Möbius Transform for Mitigating Perspective Distortions in Representation Learning

ECCV 2024 MILANO

https://prakashchhipa.github.io/projects/mpd/

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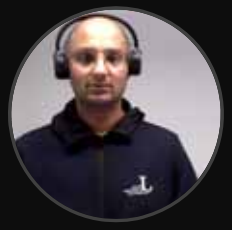

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Perspective Distortion

alters object appearance by changing shape, size, orientation, and spatial relationships in non-linear ways.

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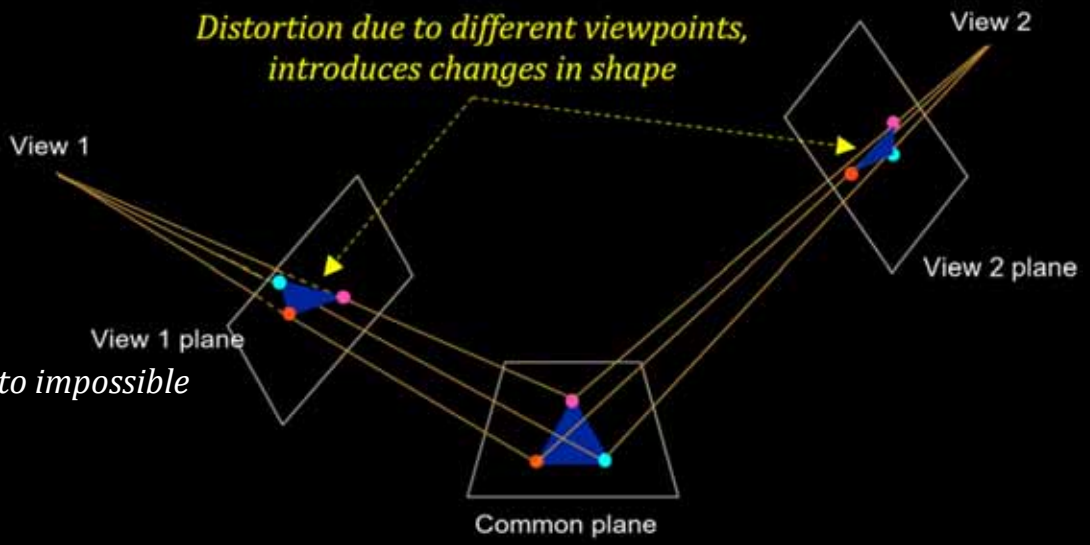
Challenges

- Distribution shifts
  - *Distortion disrupts model robustness*
- Distortion corrections is inefficient
  - *Vision tasks becomes multi-step and compute intensive.*
- Camera parameters are unknown
  - *Synthesizing distortions by estimating parameters is next to impossible*
- Affine Transformation
  - *They are either linear or non-conformal*



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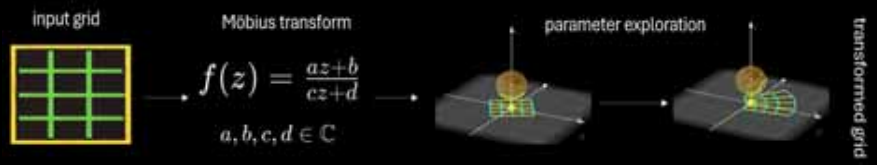
Hypothesis

Non-linear and conformal nature of transforms can synthesize perspective distortion without knowing camera parameters.

Möbius transforms – Complex theory



MPD Method

Synthetically introduces perspective distortion in learning

Algorithm 1 MPD Method for Perspective Distortion

Input: Input image I, Möbius parameters c, fixed-value complex numbers of (a, b, d)

Output: Transformed image I_{MPD} representing perspective distortion

1: Initialize $c \leftarrow c_{real} + i \cdot c_{imag}$ ▷ Set complex parameter c
2: **for** each pixel coordinate (x, y) in I **do**
3: $z \leftarrow x + iy$ ▷ Map pixel coordinates to complex vector
4: $z_m \leftarrow \frac{(a \cdot z + b)}{(c \cdot z + d)}$ ▷ Apply Möbius transformation
5: $x_m + iy_m \leftarrow z_m$ ▷ Extract real and imaginary parts as transformed coordinates
6: $(x_d, y_d) \leftarrow \text{round}(x_m), \text{round}(y_m)$ ▷ Discretize to nearest pixel values
7: $I_{MPD}(x_d, y_d) \leftarrow I(x, y)$ ▷ Assign pixel value to transformed coordinates
8: **end for**
9: $I_{MPD} \leftarrow \text{Interpolate}(I_{MPD})$ ▷ Interpolate for smoother transformed output
10: **return** I_{MPD}

11:

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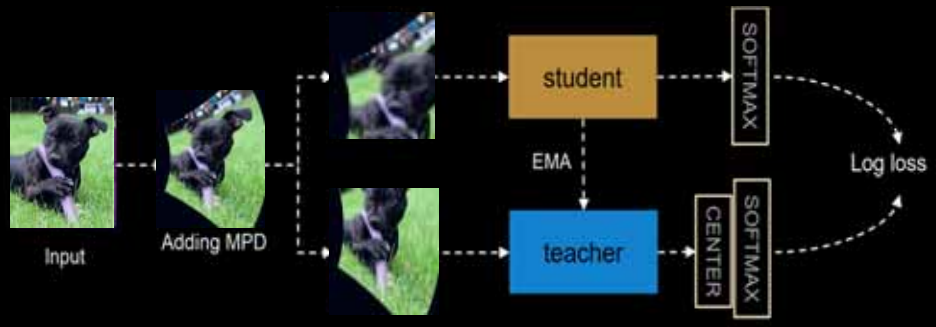
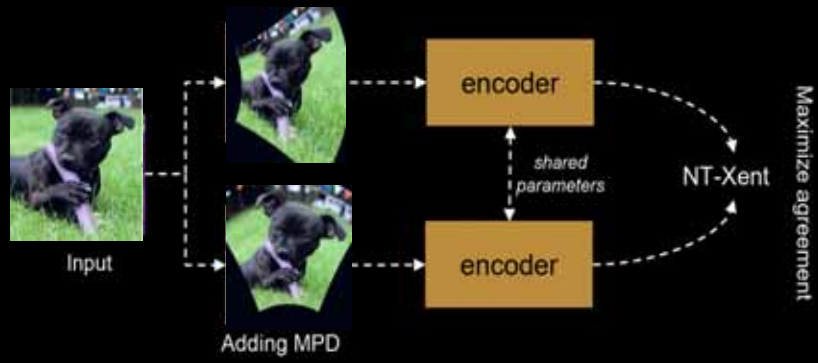
⊕ Integrating MPD *Supervised and self-supervised approaches*

DINO + MPD



SimCLR + MPD



Pretraining performed on ImageNet

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⊕ Integrating MPD

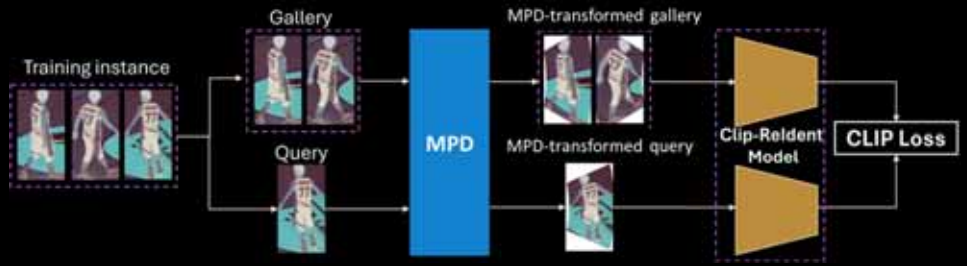
Real-world vision application

Crowd counting (MPD-AutoCrowd)

Object detection (MPD-OD)

Fisheve view recognition

Person Re-Identification + MPD



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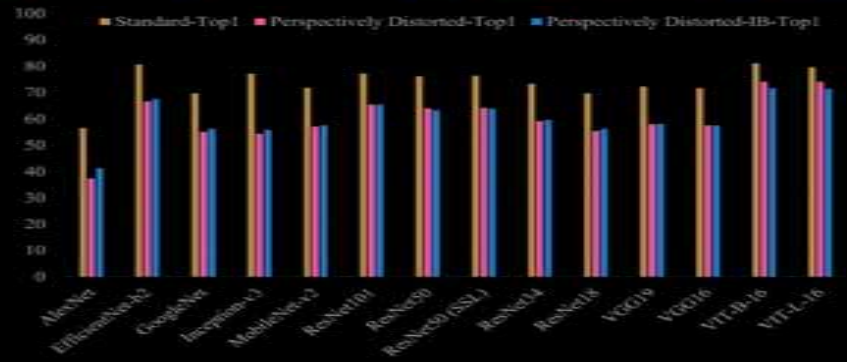
ImageNet-PD new dedicated benchmark



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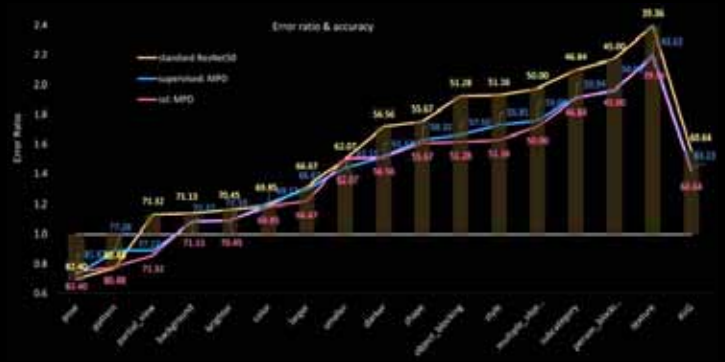
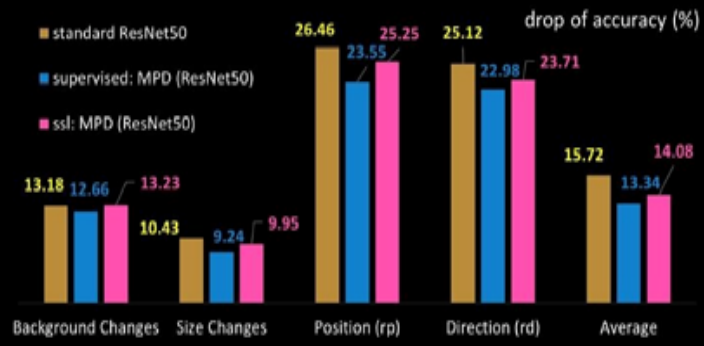
Results *Public benchmarks*

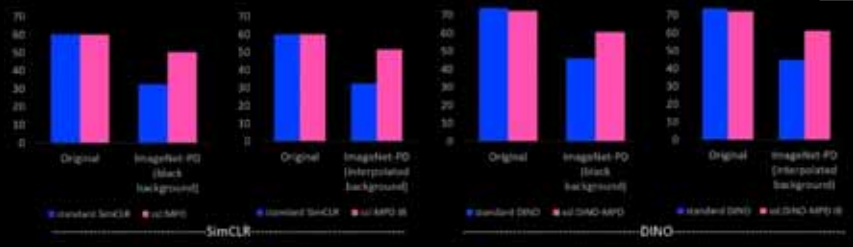
ImageNet-X (error, lower is better)



ImageNet-E (error, lower is better)



Performance on ImageNet-PD (accuracy, higher is better)



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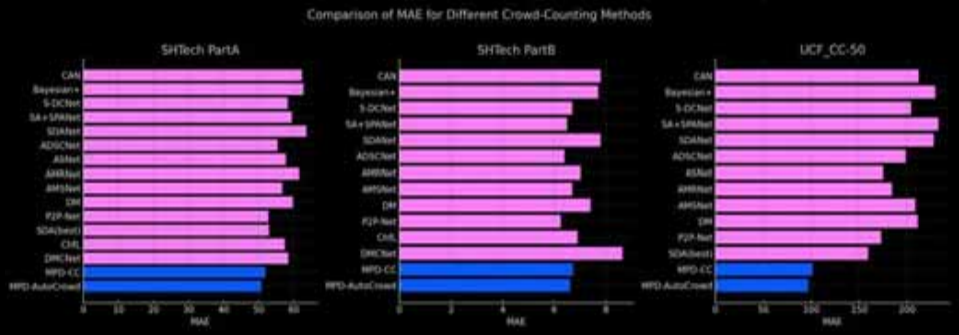
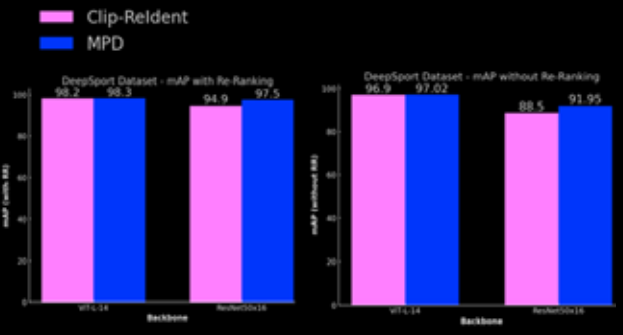
Results

Real-world vision application

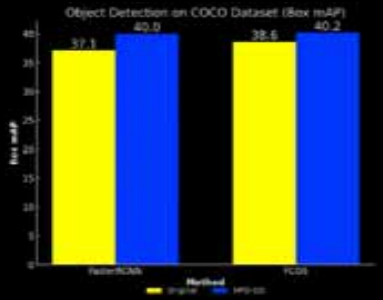
Crowd counting (MAE, lower is better, three public datasets)



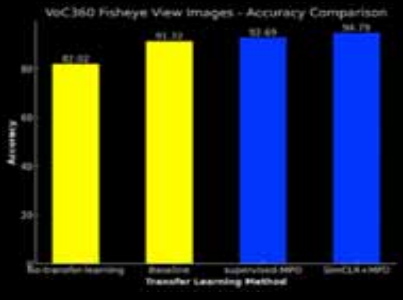
Person Re-Identification (mAP, higher is better)



Object detection (mAP, higher is better, COCO dataset)



Fisheye view recognition (accuracy, VOC360 dataset)



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Contribution + Achievements

- ✓ Mathematically modeled perspective distortion without camera parameters
  - ✓ *Mitigating perspective distortion (MPD)*
- ✓ Developed dedicated perspective distorted dataset *ImageNet-PD*
  - ✓ *8 subsets*
- ✓ Seamless integration with computer vision tasks and applications
  - ✓ *MPD- AutoCrowd, MPD-Object Detection, outperformed multiple benchmarks*
- ✓ Generalizability, transferability, and adaptability across learning paradigms, architectures, and applications.
  - ✓ *Supervised and self-supervised learning, CNNs and ViTs*

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Thank you