Annual Conference of KIPS 2025

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Complementary Learning Approaches in Image Processing

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Personal Background

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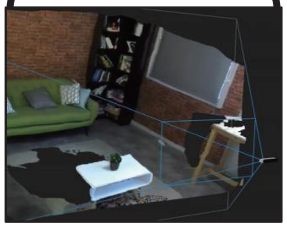
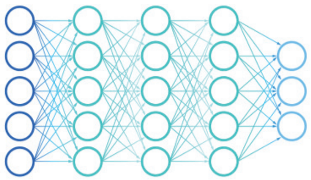
- **Education**
  - Ph.D., Korea University (Mar. 2015 – Feb. 2022)
    - Advisor: Prof. Sung-Jea Ko
  - B.S., in Korea University (Mar. 2011.03 – Feb. 2015)
- **Work Experience**
  - Assistant Professor, Konkuk University (Mar. 2025 – Present)
  - Staff Engineer & AI Specialist, AR Lab, Samsung Research (Mar. 2022 – Feb. 2025)

2015 Graduate Student KOREA UNIVERSITY **2022** Staff Engineer SAMSUNG Research **2025** Assistant Prof. KONKUK UNIVERSITY

Scene Understanding & Artificial Intelligence (AI)

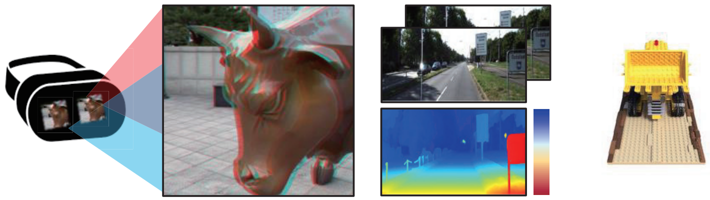


Depth / Point Cloud



2D&3D CNN / RNN / GAN

AI-based Technologies for AR/VR



Stereoscopic Contents Creation / Depth Estimation / 3D Modeling

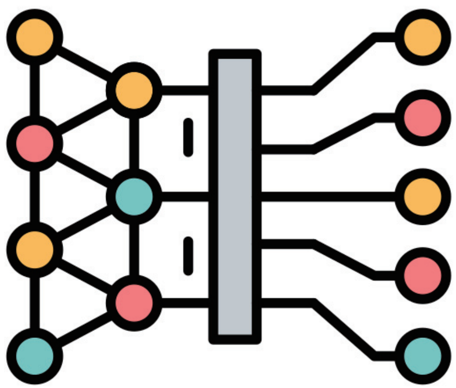
- **Efficient AI**
- **Immersive AI**
- **Medical AI**

Problem Statement: The Dilemma of Modern AI Models

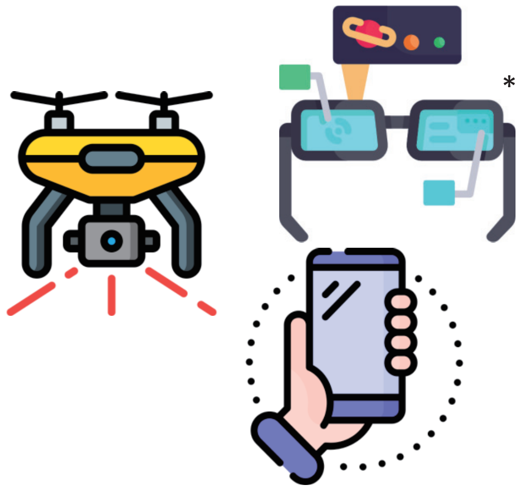
How can we achieve high performance on limited resources?

Modern AI Model

Accuracy ⇧
Cost ⇧
Energy ⇧
Memory ⇧



Edge Devices

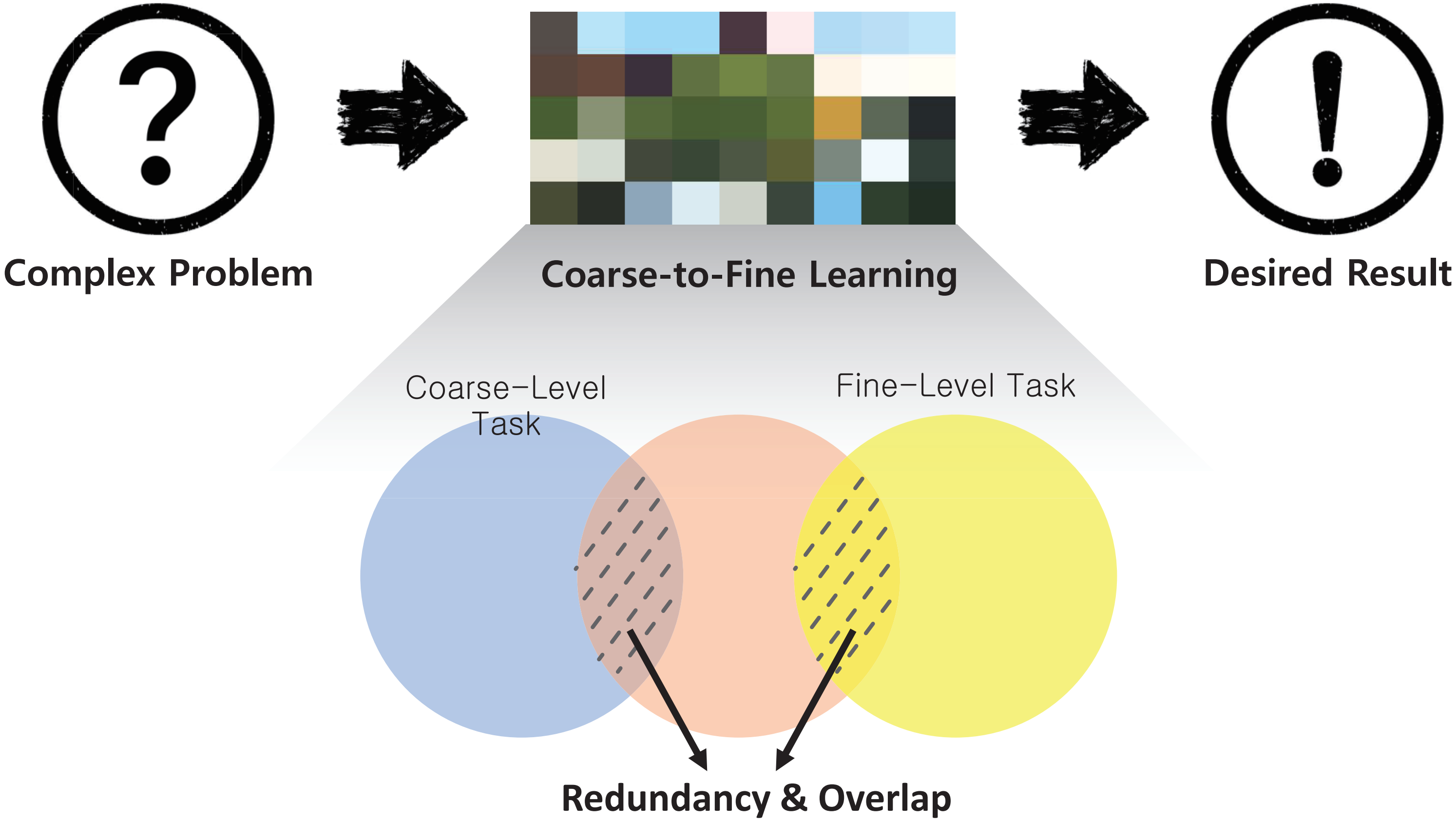


⇧ Accuracy
⇩ Cost
⇩ Energy
⇩ Memory

A fundamental rethinking of how we solve the problem is needed!

*https://www.flaticon.com/

- **Conventional Complementary Learning (e.g., Coarse-to-Fine)**



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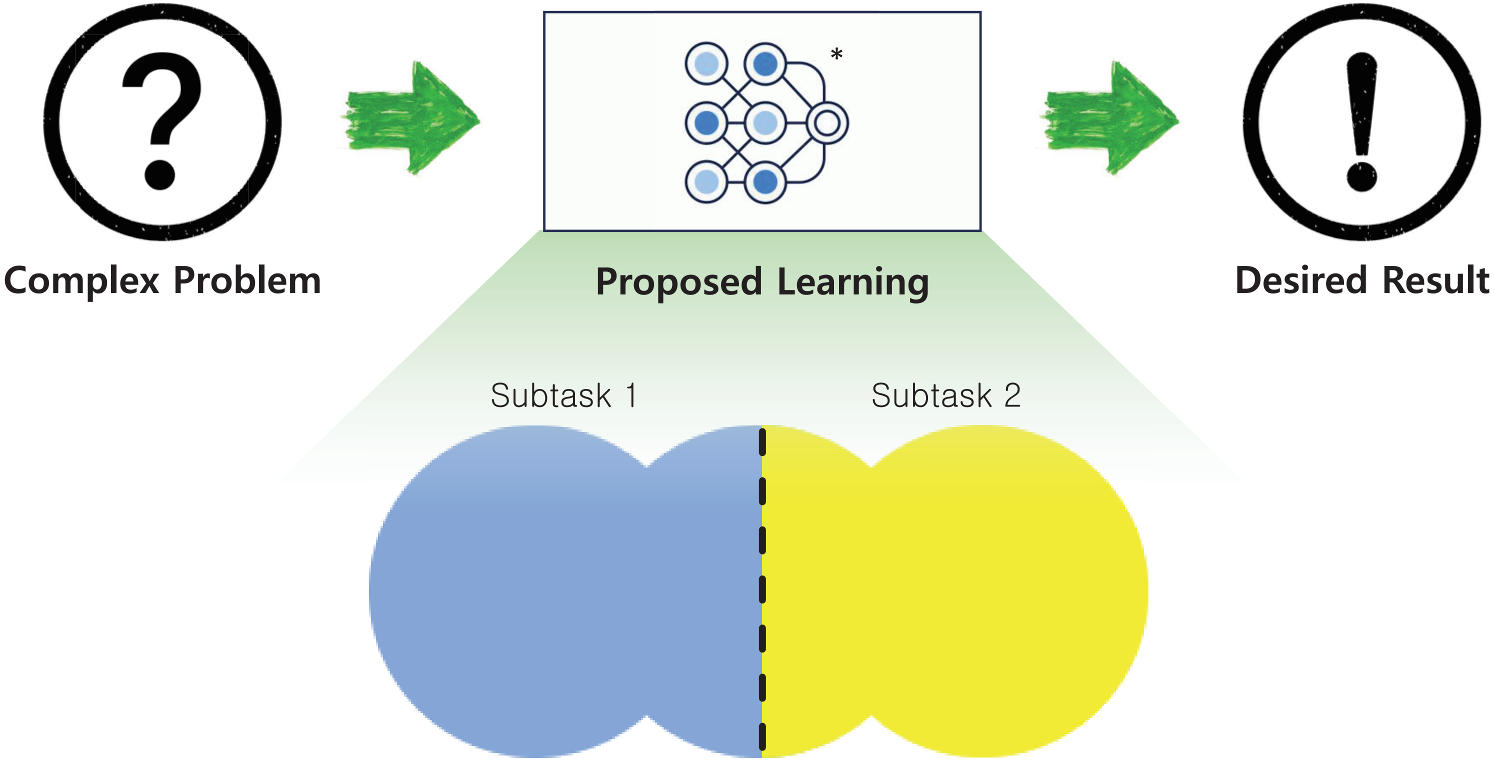
- **Complementary Learning across <u>Disjoint Subspaces</u>**



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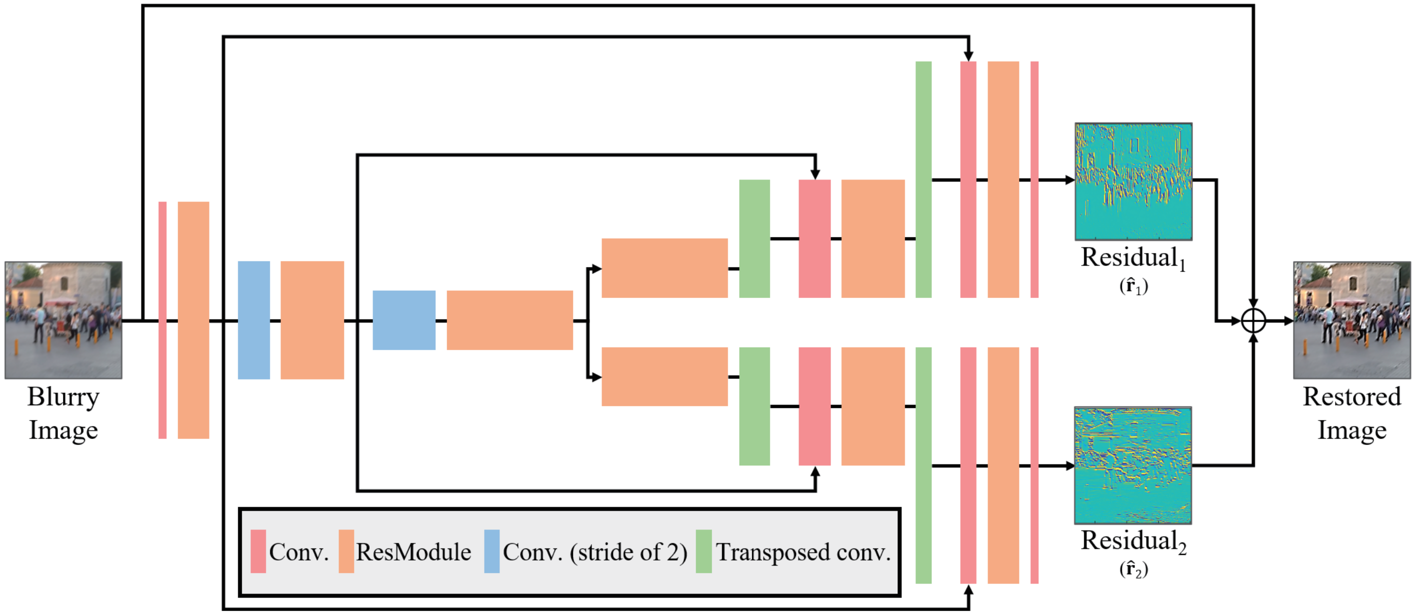
Maximal Efficiency through Disjoint Complementary Learning!

Case Study 1: XYDeblur*

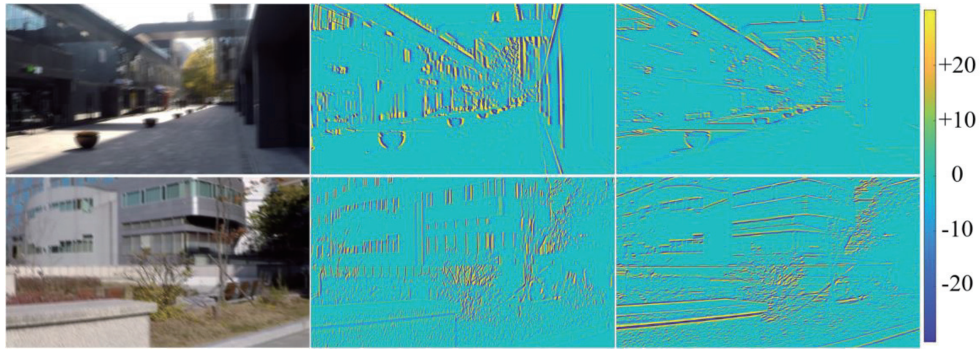
- **Problem:** Motion blur is highly complex, often resulting from a mixture of motions in multiple directions
- **XYDeblur's "Disjoint Subspace" :** Decompose the complex motion blur into two disjoint subspaces, the most fundamental **Horizontal** and **Vertical** motion blur components
- **One-Encoder, Two-Decoder Architecture**



*XYDeblur: Divide and Conquer for Single Image Deblurring, CVPR 2022

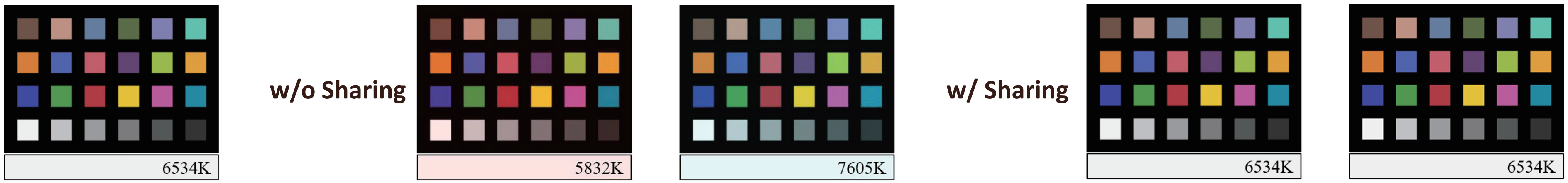
Case Study 1: XYDeblur*

- **Effectiveness of the one-encoder-two-decoder architecture**
  - Learn complementary sub-solutions that are visually orthogonal in the spatial domain
  - Achieve superior deblurring performance



Blurry image $\hat{\mathbf{r}}_1$ $\hat{\mathbf{r}}_2$

- **Regularization:** Rotated Kernel Sharing
  - **Suppresses Unwanted Degrees of Freedom:** Prevents learning irrelevant artifacts by enforcing rotational symmetry
  - Significantly reduces the parameter, limiting model complexity



Input image | Input image + $\hat{\mathbf{r}}_1$ | Input image + $\hat{\mathbf{r}}_2$ | Input image + $\hat{\mathbf{r}}_1$ | Input image + $\hat{\mathbf{r}}_2$

*XYDeblur: Divide and Conquer for Single Image Deblurring, CVPR 2022

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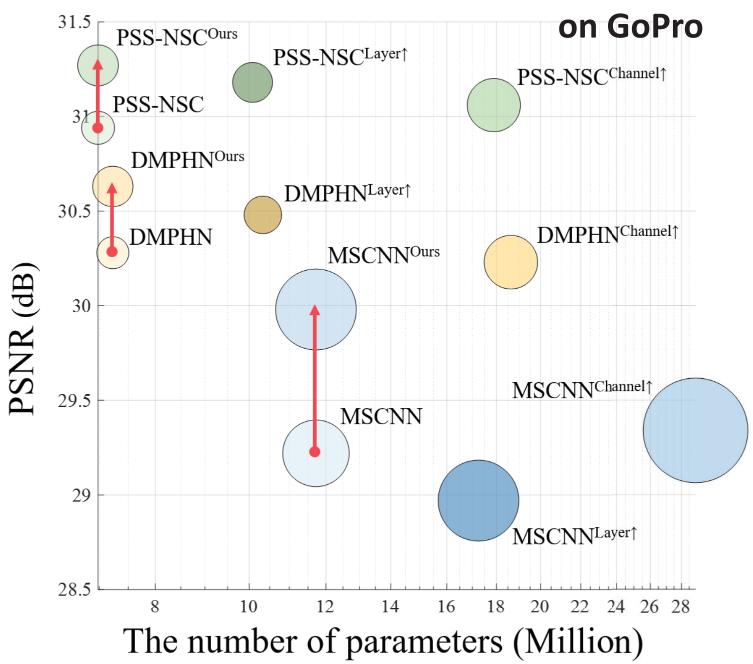
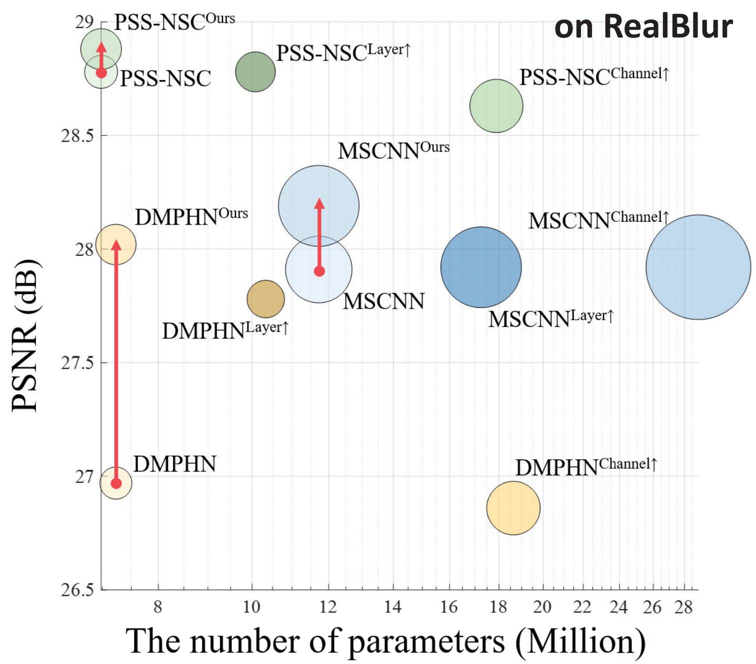
- **Results**

✓ **Effectiveness of the proposed approach on the state-of-the-art network**

(The radius of the circle indicates GMACs of the network.)

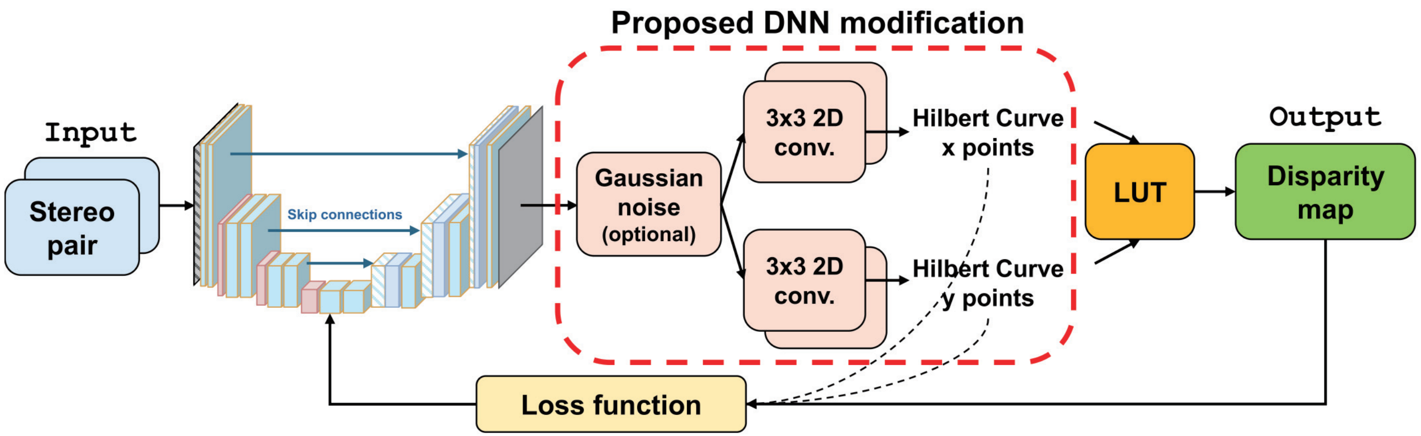




*XYDeblur: Divide and Conquer for Single Image Deblurring, CVPR 2022

Case Study 2: Hilbert Curve for High-Precision Depth*

- **Problem:** On low-power devices such as smartphones, there are inherent limitations in representing depth information that requires **10-bit or higher precision**
- **Contrast with XYDeblur:** While XYDeblur divides the task into separate decoders for blur removal, this work **divides the data representation itself into disjoint subspaces**
- **Hilbert Curve "Disjoint Subspace" :** Reinterpret a <u>high-precision 1D depth value</u> as <u>2D coordinates (X, Y) in low precision</u>, and represent it in disjoint subspaces

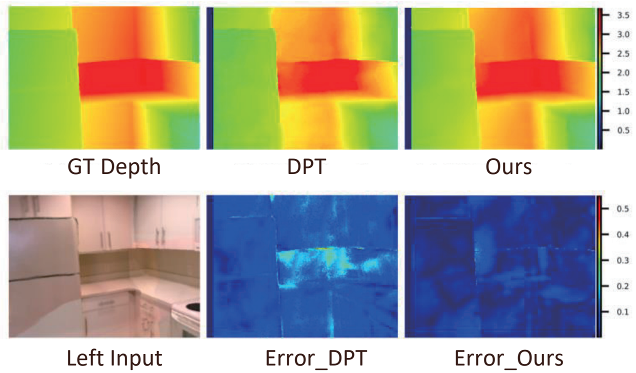


*Predicting High-precision Depth on Low-Precision Devices Using 2D Hilbert Curves, ICML 2025

Case Study 2: Hilbert Curve for High-Precision Depth*

- **Inference Workflow**
  - On-Device DSP: The model predicts (x, y) coordinates using **low-precision (8-bit)** computation.
  - On-Device CPU: A simple **lookup table (LUT, 256x256)** reconstructs the predicted (x, y) coordinates back into **high-precision (10–11-bit) depth values**.
- **Objective Performance**
  - Works consistently with both CNN and Transformer architectures
  - Achieves 16-/32-bit-level accuracy even with 8-bit quantization
- **Subjective Performance**
  - Produces visibly fewer errors and minimizes quantization artifacts

Precision	Abs Rel, %	EPE, px	D1, %	S_C	T, ms	P, mW·s/infr.
DispNet (CNN)						
FP32	1.01	0.29	1.81	0.858	-	-
FP16	1.50	0.37	1.80	0.855	19.54	19.52
W8A16	1.78	0.63	5.22	0.798	18.7	12.3
W8A8	2.02	0.69	5.34	0.585	10.5	7.1
Ours, W8A8	0.93	0.24	1.26	0.807	12.0	8.7
DPT (Transformer)						
FP32	0.75	0.21	0.95	0.889	-	-
FP16	1.14	0.27	0.97	0.884	54.1	110.5
W8A16	4.03	0.97	5.58	0.825	46.2	64.5
W8A8	4.16	1.03	5.76	0.520	26.7	28.3
Ours, W8A8	1.35	0.32	1.28	0.697	30.4	29.7



*Predicting High-precision Depth on Low-Precision Devices Using 2D Hilbert Curves, ICML 2025

Summary

	XYDeblur*	Hilbert Curve for High-Precision Depth**
Target of Decomposition	Disjoint ***Task*** Subspaces	Disjoint ***Data Representation*** Subspaces
Decomposition Method	Horizontal (X) / Vertical (Y) blur removal	1D depth → 2D (x, y) coordinates
Key Mechanism	Independent decoders + shared kernels	Independent output channels + LUT-based reconstruction
Result	Performance improvement with fewer parameters	High-precision results with low-power computation

Learning in disjoint subspaces offers a powerful way to balance efficiency and performance

*XYDeblur: Divide and Conquer for Single Image Deblurring, CVPR 2022
**Predicting High-precision Depth on Low-Precision Devices Using 2D Hilbert Curves, ICML 2025

Q & A

Thanks for listening

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