JUNE 18-22, 2023
CVPR
VANCOUVER, CANADA

Wide-angle Rectification

via content-aware conformal mapping

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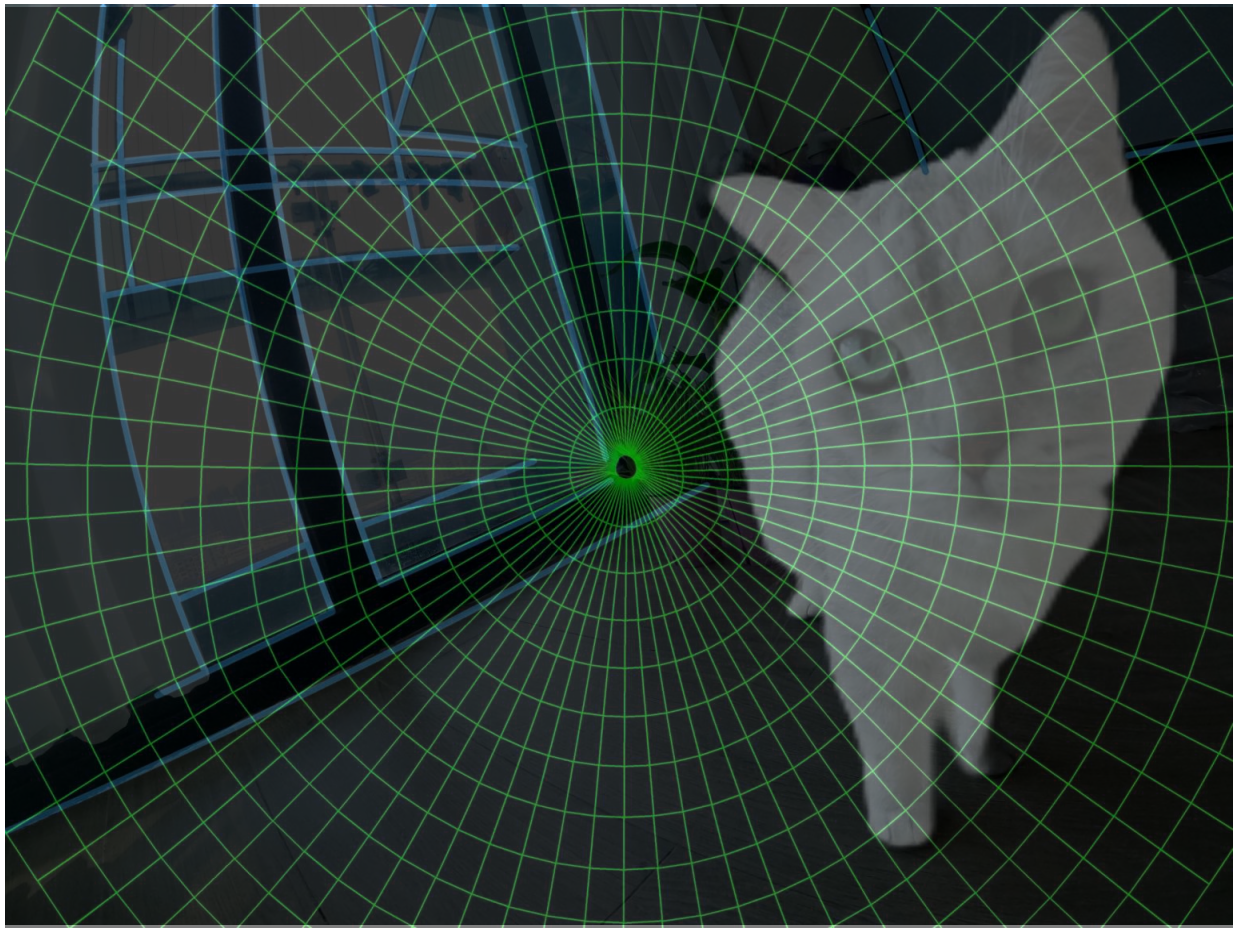
Pipeline



Input

Output

Motivation

Trend: Wide-angle camera are GROWING!

	Smartphone				VR/AR		
Make	Apple	Samsung	Huawei	Xiaomi	Meta Oculus	HTC Vive	ByteDance Pico
Flagship	iPhone 13	S22 Ultra	P50 Pro	MI11 Ultra	Quest 2	Focus Plus	Neo 3 Pro
Field-of-View (FoV)	120°	120°	120°	128°	89°	110°	98°

- Human's eyes (FoV): 114°~120°
- Major smartphone prior to 2022 (FoV): 120°~130°
- Major VR prior to 2022 (FoV): 90°~110°

Motivation

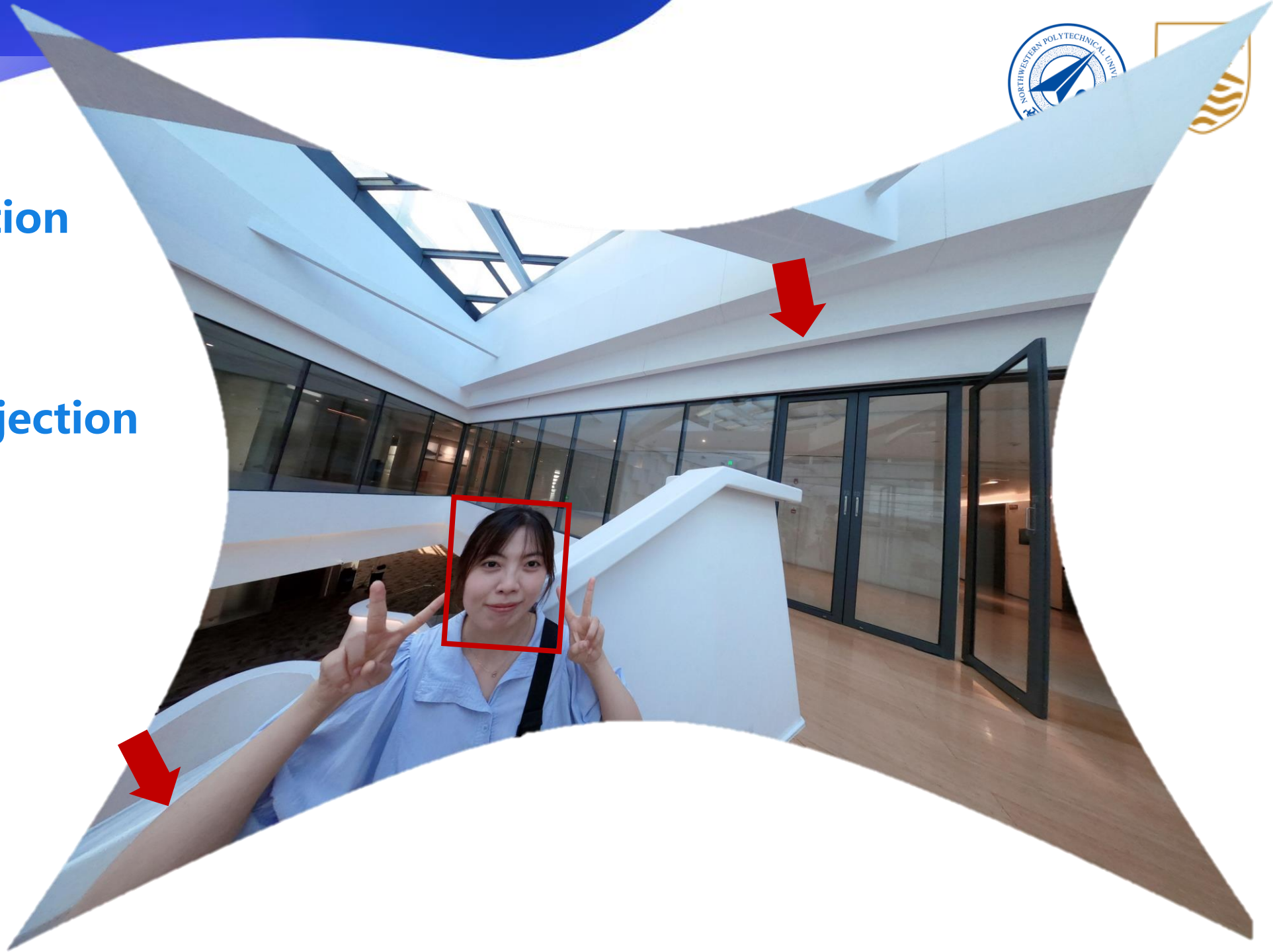
Raw input

149°FoV
GoPro

Motivation

Lens calibration

Perspective projection



149°FoV
GoPro

Motivation

Lens calibration

Perspective projection

Cropped image

Compromised field of view

149°FoV
GoPro

Motivation

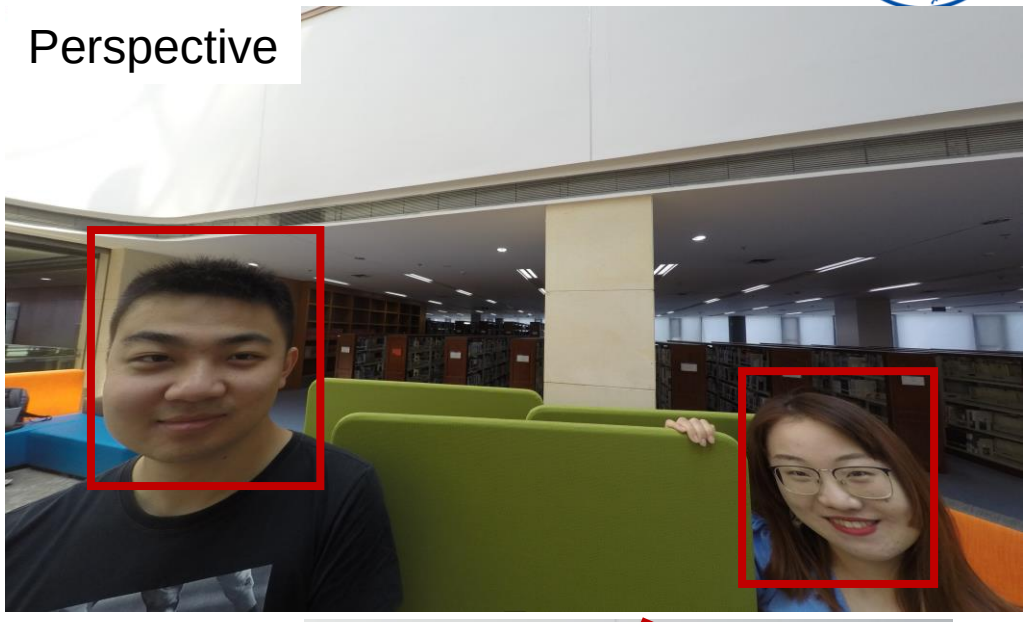
Goal: Wide-angle image rectification that minimizes those most visually salient distortions

- An **automatic** content-aware wide-angle image rectification method
  - Preservation for both local shape and global structures
  - Image content analysis via deep-learning
- Least-Squares Conformal Mapping (LSCM) in **polar domain**
  - Polar-form Cauchy-Riemann condition
  - Polar mesh placement and LSCM-based shape-preserving term.
- A new **optimization procedure** with multiple energy terms for local shape, linear structure, smoothness and image boundaries.

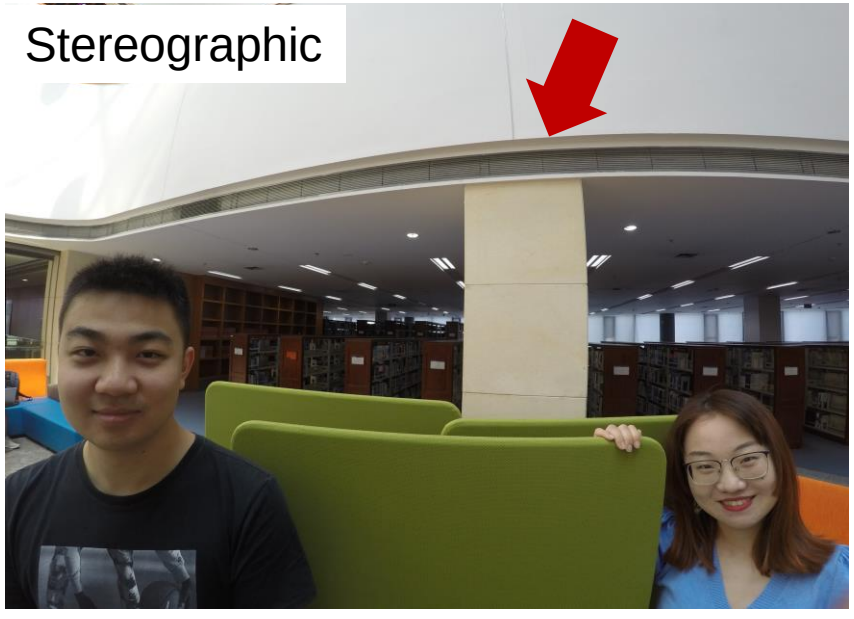
Related Work: Global Projection

Input

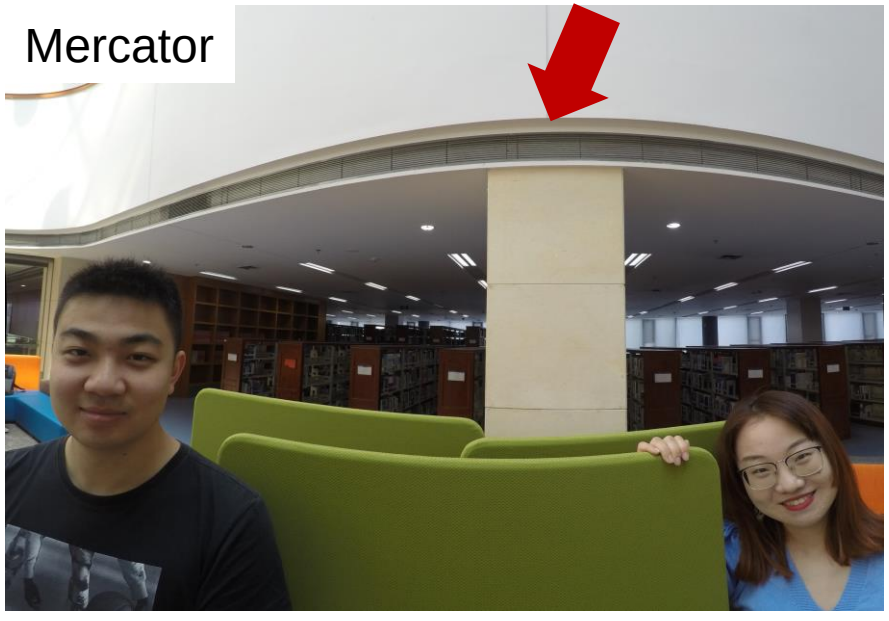
Perspective



Stereographic



Mercator



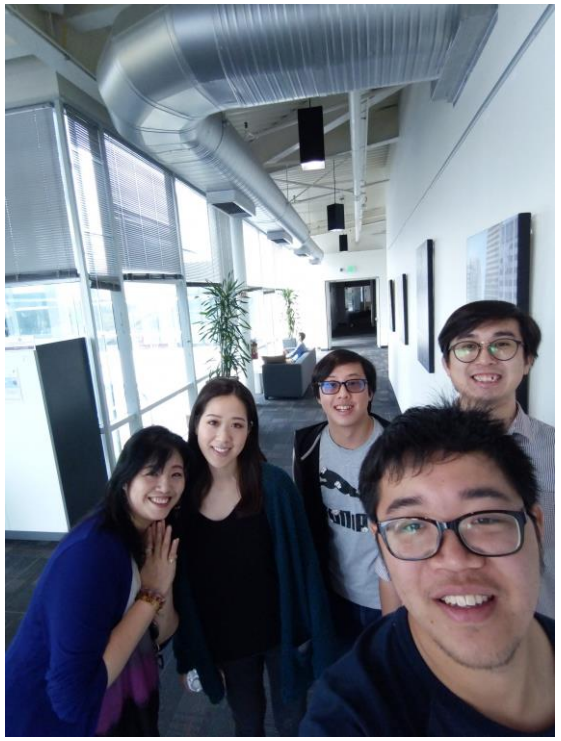
Related Work: Content-aware Warping

- Optimizing conformality under Mercator projection [Carroll *et al.* 2009]
- Optimizing wide-angle portraits under perspective projection [Shih *et al.* 2019]

Optimization with manual editing

Raw input

Carroll *et al.* 2009



Perspective input

Shih *et al.* 2019

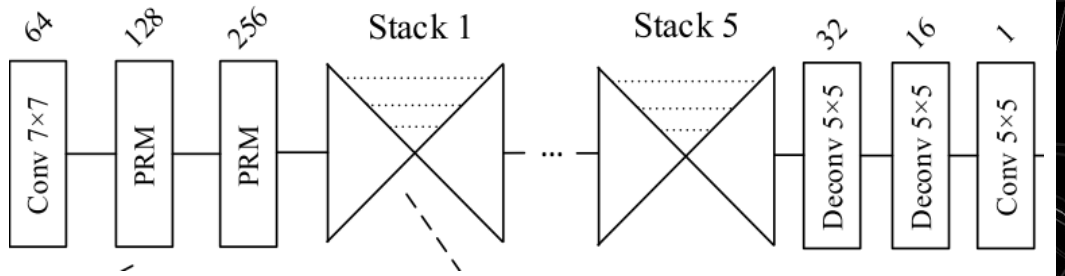
Carroll *et al.* Optimizing content-preserving projections for wide-angle images. ACM TOG, 2009, 28(3):43
Shih et al. Distortion-free wide-angle portraits on camera phones. ACM TOG, 2019, 38(4): 1-12

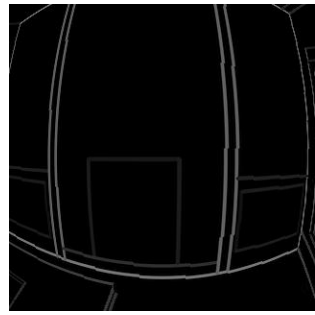
Method: Overview

Input (wide-angle image)

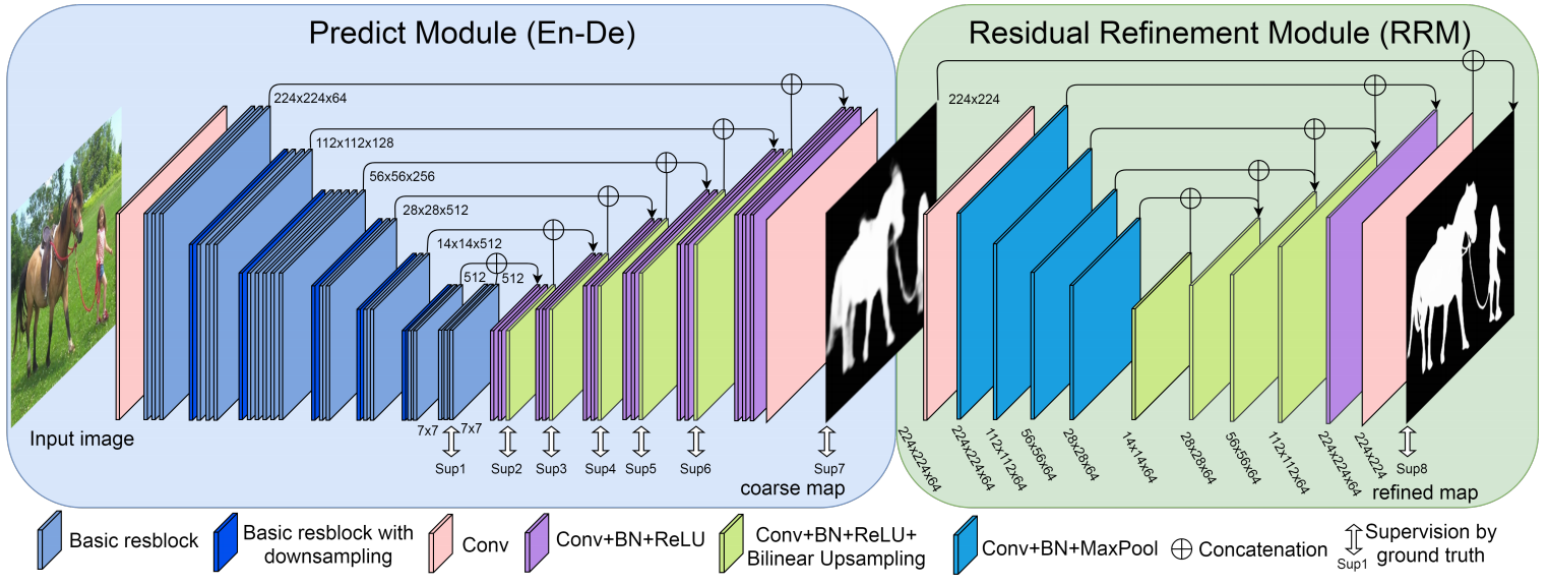
Method: Overview

Input with visual features





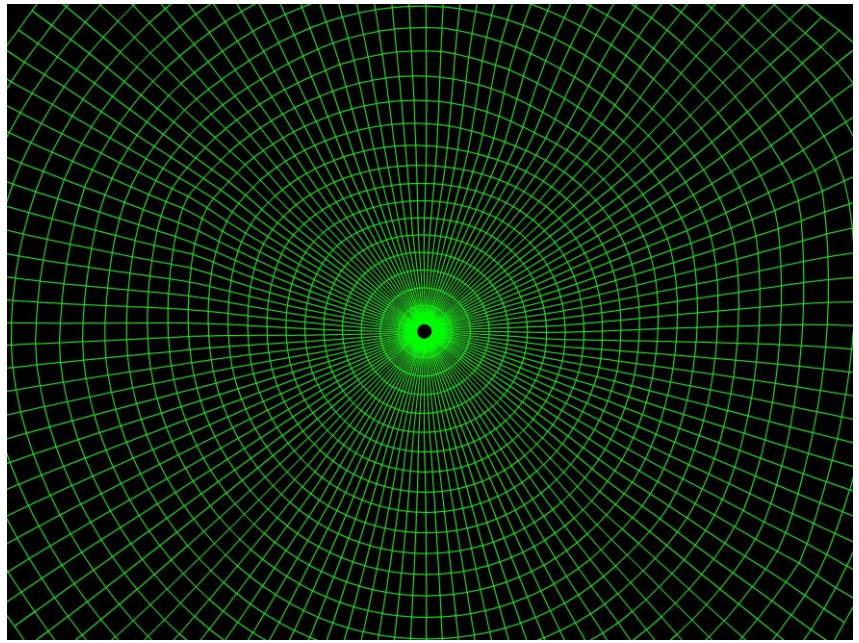
CLP-Net for curvilinear line detection



BAS-Net [Qin *et al.* 2019] for saliency detection

Method: Overview

Input with visual features



Mesh Optimization

Output

Method: LSCM-based Shape-preserving term

General Cauchy-Riemann Condition:

$$\mathcal{N}(\theta,\phi)\frac{\partial \mathcal{U}}{\partial \theta}=\frac{\partial \mathcal{U}}{\partial \phi}$$

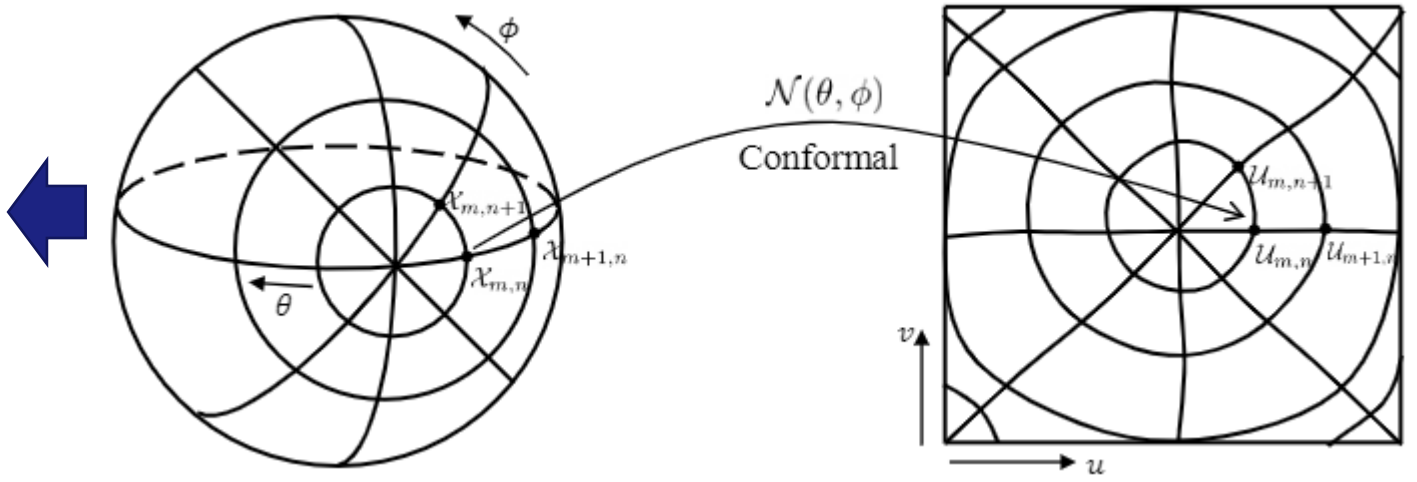
Stereographic

Polar-form Cauchy-Riemann Condition:

$$\frac{\partial \mathcal{U}}{\partial \phi}-i\sin\theta\frac{\partial \mathcal{U}}{\partial \theta}=0$$

Least-Squares Polar Conformal Map

$$C(\mathcal{U}_{m,n})=\frac{\partial \mathcal{U}}{\partial \phi}-i\sin\theta\frac{\partial \mathcal{U}}{\partial \theta}=\begin{bmatrix}1-i\sin\theta\\ i\sin\theta\\ -1\end{bmatrix}^{\top}\begin{bmatrix}\mathcal{U}_{m,n}\\ \mathcal{U}_{m+1,n}\\ \mathcal{U}_{m,n+1}\end{bmatrix}$$



Local Shape-Preserving term

$$E_C=\sum_{\mathcal{U}_{m,n}\in M}\left\|\omega_{m,n}^{C}C(\mathcal{U}_{m,n})\right\|^2$$

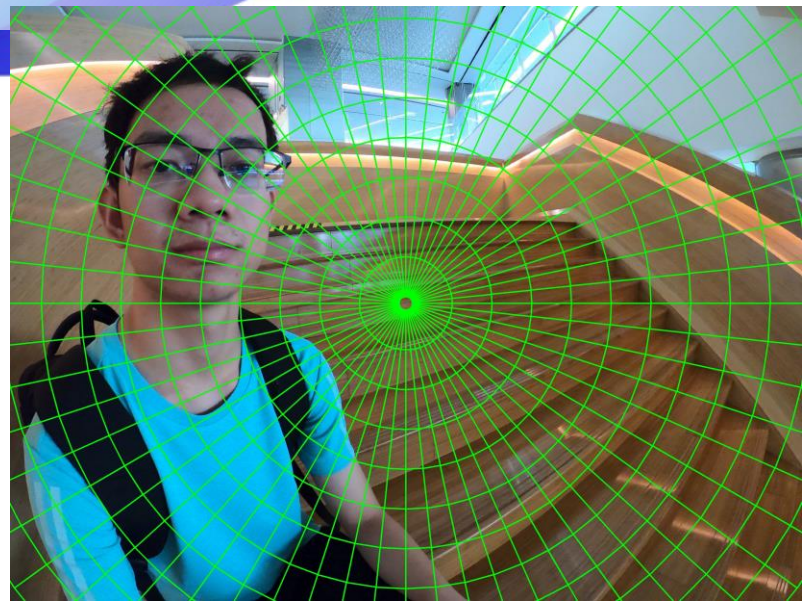
Conformality criterion indicates the strength of local shape preservation.

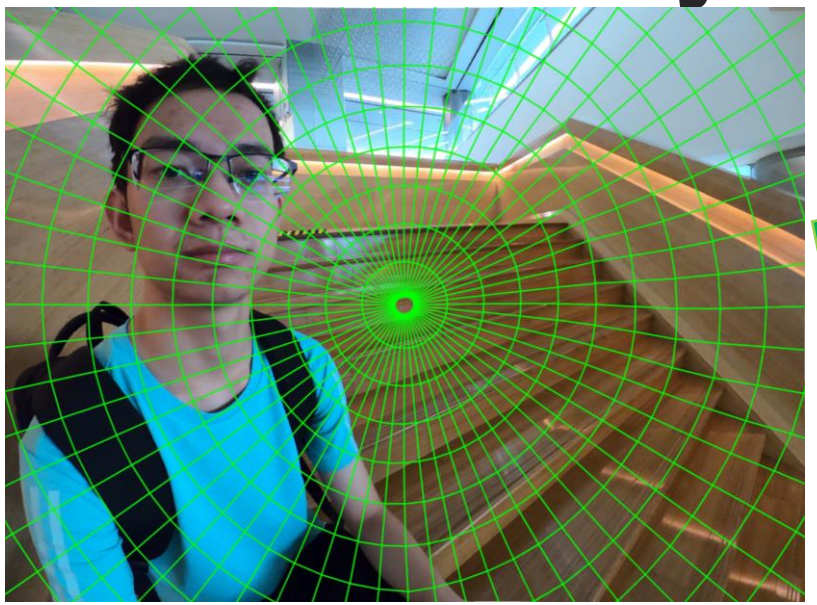
Spatially-varying weights: 5 or 1 for salient or non-salient region using BAS-Net

Method: Mesh Placement & Conformality

Mesh Placement

Conformality





(a) Input

(b) Ours

Polar mesh; Vertices are uniformly sampled in radial and angular directions

Conformality criterion; Warmer colors indicate higher distortion

Method: Line-preserving term

Line-preserving weights; increased with distance from image center

Line-orientation unit vector; defined by two endpoints of each line.

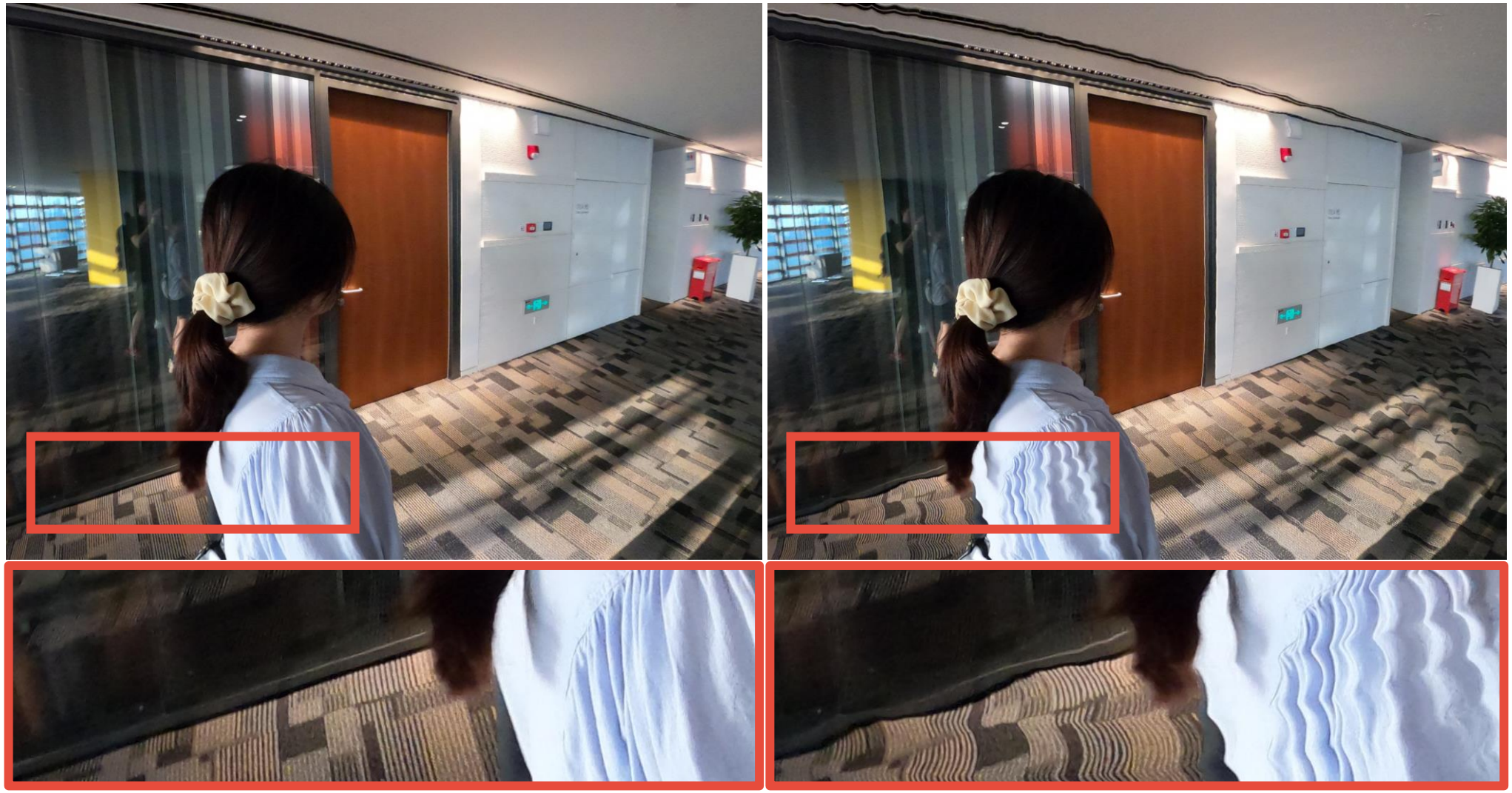
$$E_L = \sum_n \omega_{l,n} E_{l,n} \qquad E_{l,n} = \sum_k \left\| \boldsymbol{e}(\boldsymbol{u}_s^l, \boldsymbol{u}_e^l)^\top \boldsymbol{u}_k^l \right\|_2^2$$

(a) Input

(b) Ours w/o line-preserving term

Method: Smoothness

$$E_S = \sum \left\| w^C_{m,n} \left(u_{m+1,n} - 2u_{m,n} + u_{m-1,n} \right) \right\|_2^2 + \sum \left\| w^C_{m,n} \left(u_{m,n+1} - 2u_{m,n} + u_{m,n-1} \right) \right\|_2^2 + 2 \sum \left\| w^C_{m,n} \left(u_{m+1,n+1} - u_{m,n+1} - u_{m+1,n} + u_{m,n} \right) \right\|_2^2,$$



(a) Ours

(b) Ours w/o smoothness

Method: Boundary-preserving term

$$E_B = \sum_{\boldsymbol{u}_k^b \in L} \left\| u_k^b \right\|_2^2 + \sum_{\boldsymbol{u}_k^b \in R} \left\| u_k^b - W \right\|_2^2 + \sum_{\boldsymbol{u}_k^b \in T} \left\| v_k^b \right\|_2^2 + \sum_{\boldsymbol{u}_k^b \in B} \left\| v_k^b - H \right\|_2^2,$$

(a) Ours

(b) Ours w/o boundary preservation

Method: Mesh Optimization

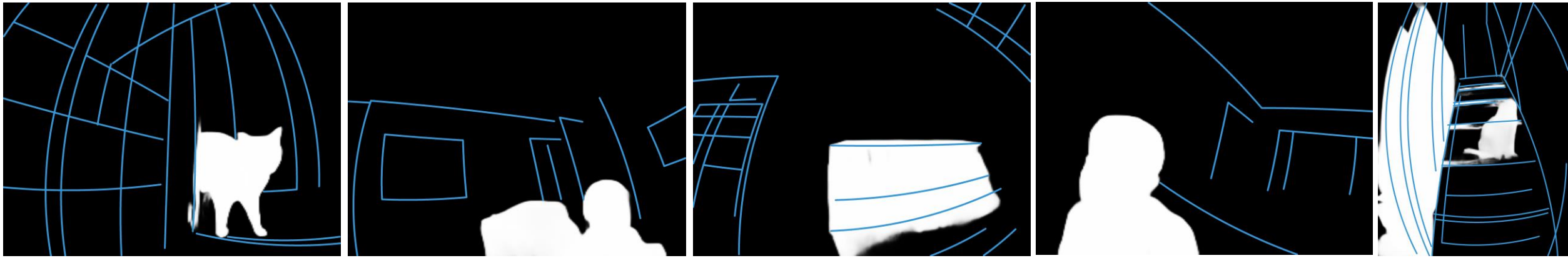
- Total energy cost by summing up
  - Local shape-preserving term
  - Line-preserving term
  - Smoothness term
  - Boundary-preserving term

$$E = \lambda_C E_C + \lambda_L E_L + \lambda_S E_S + \lambda_B E_B$$

- Solves the linear energy function with Ceres.

Results: Image content analysis

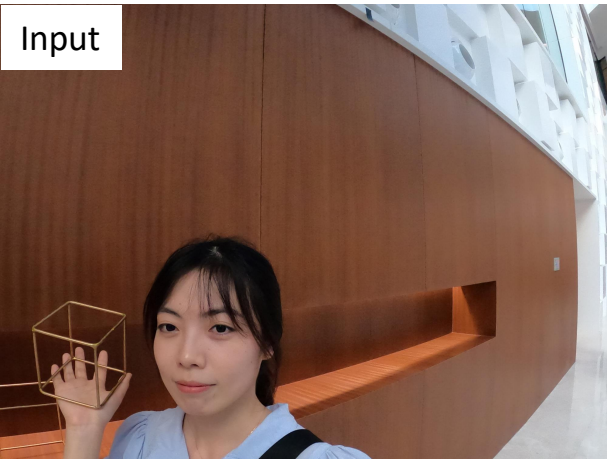
Results: Image content analysis

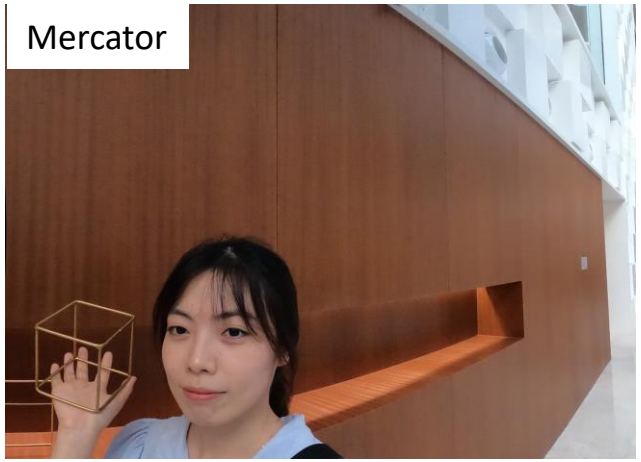


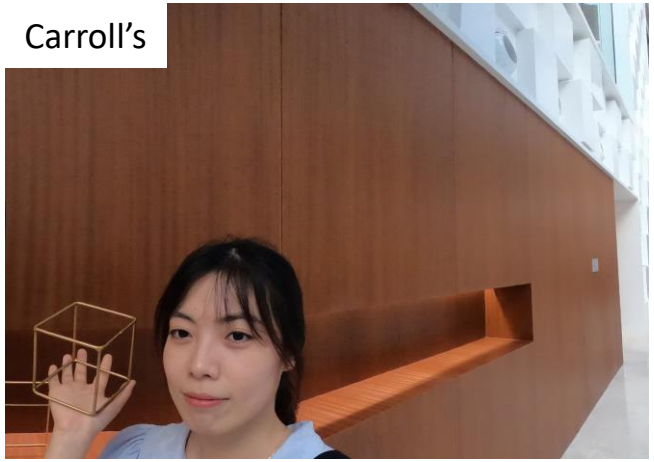
Results:

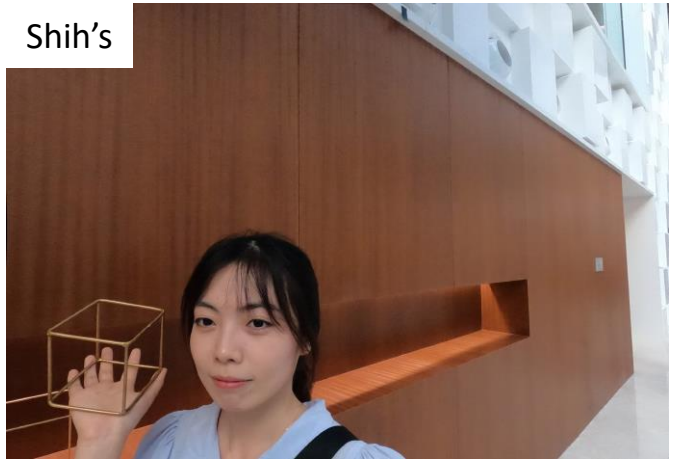
123°FoV
GoPro

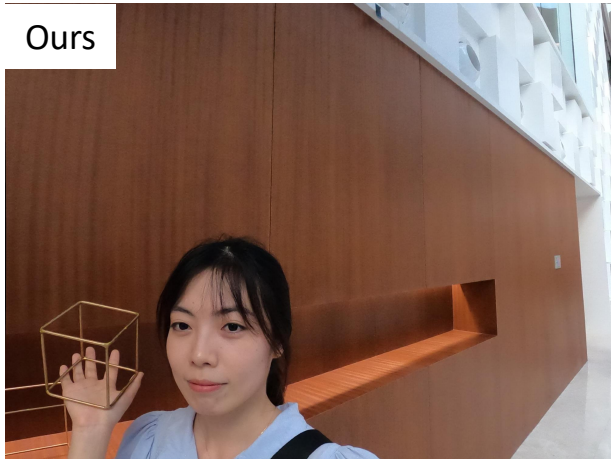
Results: Comparison









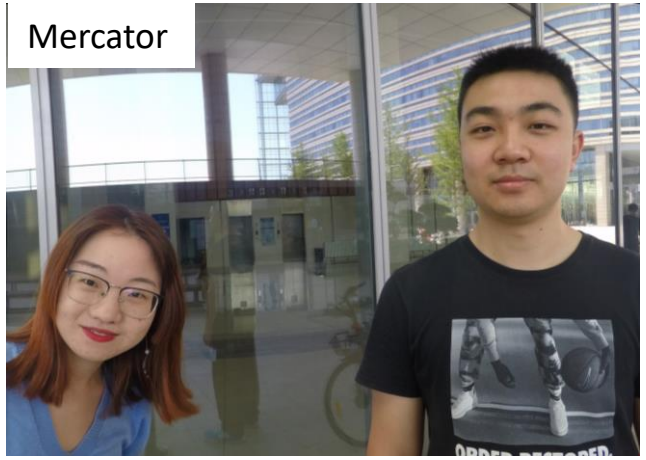


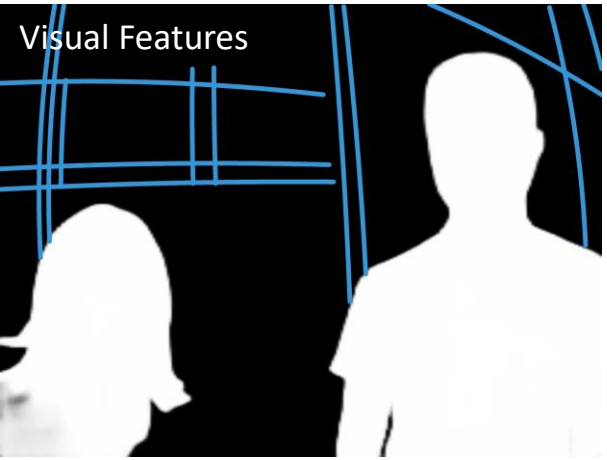
123°FoV
GoPro

Results

123°FoV
GoPro

Results: Comparison





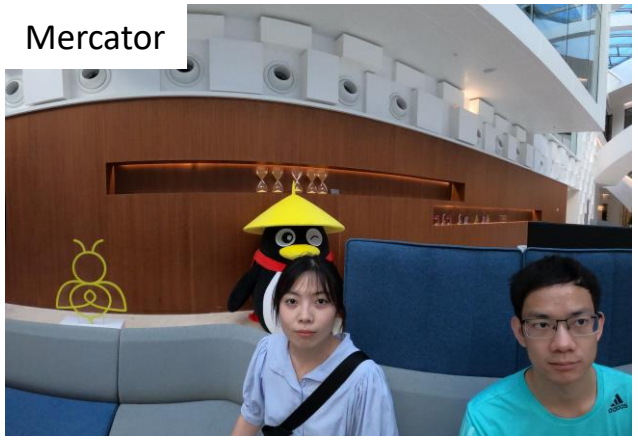
123°FoV
GoPro

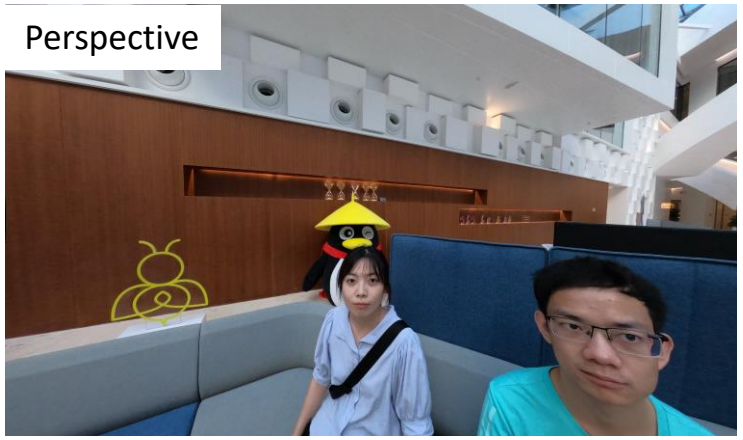
Result

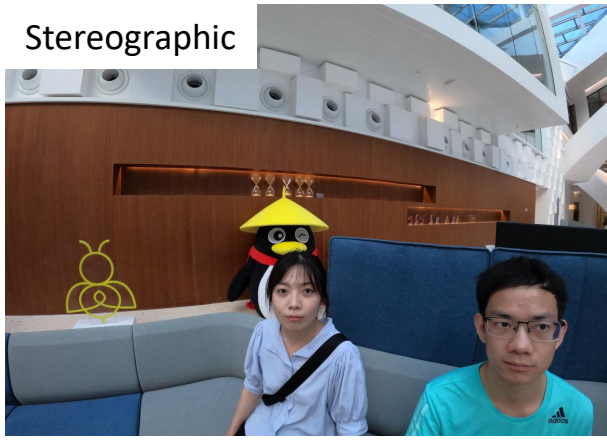
Input

149°FoV
GoPro

Results: Comparison







149°FoV
GoPro

Results: Comparison

(a) Input (b) Perspective (c) Carroll's (d) Ours

180°FoV
Fisheye

Results: Comparison

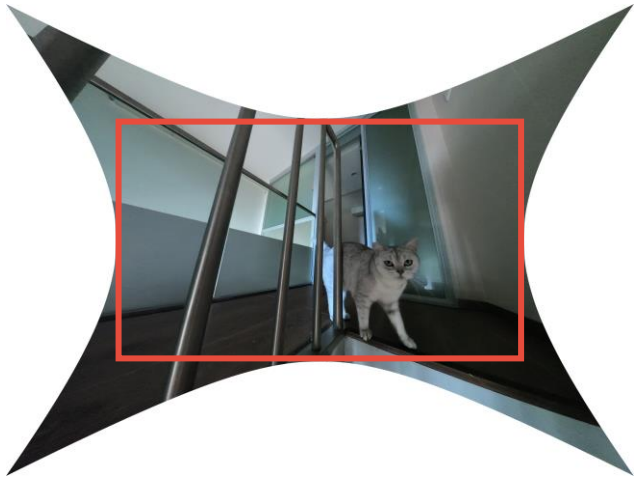
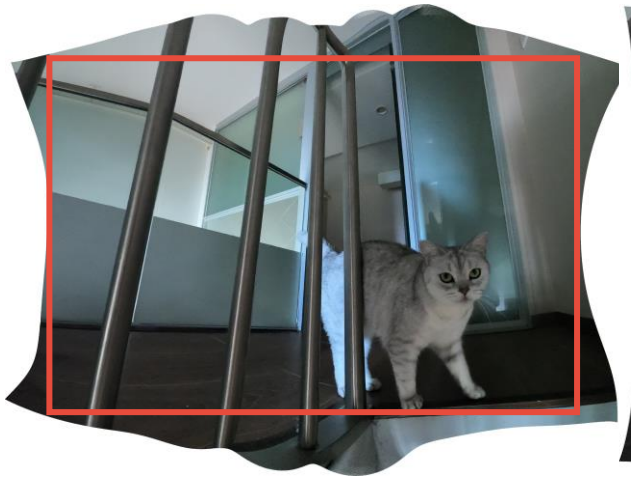
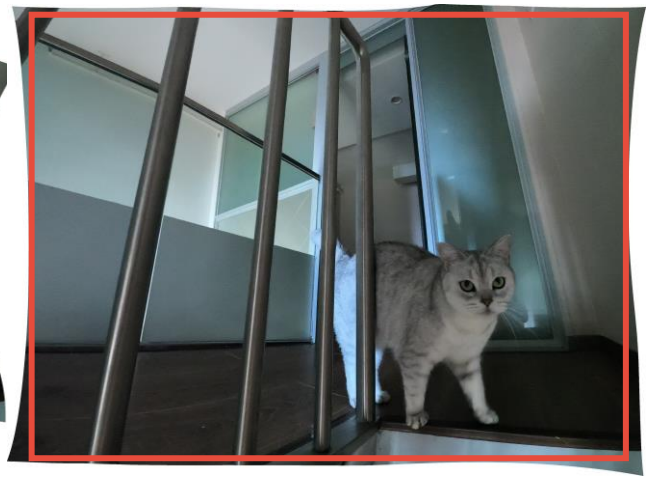
(a) Input (b) Perspective (c) Carroll's (d) Ours

149°FoV
GoPro

Results: Comparison





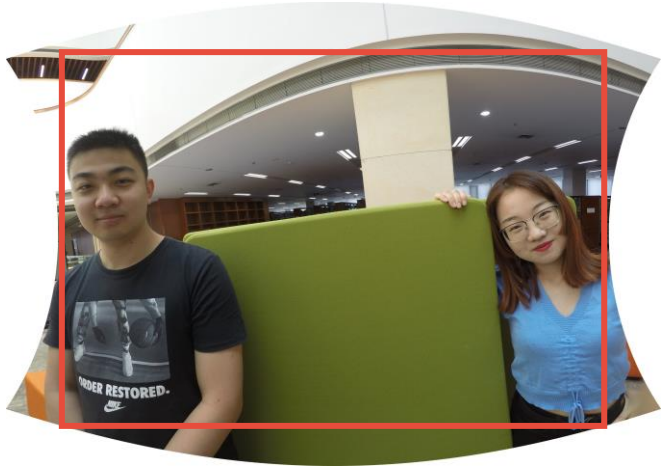





(a) Input (b) Perspective (c) Carroll's (d) Ours

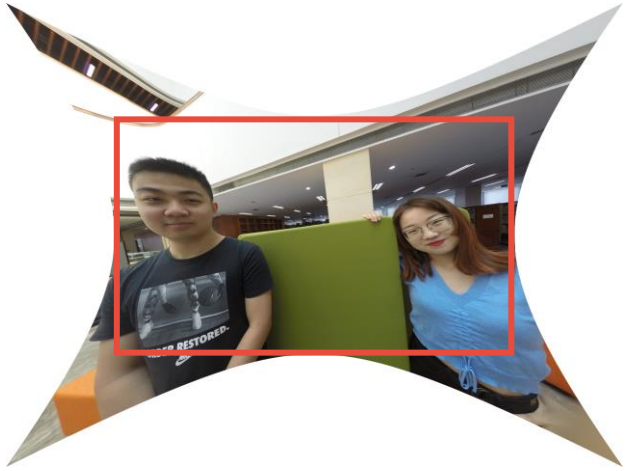
149°FoV
GoPro

Results: Comparison

Input

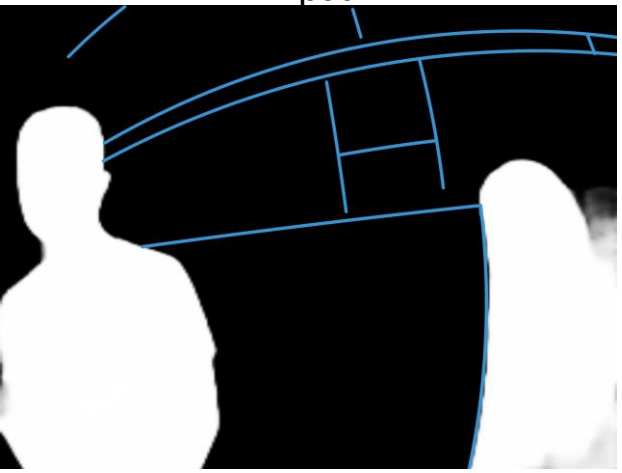


Mercator



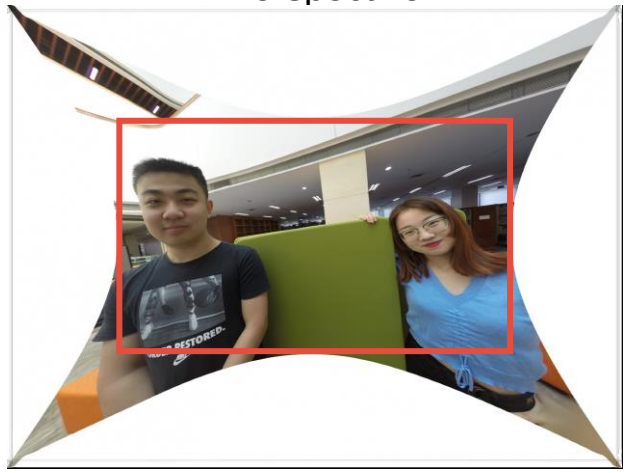
Perspective

Stereographic

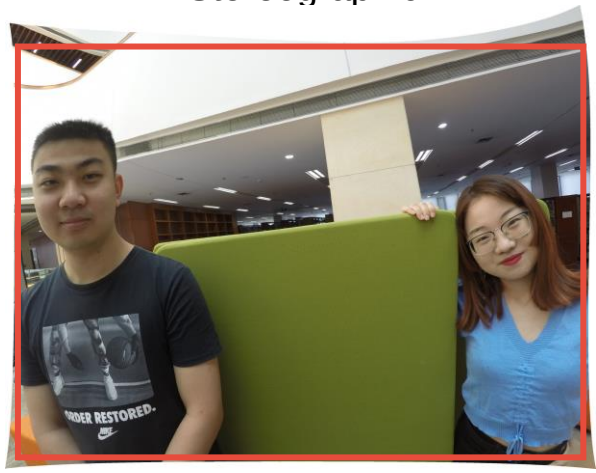


Visual Features

Carroll's



Shih's



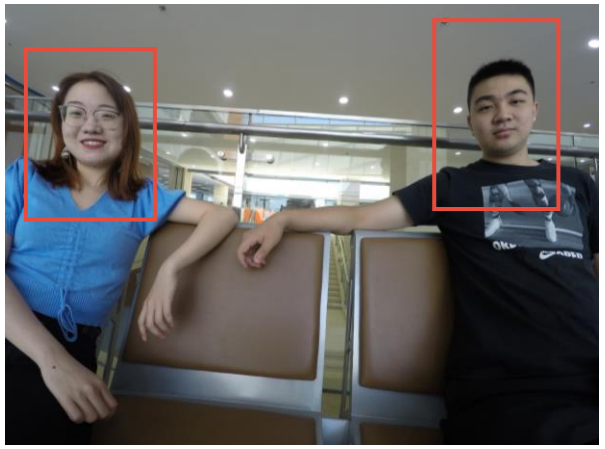
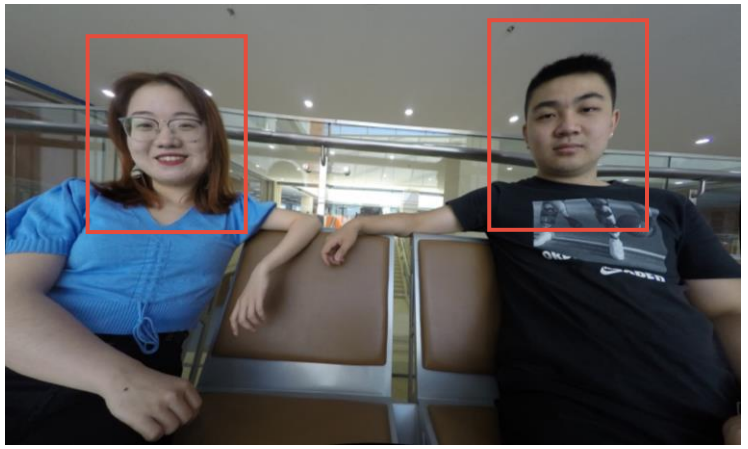
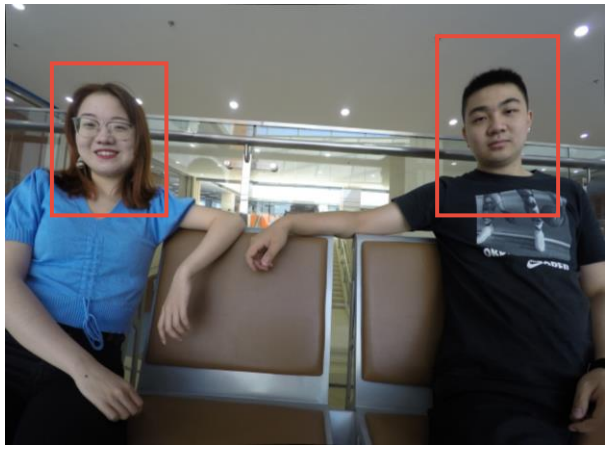
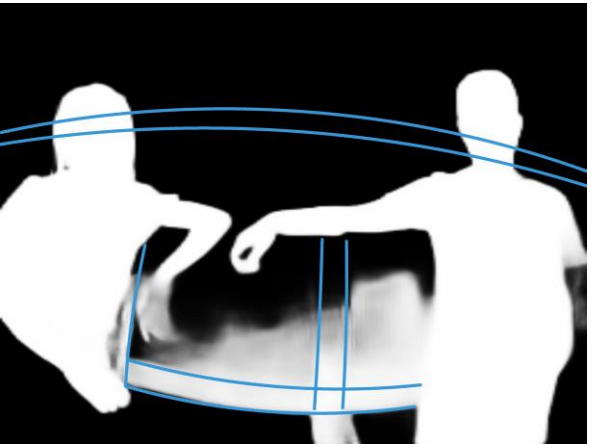
Ours

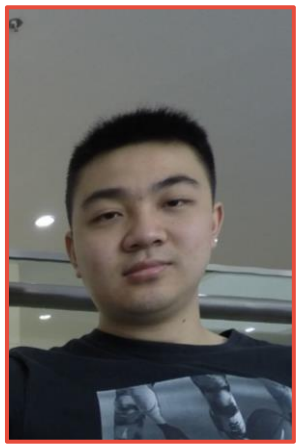
149°FoV
GoPro

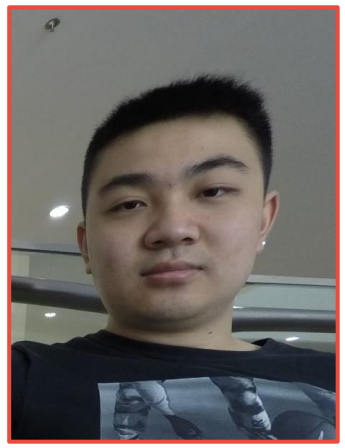
Results

Input Carroll's Shih's Ours

Results





Input | Carroll's | Shih's | Ours

149°FoV
GoPro

Limitation: Inaccurate curved line detection

(a) Input

(b) Ours

Limitation: Trade-off between shape and line preservations

(a) Input

(b) Ours

(c) Ours w/o line-preserving term

Summary

- Introduce a content-aware algorithm for wide-angle image.
- Based on Least-Squares Conformal Mapping (LSCM), polar mesh optimization and deep content analysis.
- Fully automatic and suited for mobile platform.

Thanks