Computational Imaging Lab
Department of Electrical Engineering
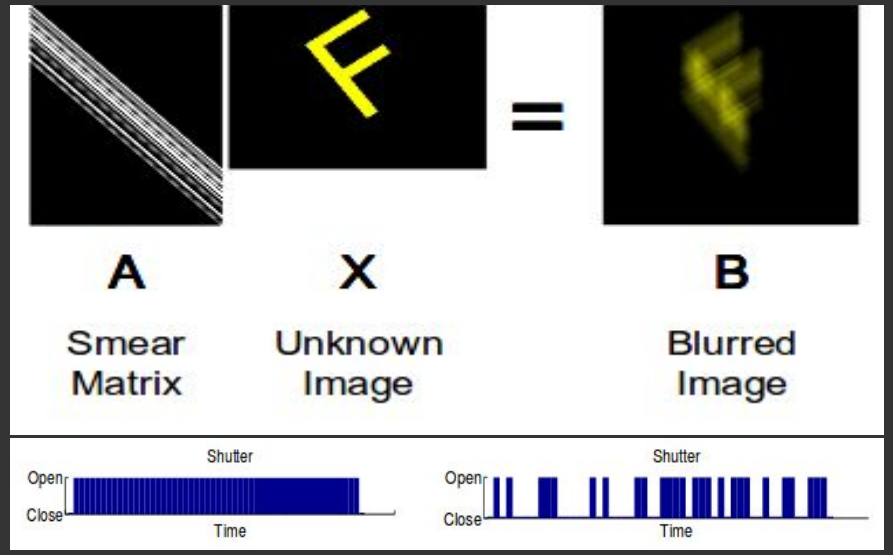Indian Institute of Technology Madras

Data Driven Coded Aperture Design for Depth Recovery

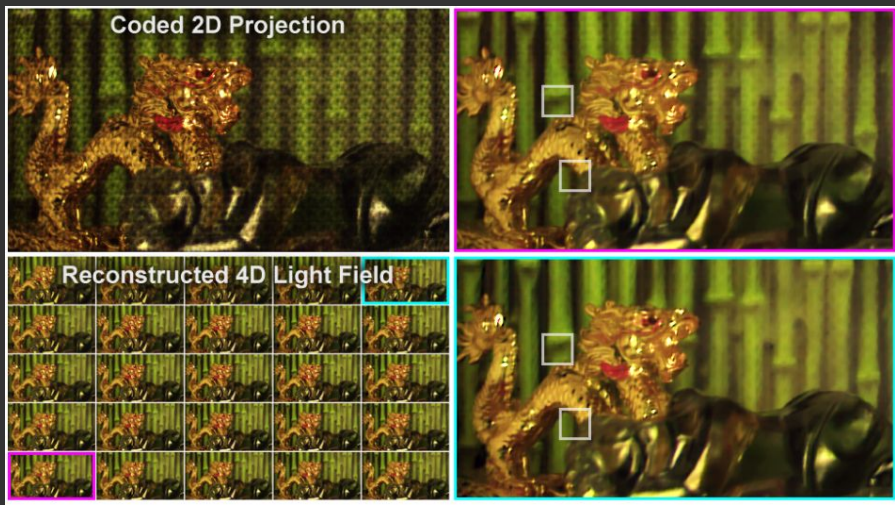Prasan Shedligeri, Sreyas Mohan, Kaushik Mitra

Computational Imaging lab, IIT Madras, India

Coded Imaging Techniques

Coded Aperture for Defocus deblurring (Levin et al '06)

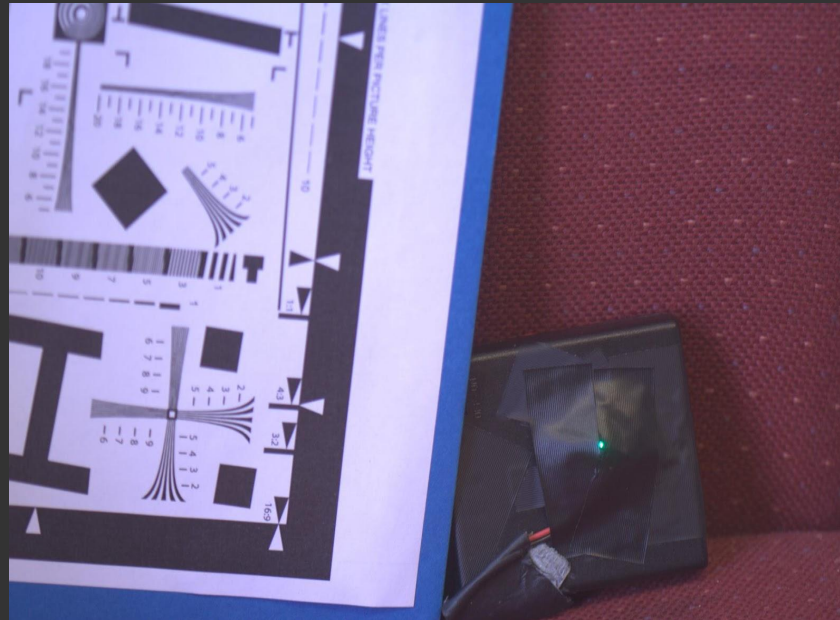Coded Exposure for motion deblurring (Raskar et al)

Compressive Light Field Recovery (Marwah et al '13)

Video from single coded image (Hitomi et al '11)
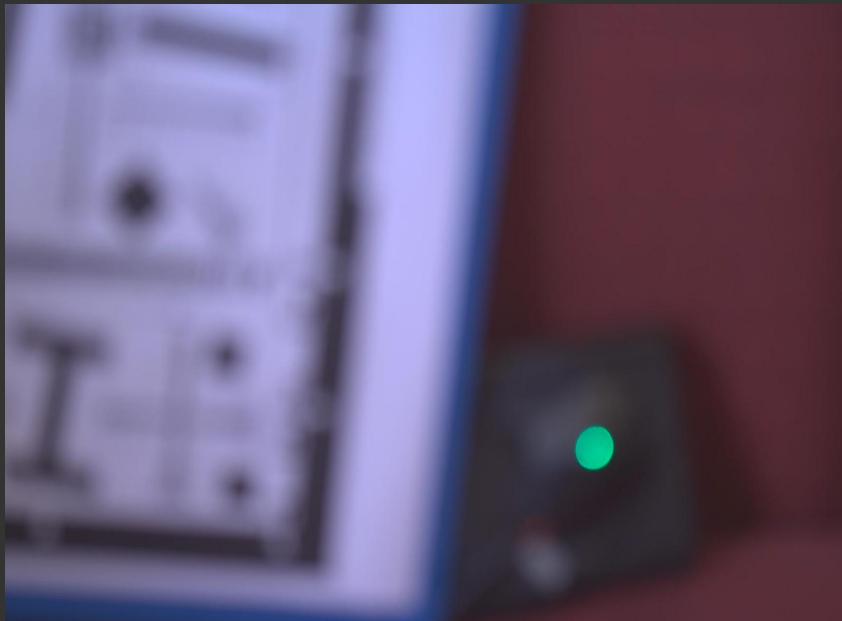
Coded aperture imaging – Overview

- Insert patterned occluder at the aperture
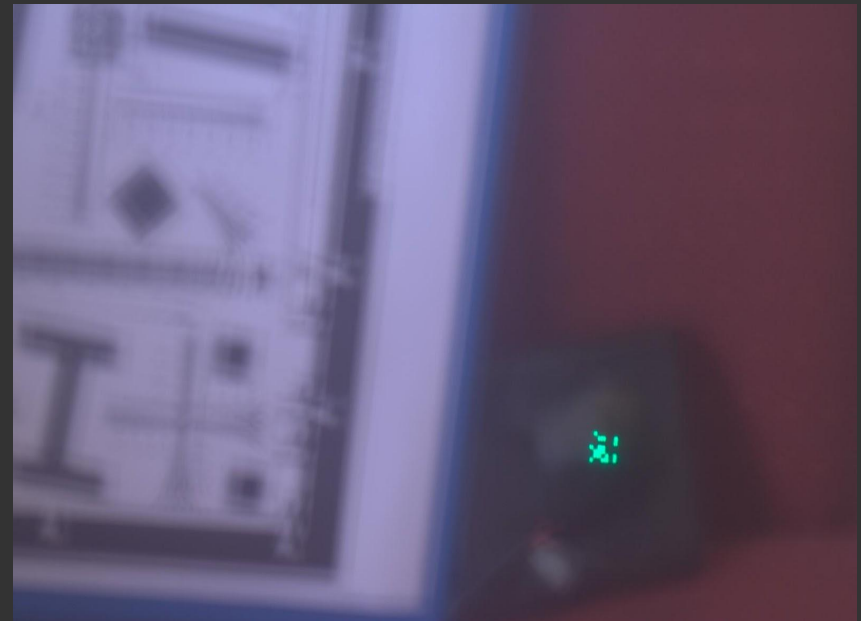
- Modifies the point spread function

All in focus photograph

Coded aperture imaging – Overview

- Insert patterned occluder at the aperture

- Modifies the point spread function
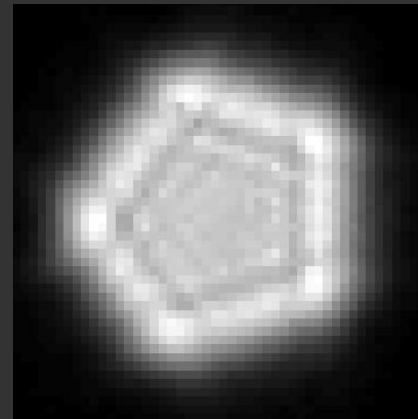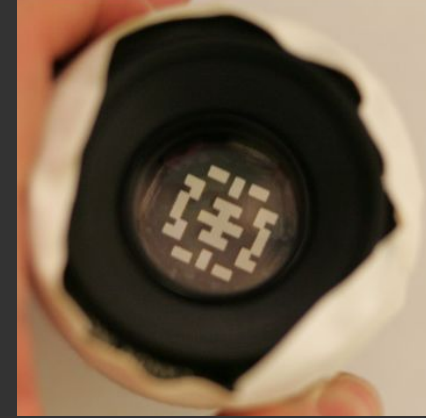
- Vary the PSF by varying the patterned occluder

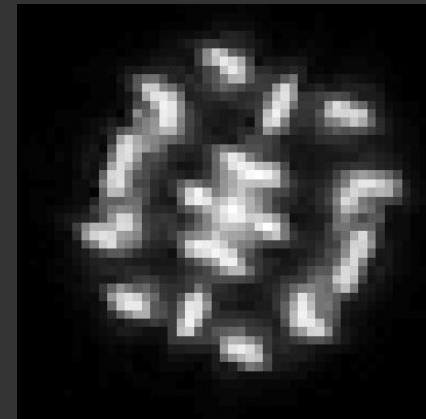
Defocused photograph with circular aperture

Defocused photograph with coded aperture

Image Credits: Ramesh Raskar, MIT Media Lab

CI lab, IIT Madras

Finding the optimal PSF – Previous works

- Levin et al (Siggraph 2006)

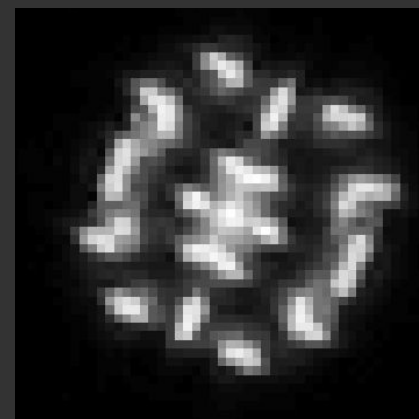 - Depth estimation and defocus

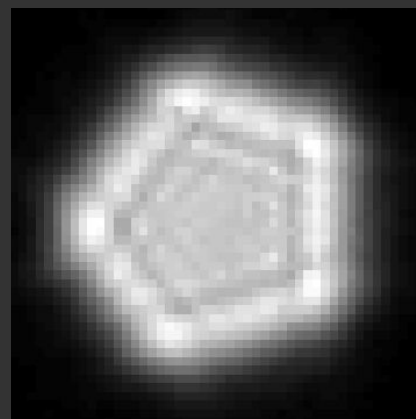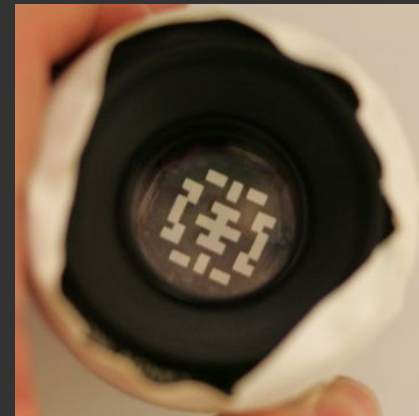   deblurring

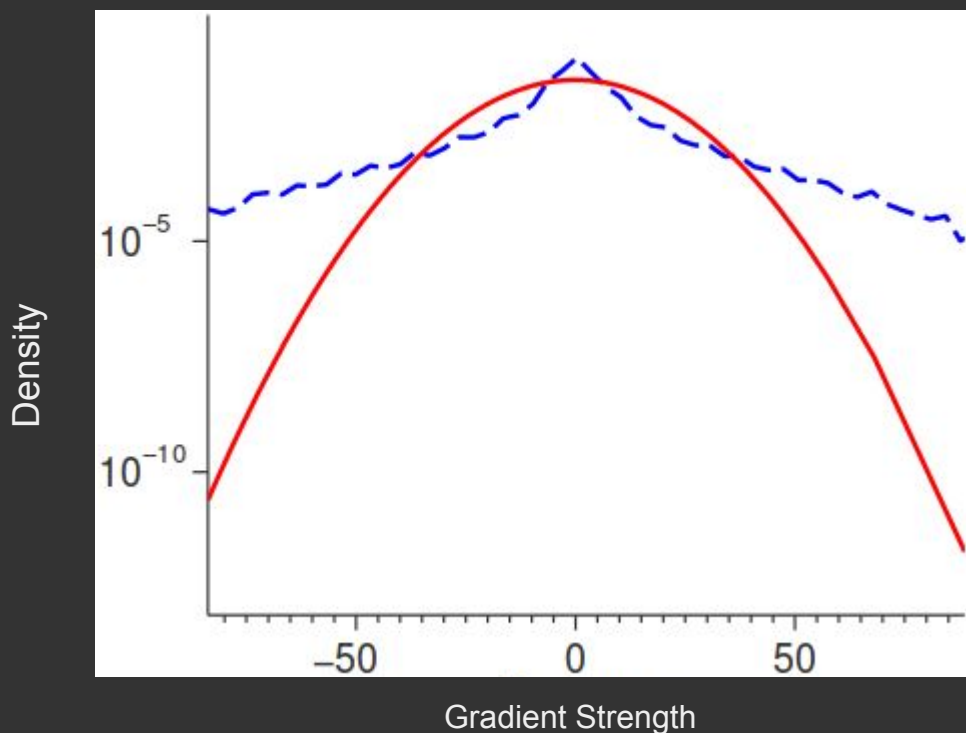Conventional Aperture   Coded Aperture

Finding the optimal PSF – Previous works

- Levin et al (Siggraph 2006)

  - Depth estimation and defocus

    deblurring

  - Use of sparse gradient prior

Conventional Aperture   Coded Aperture

Finding the optimal PSF – Previous works

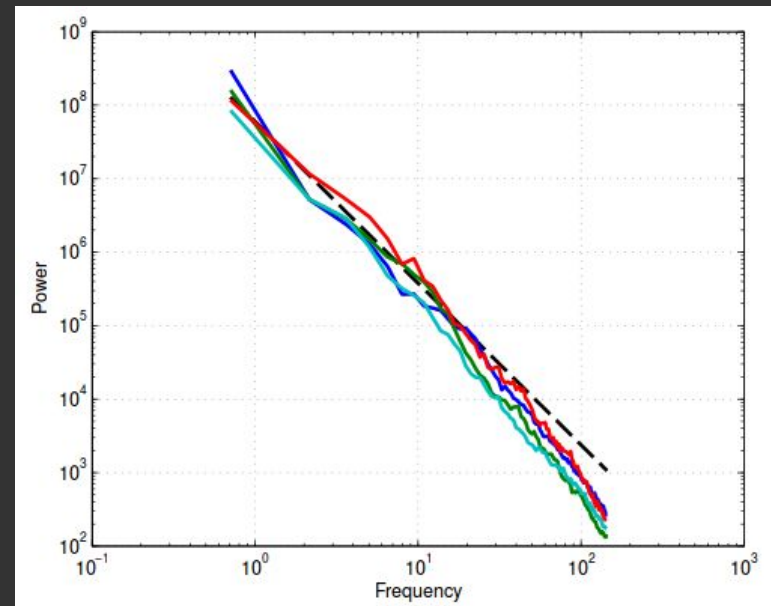- Zhou et al (IJCV 2010)

  - Two patterned occluders

Finding the optimal PSF – Previous works

- Zhou et al (IJCV 2010)

  - Two patterned occluders

  - Use of 1/f law image prior to find

    the optimal pattern

Natural Images

Power spectrum plot
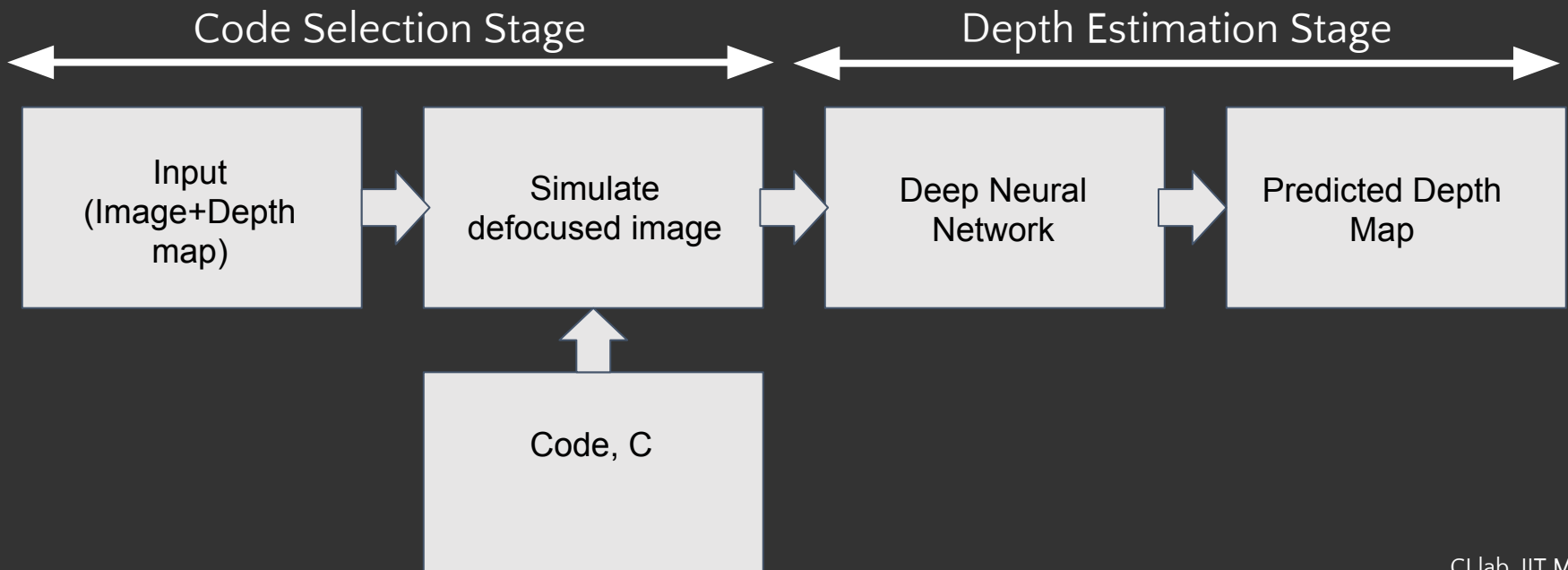
Data Driven Approach for Code Design

- Framework that does code design and inference

- No assumption of image prior

- Joint training of code design and inference framework

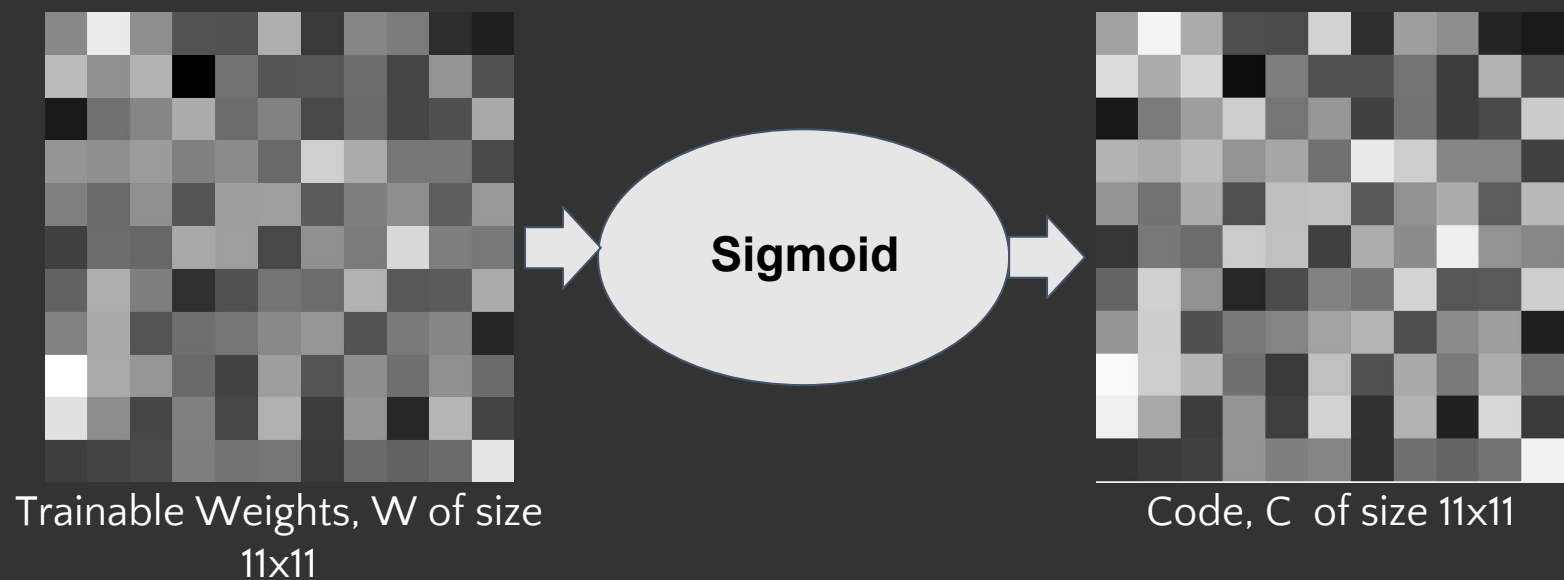- Similar work for Image demosaicing by Chakrabarti, NIPS '16

Learning Framework

- Two stages:
  - Code selection stage
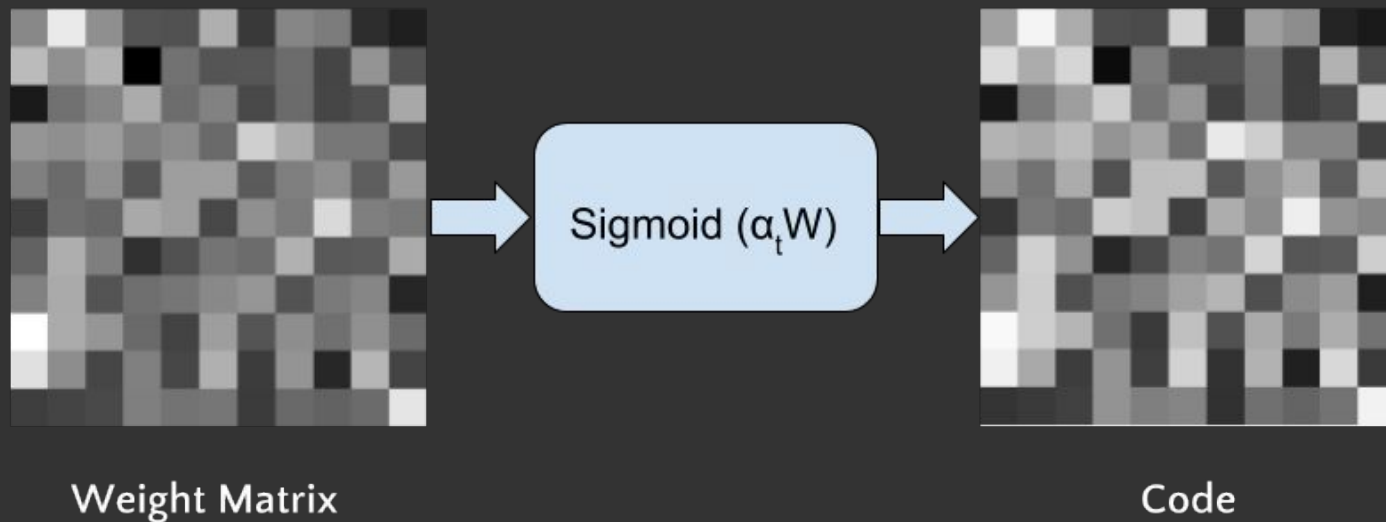 - Depth estimation stage

Code selection stage

- Trainable weights, W

- Code C, determines the pattern of the occluder

Trainable Weights, W of size 11x11

Sigmoid

Code, C of size 11x11

Code selection Stage

- Use of parameter α_t

- Helps in making sigmoid peakier

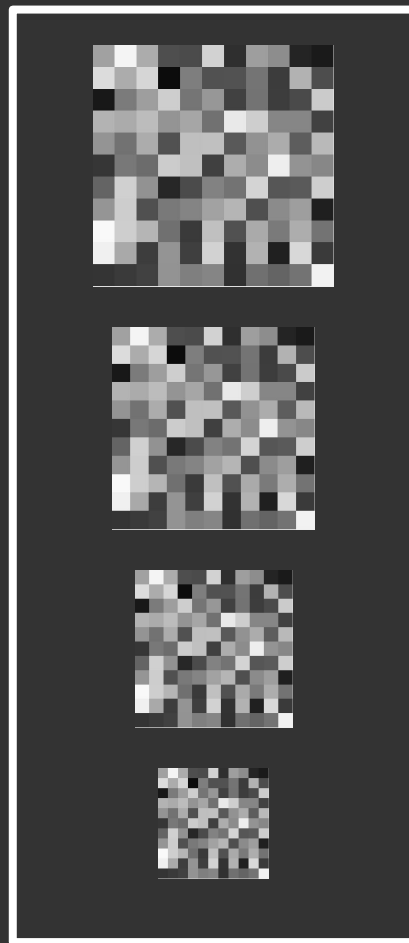Weight Matrix   Sigmoid (α_tW)   Code

Depth estimation stage

- Coded aperture simulation

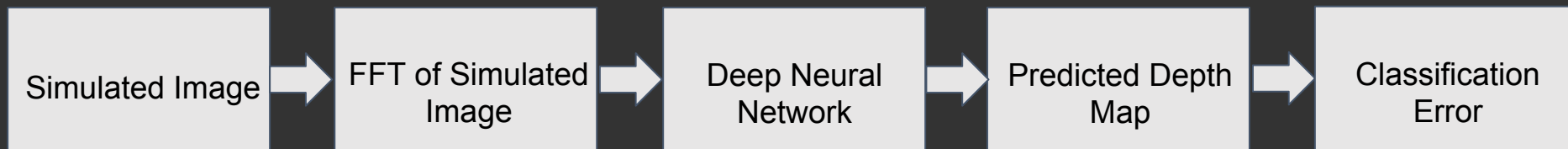 - Depth dependent blurring with modified PSF


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Depth estimation stage

- Coded aperture simulation

  - Depth dependent blurring with modified PSF

- Depth estimation of simulated image
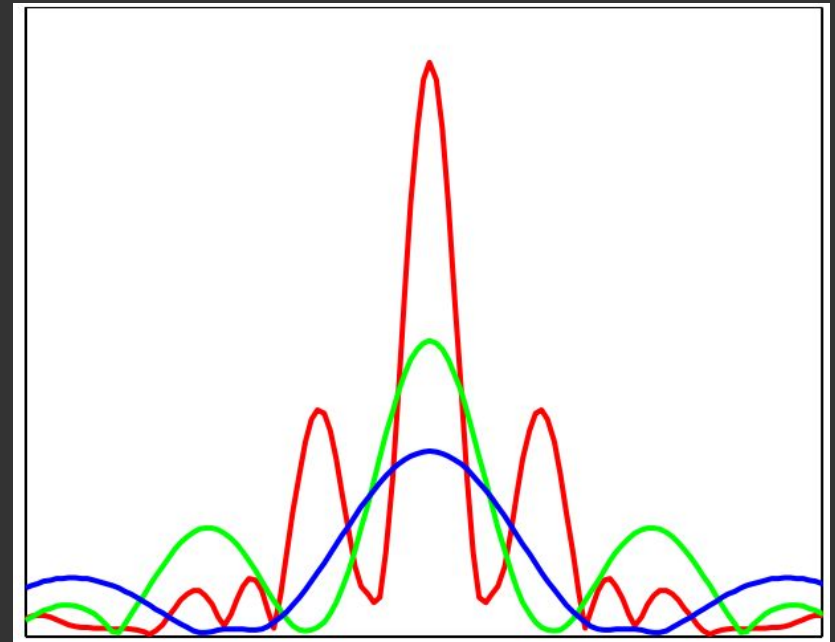
  - depth estimation in frequency domain

Simulated Image	→	FFT of Simulated Image	→	Deep Neural Network	→	Predicted Depth Map	→	Classification Error

Why FFT?

- Depth information from zeros in the Fourier domain

- Non-overlapping zeros – unambiguous depth estimation
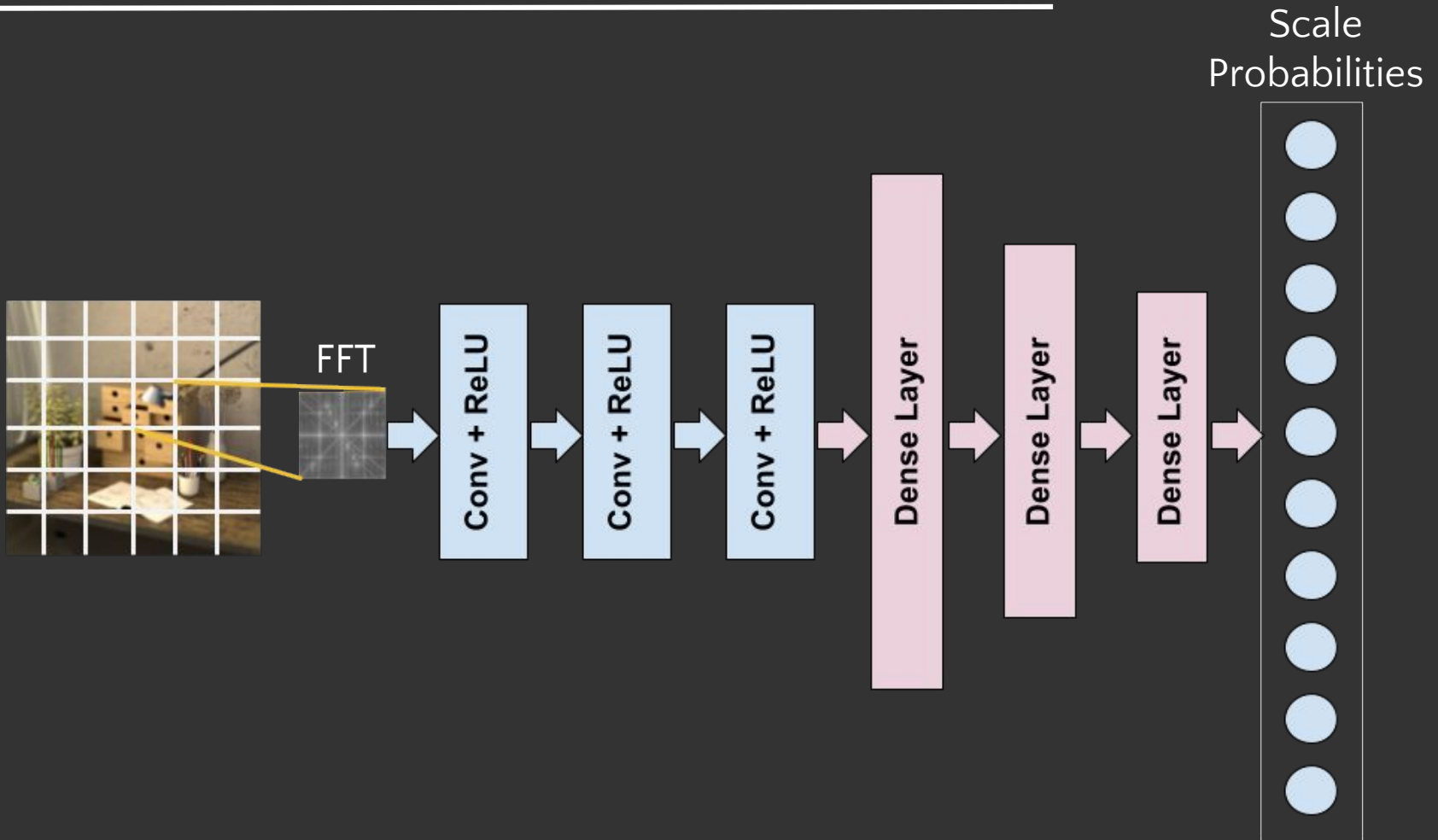
- Pattern of circles in the Fourier domain
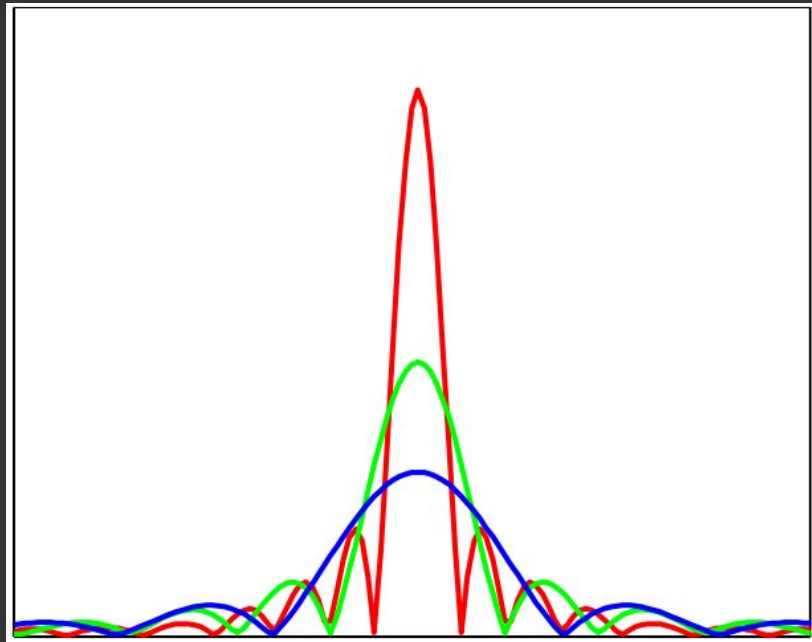
Fourier transform of PSF at different scales of
conventional aperture

Fourier transform of PSF at different scales of
coded aperture

Image Credits: Anat Levin

CI lab, IIT Madras

Depth Estimation Network

Scale Probabilities

FFT

Conv + ReLU

Conv + ReLU

Conv + ReLU

Dense Layer

Dense Layer

Dense Layer

Training

- Dataset: NYU depth dataset V2

- Use the ground truth depth to get blur kernel size at each pixel

- Simulate defocus blur with the modified PSF

- Estimate the blur size using depth prediction network

- Train the neural network with the gradients from the loss function
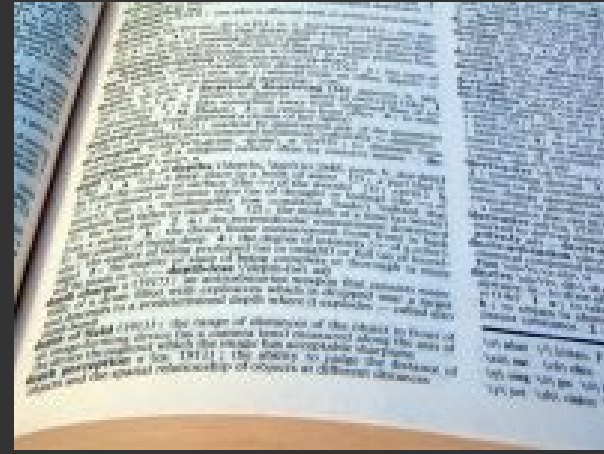
Comparison of Code design metric

- Images blurred at different levels have different distribution

- Higher KL divergence – better depth discrimination
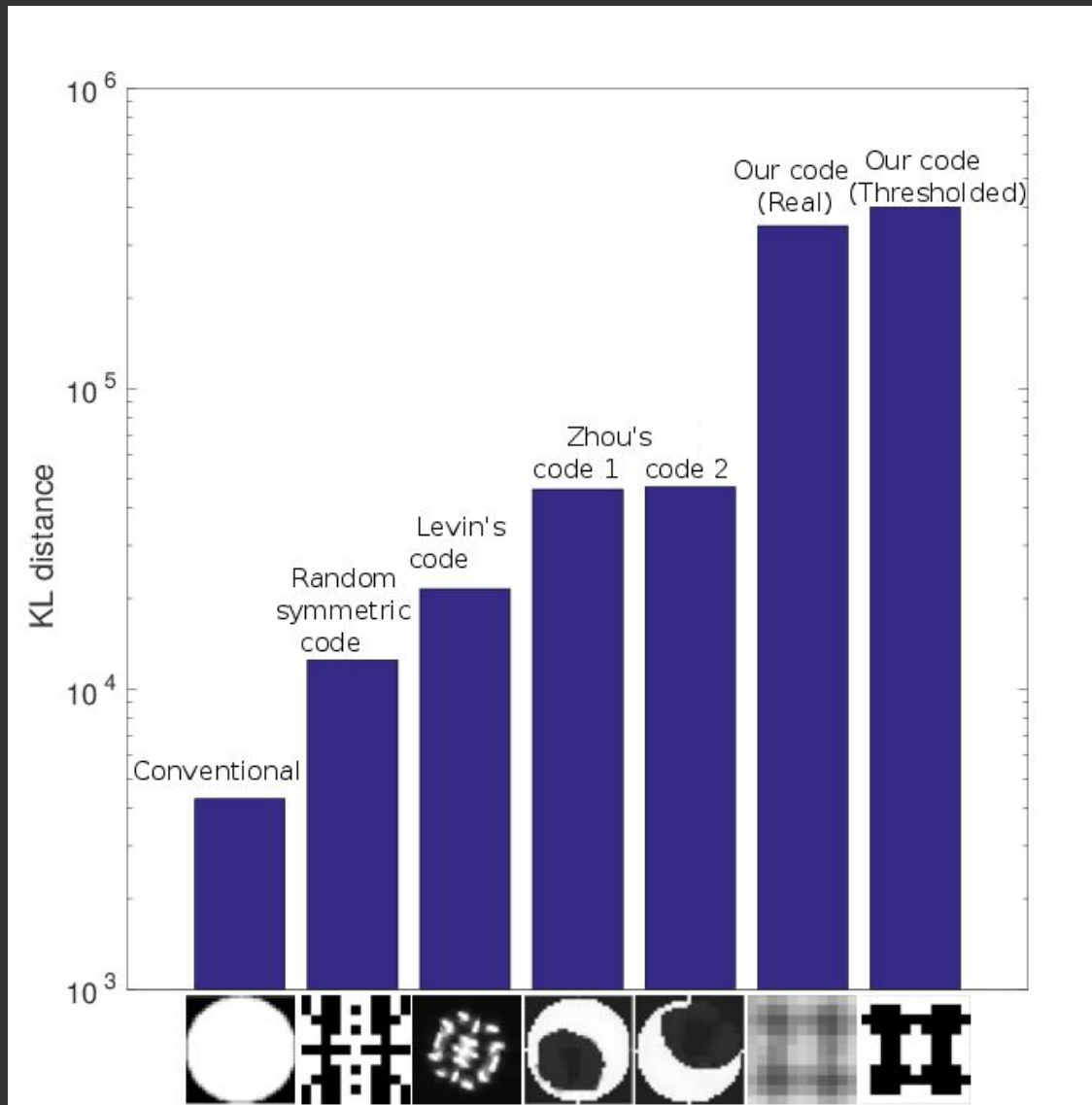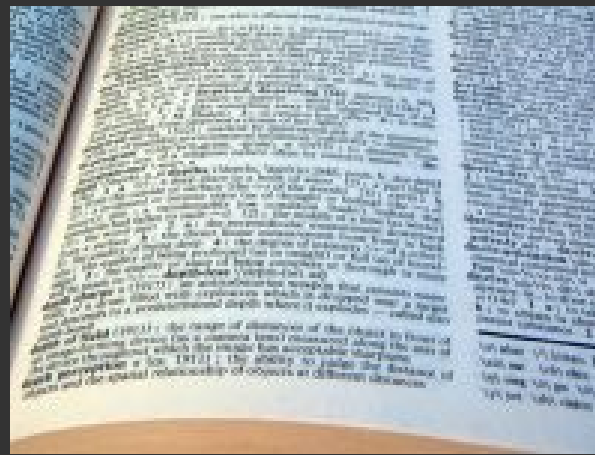
Depth estimation

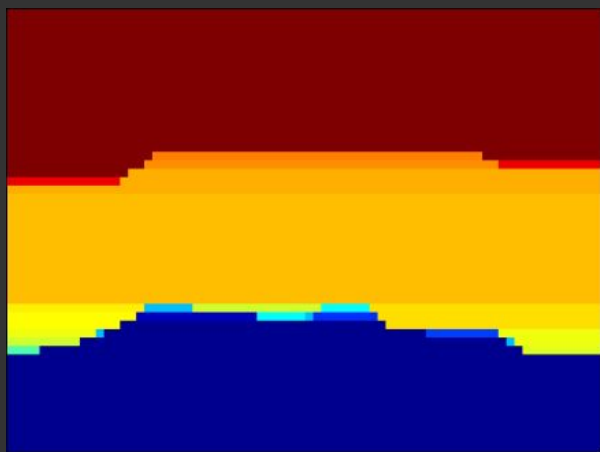GT Depth Map

RGB Image

Depth estimation

GT Depth Map

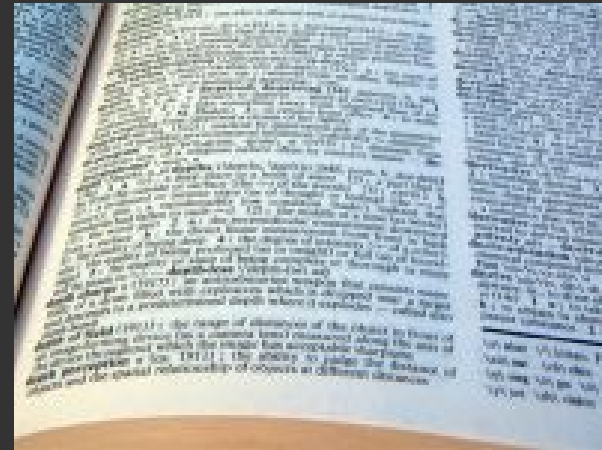RGB Image

Levin's code with
Wiener Deconvolution

Our code with Wiener
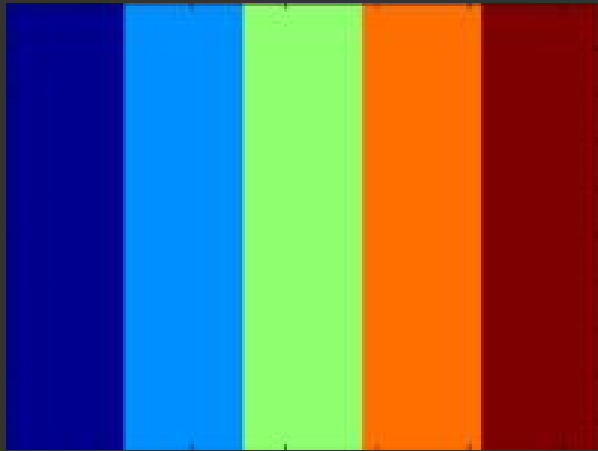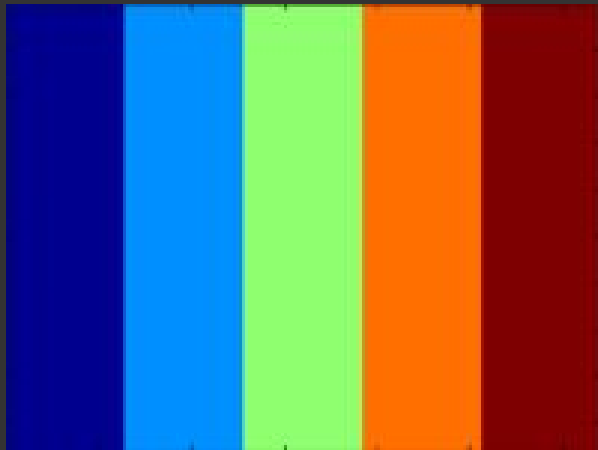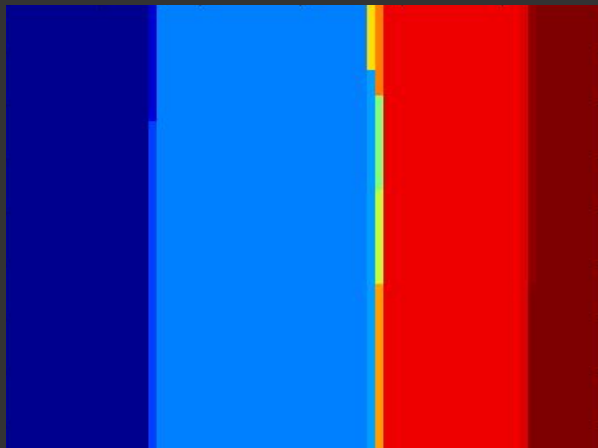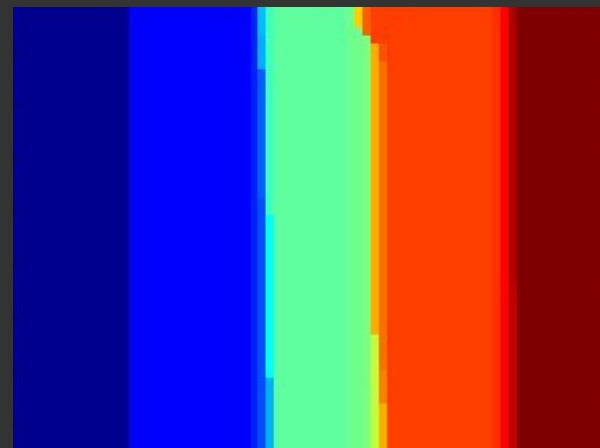Deconvolution

Depth estimation

GT Depth Map

RGB Image

Proposed Approach

Depth estimation

GT Depth Map

RGB Image

Depth estimation

GT Depth Map

RGB Image

Levin's code with
Wiener Deconvolution

Our code with Wiener
Deconvolution
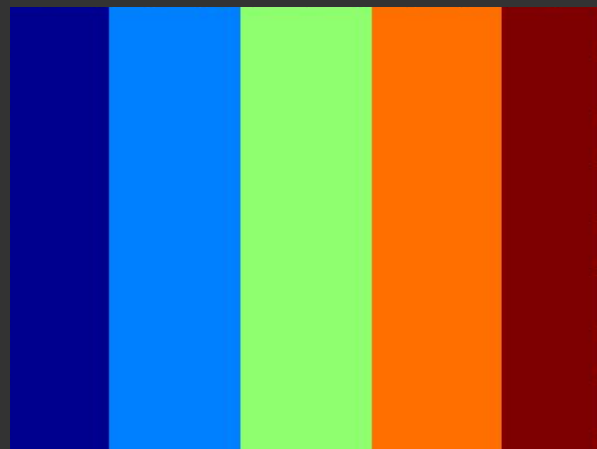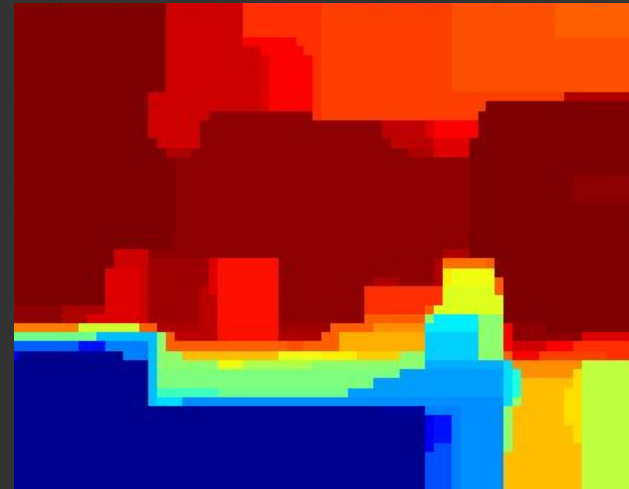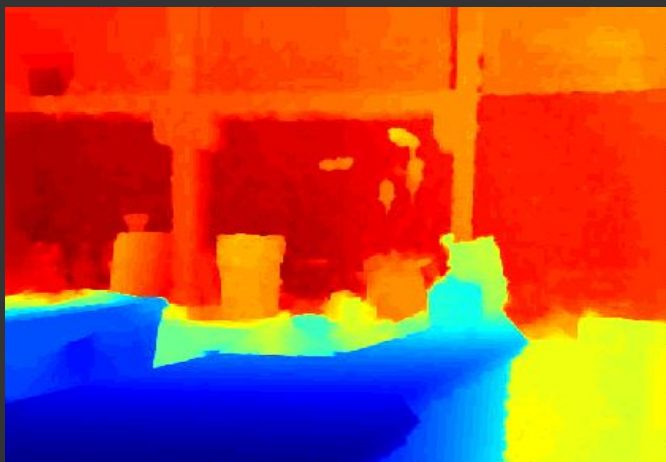
CI lab, IIT Madras

Depth estimation

GT Depth Map

RGB Image

Proposed Approach
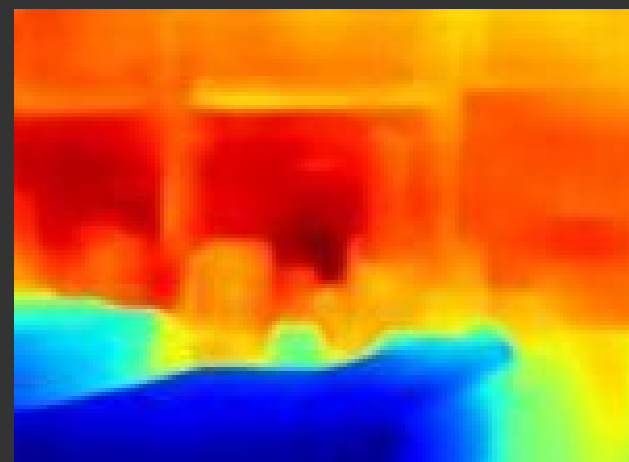
Monocular Depth estimation

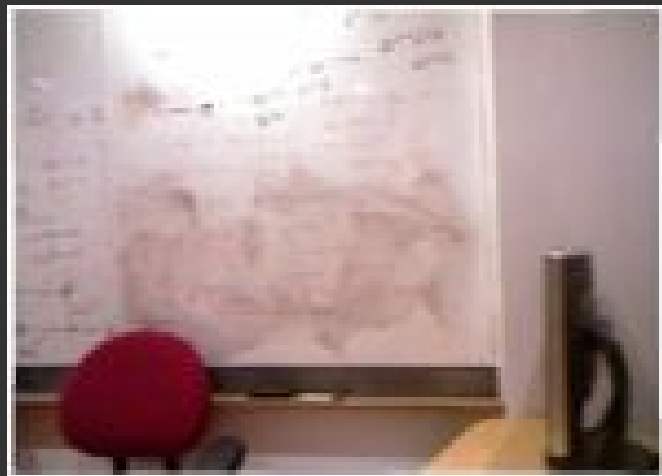RGB Image

Our approach

Ground Truth Depth

Single Image depth estimation by Eigen et al 2015

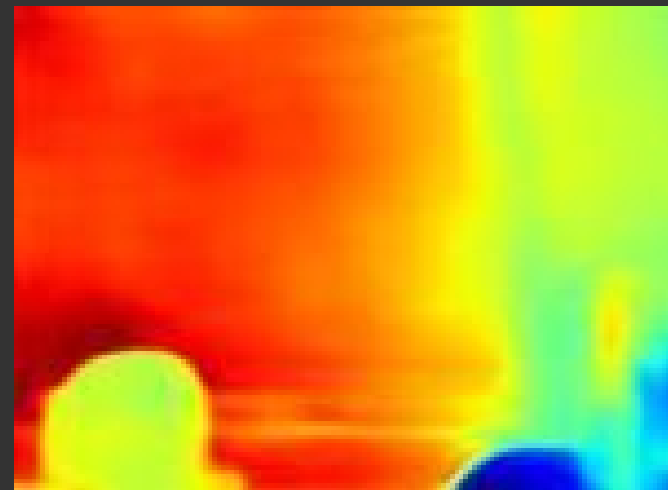# Monocular Depth estimation

RGB Image

Our approach

Ground Truth Depth

Single Image depth estimation by
Eigen et al 2015

Summary

- Data driven methods more robust than expert knowledge based prior

- Designed code satisfies domain knowledge based criterions although it's not explicitly optimized for

- Similar technique can be extended to other code design problems