Annotation by Clicks: A Point-Supervised Contrastive Variance Method for Medical Semantic Segmentation

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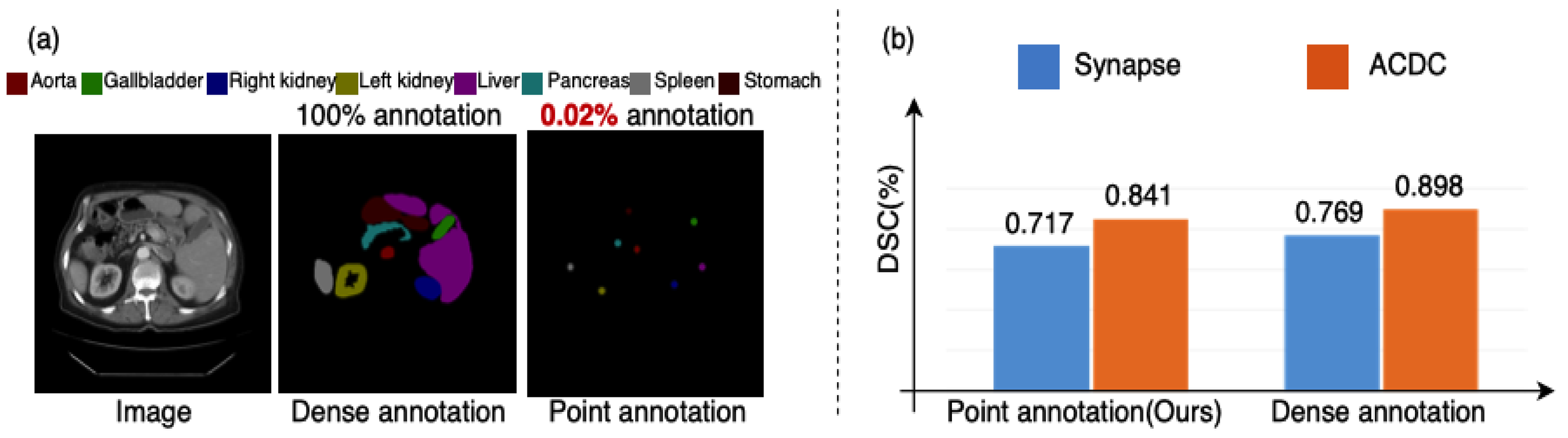
Introduction

- The proposed PSCV trains the base segmentation network by using a novel contrastive variance (CV) loss to exploit the unlabeled pixels and a partial cross-entropy loss on the labeled pixels.
- The CV loss function is designed to exploit the statistical spatial distribution properties of organs in medical images and their variance distribution map representations to enforce discriminative predictions over the unlabeled pixels.



Contribution

- Propose a novel PSCV method to tackle the medical image semantic segmentation.
- Design a novel contrastive variance function that exploits the spatial distribution properties of the organs in medical images and their variance distribution map representations to enforce discriminative predictions over the unlabeled pixels.
- Perform point-supervised medical image segmentation and surpass existing segmentation methods.

Point-Supervised Learning

- Generate the prediction

$$\hat{Y}^n = \mathrm{softmax}(f_{decoder} \circ f_{encoder}(I^n))$$

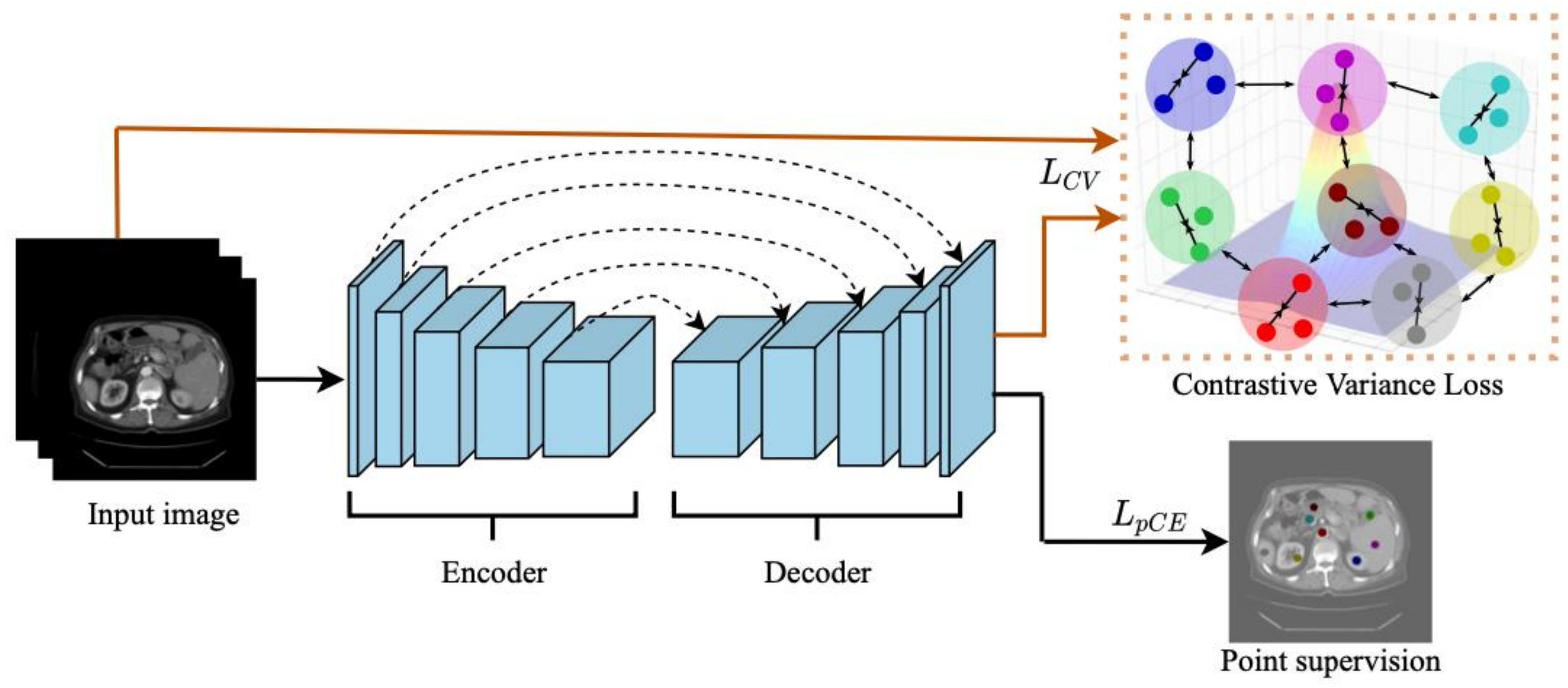
- Compute the cross-entropy loss

$$L_{pCE} = -\sum_{n=1}^{N} \sum_{r \in \Omega_y^n} \sum_{k=1}^{K} Y_k^n(r) \log \hat{Y}_k^n(r)$$

Loss Function

- Overall loss function contains: a partial cross entropy loss L_{pCE} and a contrastive variance loss L_{CV}

$$L_{total} = L_{pCE} + L_{CV}$$



Contrastive Variance Loss Function

- Compute the mean pixel value for the k-th category region on the n-th image

$$c_k^n = \frac{\int_\Omega I^n(r) \hat{Y}_k^n(r) dr}{\int_\Omega \hat{Y}_k^n(r) dr}$$

- Calculate the pixel-level variance distribution map

$$z_k^n(r) = |I^n(r) - c_k^n|^2 \hat{Y}_k^n(r), \forall r \in \Omega.$$

- Compute the contrastive variance loss

$$L_{CV} = \lambda_{cv} \sum_{n=1}^{N} \sum_{k=1}^{K} -\log \frac{pos}{pos + neg} + \mu \sum_{n=1}^{N} \sum_{k=1}^{K} \int_\Omega |\nabla \hat{Y}_k^n(r)| dr,$$

with

$$pos = \exp(\cos(z_k^n, z_k^{m_n})/\tau), \quad neg = \sum_{i \neq n} \sum_{j \neq k} \exp(\cos(z_k^n, z_j^i)/\tau)$$

Experimental Results

- Quantitative comparison results on the Synapse dataset

Method	HD95.Avg↓	DSC.Avg↑	Aor	Gal	Kid(L)	Kid(R)	Liv	Pan	Spl	Sto
pCE [20]	112.83	0.469	0.348	0.251	0.522	0.443	0.792	0.257	0.713	0.426
EntMini [10]	105.19	0.485	0.329	0.257	0.577	0.491	0.787	0.304	0.663	0.471
WSL4MIS [22]	81.79	0.497	0.315	0.189	0.625	0.526	0.817	0.290	0.722	0.491
USTM [21]	97.05	0.552	0.443	0.312	0.645	0.631	0.834	0.311	0.761	0.482
GatedCRF [24]	66.32	0.596	0.457	0.420	0.722	0.666	0.836	0.361	0.730	0.578
PSCV (Ours)	**37.38**	**0.717**	**0.803**	**0.572**	**0.770**	**0.736**	**0.901**	**0.522**	**0.840**	**0.587**
FullySup	39.70	0.769	0.891	0.697	0.778	0.686	0.934	0.540	0.867	0.756

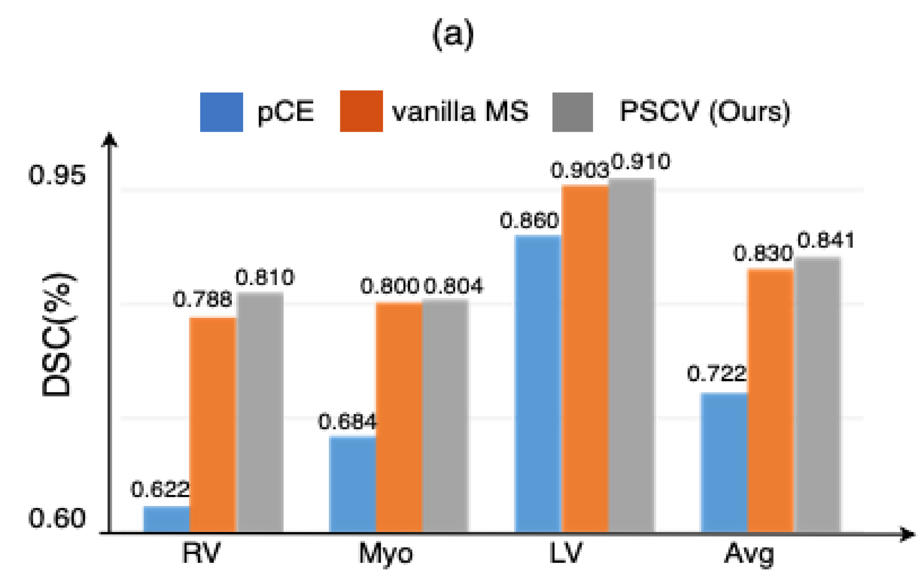
- Quantitative comparison results on the ACDC Dataset

Method	DSC.Avg↑	RV	Myo	LV	HD95.Avg↓	RV	Myo	LV
pCE [20]	0.722	0.622	0.684	0.860	39.30	40.22	40.60	37.08
EntMini [10]	0.740	0.632	0.718	0.870	28.56	25.79	30.76	29.14
USTM [21]	0.767	0.691	0.736	0.874	18.35	17.63	15.33	22.08
WSL4MIS [22]	0.768	0.664	0.745	0.896	10.00	10.73	9.37	9.92
GatedCRF [24]	0.814	0.743	0.788	**0.911**	4.03	7.45	**2.47**	**2.17**
PSCV (Ours)	**0.841**	**0.810**	**0.804**	0.910	**3.57**	**3.42**	2.98	4.33
FullySup	0.898	0.882	0.883	0.930	7.00	6.90	5.90	8.10

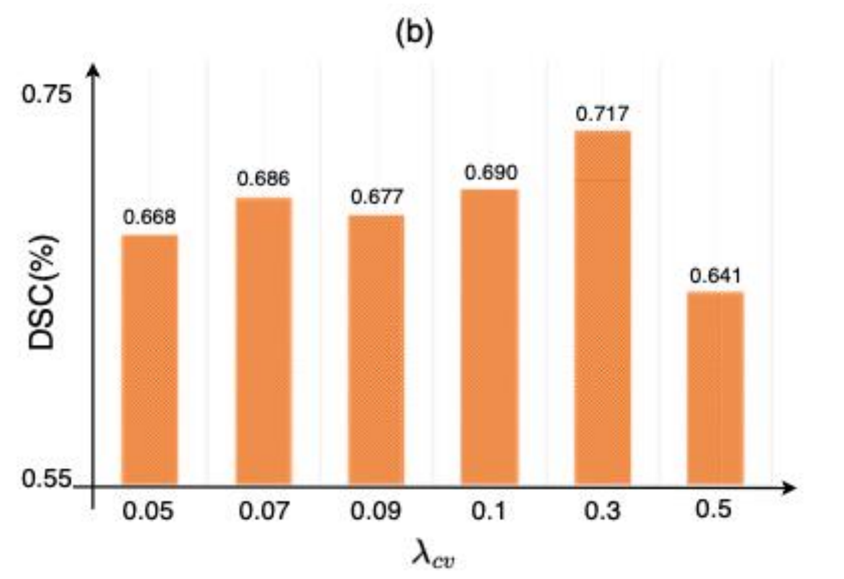
- Ablation study of the proposed method on the Synapse dataset

Method	HD95.Avg↓	DSC.Avg↑	Aor	Gal	Kid(L)	Kid(R)	Liv	Pan	Spl	Sto
pCE	112.83	0.469	0.348	0.251	0.522	0.443	0.792	0.257	0.713	0.426
vanilla MS	41.58	0.634	0.596	0.460	0.717	0.678	0.892	0.357	0.781	**0.588**
PSCV	**37.38**	**0.717**	**0.803**	**0.572**	**0.770**	**0.736**	**0.901**	**0.522**	**0.840**	0.587

- Ablation study of the proposed method on the Synapse dataset



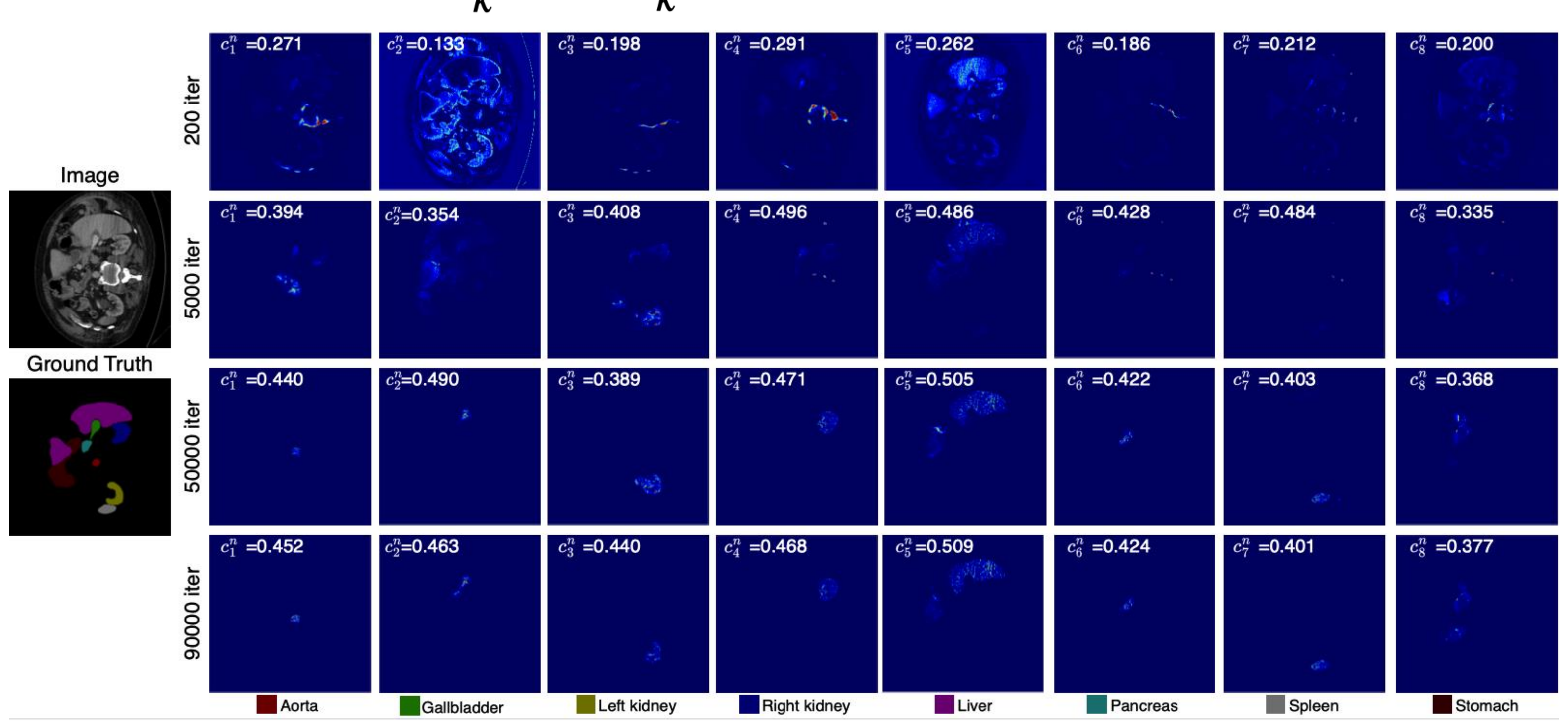
- Impact of the weight of the proposed CV loss function



- Ablation study of the hyper-parameter

τ	DSC.Avg↑	Aor	Gal	Kid(L)	Kid(R)	Liv	Pan	Spl	Sto
0.05	0.690	0.743	0.529	0.743	0.717	0.899	0.461	0.840	0.591
0.07	**0.717**	**0.803**	**0.572**	0.770	0.737	0.901	**0.522**	0.840	0.587
0.09	0.705	0.749	0.566	0.763	0.727	**0.911**	0.497	**0.844**	0.585
0.11	0.647	0.384	0.566	**0.788**	**0.745**	0.907	0.397	0.803	**0.593**
0.13	0.637	0.278	0.538	0.767	0.699	0.907	0.476	0.843	0.587

- Visualizations of z_k^n and c_k^n



- Qualitative Evaluation