



Automated Embryo Organ Segmentation in OPT Images using Deep Learning



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Objective

- Develop a scalable deep learning framework for automated segmentation of anatomical structures in Optical Projection Tomography (OPT) embryo data.
- Extend a validated heart-only system to multi-organ segmentation (heart, lungs, liver)
- Maintain stability under extreme class imbalance (85–95% empty slices).
- Integrate preprocessing, training, inference, and 3D reconstruction.
- Evaluated across developmental stages (GD 11.5 and GD 13.5) to characterize system performance.

Background

- OPT produces high-resolution 3D embryo volumes, but manual segmentation is time-intensive and not scalable.
- A central challenge is extreme sparsity and small anatomical targets, where most slices contain no organ and visibility varies across developmental stages. This creates severe class imbalance and limits segmentation performance.

Methods

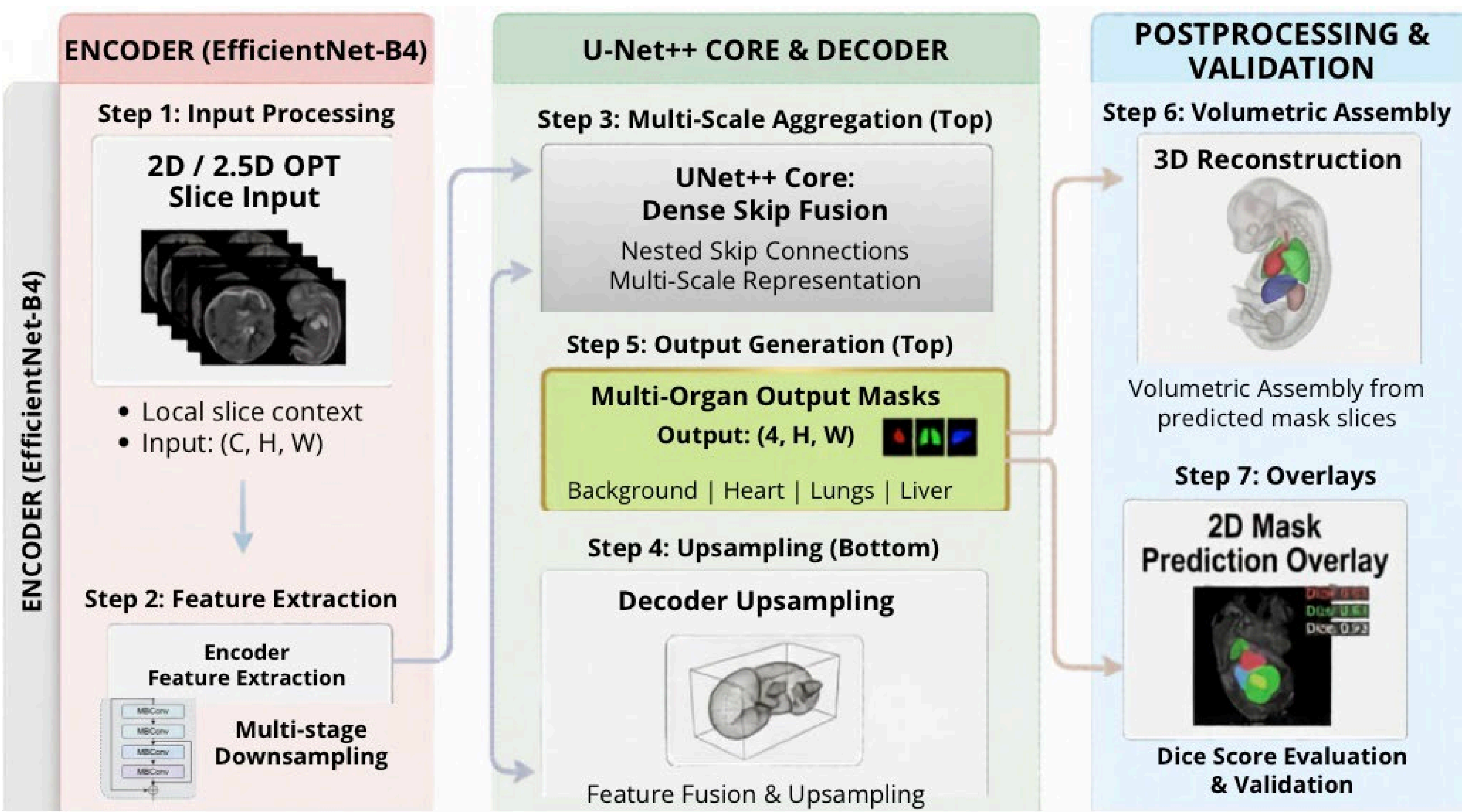


Fig. 1 - End-to-end pipeline from preprocessing to 3D reconstruction

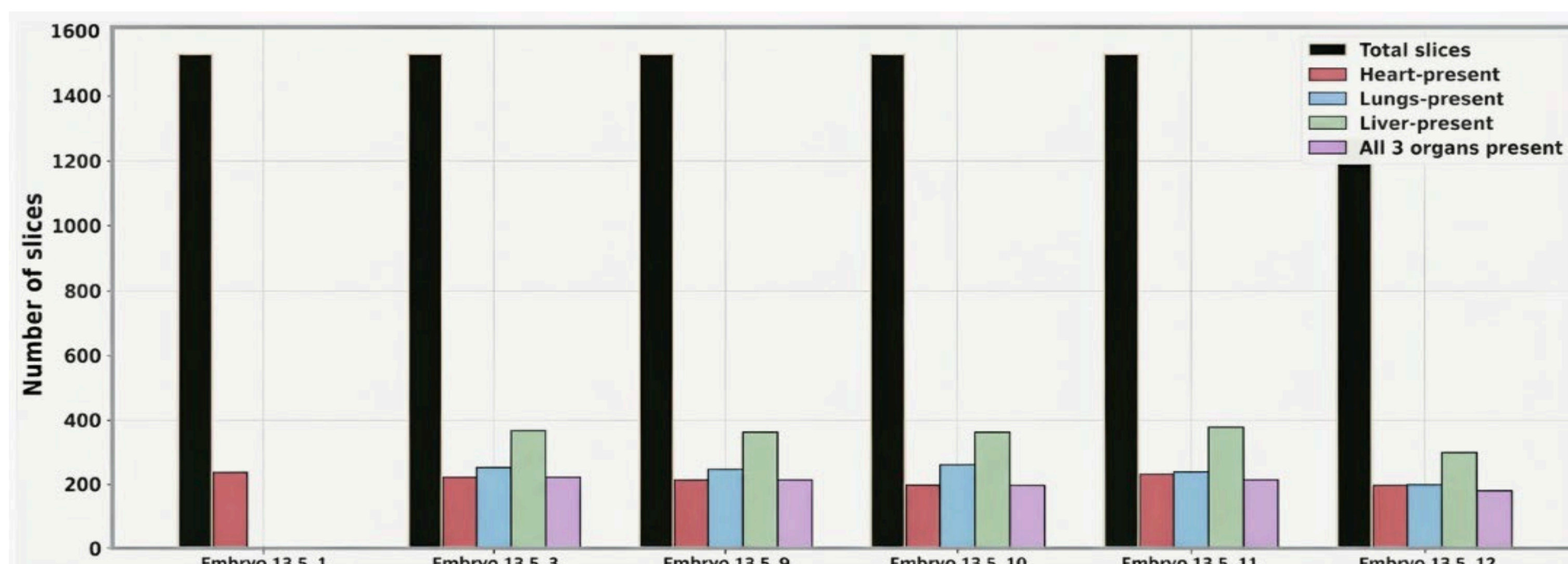


Fig. 2 - Slice-level dataset distribution for GD 13.5 embryos.

- Extended a validated heart-only pipeline into a parallel multi-class framework, allowing for multi-organ expansion without affecting baseline stability.
- Utilized 2.5D inputs (5-slice context) and a U-net++ architecture to independently segment the heart, lungs, and liver via multi-channel supervision.
- Employed a combined loss strategy to balance pixel-level accuracy with shape overlap, specifically targeting small structures and class imbalance.
- Improved training stability for batch-size-1 through weighted sampling of organ-present slices and automated learning rate reduction.

Results

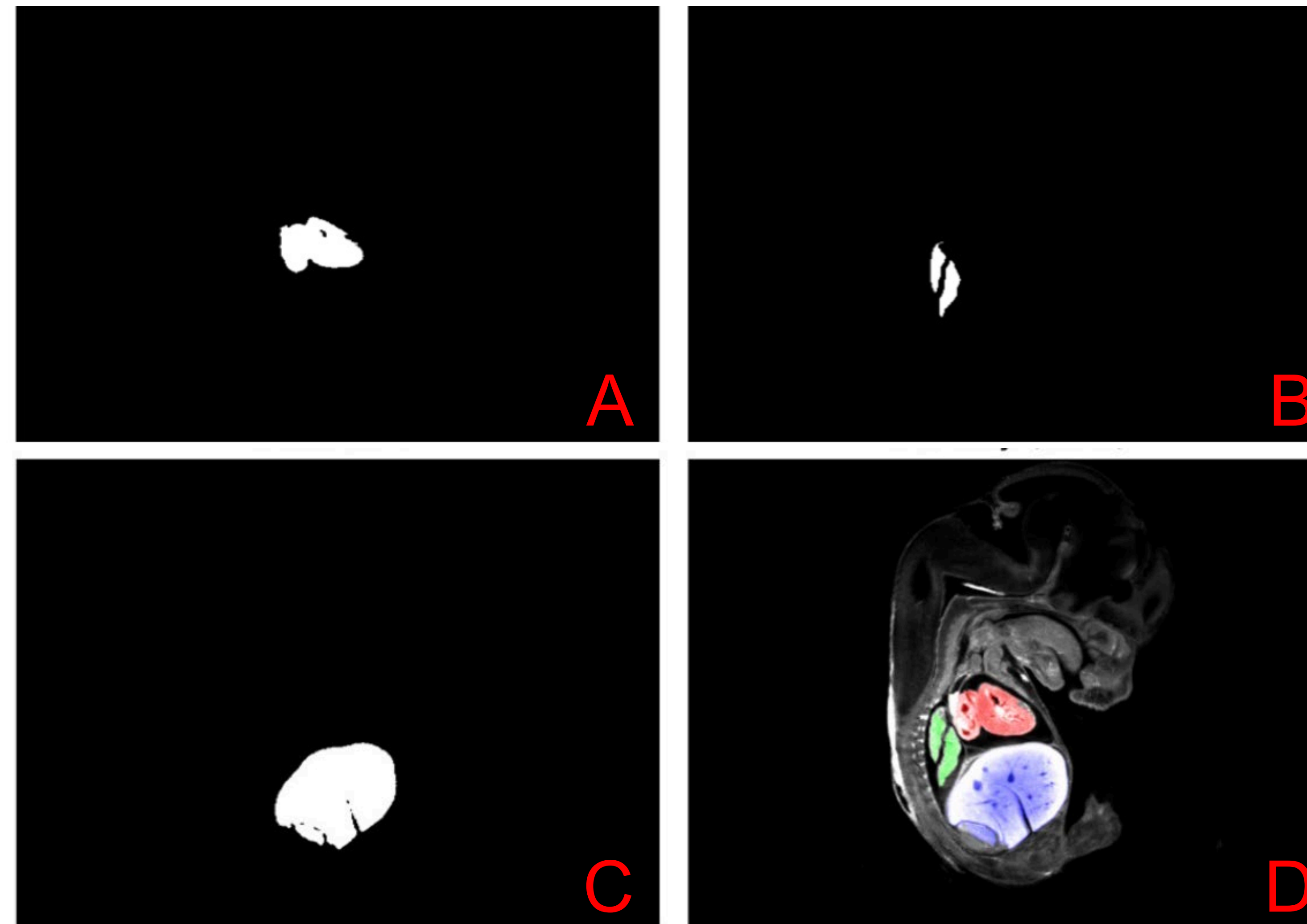


Fig. 3 - Multi-organ segmentation results in OPT embryo slices. (A) Predicted heart, (B) predicted lungs, (C) predicted liver, and (D) combined overlay of all organ predictions.

Stable multi-organ segmentation was achieved on GD 13.5 embryos:

- Heart: 0.82–0.90 Dice
- Lungs: 0.80–0.85 Dice
- Liver: 0.93–0.95 Dice
- Predictions supported coherent 3D reconstruction, indicating effective spatial learning across slices.
- Simpler configurations produced the strongest results; increasing complexity did not improve performance and occasionally reduced stability.
- Left and right lungs were frequently merged despite correct localization.
- Segmentation quality degraded due to smaller organ size, high sparsity (90–95% empty slices), and weaker anatomical definition.

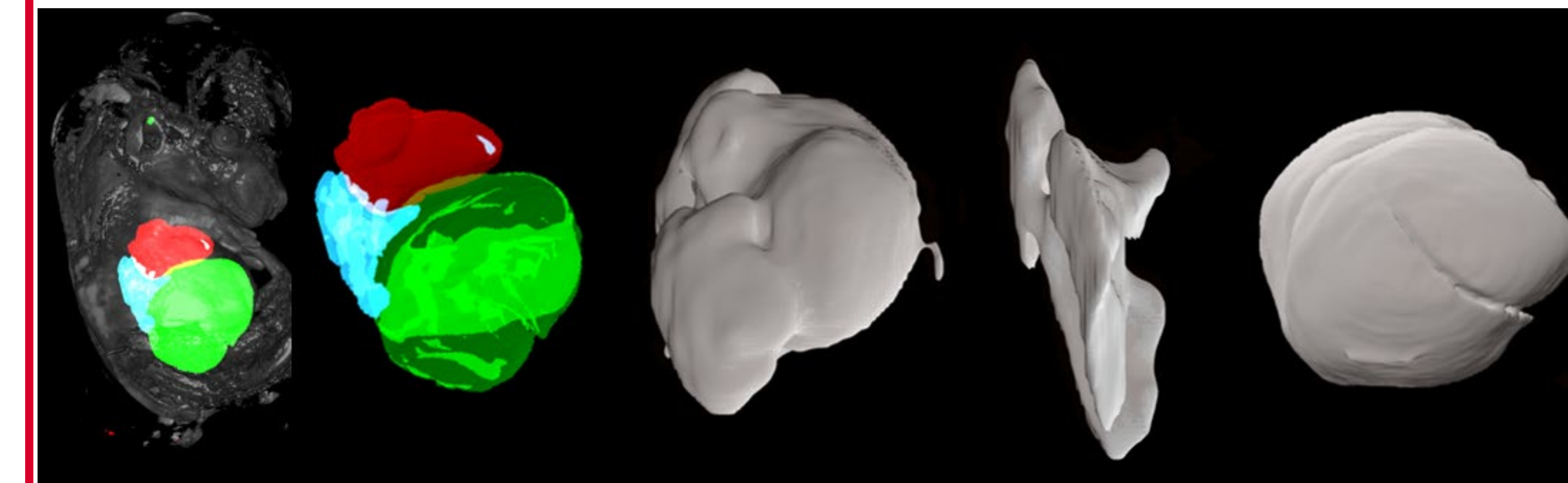


Fig. 4 - 3D reconstruction of segmented organs in a GD 13.5 embryo. (A) Full embryo with reconstructed organs. (B) Segmented organs without embryo context. (C-E) Individual organ renderings: (C) heart, (D) lungs, (E) liver.

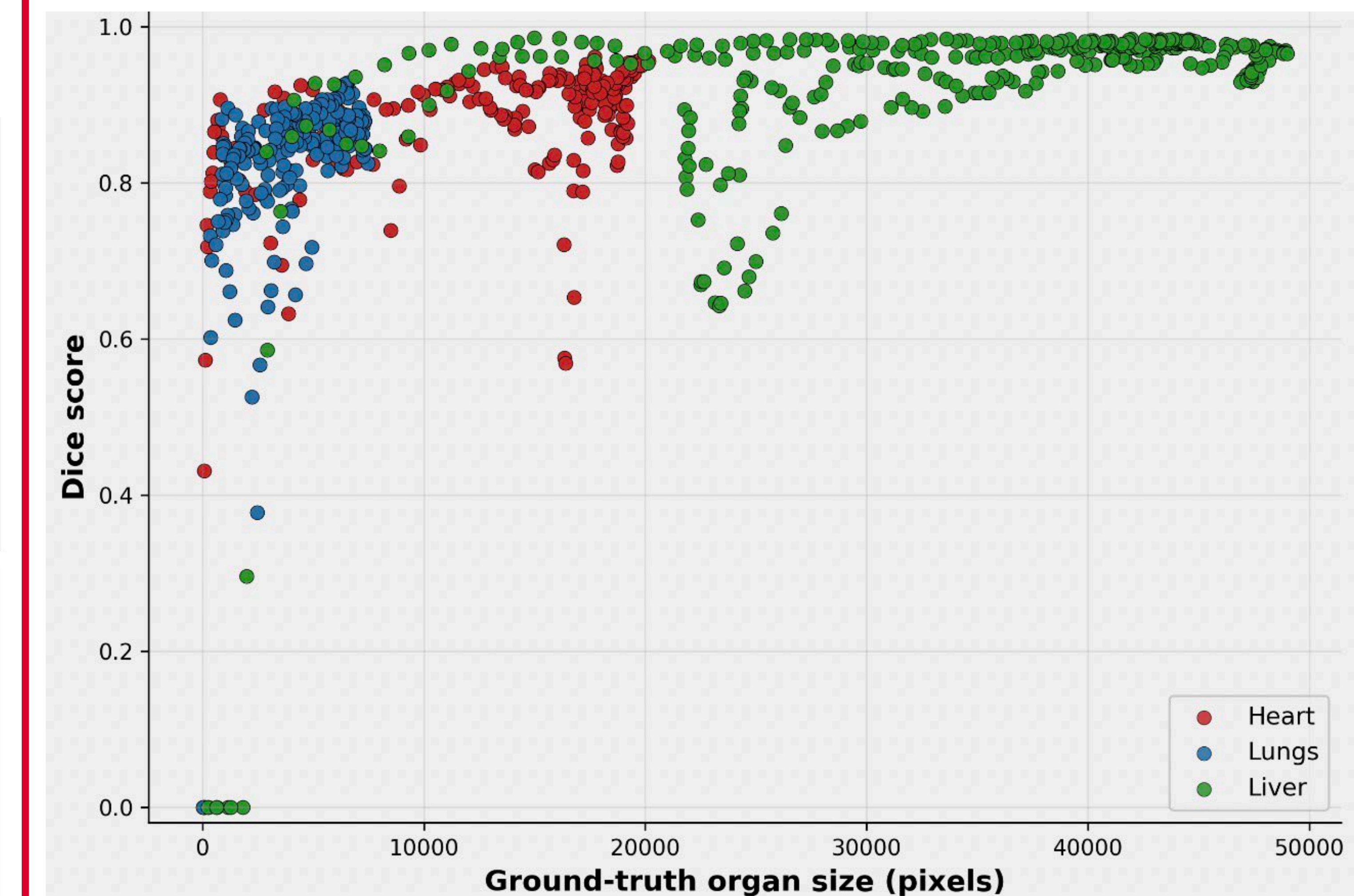


Fig. 5 - Relationship between organ size and segmentation performance (Dice) for GD 13.5 embryos.

Conclusion

- Developed a stable end-to-end multi-organ framework (preprocessing to 3D reconstruction) that scales from single to triple-organ segmentation without redesign.
- Maintained robust performance under extreme class imbalance, generalizing effectively across GD 13.5 embryos.
- Identified GD 11.5 as a performance bottleneck due to small organ size, high data sparsity, and poor anatomical definition.
- Confirmed that multi-organ segmentation in OPT data is achievable and scalable, with limitations driven by data characteristics rather than model architecture.

Acknowledgements

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