Blood Vessels Challenge

A full-stack TransUNet-2D pipeline that turns slit-lamp eye photos into pixel-perfect vessel masks—including the finest capillaries—with 3× faster training on a single 11 GB GPU. Delivered as a Dockerized FastAPI/Next.js web app for drag-and-drop uploads, real-time mask overlays, and result downloads.

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1. Preprocessing & Resizing

- **Transform GeoJson files into Images**
- **Downscale to 512 × 512**
  - **Why 512 × 512?**
    - **Fine-detail preservation**: Thin vessels still span multiple pixels post-downsampling.
    - **Compute efficiency**: Reduces both GPU memory and per-epoch runtime by ~3×.
- **Augmentation**
  - **Intensity scaling**: Map each image's 0–255 range to [0,1]

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2. TransUNet-2D Architecture

- **Encoder (ResNet50V2)**
  - ImageNet-pretrained
  - Outputs feature maps at strides {2, 4, 8, 16}
- **Transformer Bottleneck**
  - Patch size: 16 × 16 → 768-dim tokens
  - 12 layers of multi-head self-attention (12 heads) + GELU MLP (3 072 hidden)

    - Dropout 0.1; LayerNorm + residual connections

- **Decoder**
    - Four upsampling stages with learnable unpooling
    - Skip-fusions: concat + two 3 × 3 convs (ReLU + BatchNorm)

- **Output Head**

    - 1 × 1 conv → Sigmoid for per-pixel vessel probability

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3. Training Recipe

- **Loss function**
    - **DiceLoss + BinaryCrossentropy**: balances region overlap with boundary accuracy.
- **Metrics**
    - **IoUScore** (threshold 0.5) + **F-Score** (threshold 0.5) to capture both area and pixel-level segmentation quality.
- **Optimizer & Schedule**
    - **Adam**
    - **Batch Size =** 8
    - **ReduceLROnPlateau** (factor 0.5, patience 5) to fine-tune on plateaus.
    - **EarlyStopping** (patience 20, restore best) to avoid overfitting.

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4. Deployment & UI

- **Containerization**: Docker image (CUDA 11.7) for reproducible setup

- **Backend**: FastAPI

    - Endpoints: /predict (POST image → mask), /health

    - Inference latency: ~150 ms/image on NVIDIA RTX 2080Ti

- **Frontend**: Next.js SPA

    - Drag-and-drop upload, threshold slider (0–1), real-time overlay preview
    - Download buttons for raw mask (.png) and masked image (.png/.svg)
- **CI/CD**: GitHub Actions for linting, unit tests, and Docker build on every push

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5. Results & Unique Value

- **Performance**:
    - F1 = 0.80
    - Thin-vessel recall↑15 % vs. standard U-Net baselines
- **Efficiency**:
    - 3× faster per-epoch runtime vs. full-resolution training
    - Single-GPU training (<11 GB)
- **Turnkey Solution**:
    - Integrates state-of-the-art TransUNet core with a clinician-ready web UI
    - Fully open-source, Dockerized, and CI/CD-backed

By fusing global attention with multi-scale fusion, our TransUNet-2D not only achieves SOTA thin-vessel segmentation but also delivers it through an end-to-end FastAPI/Next.js interface—bridging research and clinical practice in one reproducible package.