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Bayesian Optimization-Driven U-Net Architecture Tuning for Brain Tumor Segmentation

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Motivation and Background

- **B**rain-tumor segmentation from MRI is crucial for diagnosis and treatment planning.
- Manual delineation → time-consuming and subjective.
- U-Net performs well, but architecture tuning (filters, depth, decoder width) is mostly manual.
- Need: Automated, data-driven optimization to improve accuracy and reproducibility.

Key Problem:

- U-Net's manual design leads to suboptimal results across modalities and tumor types.

Related Works

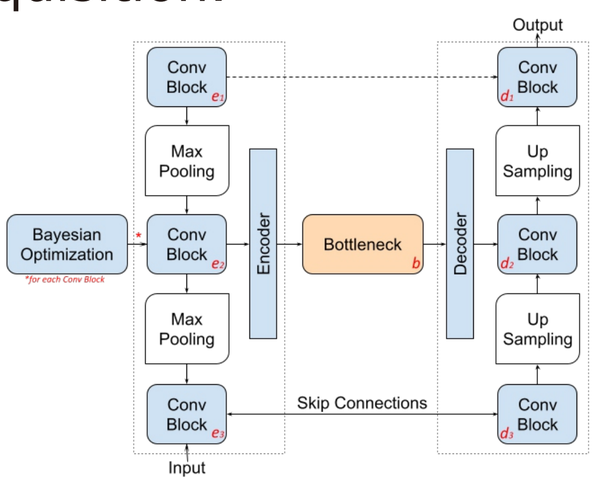
Category	Example Methods	Limitation
U-Net Variants	ResUNet, Unet++, Attention U-Net	Manual architecture design
Hybrid Models	ViT-UNETR, ASPP-U-Net	High complexity
Optimization Methods	PSO-UNet, GA-UNet	Expensive, premature convergence
BO in ML	Classification/egression	Rarely applied to segmentation
Gap → Need for architecture-level BO		

Proposed Method: BO-UNet

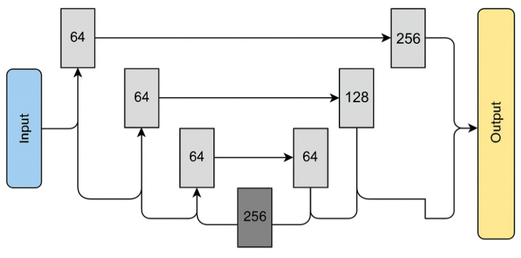
Core Idea

- **Bayesian Optimization (BO)** iteratively selects encoder, bottleneck, and decoder filter configurationsusing a **Gaussian Process (GP)** surrogate and **Expected Improvement (EI)** acquisition.

- **Architecture**



- **Best**



1. Define search space: $E_1, E_2, E_3, B, D_3, D_2, D_1$ filters.
2. Train candidate U-Net → evaluate (DSC, JI).
3. GP models fitness landscape.
4. EI selects next candidate.
5. Update GP until convergence.

Experimental Setup

Datasets

- FBTS: Meningioma, Glioma, Pituitary
- BraTS 2021: (T1, T1CE, T2, FLAIR Modalities

Preprocessing

- 256×256 grayscale images, normalization.

Training Settings:

- Adam optimizer (1e-4), 50 epochs, batch size 8,hardware: 8× NVIDIA A100-SXM4-40GB GPUs.

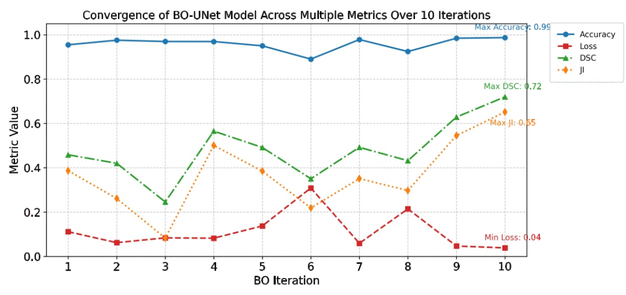
Evaluation Metrics:

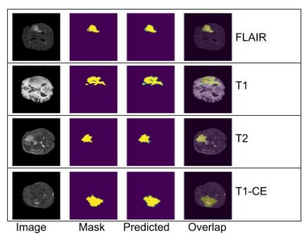
- Accuracy, DSC, JI, BCE loss, Wilcoxon significance test ($p < 0.01$).

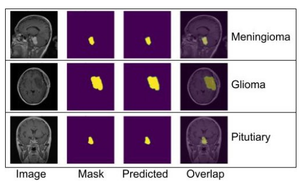
Results & Discussion

Quantitative Results

- **FBTS**
  - **DSC:** 0.9559
  - **JI:** 0.9156
  - **Accuracy:** 0.9824
- **BraTS 2021**
  - **DSC:** 0.9456
  - **JI:** 0.8970
  - **Accuracy:** 0.9768







- Improved over baseline and SOTA models.
- BO-UNet achieved faster convergence and better generalization.
- Wilcoxon test: $p < 0.01$ confirms statistical significance.

Conclusion

- BO-UNet automates U-Net architecture tuning via Bayesian Optimization.
- Achieves higher Dice and Jaccard scores across datasets.
- Reduces manual effort, improves reproducibility.
- Future works: multi-objective BO, hybrid BO-PSO for faster convergence, and federated validation across hospitals.