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Controllable 3D Brain MRI Generation with Clinical Attribute Conditioning, Counterfactual Modelling, and Longitudinal Forecasting

Stanford researchers have developed a generative artificial intelligence platform for controllable synthesis and analysis of three-dimensional (3D) brain magnetic resonance imaging (MRI). The technology architecture allows for the generation of clinically informative image representation and anatomically faithful image reconstruction.

Generative models for brain MRI could support data augmentation, privacy-preserving data sharing, disease-progression modeling, and clinical-trial design. However, conventional latent-diffusion approaches may reproduce images well but fail to retain the clinical features needed for downstream prediction and analysis. Existing solutions may also require separate models for distinct tasks, such as generating scans for a particular diagnosis, creating counterfactual images, or forecasting longitudinal disease progression.

The Stanford platform combines a frozen, self-supervised 3D masked-autoencoder (MAE) encoder with a dedicated convolutional neural-network decoder. The encoder produces clinically informative embeddings, while the decoder reconstructs anatomically faithful MRI volumes from those representations. A conditional diffusion transformer can synthesize based on clinical variables.

The encoder was pretrained on 35,309 brain-MRI volumes from 18 public cohorts, spanning four MRI modalities, ten disease categories, and more than 200 acquisition sites. In a 23-task linear-probing benchmark, the technology outperformed or matched published 3D brain-MRI foundation models on 21 tasks. Although initially developed for brain MRI, the architecture may be adapted to other 3D imaging

modalities and anatomical regions with appropriate training data.

Applications

- Augmentation of imaging datasets for underrepresented diseases or demographic groups
- Longitudinal disease-progression forecasting
- Counterfactual imaging for clinical research and trial design
- Synthetic control or placebo-arm support for neurology and neuro-oncology clinical trials

Advantages

- Decouples clinical representation learning from image reconstruction
- Produces embeddings that retain clinically meaningful information for downstream tasks
- Generates anatomically faithful 3D brain MRI volumes
- Pretrained using a large, diverse, multi-cohort and multi-site brain-imaging dataset

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