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

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

1

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

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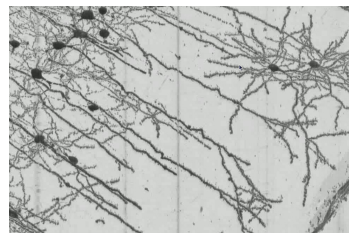
2

Long-Term Goal of the BNL

C57BL/6 mouse
http://mouseatlas.org

Mouse brain
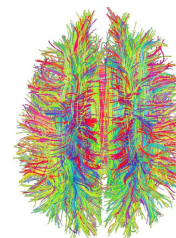http://nervenet.org

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 → function.
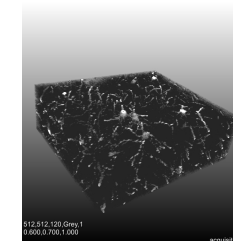
3

Background: Connectomics

|		
Imaging: Diffusion Tensor Imaging	Light Microscopy	Electron Microscopy
Scale: ∼ 10 cm cube	∼ 1 cm cube	∼ 100 μm cube
Human brain	Mouse brain	Several neurons
Resolution: ∼ 1 mm cube	∼ 1 μm cube	∼ 10 nm cube
Time: hours	weeks	year
Hagmann et al. (2007)	Mayerich et al. (2008)	Denk and Horstmann (2004)
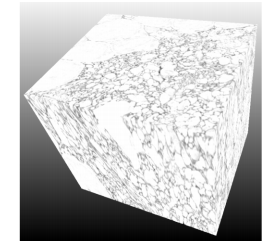
- Study of the connectome, the full connection matrix of the brain (Sporns et al. 2005).

4

Motivation and Research Issues
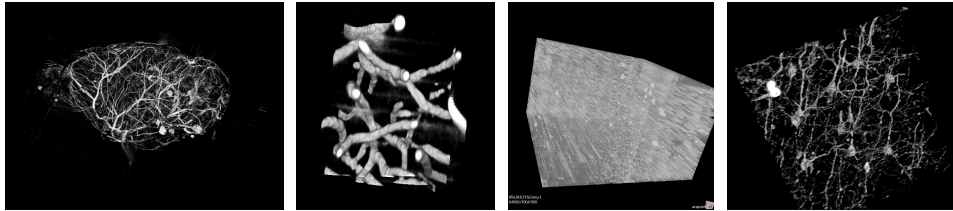
Vasculature	Vasculature	Neurons	Neurons
Whole brain: 1 cm cube	∼50 µm cube	Whole brain: 1 cm cube	∼200 µm cube

- 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
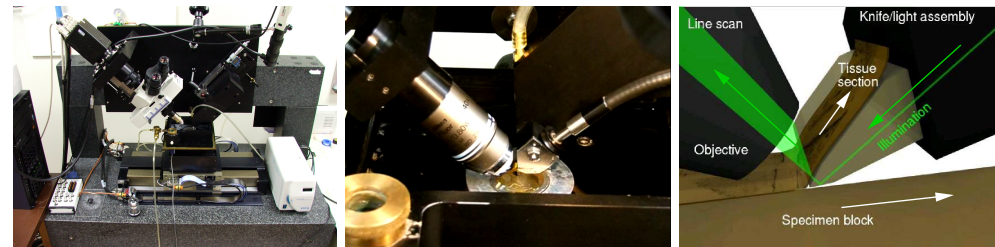
3. Visualization

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).
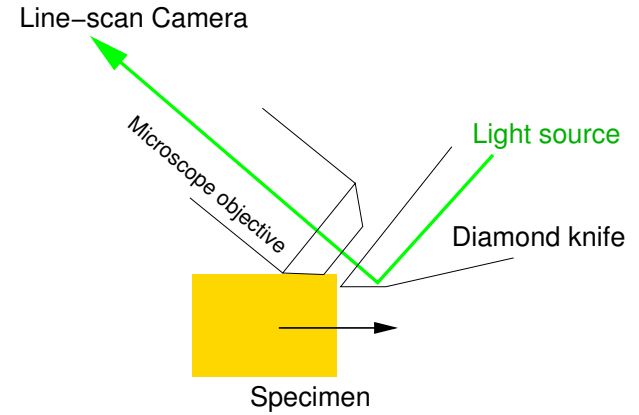
Operational Principles of the KESM
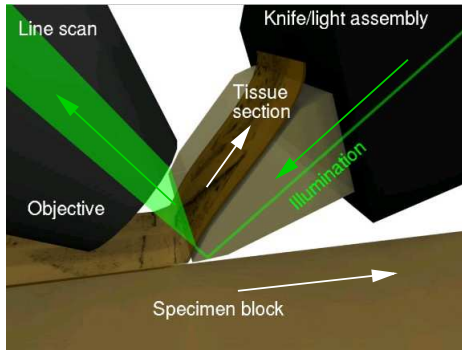
- Image while cutting (line-scan at the tip of the knife).

- Back-illumination through the diamond knife.

- Tissue thickness: 1 μm (or possibly less).

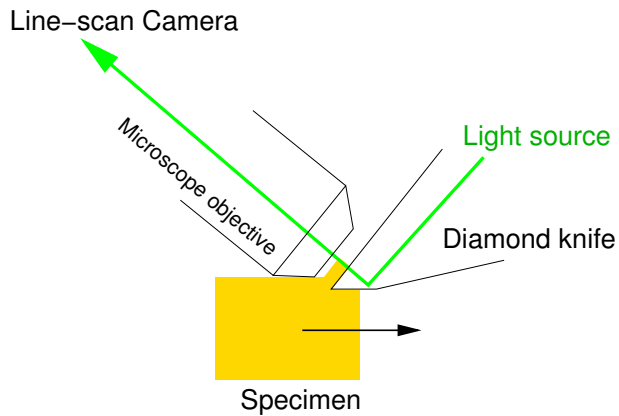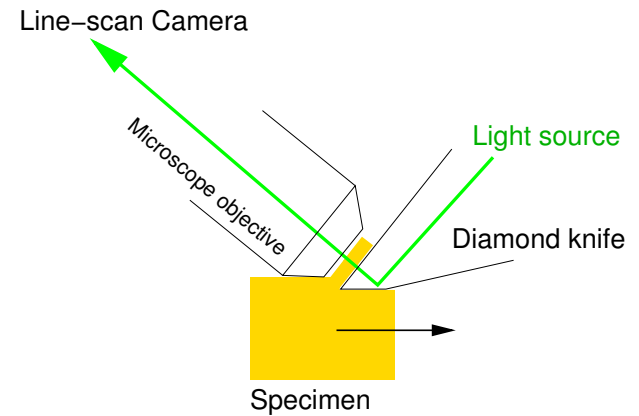# KESM Imaging

Brain specimen is embedded in plastic block.
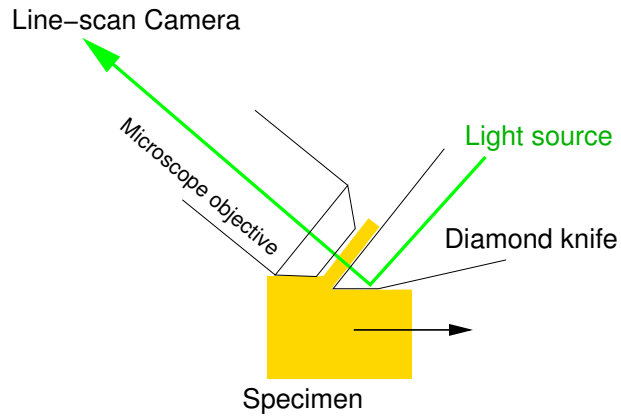
KESM Imaging

Plastic block is moved toward the knife.

KESM Imaging
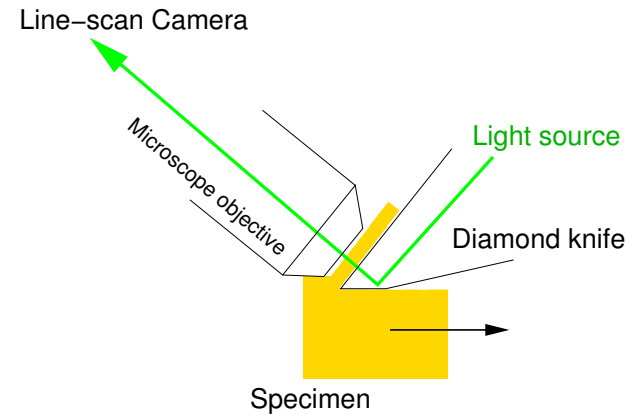

Thin tissue slides over knife and gets imaged.

KESM Imaging

Line–scan Camera

Microscope objective

Light source

Diamond knife

Specimen

Successive line scan constructs a long image.

KESM Imaging

Line–scan Camera

Microscope objective

Light source

Diamond knife

Specimen

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

KESM Imaging

Line–scan Camera

Microscope objective
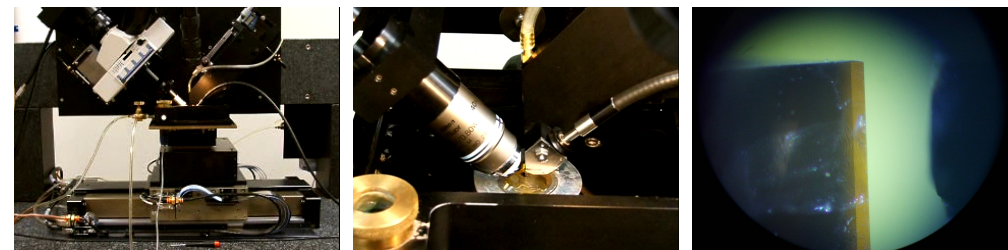
Light source

Diamond knife

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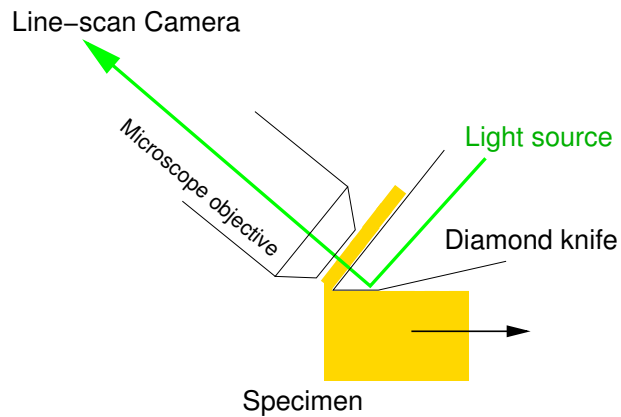
One brain results in $\sim 25,000$ to $40,000$ images.

KESM [Movies]

Macro view   Close-up   Observation port

- Movies showing the KESM in action.

Related 3D Microscopy
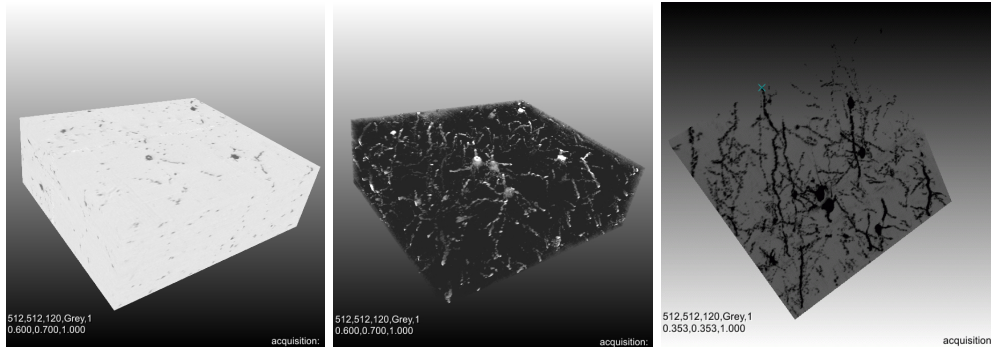
Physical sectioning:

- 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.
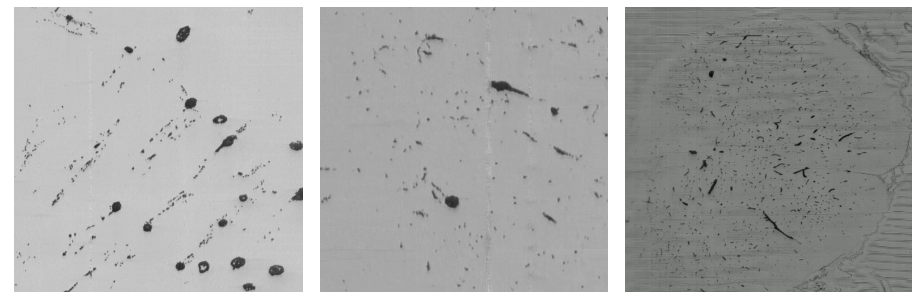
- Details such as dendritic spines can be observed.

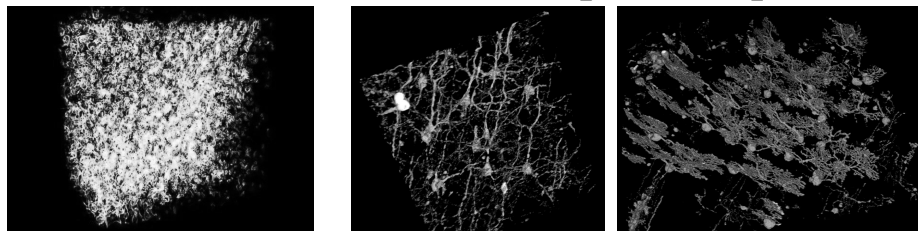# KESM Data [Movies]

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

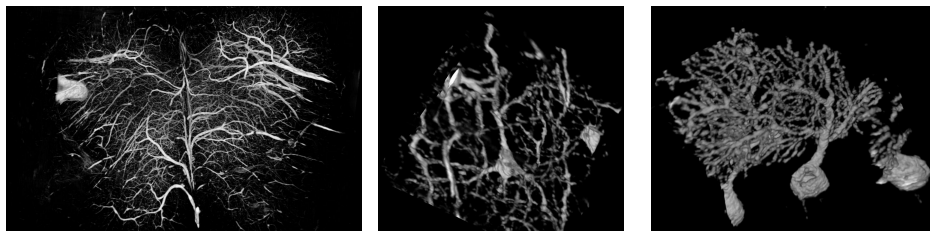- Flythrough of 3D stack: Looks like a movie in 2D.

KESM: Volume Vis. [Movies]

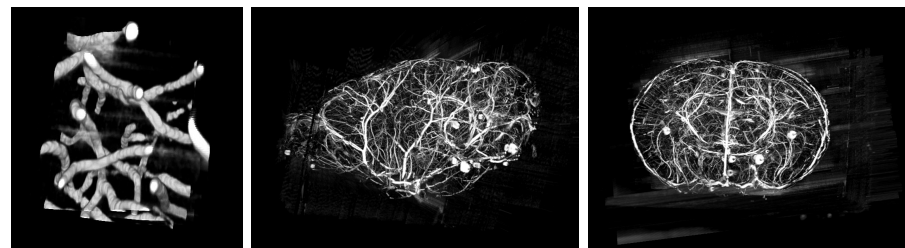Nissl (Cortex)

Golgi (Cortex)

Golgi (Cerebellum)

India ink (Spinal cord)

Golgi (Pyramidal cell)

Golgi (Purkinje cell)

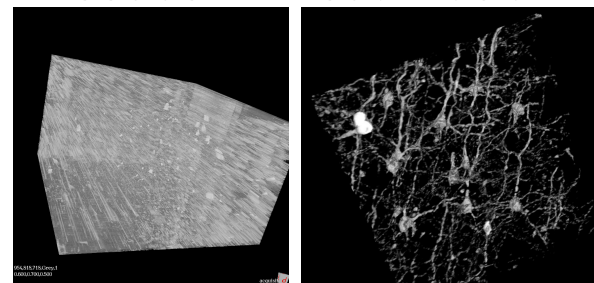# KESM: Whole Brain [Movies]

Close-up

Sagittal

Coronal

- Vascular network in the mouse brain stained with India ink.

- Whole brain at 0.6 μm × 0.7 μm × 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

∼200 μm cube

- Very large volume ($\sim 24{,}000 \times 12{,}000 \times 5{,}500 \approx 2$ TB)

- Fine detail (typical fibers ~ 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
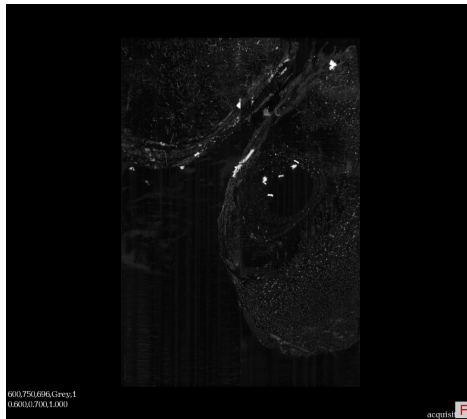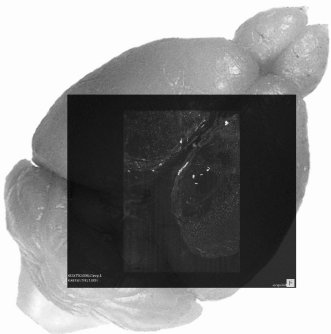
- Partial view of the whole-brain Golgi data set
  (horizontal section, seen from above).

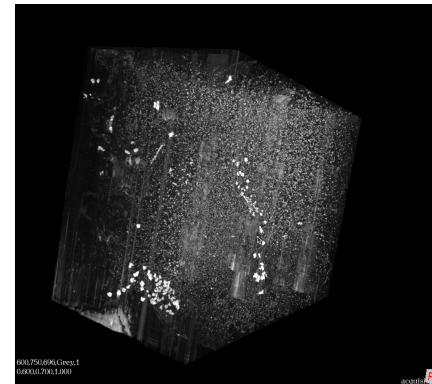- Data block width = 2.88 mm. Horizontal section.
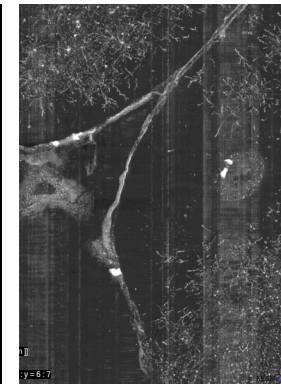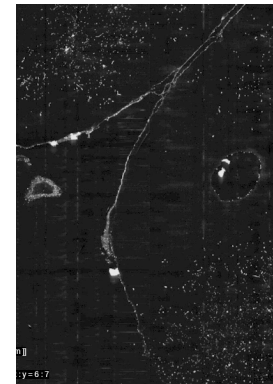
Whole Block Reveals Little

Whole Block   100 µm-thick slab   Single layer
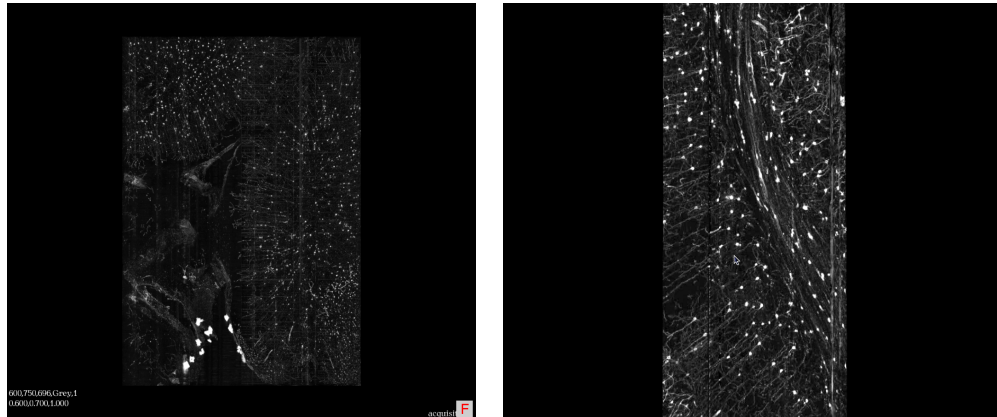
- Looking at entire block is not informative.

- Nor is looking at a single layer.
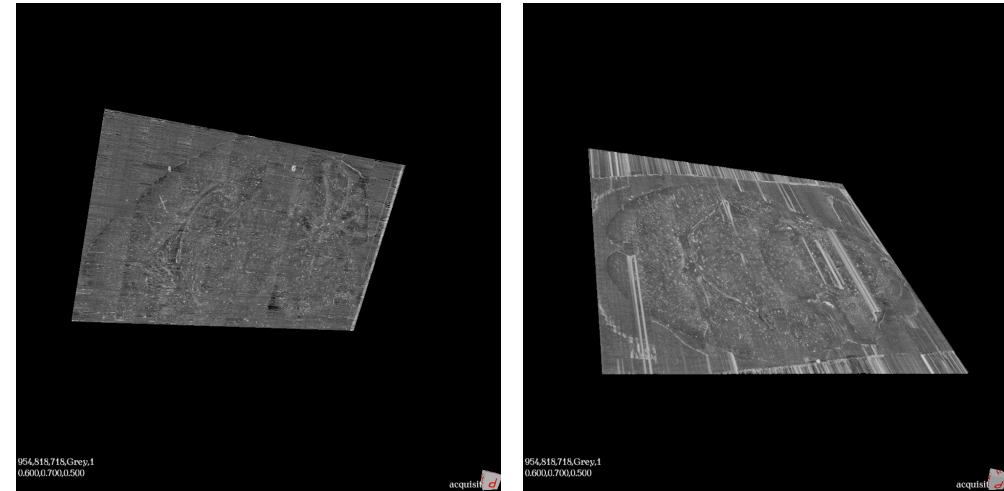
Thin-Slab Visualization [1/2]

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

Thin-Slab Visualization [2/2]

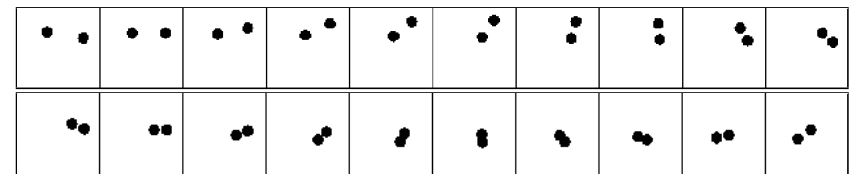Sagittal   Horizontal

- 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.
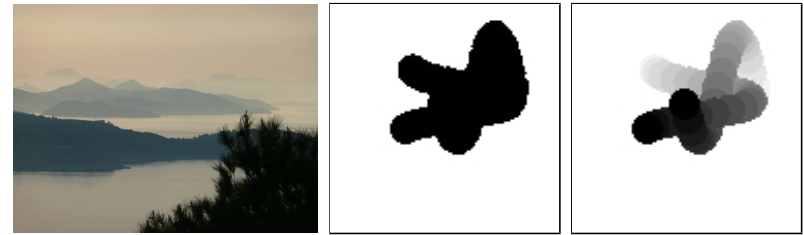
- Try that for a 2 TB image stack!

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.

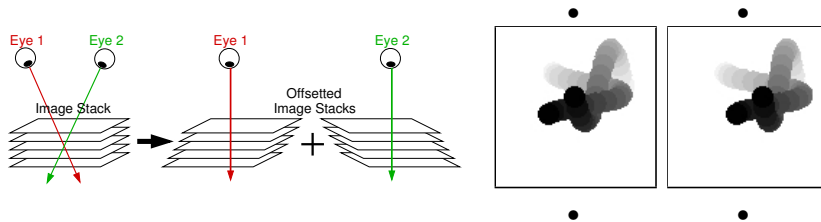# Approach: Overlay w/ Dist. Attenuation

Off the coast of Dubrovnik, Croatia   MIP   Distance Attenuation

(The inspiration)

How to visualize an image stack? (Eng and Choe 2008)
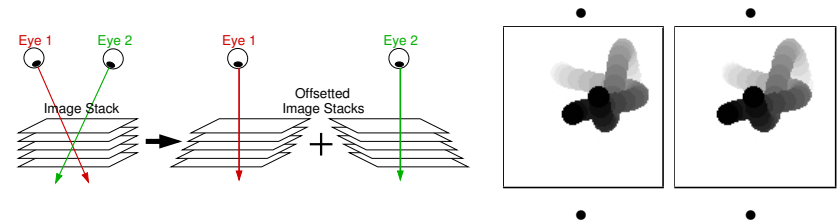
- We can overlay the images in HTML, using CSS.

- Simple overlay (MIP) is not good.

- We need distance attenuation (haze effect).

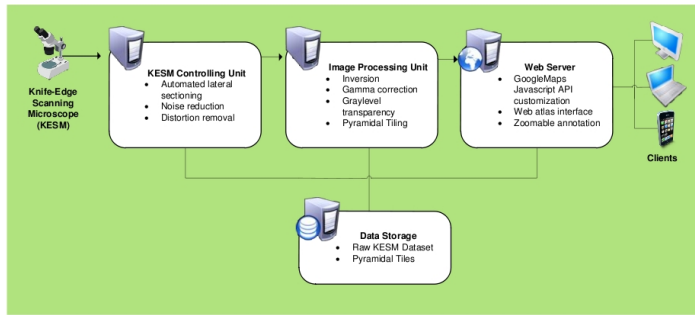# Approach: Pseudo-3D Rendering

- 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).

  $\rightarrow$ KESM Brain Atlas

37

Putting It Together: KESM Brain Atlas

API layers

Tiling Scheme
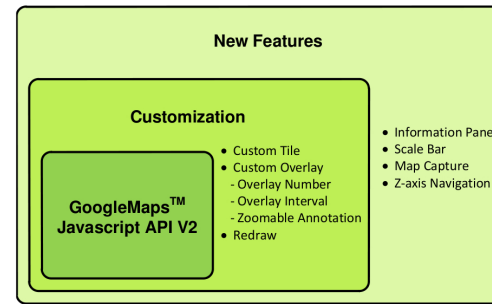
- Multi-scale tiles.

- Semi-transparent images.

- Google Maps API (v2).

  $\rightarrow$ KESM Brain Atlas

38

KESMBA: Live Demo

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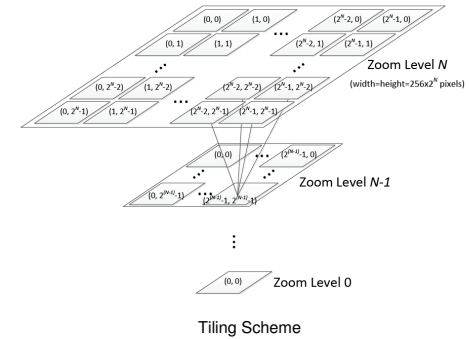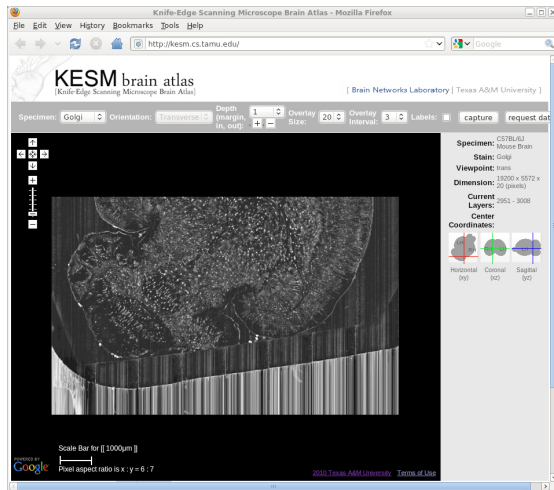
- Email `choe@tamu.edu` for username/password.

39

KESMBA: Live Demo
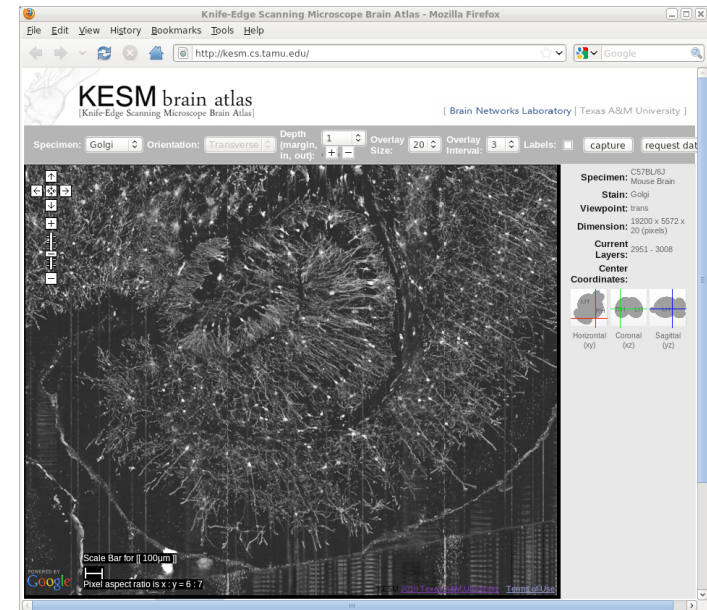
40

KESMBA: Live Demo

41

KESMBA: Live Demo

42

KESMBA: Live Demo

43

Stereo Pseudo-3D Rendering

Cross viewing.

44

Stereo Pseudo-3D Rendering

Parallel viewing.

45

Stereo Pseudo-3D Rendering

Cross viewing.

46

Stereo Pseudo-3D Rendering

Parallel viewing.

47

Wrap Up

48

Conclusion

- High-throughput physical sectioning microscopes are enabling the acquisition of detailed neural circuitry data at the whole brain scale.
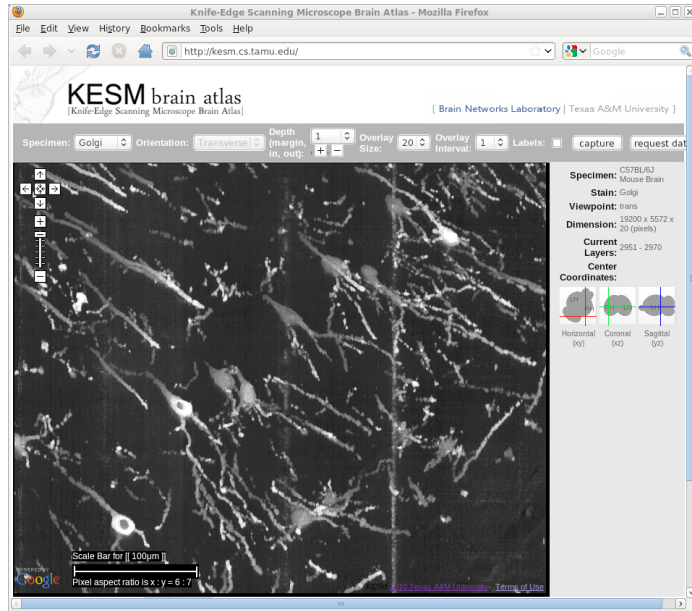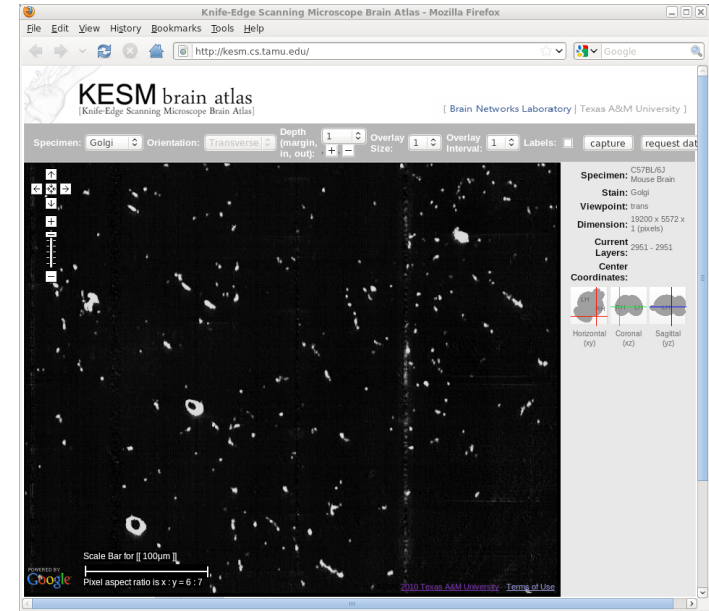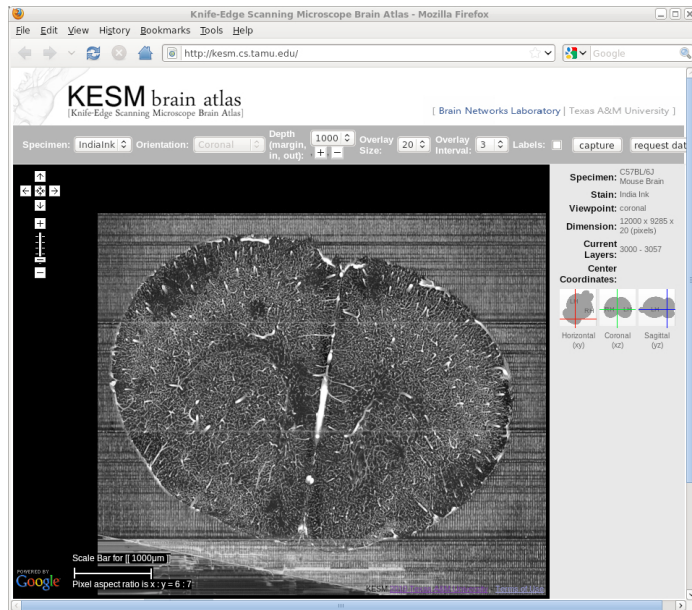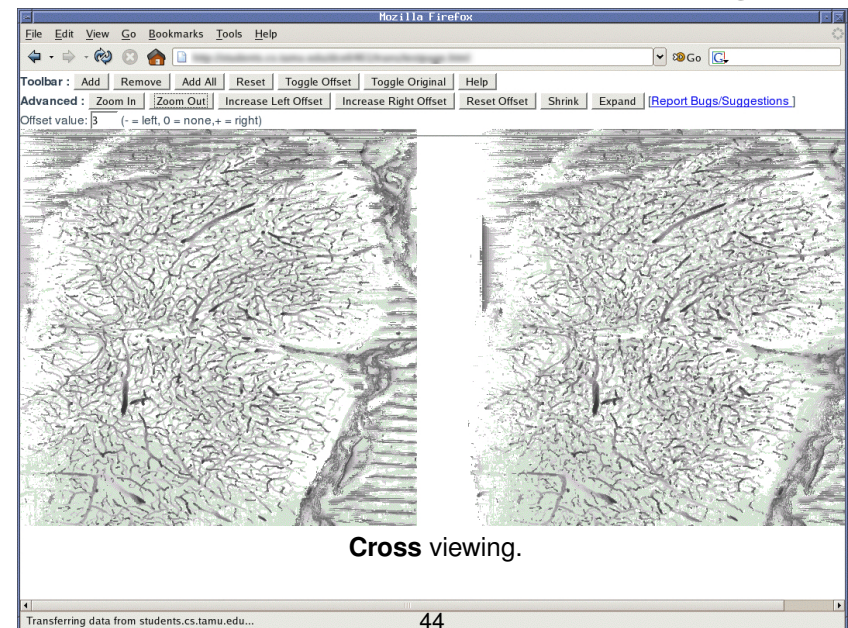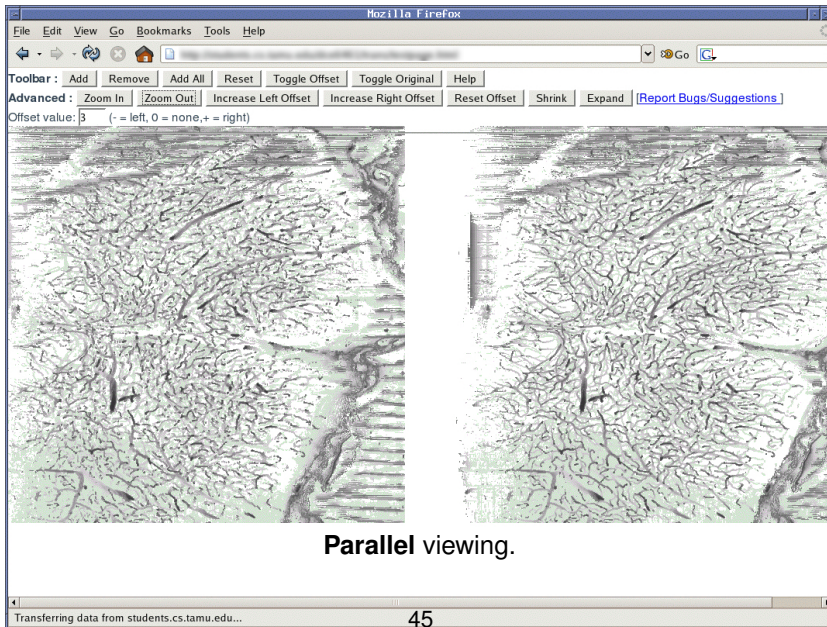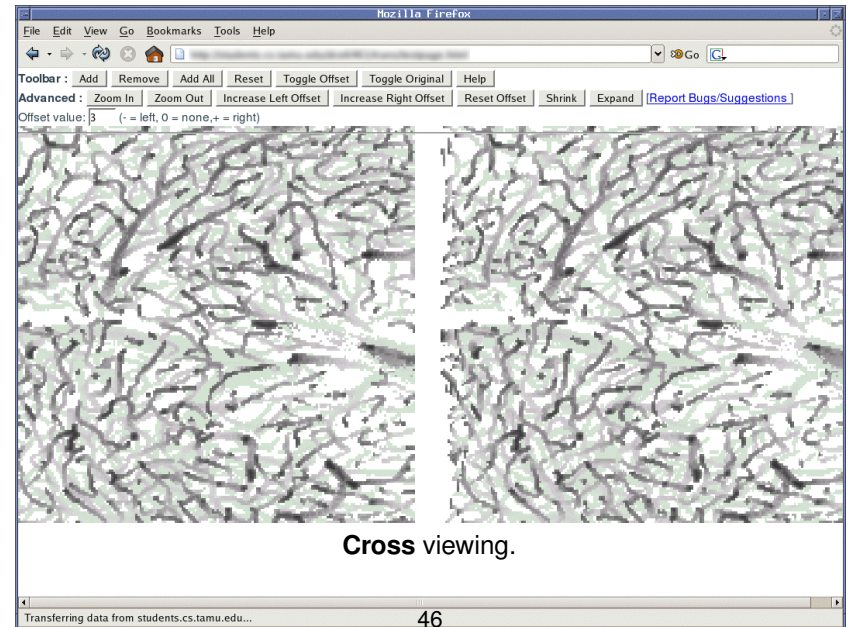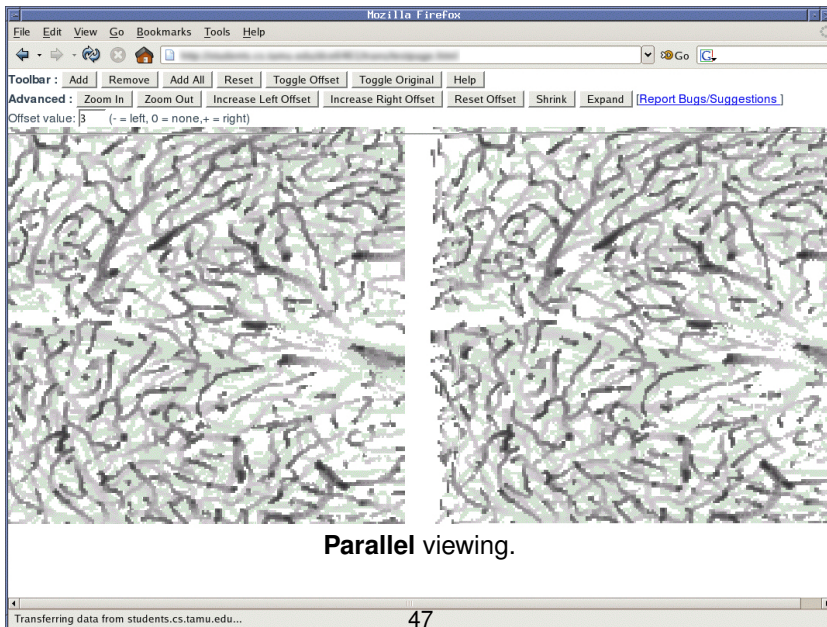
- New visual exploration techniques are needed.

- Web-based light-weight database interface allows quick, intuitive exploration of the data.

49

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)

51

References

Abbott, L. C. (2008). High-throughput imaging of whole small animal brains with the knife-edge scanning microscope. In *Neuroscience Meeting Planner, Washington, DC: Society for Neuroscience*. Program No. 504.2.

Choe, Y., Abbott, L. C., Han, D., Huang, P.-S., Keyser, J., Kwon, J., Mayerich, D., Melek, Z., and McCormick, B. H. (2008). Knife-edge scanning microscopy: High-throughput imaging and analysis of massive volumes of biological microstructures. In Rao, A. R., and Cecchi, G., editors, *High-Throughput Image Reconstruction and Analysis: Intelligent Microscopy Applications*, 11–37. Boston, MA: Artech House.

Choe, Y., Abbott, L. C., Miller, D. E., Han, D., Yang, H.-F., Chung, J. R., Sung, C., Mayerich, D., Kwon, J., Micheva, K., and Smith, S. J. (2010). Multiscale imaging, analysis, and integration of mouse brain networks. In *Neuroscience Meeting Planner, San Diego, CA: Society for Neuroscience*. Program No. 516.3. Online.

Choe, Y., Han, D., Huang, P.-S., Keyser, J., Kwon, J., Mayerich, D., and Abbott, L. C. (2009). Complete submicrometer scans of mouse brain microstructure: Neurons and vasculatures. In *Neuroscience Meeting Planner, Chicago, IL: Society for Neuroscience*. Program No. 389.10. Online.

Choe, Y., Mayerich, D., Kwon, J., Miller, D. E., Chung, J. R., Sung, C., Keyser, J., and Abbott, L. C. (2011). Knife-edge scanning microscopy for connectomics research. In *Proceedings of the International Joint Conference on Neural Networks*. Piscataway, NJ: IEEE Press. Submitted.

Denk, W., and Horstmann, H. (2004). Serial block-face scanning electron microscopy to reconstruct three-dimensional tissue nanostructure. *PLoS Biology*, 19:e329.

Eng, D. C.-Y., and Choe, Y. (2008). Stereo pseudo 3D rendering for web-based display of scientific volumetric data. In *Proceedings of the IEEE/EG International Symposium on Volume Graphics*.

Hagmann, P., Kurant, M., Gigandet, X., Thiran, P., Wedeen, V. J., Meuli, R., and Thiran, J.-P. (2007). Mapping human whole-brain structural networks with diffusion MRI. *PLoS ONE*, 2:e597.

Hayworth, K. (2008). Automated creation and SEM imaging of Ultrathin Section Libraries: Tools for large volume neural circuit reconstruction. In *Society for Neuroscience Abstracts*. Washington, DC: Society for Neuroscience. Program No. 504.4.

Kwon, J., Mayerich, D., Choe, Y., and McCormick, B. H. (2008). Lateral sectioning for knife-edge scanning microscopy. In *Proceedings of the IEEE International Symposium on Biomedical Imaging*, 1371–1374.

Mayerich, D., Abbott, L. C., and McCormick, B. H. (2008). Knife-edge scanning microscopy for imaging and reconstruction of three-dimensional anatomical structures of the mouse brain. *Journal of Microscopy*, 231:134–143.

McCormick, B. H. (2004). System and method for imaging an object. USPTO patent #US 6,744,572 (for Knife-Edge Scanning; 13 claims).

McCormick, B. H., Abbott, L. C., Mayerich, D. M., , Keyser, J., Kwon, J., Melek, Z., and Choe, Y. (2006). Full-scale submicron neuroanatomy of the mouse brain. In *Society for Neuroscience Abstracts*. Washington, DC: Society for Neuroscience. Program No. 694.5. Online.

Micheva, K., and Smith, S. J. (2007). Array tomography: A new tool for imaging the molecular architecture and ultrastructure of neural circuits. *Neuron*, 55:25–36.

Sporns, O., Tononi, G., and Kötter, R. (2005). The human connectome: A structural description of the human brain. *PLoS Computational Biology*, 1:e42.

Tsai, P. S., Friedman, B., Ifarraguerri, A. I., Thompson, B. D., Lev-Ram, V., Schaffer, C. B., Xiong, Q., Tsien, R. Y., Squier, J. A., and Kleinfeld, D. (2003). All-optical histology using ultrashort laser pulses. *Neuron*, 39:27–41.