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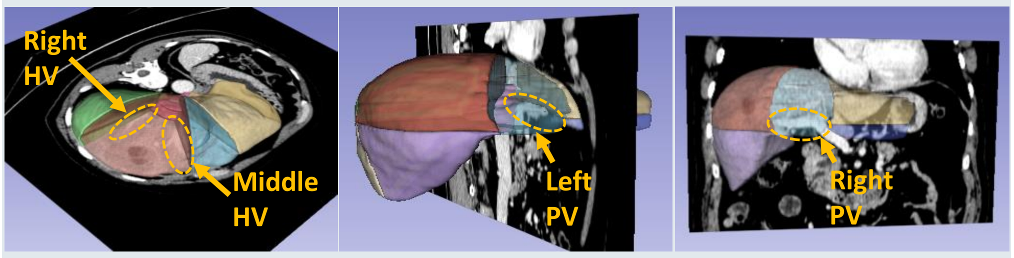
# Skip priors and add graph-based anatomical information, for point-based Couinaud segmentation

## 1. Why skip the liver vessel prior?

- Liver vessel prior requires expert annotation or pre-trained models.
- Manual expert annotation is time-consuming.
- Pre-trained models can introduce errors.



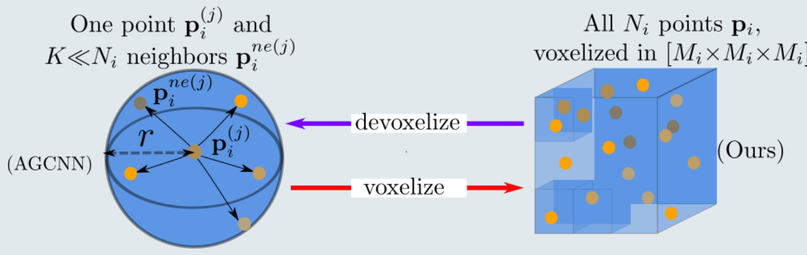

HV: hepatic vein PV: portal vein

## 2. Dynamic graph reasoning in 3D

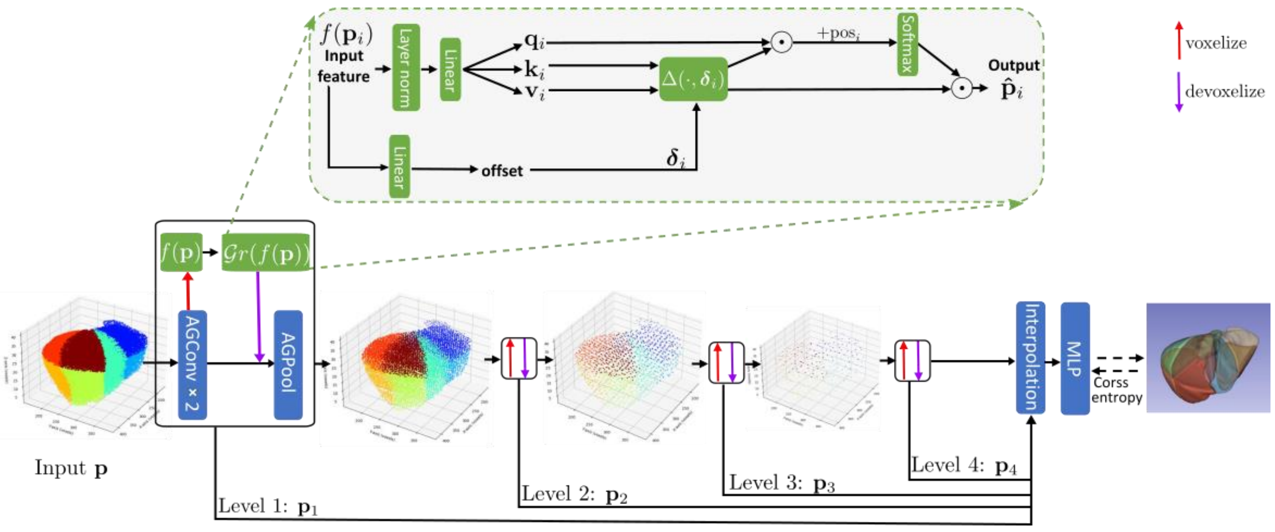
Voxelize 3D point feature to a grid space at each level $i$, and learn the dynamic offsets for $3^3$ neighbors of each central.

$$\widehat{p}_i = softmax(q_i \cdot \Delta(k_i, \delta_i) + pos_i) \cdot \Delta(v_i, \delta_i)$$

where $\delta_i = Linear(f(p_i))$, $\delta_i \in \mathbb{R}^{3 \times 3^3}$, $\Delta(\cdot, \delta_i)$ is a deformable unfold layer, $pos_i \in \mathbb{R}^{3^3}$ are the positional embeddings for the query $q_i$.




## 3. Network architecture




## 4. Model ablation study

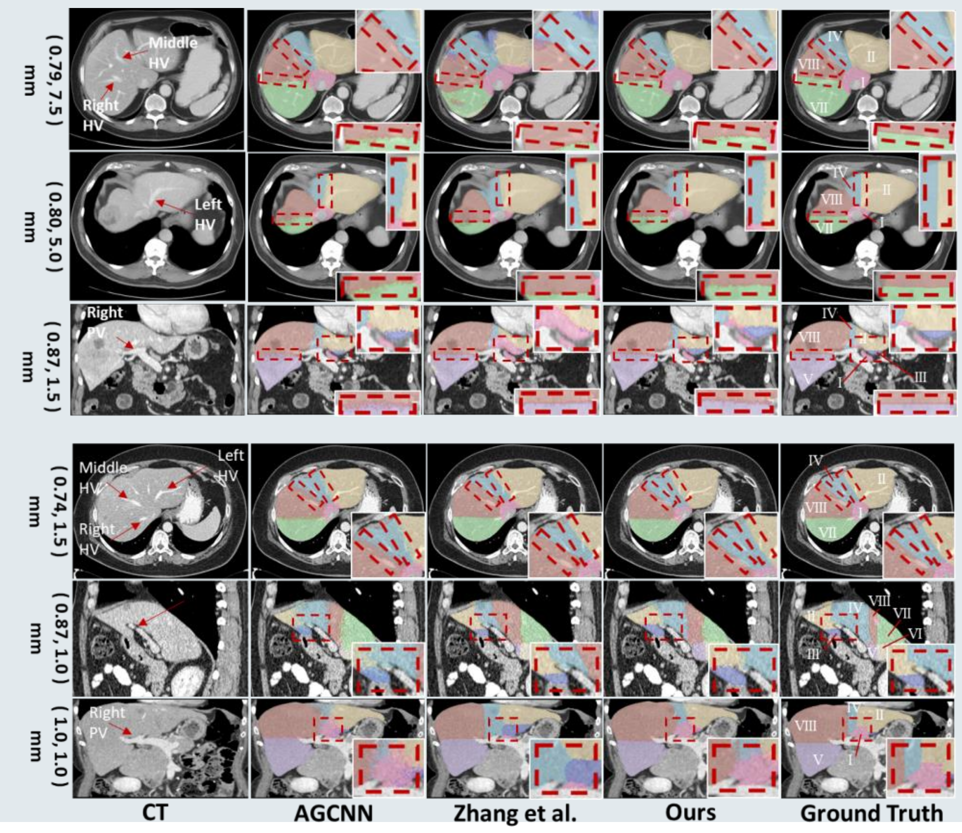
| | *MSD* | | *LiTS* | |
|---|---|---|---|---|
| | Dice ↑ (%) | ASD ↓ (mm) | Dice ↑ (%) | ASD ↓ (mm) |
| (a) | 70.29 (± 16.69) | 6.70 (± 5.80) | 76.52 (± 8.90) | 6.56 (± 2.65) |
| (b) | 78.02 (± 11.06) | 4.00 (± 3.39) | 77.46 (± 10.87) | 6.58 (± 4.03) |
| (c) | 68.98 (± 14.58) | 7.73 (± 5.19) | 72.67 (± 10.30) | 9.81 (± 5.44) |
| (d) | **80.41** (± 10.74) | **3.76** (± 4.04) | **79.56** (± 6.95) | **5.50** (± 2.42) |

(a) AGCNN baseline (bottom point net in network figure)
(b) Our model without graph reasoning ($\mathcal{G}_r(f(p))$)
(c) Our model without grid feature embeddings ($f(p)$)
(d) Our proposed model

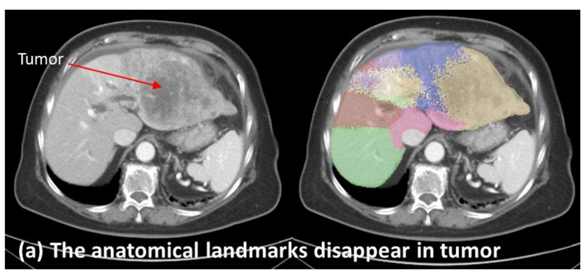
## 5. Experimental results

| | *MSD* (Dice %) ↑ | | | | | *MSD* (ASD mm) ↓ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PointNet [17] | PointNet++ [18] | AGCNN [25] | Zhang *et al.* [28]* | Ours | PointNet [17] | PointNet++ [18] | AGCNN [25] | Zhang *et al.* [28]* | Ours |
| (I) | 62.26 | 72.26 | 63.96 | 80.45 | **83.31** | 4.04 | 5.01 | 2.76 | 2.96 | **1.97** |
| (II) | 81.53 | 80.27 | 77.79 | 82.39 | **86.71** | 1.67 | **1.02** | 6.19 | 4.75 | 1.89 |
| (III) | 69.80 | 72.75 | 64.55 | 75.06 | **79.35** | 3.31 | **1.96** | 5.78 | 3.30 | 2.51 |
| (IV) | 61.74 | 68.04 | 63.26 | 69.83 | **73.26** | 5.76 | 5.90 | 6.52 | 5.46 | **4.12** |
| (V) | 70.55 | 71.78 | 68.78 | 71.49 | **75.89** | **3.56** | 5.61 | 11.75 | 5.91 | 6.36 |
| (VI) | 75.88 | 75.29 | 69.91 | 72.51 | **79.51** | **2.68** | 4.57 | 8.20 | 5.23 | 5.15 |
| (VII) | 82.38 | 82.24 | 80.35 | 80.56 | **85.11** | **2.47** | 3.02 | 5.62 | 5.57 | 3.27 |
| (VIII) | 75.86 | 76.03 | 73.72 | 75.74 | **80.16** | **4.10** | 4.19 | 6.79 | 4.82 | 4.84 |
| Avg | 72.50 | 74.83 | 70.29 | 76.00 | **80.41** | **3.45** | 3.91 | 6.70 | 4.75 | 3.76 |
| | Time (s) per case | | | | | *GFLOPs* | | | | |
| | 2.81 | 21.55 | 6.13 | 1.73 | 10.03 | 302.38 | 64.65 | 638.54 | 608.85 | 771.15 |

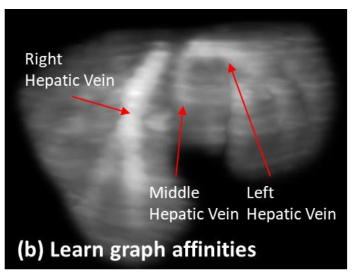
| | *LiTS* (Dice %) ↑ | | | | | *LiTS* (ASD mm) ↓ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PointNet [17] | PointNet++ [18] | AGCNN [25] | Zhang *et al.* [28]* | Ours | PointNet [17] | PointNet++ [18] | AGCNN [25] | Zhang *et al.* [28]* | Ours |
| (I) | 49.80 | 37.85 | 69.20 | **73.64** | 68.84 | 8.39 | 8.58 | **4.36** | 6.54 | 6.97 |
| (II) | 70.69 | 72.78 | 82.62 | 82.82 | **86.17** | 9.39 | 5.31 | 4.58 | 4.81 | **3.18** |
| (III) | 58.26 | 65.68 | 76.09 | 72.46 | **80.82** | 15.18 | 7.42 | 6.04 | 5.09 | **3.18** |
| (IV) | 53.87 | 70.19 | 73.88 | **75.40** | 75.24 | 8.46 | 9.69 | 10.00 | **7.88** | 8.38 |
| (V) | 80.46 | 80.51 | 78.97 | 81.92 | **83.03** | **5.04** | 5.85 | 7.25 | 6.49 | 6.20 |
| (VI) | 77.69 | 79.23 | 73.45 | 79.28 | **79.29** | 4.55 | 6.02 | 5.76 | 6.67 | **3.78** |
| (VII) | 79.92 | 81.71 | 80.42 | **83.40** | 82.79 | **4.38** | 4.93 | 6.75 | 4.63 | 4.60 |
| (VIII) | 77.20 | 79.29 | 77.53 | 80.02 | **80.26** | 6.45 | 6.67 | 7.71 | **5.84** | 7.71 |
| Avg | 68.49 | 70.90 | 76.52 | 78.62 | **79.56** | 7.73 | 6.81 | 6.56 | 6.00 | **5.50** |
| | Time (s) per case | | | | | *GFLOPs* | | | | |
| | 10.62 | 106.97 | 19.81 | 6.52 | 13.83 | 302.38 | 64.65 | 256.10 | 608.85 | 141.56 |




## 6. Conclusion and limitations




(a) The anatomical landmarks disappear in tumor




(b) Learn graph affinities

- We propose a 3D point-based model that incorporates anatomical information implicitly, by learning graph affinities between voxels.
- Experiment results show that our method is competitive compared to the other point-based methods with or without a liver vessel prior.

**Limitations:**

The proposed method cannot accurately discriminate segments in the liver when a large tumor appears.