Joint Topology-preserving and Feature-refinement Network for Curvilinear Structure Segmentation

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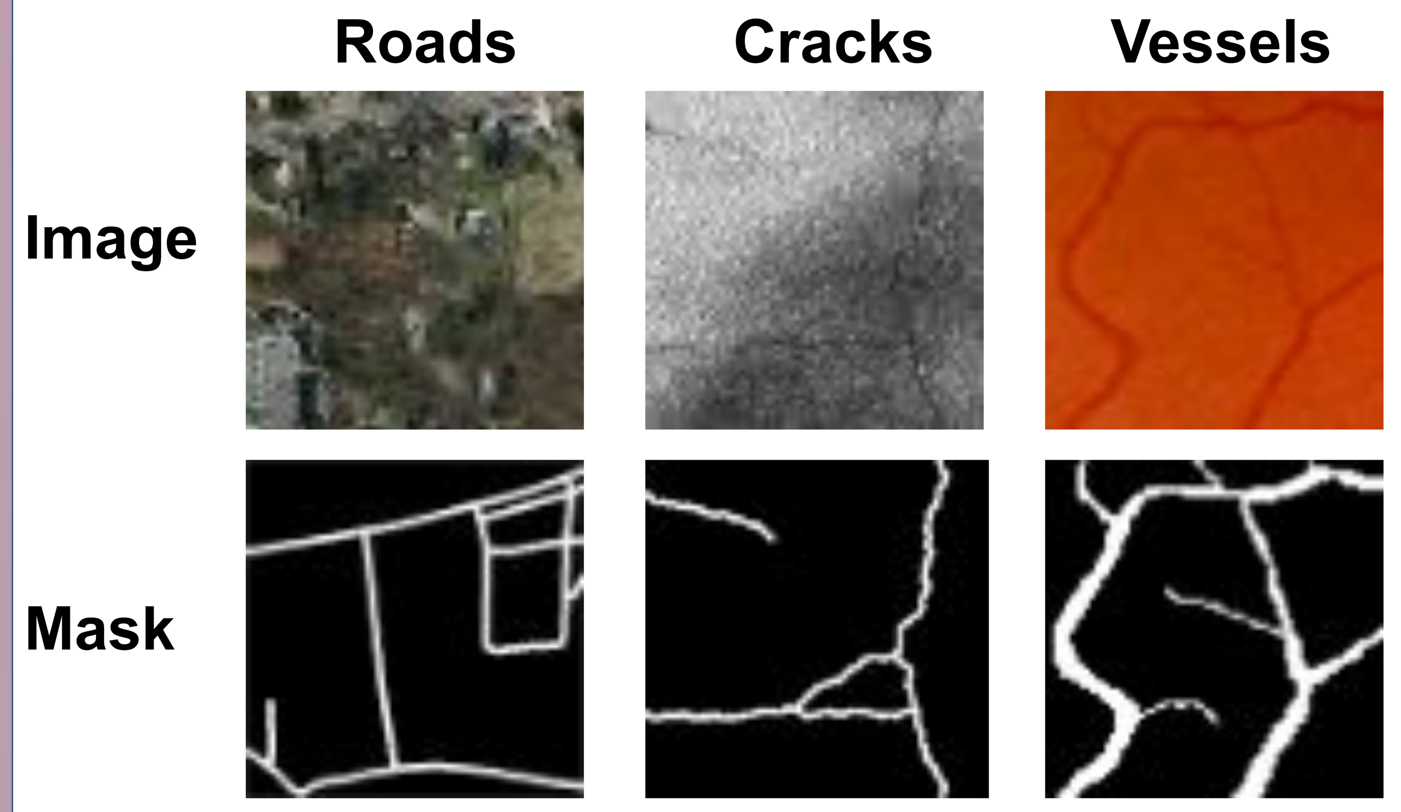
Problem

- **Curvilinear Structure Segmentation (CSS)** is to segment binary masks of curvilinear objects such as:

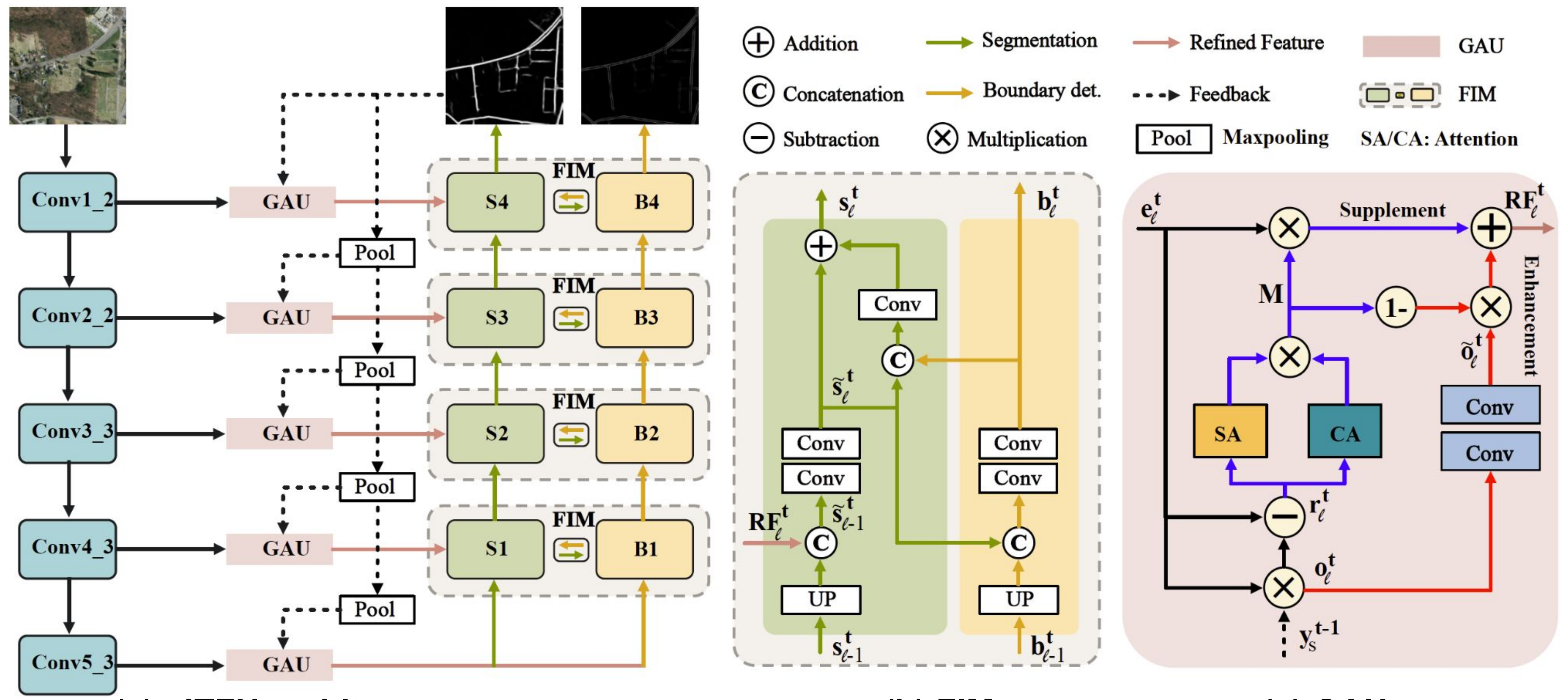


- **Two critical aspects:**
  (1) preserve topology for connected structures;
  (2) refine features for rendering details.
- **Related work**

Methods	Topology preserving	Feature refinement
General semantic segmentation	✗	skip-connection; dilated conv; multi-scale; non-local conv.
CSS	extra ImageNet features; pre-defined connected-components/holes.	✗

- **Observation**: most semantic segmentation methods only focus on enhancing features while existing CSS techniques emphasize preserving topology alone.

Joint Topology-preserving and Feature-refinement Network (JTFN)



(a) JTFN architecture (b) FIM (c) GAU

- ☐ **Feature Interactive Module (FIM):**
  (1) *topology* and boundary connectivity are related;
  (2) reciprocates features between boundary detection & CSS.
- ☐ **Gated Attention Unit (GAU):** supplements & enhances saliencies during *feature refinement.*
- ☐ **JTFN iteratively refines predictions.**

Take-away: JTFN jointly refines features and preserves topology, achieving SoTA results.

▷ Comparisons with SoTA CSS methods on Cracks, DRIVE, and Roads. *All references can be referred to our published paper.

Method	CrackTree200 Precision	CrackTree200 Recall	CrackTree200 F1	Crack500 Precision	Crack500 Recall	Crack500 F1	DRIVE Precision	DRIVE Recall	DRIVE F1	Roads Precision	Roads Recall	Roads F1
UNet [31]	79.16	78.95	78.42	62.22	68.85	61.83	82.74	80.59	81.41	62.55	52.63	55.70
VGG-UNet [26]	83.49	80.43	81.84	58.18	60.26	51.79	81.17	82.05	81.25	64.79	57.47	59.65
TopoNet [14]	81.85	77.80	79.03	66.81	62.68	60.06	82.94	80.29	81.36	62.25	55.83	57.36
DRU [41]	84.80	77.46	80.49	61.94	71.43	62.82	84.36	80.82	82.30	60.62	56.96	57.42
JTFN (ours)	85.87	82.58	84.19	68.81	69.06	65.76	82.71	83.40	82.81	65.14	59.04	60.65
Method	**Correct.**	**Complete.**	**Quality.**	**Correct.**	**Complete.**	**Quality**	**Correct.**	**Complete.**	**Quality**	**Correct.**	**Complete.**	**Quality**
UNet [31]	82.05	85.93	76.15	31.66	34.98	19.56	55.60	46.29	33.82	62.89	58.06	48.56
VGG-UNet [26]	86.95	85.36	80.08	25.45	32.75	15.67	53.04	33.36	31.25	67.23	61.34	53.98
TopoNet [14]	85.50	83.92	77.36	30.02	37.26	19.83	55.67	46.95	34.22	62.46	61.47	50.77
DRU [41]	87.81	84.02	79.47	30.51	36.02	19.78	56.03	48.86	35.36	62.04	60.42	49.83
JTFN (ours)	88.30	87.42	82.96	36.72	39.26	24.12	57.09	49.28	36.02	68.65	63.37	56.05

Code and model are available online: https://github.com/zkl20061823

Experiment

▷ Datasets:
(1) Cracks: CrackTree200, Crack500
(2) Vessel: DRIVE
(3) Road: Roads

▷ Metrics:
Pixel-wise: F1/Precision/Recall
Topology--wise: Correctness/Completeness/ Quality.

▷ Ablation study:
Base: UNet-like network
BO: boundary detection only

Architecture	+BO	+FIM	+GAU	F1	Quality
Base				78.86	77.56
Base-C				80.44	79.60
Base-BO	✓			80.27	78.79
Base-FIM	✓	✓		82.07	80.75
Base-GAU			✓	81.84	81.55
JTFN	✓	✓	✓	84.19	82.96

Summary 1: The proposed FIM and GAU both help improve results.

▷ Comparisons with SoTA on DRIVE

Method	F1	Correct.	Complete.	Quality
Wavelets [36]	76.18	49.18	21.34	17.82
SE [10]	65.84	37.94	16.03	12.59
CE-Net [12]	71.09	33.69	25.96	17.14
HED [50]	79.59	43.83	41.57	27.03
KBoost [5]	80.03	46.89	42.01	28.40
N^4Fields [11]	80.52	56.50	36.46	28.43
CRFs [28]	78.12	49.39	40.31	28.56
CS^2 [27]	81.63	56.62	46.26	34.12
DRIU [24]	82.21	47.34	47.25	31.37
PolicyNet [39]	83.53	57.68	46.39	34.32
JTFN (ours)	82.81	57.09	49.28	36.02

▷ Comparisons on CrackTree200

Method	Correct.	Complete.	Quality
CrackTree [60]	79.0	92.0	73.92
Reg-AC [35]	10.7	92.83	10.61
VGG-UNet [26]	85.50	83.92	77.36
TopoNet [14]	86.95	85.36	80.08
JTFN (ours)	88.3	87.42	82.96

▷ Comparisons on Roads

Method	Correct.	Complete.	Quality
Reg-AC [35]	25.37	34.78	17.19
RoadTracer [3]	43.50	51.30	30.80
MSP-Tracer [45]	48.80	55.20	34.30
JTFN (ours)	68.65	63.37	56.05

Summary 2: JTFN consistently achieves best results compared to SoTA alternatives on three datasets of different applications.

▷ Segmentations. ☐ and ☐ indicate connectivity and rendering details.