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Sph2Pob: Boosting Object Detection on Spherical Images with Planar Oriented Boxes Methods

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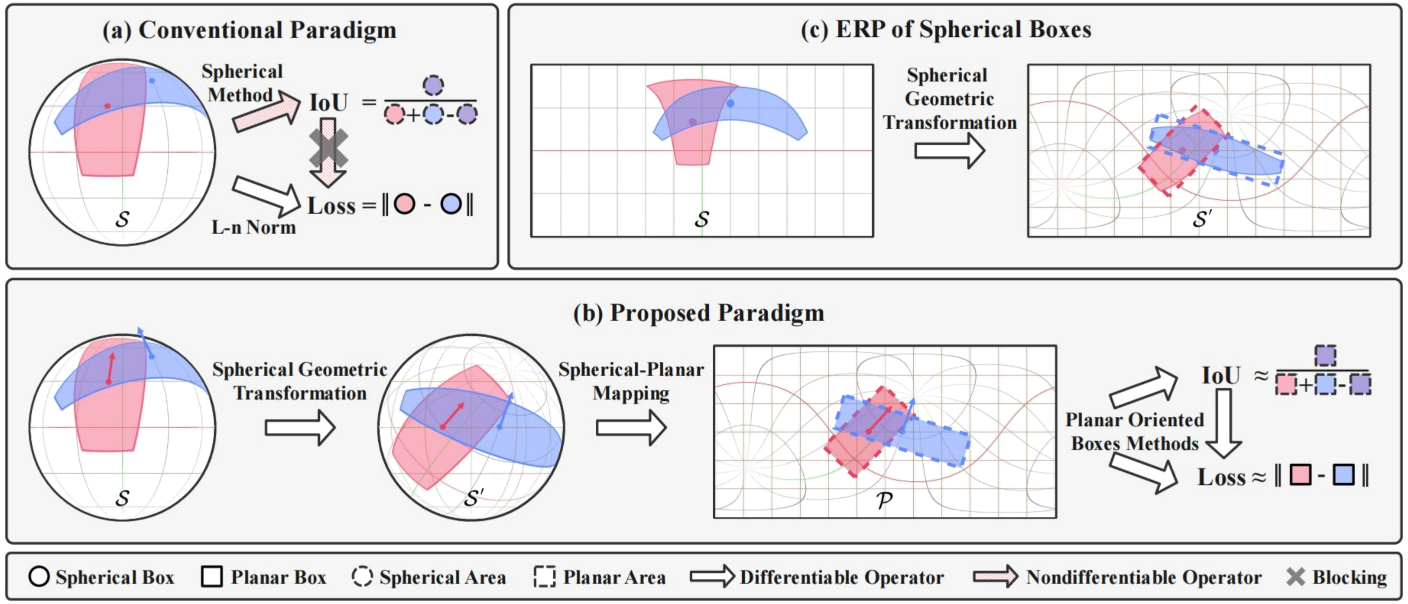
Overview

- Unlike conventional paradigm, in proposed paradigm spherical boxes are transformed to planar oriented boxes, and then IoU and Loss are indirectly calculated.
- The proposed paradigm overcomes the nondifferentiable issue of spherical IoU and enriches Loss design for spherical detection.



★Sph2Pob-IoU★
differentiable, precise, quick

★Sph2Pob-Loss★
metric-consistent, choice-rich

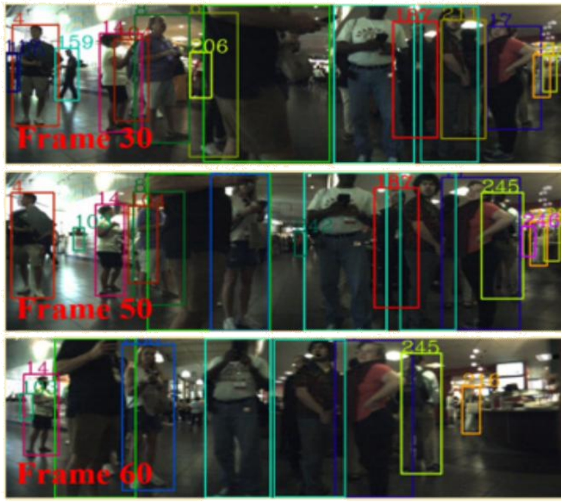
★Sph2Pob★ : well approximated box transform

Spherical/Panoramic Image

- Spherical/Panoramic image is a natural extend of comon planar image.
- It has the whole 360° view with richer information and higher practice value.

Environment Perception

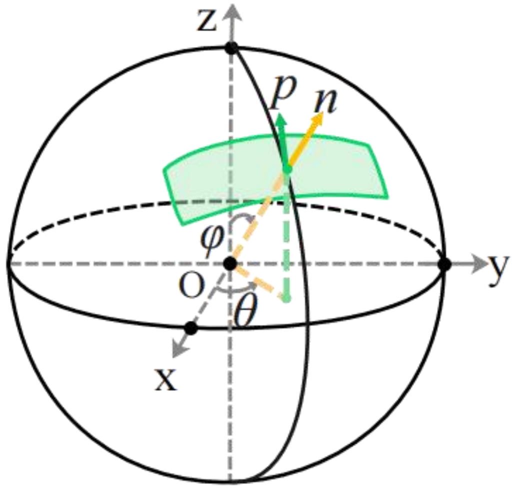
Visual Question&Answer



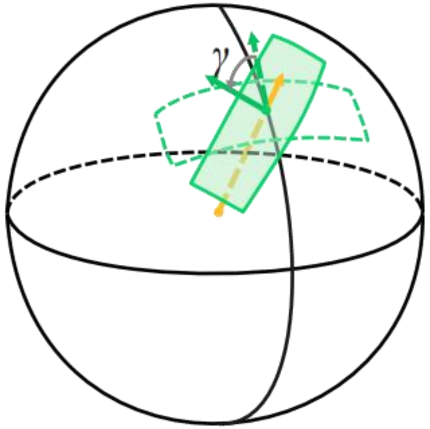
Security Tracking

Spherical Bounding Box

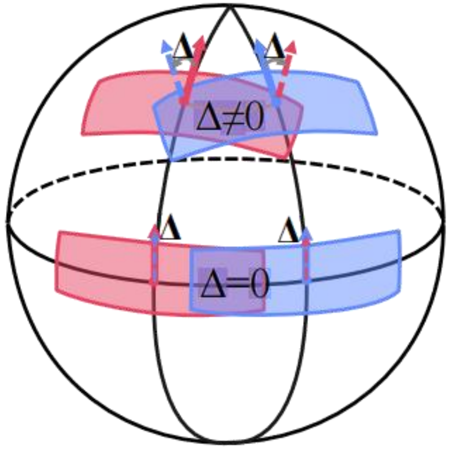
- Spherical bounding box is defined as $(\theta, \phi, \alpha, \beta, \gamma)$.
- $p(\theta, \phi)$ is the tangent point of the sphere and rectangular tangent plane.
- α and β are the horizontal and vertical fields of view of the spherical bounding box.



- γ is rotated angle around center-axis $n(\theta, \phi)$.
- Apart from γ , another rotated angle Δ coupled with box-pair exists on sphere. **[our insight]**
- we call γ as *external angle*, while Δ as *internal angle*.



external angle



internal angle

Overlap(IoU) Calculation

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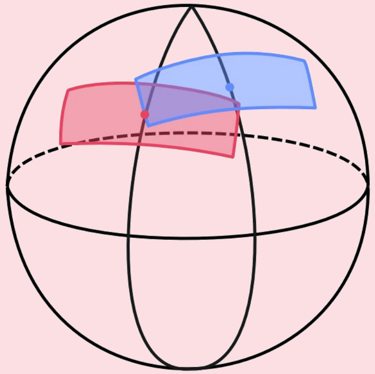
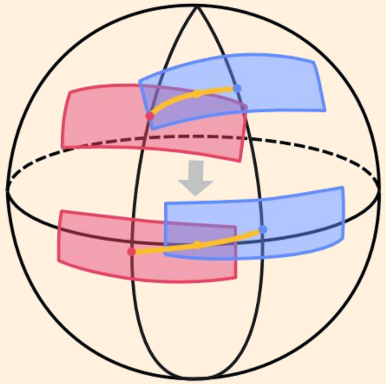
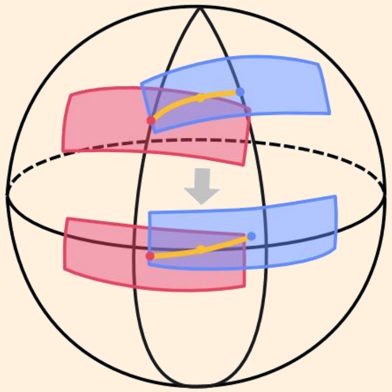
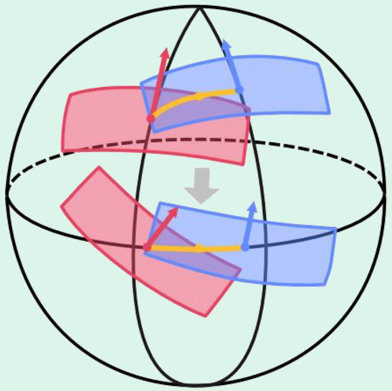
	Exact Method	Approximate Method		Approximate Method
Method	 Unbiased-IoU	 Sph-IoU	 FoV-IoU	 Sph2Pob-IoU(Our)
differentiablity	☆☆☆☆☆	★★★★★	★★★★★	★★★★★
speed	★☆☆☆☆	★★★★★	★★★★★	★★★★☆
accuracy	★★★★★	★☆☆☆☆	★★☆☆☆	★★★★☆

Overlap(IoU) Calculation

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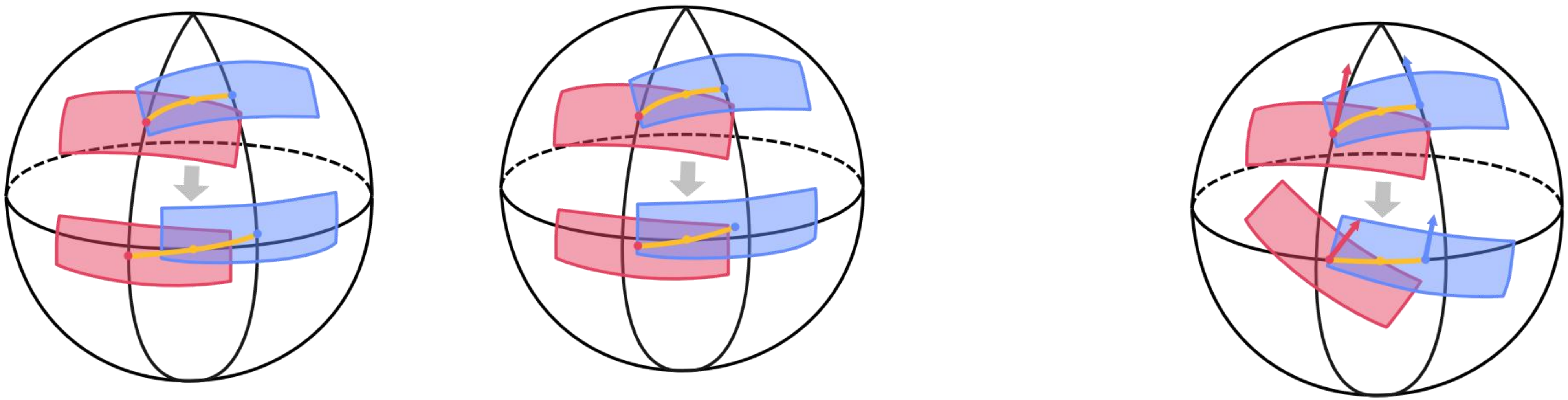


Sph-IoU FoV-IoU Sph2Pob-IoU(Our)

✓ Try to move boxes to the equator, which is the line with no distortion on ERP-images.

× Fail to ensure the boxes after moving on the equator.

× Ignore the internal angle, so relative poses change.

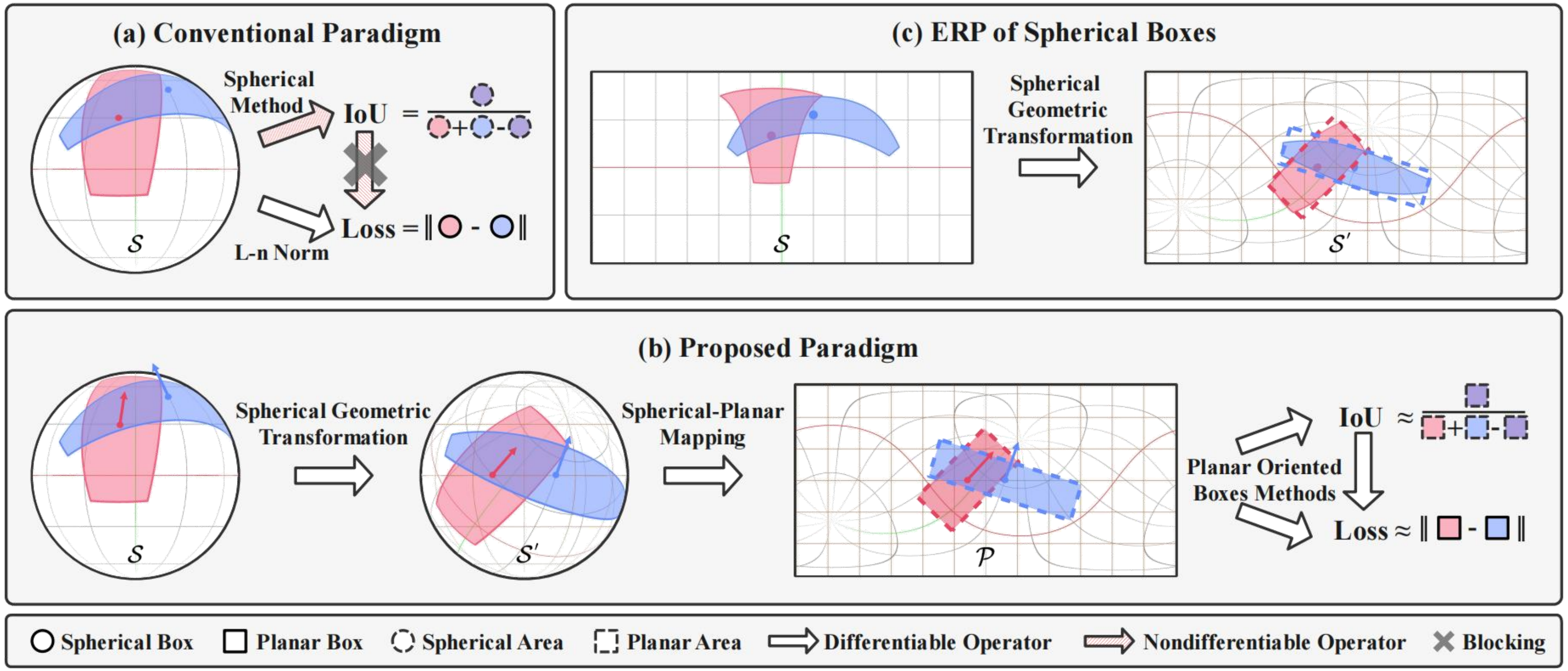
✓ Continue to move boxes to the equator.

✓ Ensure the boxes on the equator.

✓ Preserve the internal angle and relative pose.

Sph2Pob

- **S**pherical **G**eometric **T**ransformation can move boxes without any infoloss.
- **S**pherical-**P**lanar **M**apping is also used to calculate more general loss beyond IoU.



Mathematical Details

1. Compute position and pose.

$$\boldsymbol{n} = \boldsymbol{n}(\theta, \phi) = [nx, ny, nz]^\top$$
$$= [\sin(\phi)\cos(\theta), \sin(\phi)\sin(\theta), \cos(\phi)]^\top$$
$$\boldsymbol{p} = \boldsymbol{p}(\theta, \phi) = \frac{\partial \boldsymbol{n}(\theta, \phi)}{\partial \phi} = [px, py, pz]^\top$$
$$= [\cos(\phi)\cos(\theta), \cos(\phi)\sin(\theta), -\sin(\phi)]^\top$$

2. Construct spherical transformation.

$$\boldsymbol{R} = [\boldsymbol{v}_x, \boldsymbol{v}_y, \boldsymbol{v}_z]^\top = \left[\frac{\boldsymbol{n}_1+\boldsymbol{n}_2}{\|\boldsymbol{n}_1+\boldsymbol{n}_2\|}, \frac{\boldsymbol{n}_1-\boldsymbol{n}_2}{\|\boldsymbol{n}_1-\boldsymbol{n}_2\|}, \boldsymbol{v}_x \times \boldsymbol{v}_y\right]^\top$$

3. Transform position and pose.

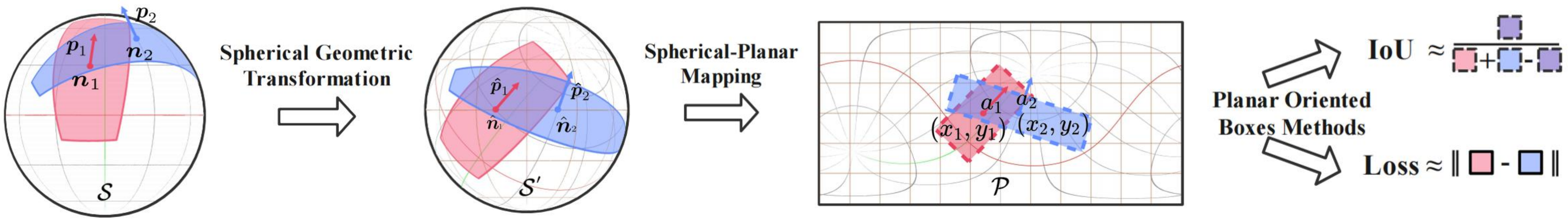
$$\hat{\boldsymbol{n}}(\hat{\theta}, \hat{\phi}) = \boldsymbol{R}\, \boldsymbol{n}(\theta, \phi) \qquad [\hat{\boldsymbol{p}}_1, \hat{\boldsymbol{p}}_2] = \boldsymbol{R}\, [\boldsymbol{p}_1, \boldsymbol{p}_2]$$

4. Compute *Internal Angle*.

$$\Delta = \Delta_1 + \Delta_2 = \arccos(\hat{\boldsymbol{p}}_1 \cdot \hat{\boldsymbol{p}}_{ref}) + \arccos(\hat{\boldsymbol{p}}_2 \cdot \hat{\boldsymbol{p}}_{ref})$$

5. Map spherical boxes to planar boxes.

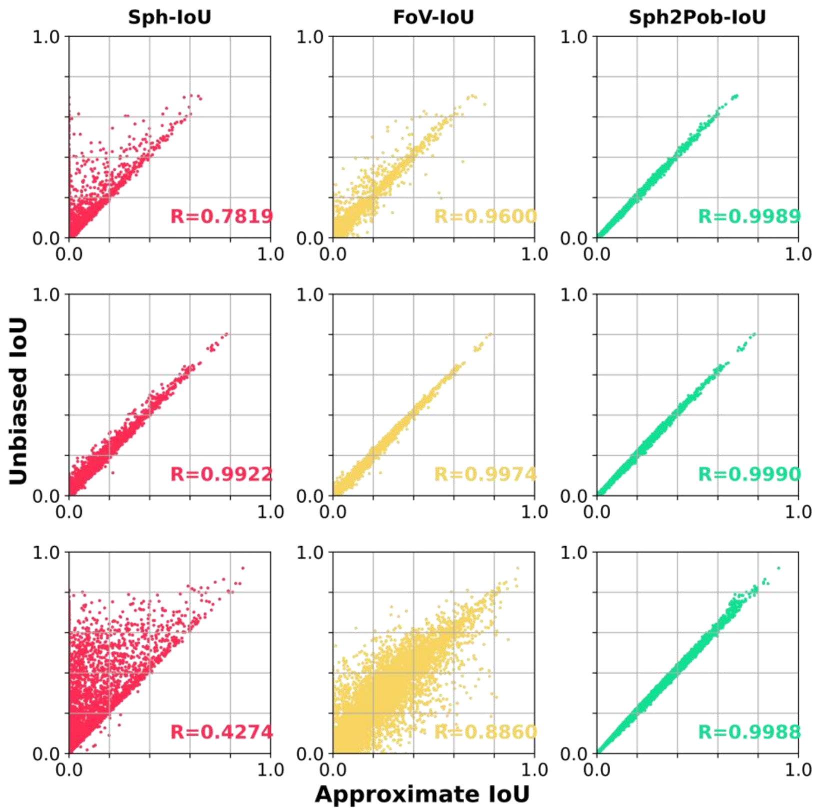
$$\mathcal{B}_i^{\mathcal{P}} = (x_i, y_i, w_i, h_i, a_i) = (\hat{\theta}_i, \hat{\phi}_i, \hat{\alpha}_i, \hat{\beta}_i, \hat{\Delta}_i)$$
$$a_i = \Delta_i + \gamma_i, i = 1, 2$$



★ IoU & Loss ★ $IoU^{\mathcal{S}}(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}) \approx IoU^{\mathcal{P}}(Sph2Pob(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}))$ $Loss^{\mathcal{S}}(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}) \approx Loss^{\mathcal{P}}(Sph2Pob(\boldsymbol{B}_1^{\mathcal{S}}, \boldsymbol{B}_2^{\mathcal{S}}))$

Experiments

- Scatter of different IoU.



- Comprehensive comparison of box transform methods.

Method	Consistency			Time-cost		Detection		
	$R_{all}\uparrow$	$R_{low}\uparrow$	$R_{high}\uparrow$	$T_{cpu}\downarrow$	$T_{cuda}\downarrow$	AP↑	$AP_{50}\uparrow$	$AP_{75}\uparrow$
Sph	0.7819	0.9922	0.4274	0.0364	0.0033	10.7	24.3	7.8
Fov	0.9600	0.9974	0.8860	0.0372	0.0034	10.9	25.0	7.9
Sph2Pob	0.9989	0.9990	0.9988	2.2275	0.0096	11.5	25.7	8.2
Unbiased	1.0000	1.0000	1.0000	46.4417	-	-	-	-

- Ablation studies about edge & angle calculation.

Edge	Error↓(mean±std)	R↑
arc	0.0016±0.0042	0.9989
chord	0.0023±0.0063	0.9974
tangent	0.0086±0.0192	0.9681

Angle	Error↓(mean±std)	R↑
original	0.0025±0.0086	0.9946
equator	0.0016±0.0042	0.9989
project	0.0017±0.0043	0.9987

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Evaluations

- Evaluation on different Loss.

Loss	360-Indoor AP↑	360-Indoor AP_{50} ↑	360-Indoor AP_{75} ↑	PANDORA AP↑	PANDORA AP_{50} ↑	PANDORA AP_{75} ↑
L1	10.2	23.0	7.8	10.3	24.3	6.6
L1†	9.9	21.9	7.7	10.1	23.7	6.8
GWD† [Yang *et al.*, 2021b]	6.8	14.5	5.6	5.9	12.3	5.0
KLD† [Yang *et al.*, 2021c]	9.5	21.5	6.8	10.3	23.5	7.1
KFIoU† [Yang *et al.*, 2022b]	8.5	19.7	6.2	9.6	23.2	5.6
IoU† [Yu *et al.*, 2016]	9.8	22.1	6.8	10.4	24.8	6.9
GIoU† [Rezatofighi *et al.*, 2019]	10.5	23.9	7.8	10.3	24.7	6.8
DIoU† [Zheng *et al.*, 2020]	11.0	24.6	8.2	10.4	24.8	7.0
CIoU† [Zheng *et al.*, 2021]	11.5	25.7	8.2	10.5	25.3	7.0

- Evaluation on different detectors.

Detector	Loss	360-Indoor AP↑	360-Indoor AP_{50} ↑	360-Indoor AP_{75} ↑	PANDORA AP↑	PANDORA AP_{50} ↑	PANDORA AP_{75} ↑
Faster R-CNN	L1	12.5	28.1	9.1	11.0	27.8	6.2
	CIoU†	12.9	29.1	9.4	11.3	28.6	7.1
SSD	L1	10.8	27.6	6.3	9.5	25.8	4.6
	CIoU†	12.0	28.7	8.0	10.5	26.9	6.0
FCOS	L1	8.8	20.2	6.7	7.7	19.7	4.4
	CIoU†	9.2	21.0	7.0	8.8	21.2	5.6

- Evaluation on different components, including Lable Assignment, Loss, NMS.

Label Assignment	Loss	NMS	360-Indoor AP↑	360-Indoor AP_{50} ↑	360-Indoor AP_{75} ↑	PANDORA AP↑	PANDORA AP_{50} ↑	PANDORA AP_{75} ↑
			9.8	22.2	7.0	10.4	23.8	6.9
✓			10.2	23.0	7.8	10.3	24.3	6.6
	✓		11.0	25.4	7.8	10.6	24.5	6.9
		✓	9.8	22.1	6.8	10.4	23.9	6.9
✓	✓		11.5	25.7	8.2	10.5	25.3	7.0
✓	✓	✓	11.6	26.1	8.4	10.6	25.7	7.1

Visualized Comparsions (360Indoor)

- Some easily confused bed/sofa/table-like objects are labeled as bed.
- With L1, predicted bboxes are coarse and category-wrong.

Ground Truth

L1

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Visualized Comparsions (360Indoor)

- Some easily confused bed/sofa/table-like objects are labeled as bed.
- With our CIoU†, predicted bboxes are more compact even though category-wrong.

Ground Truth

(Ours) CIoU†

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Visualized Comparsions (PANDORA)

- The cablinet is rotated with some angle, and lights are tiny.
- With L1, predicted box of the cablinet is corse with wrong angle, and lights are missing.

Ground Truth

L1

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Visualized Comparsions (PANDORA)

- The cablinet is rotated with some angle, and lights are tiny.
- With our CIoU†, the cablinet is more tight with right angle, and lights are catched.

Ground Truth

(Ours) CIoU†

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Thank You !

- Paper: Sph2Pob: Boosting Object Detection on Spherical Images with Planar Oriented Boxes Methods
- Codes: https://github.com/AntXinyuan/sph2pob

- Contact:

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