3D computational neuroimaging via slab photography and deep learning

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Traditional neuroimaging relies on MRI and histological sectioning as a reference for postmortem reconstruction of brain structures, limiting the utility and scalability of studies in which either modality is unavailable. Here, we present a 3D computational neuroimaging modality based entirely on photography of brain slabs. Our approach is based on self-supervised deep learning for 3D volume reconstruction, enabling an accurate spatial map between individual brain slabs and underlying brain without the need for an additional imaging modality, such as MRI. Tested on postmortem brain specimens, this approach leads to a higher level of resolution and accuracy compared to MRI-based methods while maintaining anatomical integrity. This computational imaging modality offers a cost-effective and non-invasive alternative for postmortem brain imaging, with potential applications in neuropathology and neurology, as well as forensic investigations. By eliminating dependence on expensive imaging systems such as MRI scanners, this neuroimaging modality democratizes neuroimaging and enables new avenues of large-scale studies of neuroimaging–pathology correlations through retrospective reconstruction of historical and current slab photographs for neurological conditions of interest, such as Alzheimer's disease.

Neuroimaging plays a key role in correlating the brain's structures and its pathology, with magnetic resonance imaging (MRI) and histological sectioning serving as the "gold-standard" techniques for postmortem brain reconstruction. Although these modalities can provide valuable insights into neurodegenerative diseases, traumatic brain injury, and structural abnormalities, they come with significant limitations. MRI, though widely used, offers limited histological resolution and requires expensive infrastructure, rendering it inaccessible for many research environments. Logistical issues can further complicate both cadeveric and ex vivo MRI of the brain, as tissue degradation due to autolysis and bacteria introduces artifacts in acquired MR images. These constraints significantly restrict the applicability and accessibility of postmortem neuroimaging, particularly if only slab photographs are available, such as in the case of historical brain banks. Several recent works attempt to reconstruct brain models from a combination of slab photographs and MRI (or brain surface scans) using numerical methods[1,2]. However, slab photography as a stand-alone neuroimaging modality on par with MRI has remained elusive due to the computational challenges of piecing together different brain slabs, each of which is subjected to geometric distortions from tissue deformation as well as camera distortion.

Here, we introduce a computational neuroimaging modality that is capable of imaging high-fidelity 3D brain volumes from conventional photographs of postmortem brain slabs, eliminating the need for MRI and other imaging modalities. Our method leverages fully supervised deep learning to learn spatial correspondences between 2D brain slab images and the underlying 3D brain, enabling an accurate volumetric reconstruction without additional imaging modalities. By leveraging deep learning's ability to infer complex spatial structures from limited textural cues, this approach achieves reconstruction accuracies which surpass MRI-based methods while preserving anatomical integrity. We test our approach on postmortem brain specimens, demonstrating its ability to reconstruct 3D brains with high spatial fidelity. Our findings highlight the potential of deep-learning-driven photographic imaging as a cost-effective, standalone computational imaging modality for 3D postmortem neuroimaging. This paradigm shift will enable large-scale studies utilizing existing slab photographs from brain banks to unlock new avenues for neuropathology and neurodegeneration studies, and forensic investigation. By removing reliance on conventional imaging systems, our method democratizes high-resolution neuroimaging for the studies of neurological conditions and diseases, and facilitates new insights into their structural underpinnings.

This approach not only democratizes high-resolution neuroimaging for the fields of neuropathology and forensic science, but also paves the way for a range of future applications. For example, it can enable large-scale retrospective studies of neurodegenerative diseases by transforming archived slab photographs into three-dimensional data, thus unlocking the potential of existing brain banks. In the realm of forensic investigations, this technique offers the ability to create accurate 3D reconstructions of injury patterns from autopsy photos, providing courts and investigators with a new level of spatial detail. Moreover, it allows researchers to revisit historical neurological archives with modern analytical techniques, fostering new insights into the structural underpinnings of neurological conditions. In summary, this innovation extends the reach of 3D neuroimaging into new domains and facilitates a broader understanding of the brain through purely photographic data.

Conventional slab photography

2D slab photographs of the brain are routinely captured at brain banks for postmortem neuroimaging, providing a detailed visual record of a brain's anatomy for neuropathological assessments as well as forensic investigation. Unlike in vivo neuroimaging modalities such as MRI and CT, slab photography can capture high-resolution surface detail of the dissected brain tissue, enabling direct visualization of morphological changes due to neurodegeneration, traumatic injuries, and pathology in the vasculature. However, slab photography is a destructive form of imaging—brain dissection is an irreversible process as slabs undergo a

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