Nanotomography of brain networks

[1] R. Mizutani *et al.* (2010) *Cerebral Cortex* **20**, 1739-1748.
[2] R. Mizutani, R. Saiga *et al.* (2013) *J. Struct. Biol.* **184**, 271-279.
[3] First 3-D Map of a Fruit Fly's Brain Network, *MIT Technology Review*, Sep 16 (2016).
[4] R. Mizutani and Y. Suzuki (2012) *Micron* **43**, 104-115.
[5] R. Mizutani, R. Saiga *et al.* (2016) *J. Microsc.* **261**, 57-66.

YouTube GitHub

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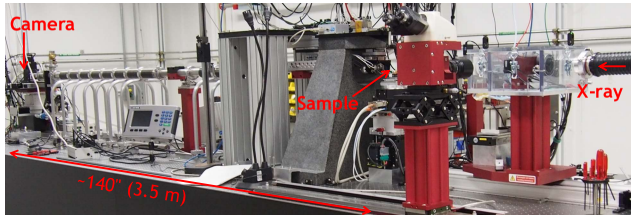
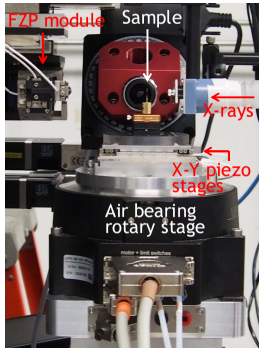
X-ray nanotomography of brain networks

The first step to understanding how the brain functions is to analyze its 3D network. The brain consists of a huge number of neurons having micrometer to nanometer sized structures. Therefore, 3D analysis of brain tissue at the relevant resolution is essential for elucidating brain's functional mechanisms. Here, we report 3D structures of human [1] and fly brain networks [2] revealed with synchrotron radiation nanotomography, or nano-CT. An article reviewing our study appeared in MIT Technology Review [3].





Nanotomography at 32-ID-C of APS Argonne

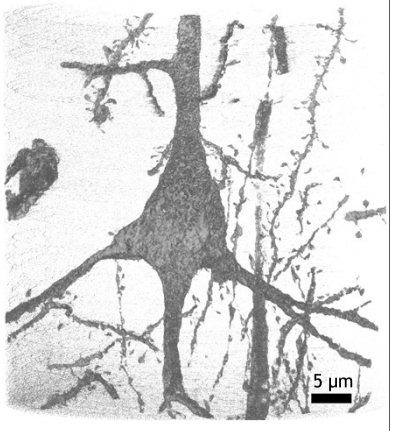
Post-mortem human brain tissues were collected with informed consent from the legal next of kin using protocols approved by ethical committees of the related organizations. Fly brains were dissected from adult fruit flies *Drosophila melanogaster*. The brain tissues were then subjected to high-Z element staining to visualize their structures with X-rays [4].

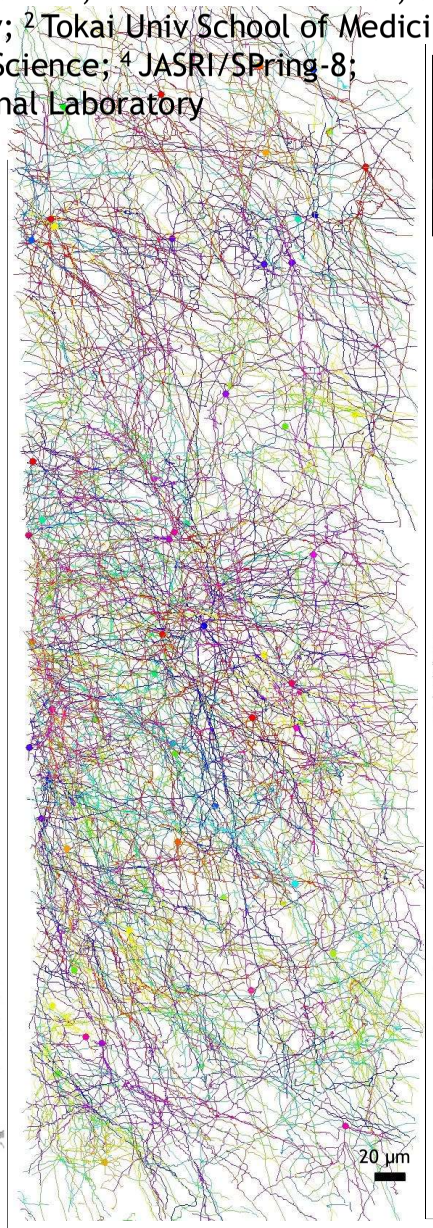
Nano-CT experiments were performed at the 32-ID beamline of the Advanced Photon Source (APS), Argonne National Laboratory, and at the BL37XU and BL47XU beamlines of SPring-8. Phase-contrast images produced by 8-keV x-rays were taken with these nano-CTs equipped with Fresnel zone plate (FZP) optics. A total of 1500-1800 images per dataset were acquired with exposure time of 0.15-1.00 s per image.

Structure of a human neuron at 120 nm resolution →

This 3D structure was determined using the nano-CT at BL37XU of SPring-8. The image resolution was estimated to be 120 nm from a logarithmic intensity plot [5].

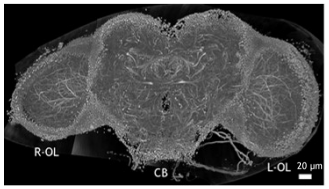
A large number of dendritic spines were observed as small claviform structures protruding from dendrites. Most of excitatory synapses form on these spines. The spines have spheroidal heads with major diameters of 300-950 nm and minor diameters of 150-350 nm. They are connected to the dendrites by thin necks with typical diameters of 150 nm and lengths of 300-1500 nm.

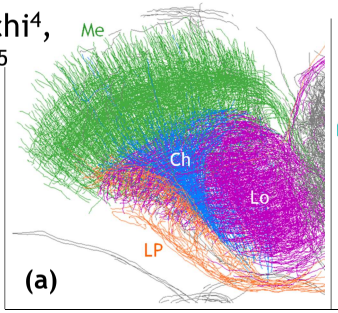


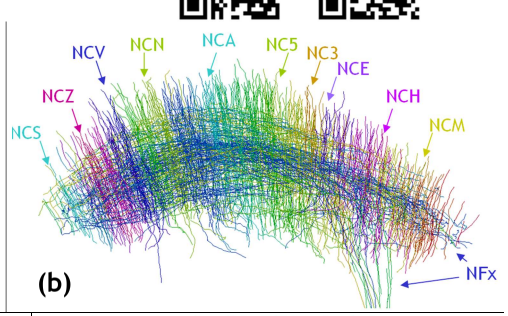


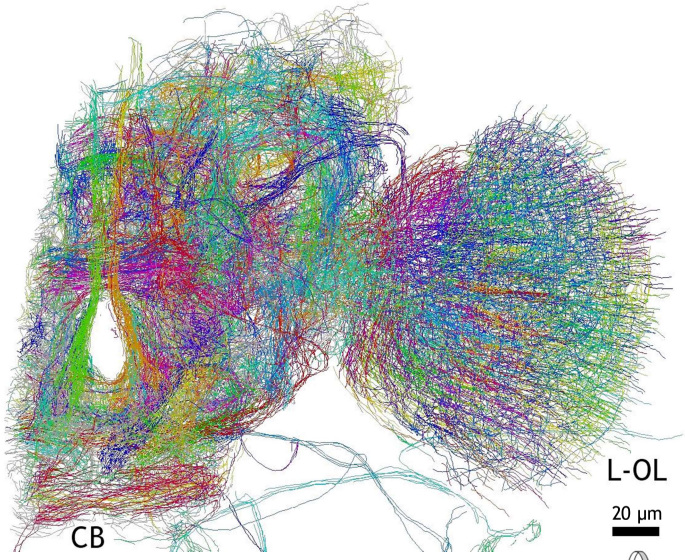
↑ Skeletonized model of human cerebral network

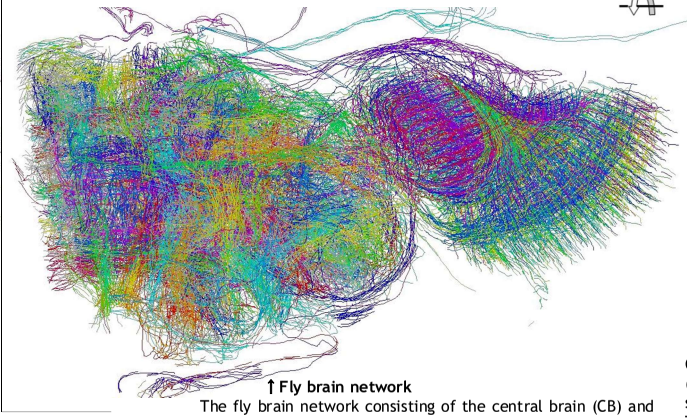
The obtained 3D distributions of x-ray coefficients were traced to build skeletonized models of brain networks [1-4]. The 3D images themselves were so complicated that they were difficult to comprehend, whereas skeletonized models described in 3D Cartesian coordinates were rather intelligible and better suited for exploring the network configuration.





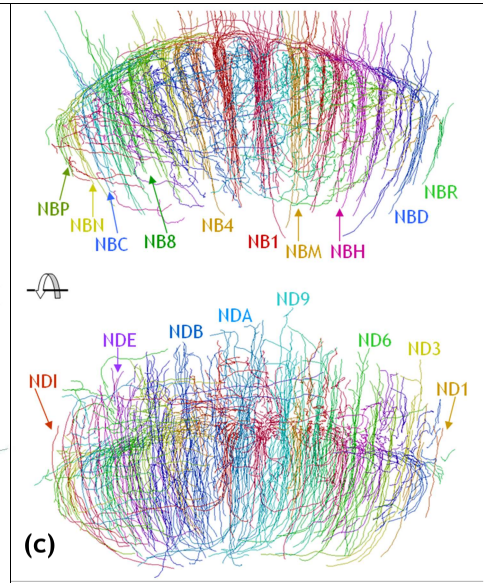


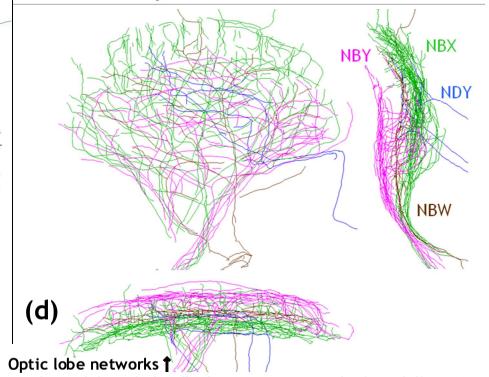




↑ Fly brain network

The fly brain network consisting of the central brain (CB) and the optic lobes (OL) was reconstructed from its 3D image. The obtained models revealed that the fly brain exhibits well-organized structures, of which each wiring should be dedicated for a certain information path. In contrast, the network of the human brain tissue of comparable size showed randomness and redundancy (left), which should be relevant to the versatility of our brains.





Optic lobe networks ↑

(a) Optic lobe of the fly brain is composed of medulla (Me), second optic chiasma (Ch), lobula (Lo), and lobula plate (LP). (b) The medulla is composed of neuronal processes perpendicular to the brain surface (NCx) and those parallel to the surface (NFx). (c) The second optic chiasma is divisible into 25-27 segments. In spans of these segments, neuronal processes of the lobula (NDx) are interlaced. (d) A posterior face of the lobula plate (NBY, magenta) corresponds to vertical motion sensitive neurons. An anterior face (NBX, green) corresponds to horizontal motion sensitive neurons [2].