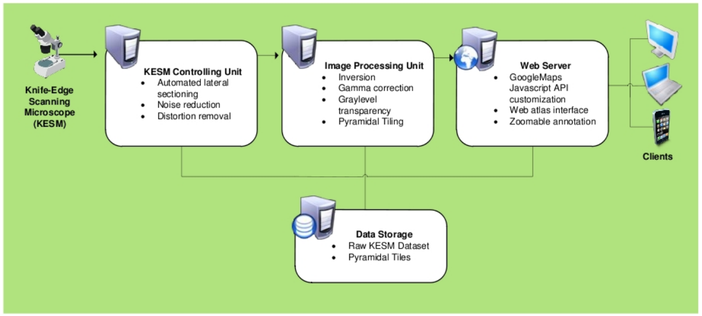
- Generate stereo pair by shearing the image stack.
- **Cross** merge the above pair.

Approach: Pseudo-3D Rendering



- Generate stereo pair by shearing the image stack.
- **Parallel** merge the above pair.

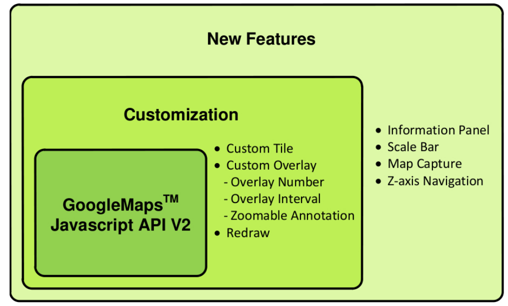
Putting It Together: KESM Brain Atlas



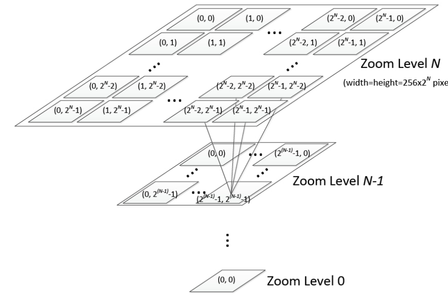
- Multi-scale tiles.
- Semi-transparent images.
- Google Maps API (v2).

$\longrightarrow$ KESM Brain Atlas

Putting It Together: KESM Brain Atlas



API layers

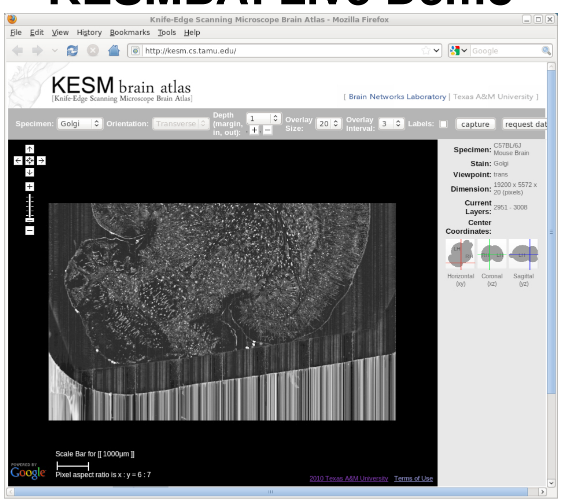


Tiling Scheme

- Multi-scale tiles.
- Semi-transparent images.
- Google Maps API (v2).

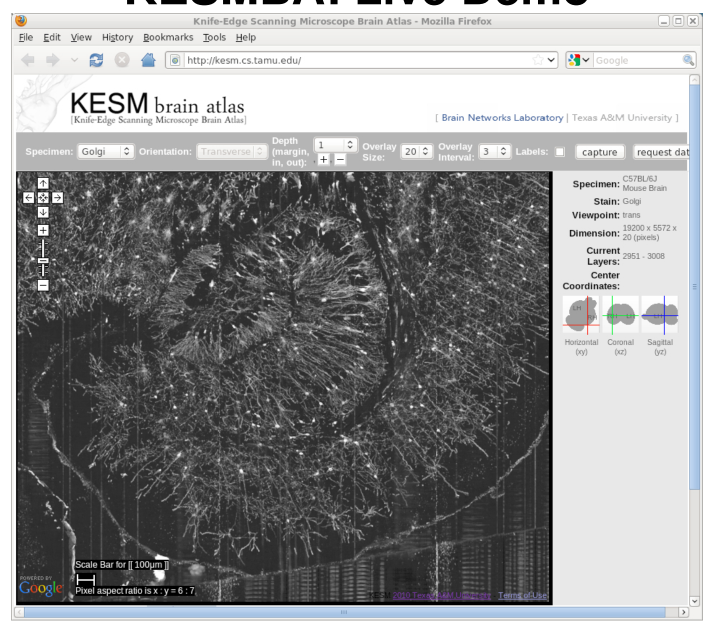
$\longrightarrow$ KESM Brain Atlas

KESMBA: Live Demo

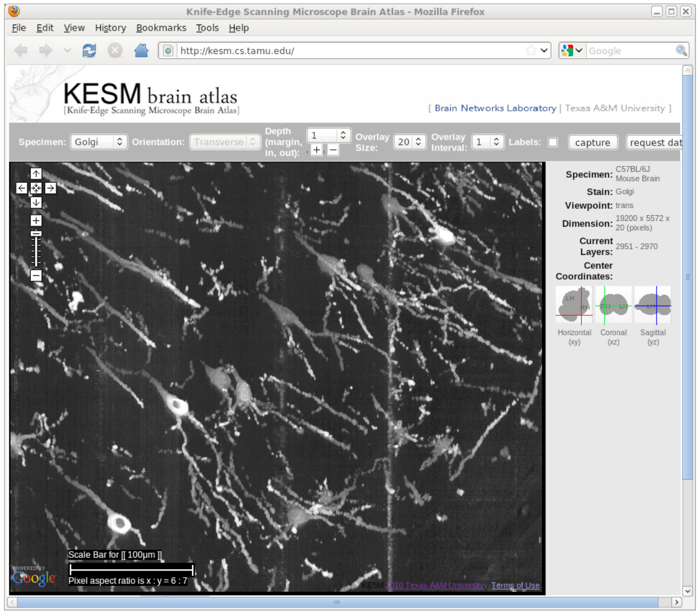


- `http://kesm.cs.tamu.edu`.
- Email `choe@tamu.edu` for username/password.

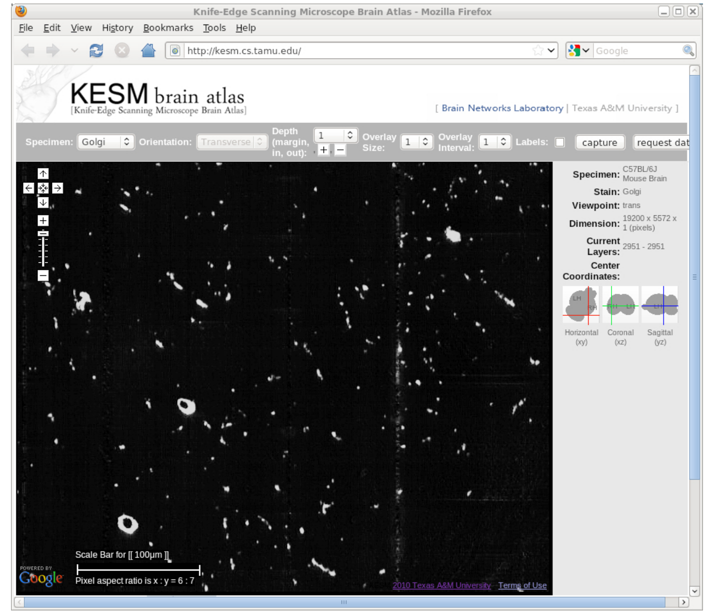
KESMBA: Live Demo



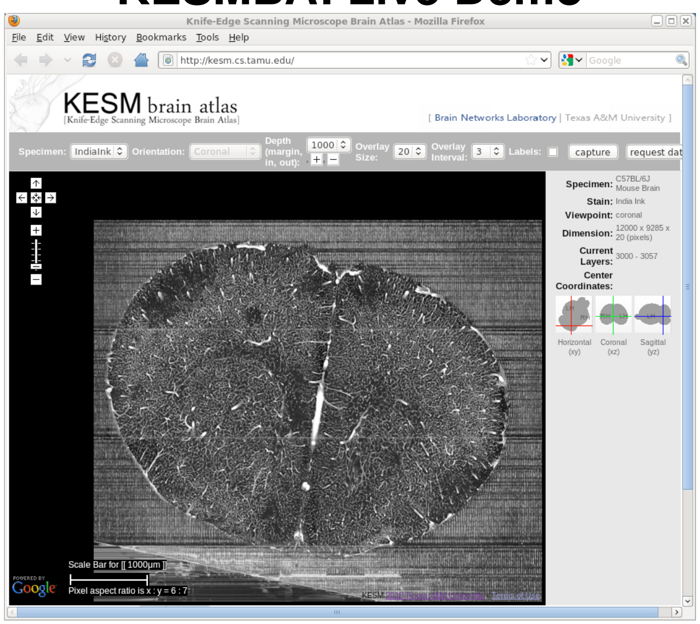
KESMBA: Live Demo



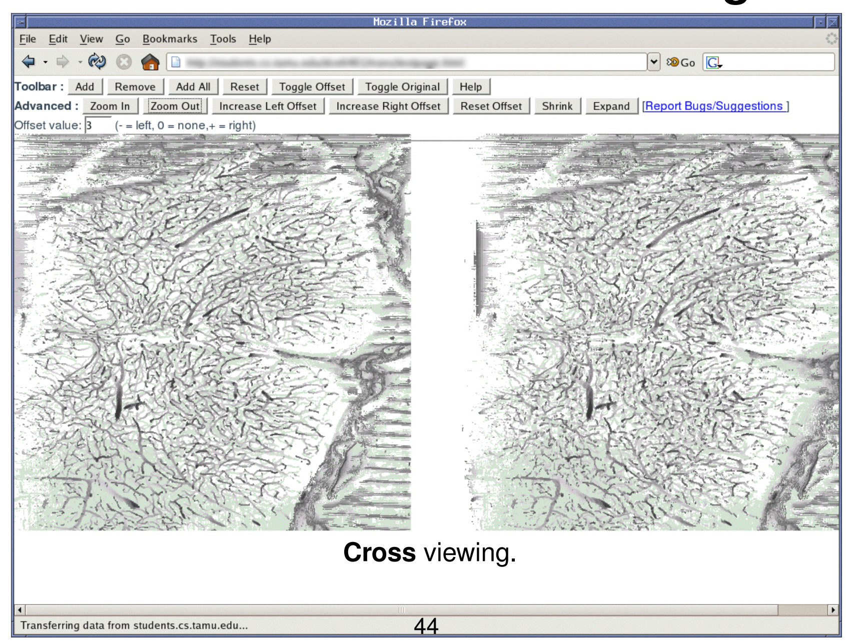
KESMBA: Live Demo



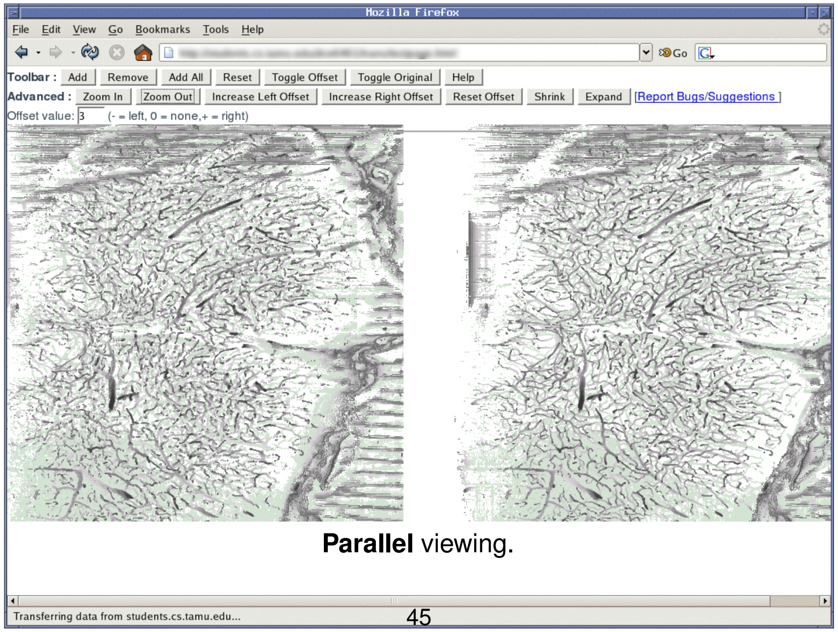
KESMBA: Live Demo



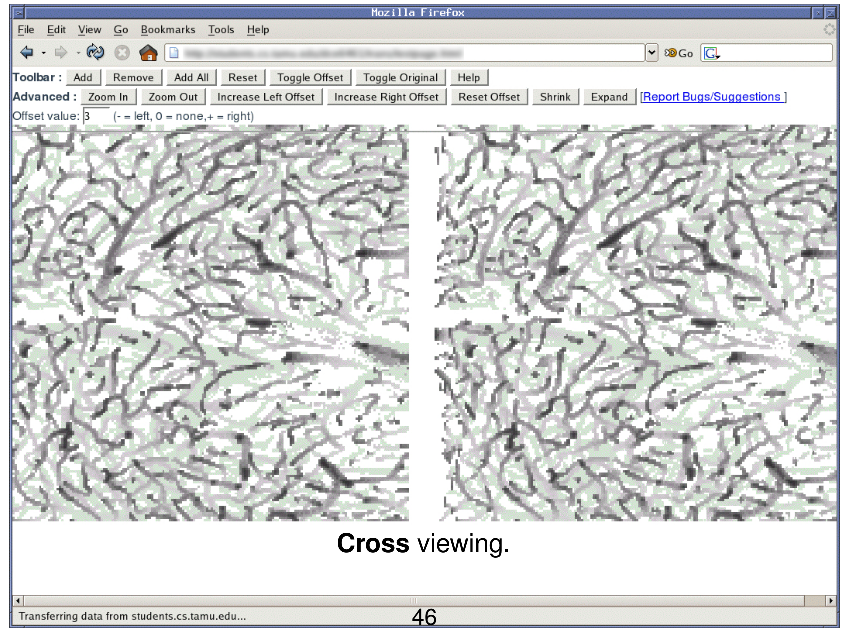
Stereo Pseudo-3D Rendering



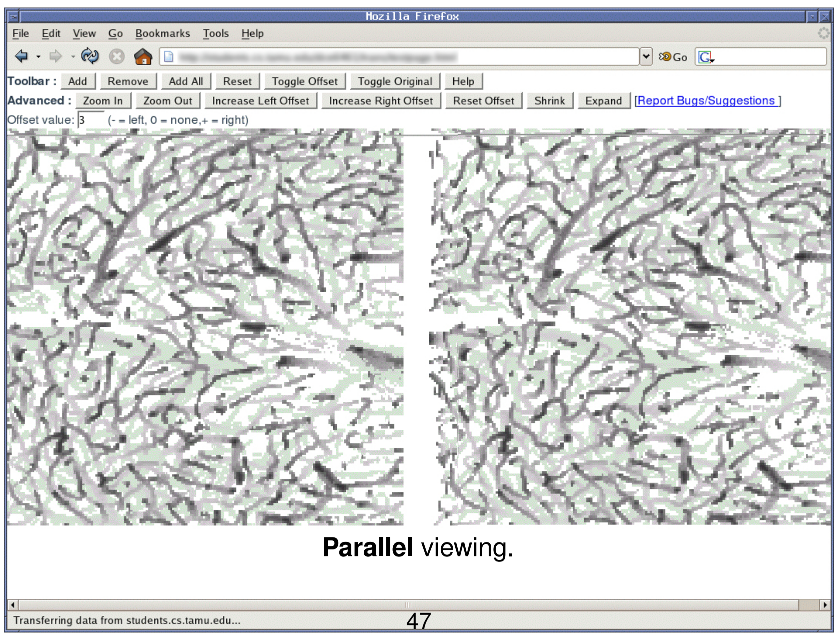
Stereo Pseudo-3D Rendering



Stereo Pseudo-3D Rendering



Stereo Pseudo-3D Rendering



Wrap Up

Conclusion

- High-throughput physical sectioning microscopes are enabling the acquisition of detailed neural circuitry data at the whole brain scale.
- New visual exploration techniques are needed.
- Web-based light-weight database interface allows quick, intuitive exploration of the data.

Acknowledgments

- People:
  - **BNL**: John Keyser, Louise C. Abbott, Bruce McCormick
  - **KESM**: Bruce McCormick, David Mayerich, Jaerock Kwon, Daniel Miller, Bernard Mesa (Micro Star)
  - **KESM Brain Atlas**: Chul Sung, Ji Ryang Chung, Daniel Eng
- Funding:
  ● IAMCS/KAUST (2010–2011); ● NSF CRCNS Data Sharing (#0905041); ● NIH/NINDS (#1R01-NS54252 & 03S1); ● NSF MRI (#0079874) and NSF ITR (#CCR-0220047), ● Texas Higher Education Coordinating Board (ATP #000512-0146-2001), ● TAMU CSE ● TAMU VPR ● 3Scan.

In Memory of Bruce H. McCormick

Bruce H. McCormick (1928–2007)

- Designer of the Knife-Edge Scanning Microscope
- Co-Founder of Scientific Visualization (with Tom DeFanti and Maxine D. Brown)

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