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Interactive GUI for HDR Brachytherapy Planning with Multi-Criteria Optimization

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ABSTRACT

Purpose: To develop a GPU-accelerated multi-criteria optimization (MCO) framework for HDR brachytherapy—including advanced applicators such as Direction-Modulated Brachytherapy (DMBT)—integrated within a web-based platform for clinically practical use.
Methods: A PyTorch-based GPU-accelerated MCO framework was developed to generate multiple candidate treatment plans in parallel, enabling systematic exploration of trade-offs between target coverage and OAR sparing. A dedicated DMBT workflow is under development to account for applicator-specific dose characteristics. The system was implemented as a full-stack web application: a FastAPI backend handles DICOM I/O, TG-43 dose calculation, and GPU-based optimization, with MongoDB for data storage; a React/TypeScript frontend provides DVH plotting (Recharts) and DICOM visualization (Cornerstone.js). The application is containerized via Docker, with Nginx reverse-proxying unified API/UI access and GPU passthrough to the backend, decoupling computation from rendering for browser-based access.
Results: The platform was successfully implemented, featuring three-plane DICOM navigation (pan/zoom/window-level), a single-plan view with real-time clinical-vs-optimized DVH comparison, and an MCO view that batch-generates plans with a sortable DVH-metric table (PTV D90, bladder/rectum D2cc) for plan selection. Optimized plans can be exported directly as DICOM RT-Plan files. Initial testing confirms computational feasibility and a streamlined, reproducible planning workflow.
Conclusion: This work demonstrates a feasible GPU-accelerated MCO framework delivered through a scalable, containerized web platform.

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INTRODUCTION

HDR brachytherapy planning requires balancing target coverage against organ-at-risk dose constraints, often yielding only a single plan from conventional methods[1]. Multi-criteria optimization (MCO) improves this by generating a spectrum of Pareto-optimal plans, making trade-offs explicit for patient-specific selection[1]. Clinical translation, however, requires an accessible GUI for smooth implementation— and web-based deployment removes the local-GPU barrier, enabling multi-user access. This work presents a GPU-accelerated multi-criteria optimization (MCO) framework for HDR brachytherapy — including advanced applicators such as Direction-Modulated Brachytherapy (DMBT) — and to deploy it behind a clinically practical, web-based planning interface.

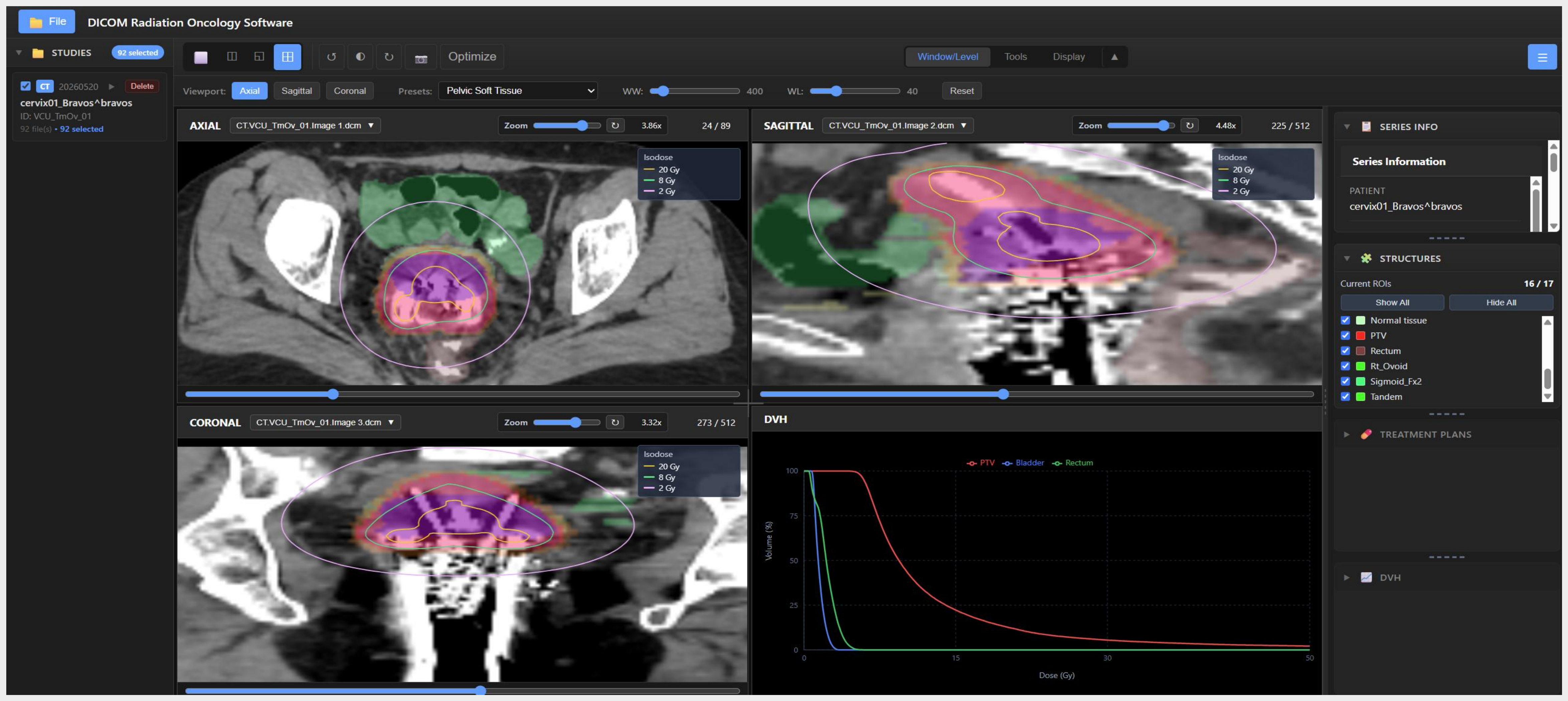

Figure 1. GUI Home web page with three transverse planes and DVH display.

METHODS AND MATERIALS

1. Software Architecture
   - Backend (FastAPI) — REST endpoints for DICOM I/O, kernel precomputation, and plan optimization; pydicom + TG-43 dose calc + PyTorch (GPU) run server-side; MongoDB storage; Uvicorn/ASGI.
   - Frontend (React + TypeScript) Recharts DVH plots, Cornerstone.js DICOM viewer; communicates via JSON REST API.
   - Deployment (Docker) — backend, frontend, MongoDB as separate containers via docker-compose; Nginx reverse proxy unifies API/UI; GPU passthrough to backend container.
   - Decouples GPU computation from UI rendering — browser access from anywhere, computation centralized on GPU infrastructure.
2. Optimization Engine
   - GPU-accelerated MCO framework built in PyTorch; generates multiple candidate HDR plans in parallel.
   - Systematically explores target coverage vs. OAR-sparing trade-offs.
   - Dedicated DMBT workflow for direction-modulated applicators — under development/validation.
3. Interface Features
   - Three plane view with easy-to-use navigation tools like pan, zoom, window width/level and toggle display control **Figure 1.**
   - Single-plan view — adjustable dose limits/weights with real-time clinical-vs-optimized DVH comparison.
   - MCO view — batch-generates plans; sortable DVH-metric table (PTV D90, bladder/rectum D2cc) for plan selection.
   - Export button to download plans as ready to use DICOM RT-Plans format.

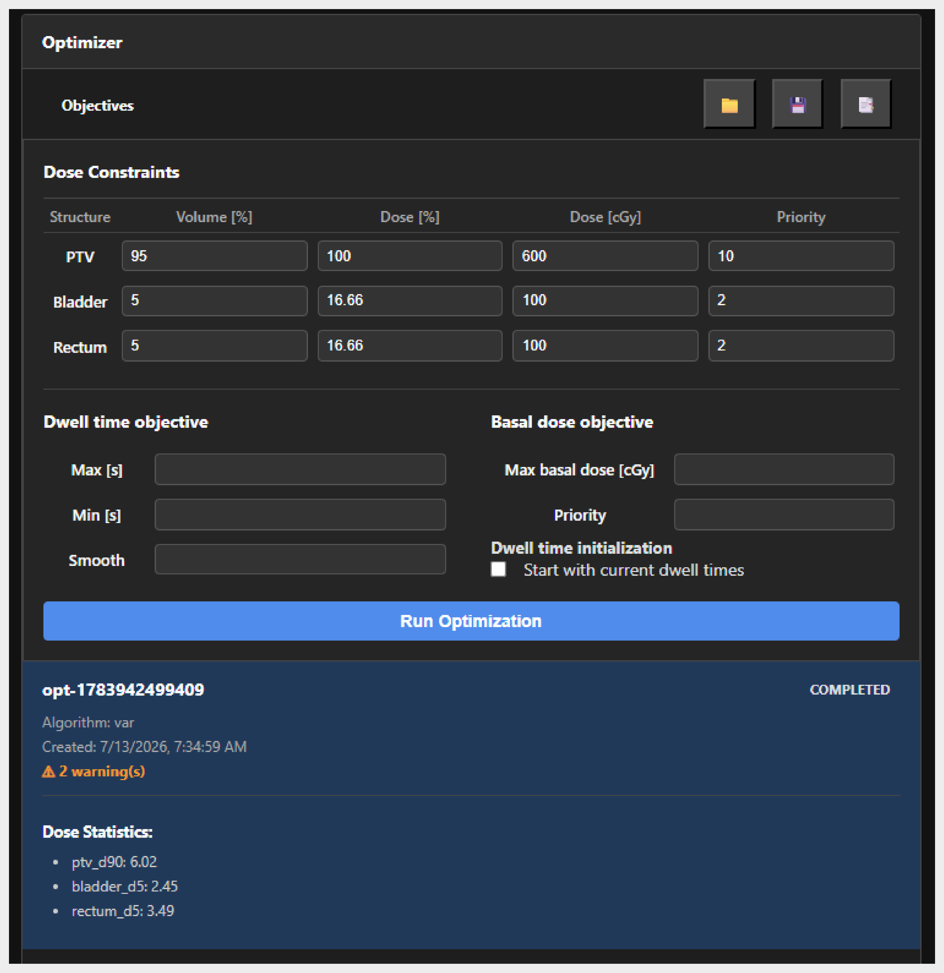

Figure 2. Optimizer pop-up for a quick plan optimization.

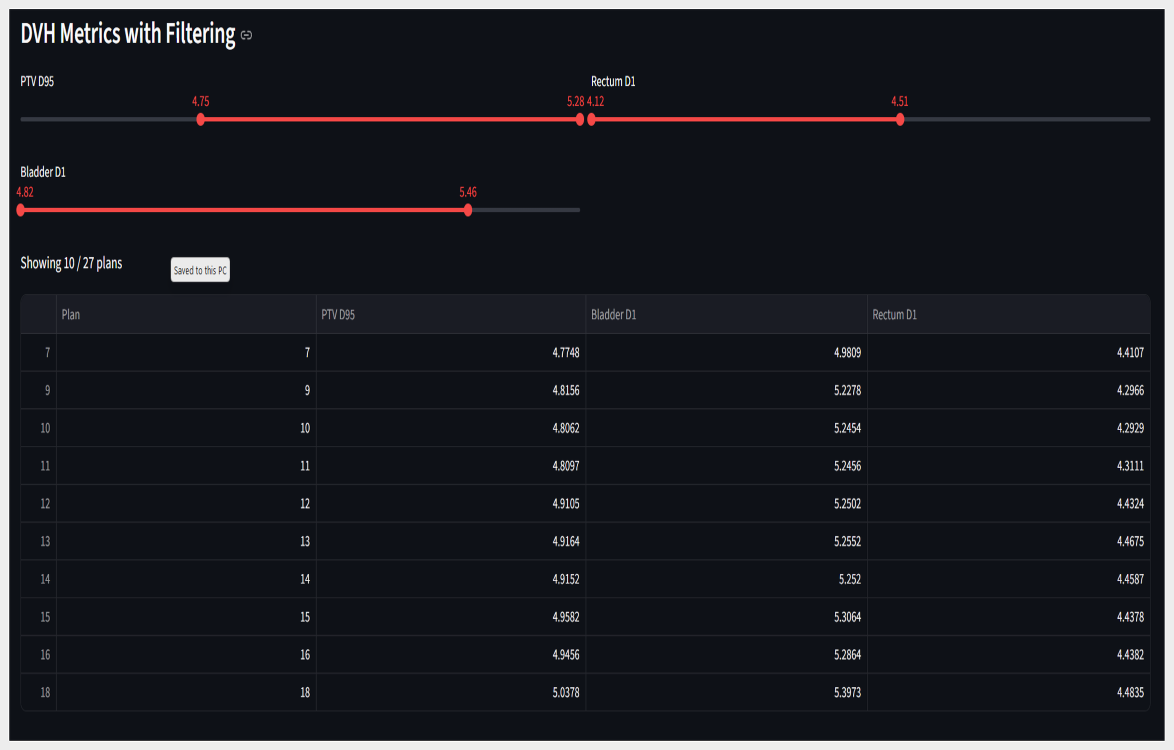

Figure 3. MCO plans filtering based on DVH metrices.

RESULTS

The MCO framework and web-based GUI were successfully implemented, enabling GPU-accelerated generation of multiple HDR plans through an interactive, browser-based workflow. Initial testing confirms computational feasibility and a streamlined planning workflow; the DMBT pathway remains in active validation.

DISCUSSION

These results suggest that pairing MCO with a browser-based GUI can meaningfully lower the barrier between algorithmic planning research and clinical use, letting planners explore trade-offs interactively rather than accepting a single fixed plan. Remaining work centers on completing DMBT validation and benchmarking plan quality and runtime against clinical standard-of-care. Future efforts will focus on clinical pilot testing and integration with existing treatment planning workflows.

CONCLUSIONS

This work demonstrates the feasibility of a GPU-accelerated, multi-criteria optimization framework for HDR brachytherapy delivered through a modern, decoupled web architecture (FastAPI backend, React frontend, containerized deployment). By enabling parallel optimization, interactive trade-off exploration, and a growing DMBT capability, the system provides a foundation for efficient, clinically deployable brachytherapy treatment planning.

REFERENCES

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