THU-AM-085

All-in-focus Imaging from Event Focal Stack

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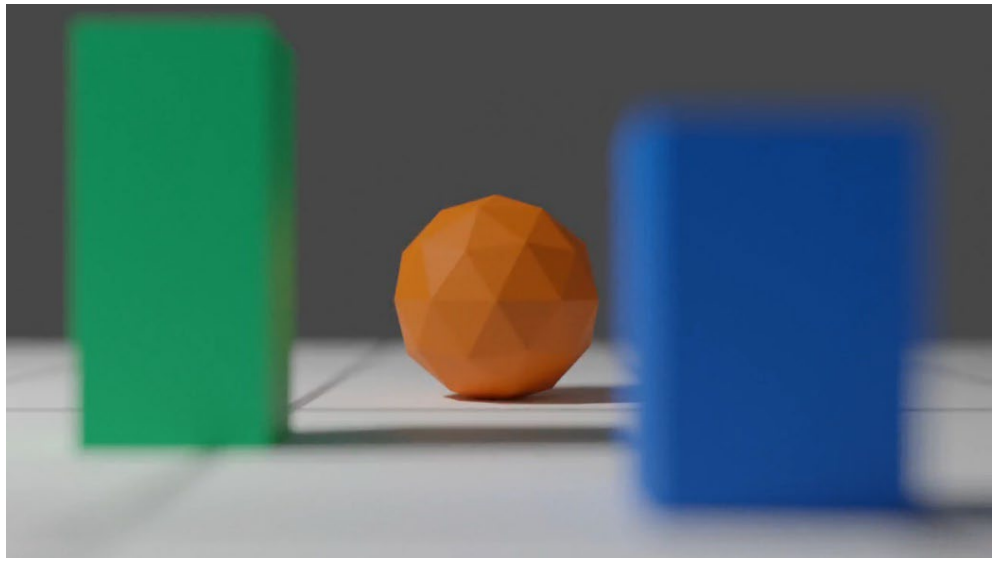
[#] Contributed equally to this work as first authors

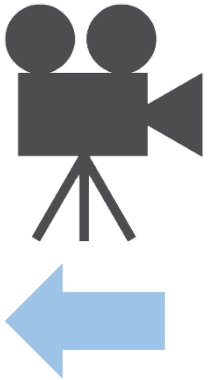
北京大学
PEKING UNIVERSITY

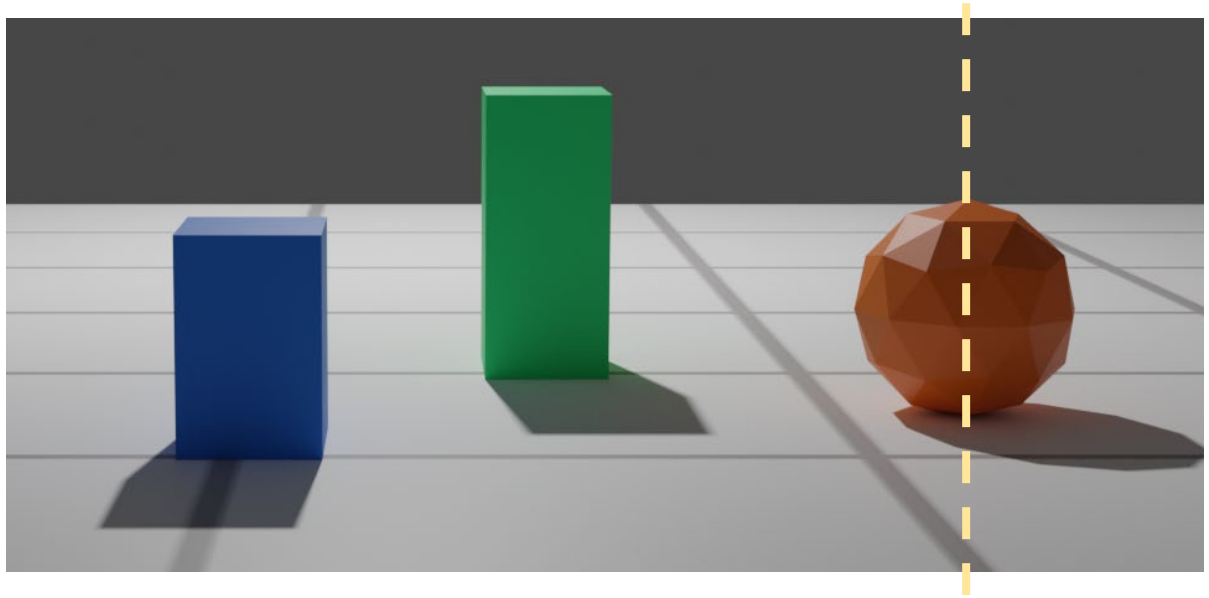
Abstract

Traditional Camera

Scene





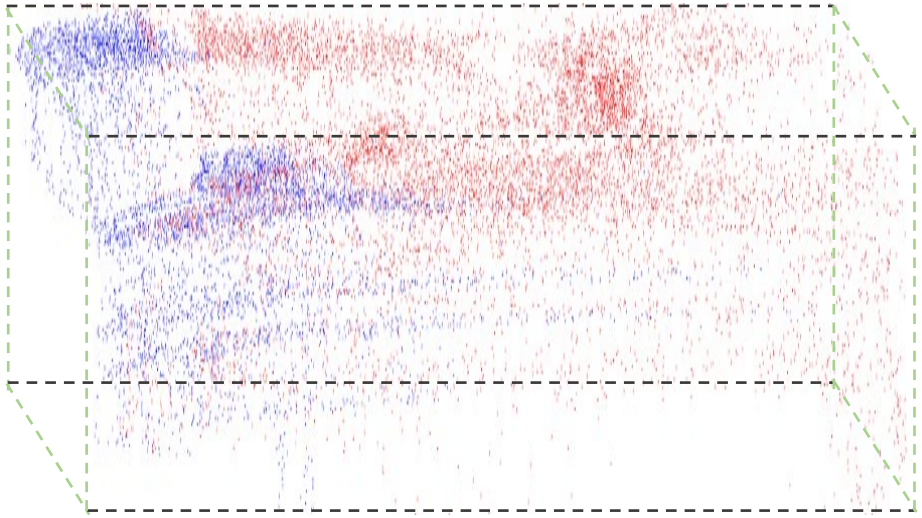


One depth in focus

Focal Depth

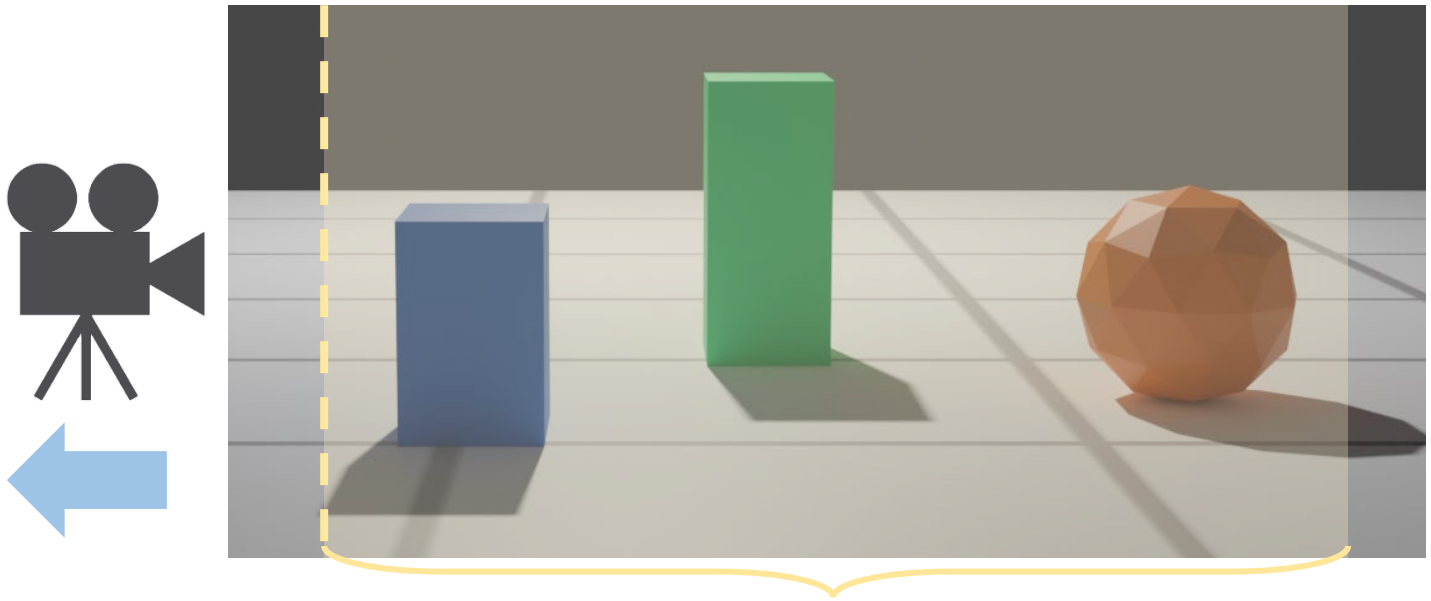
Abstract

Event Focal Stack



All depths in focus

Scene



Focal Depths

Abstract

Single image + EFS

↓ Golden search

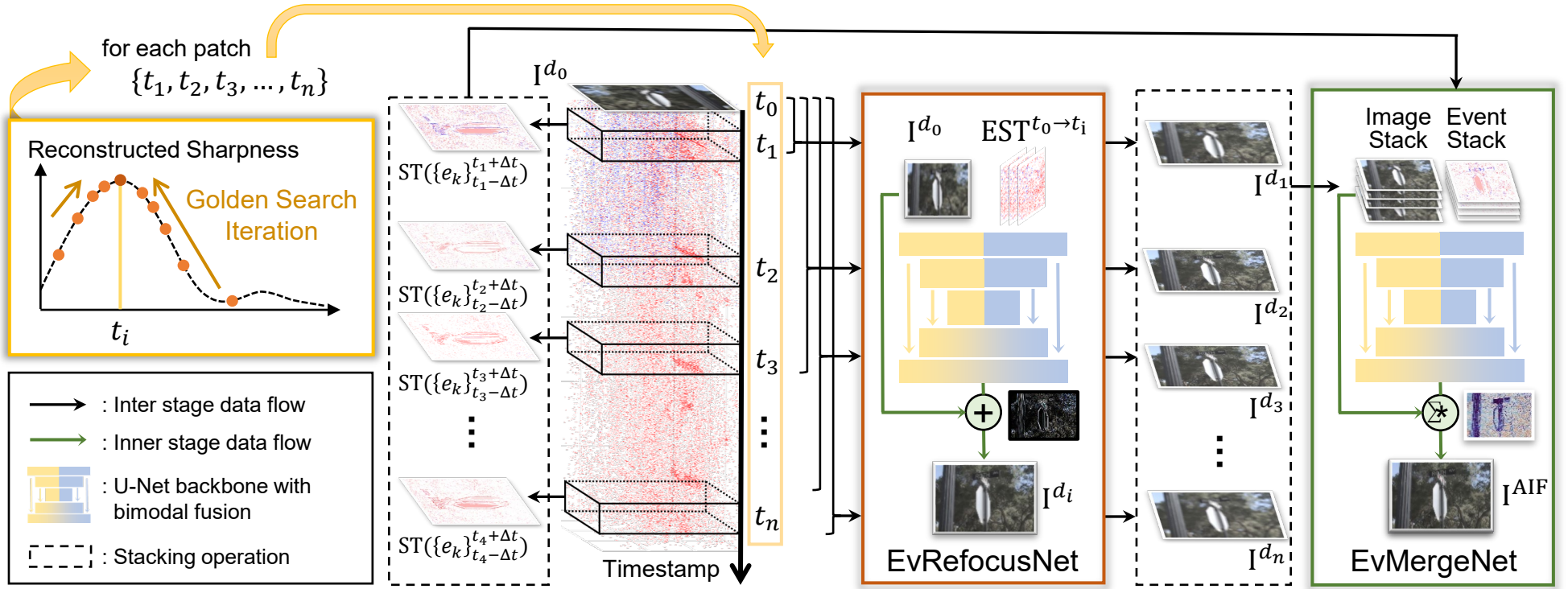
Refocus timestamps

↓ Reconstruction

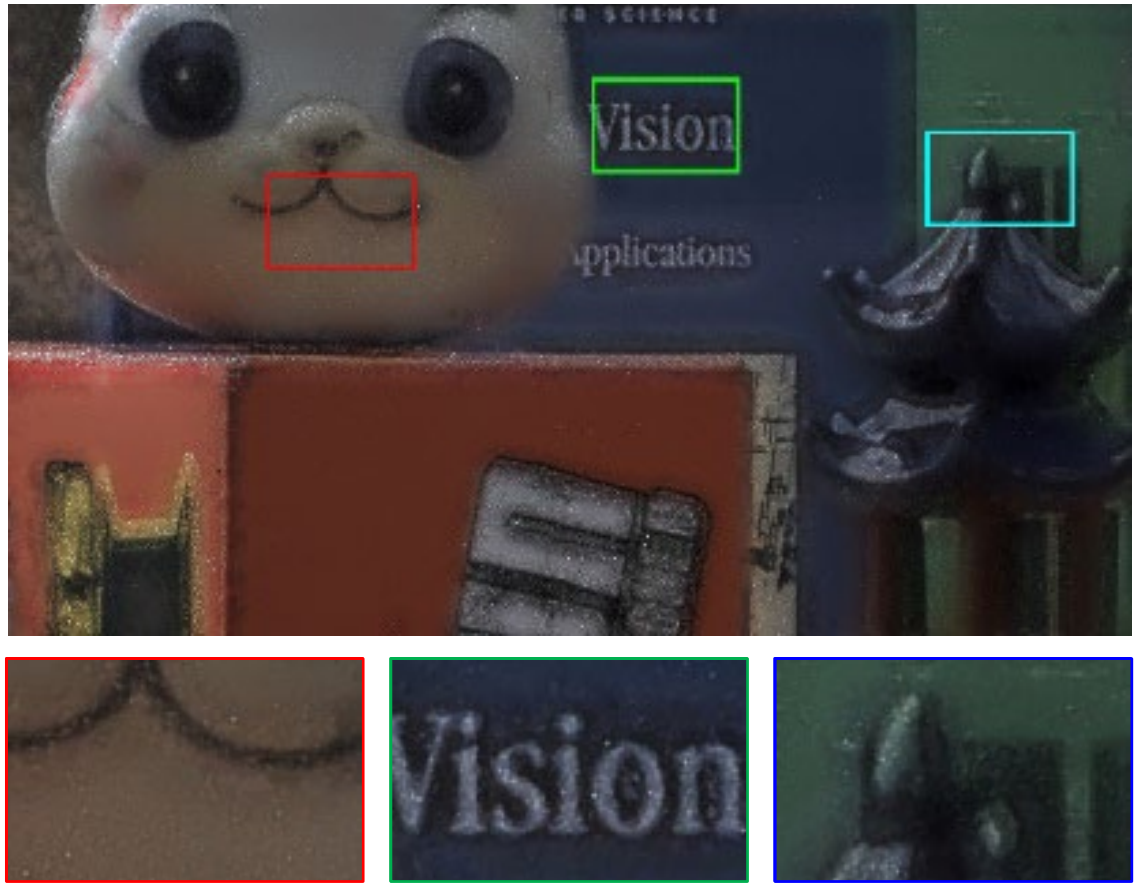
Image focal stack

↓ Merge

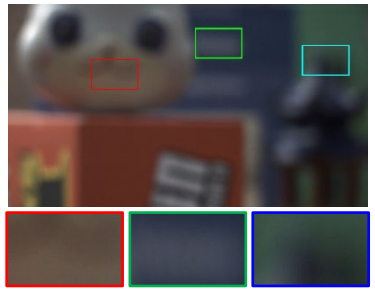
All-in-focus Image



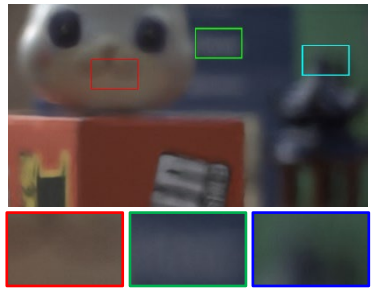
Abstract



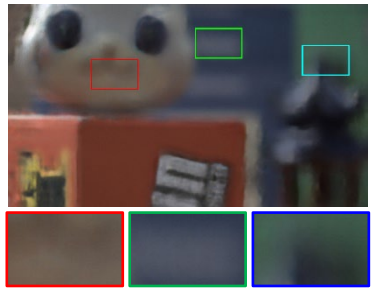
Ours



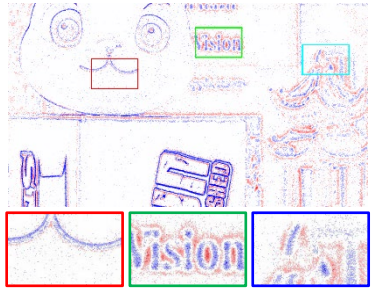
Defocused Image



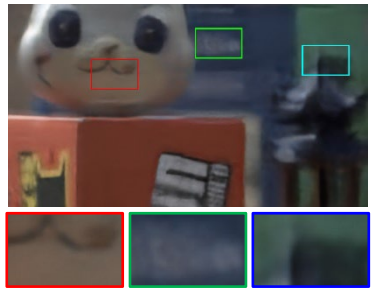
DRBNet



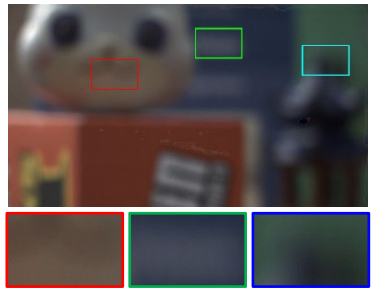
KPAC



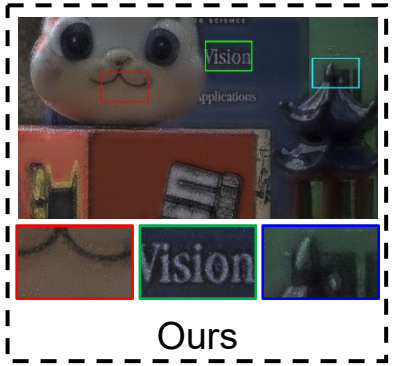
Events



IFAN



APL

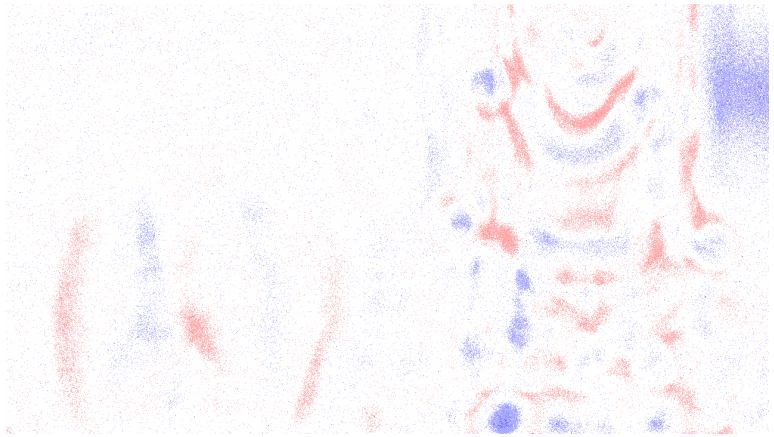


Ours

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

Abstract

Input Events



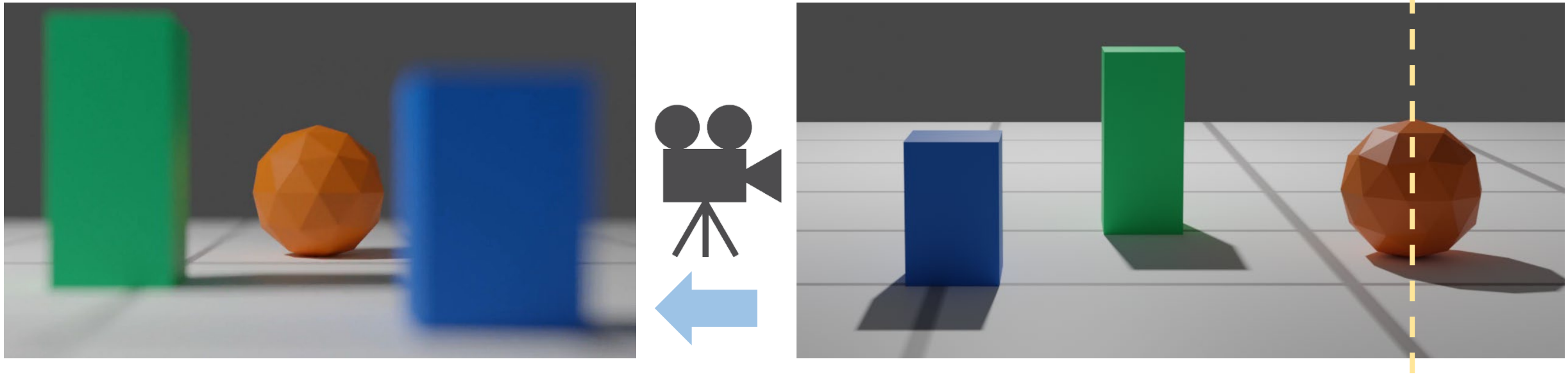
Input Image

Refocus Results

Previous Works

Traditional Camera

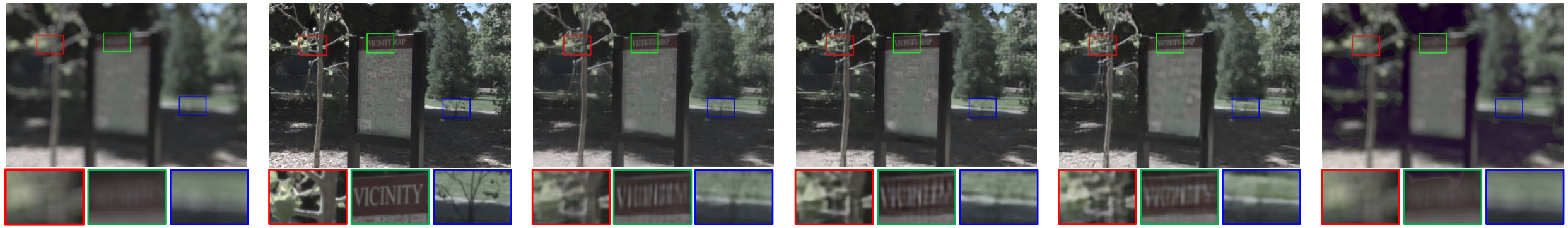
Scene



One depth in focus

Focal Depth

Previous Works



Defocused Image | Ground Truth | DRBNet | IFAN | KPAC | APL

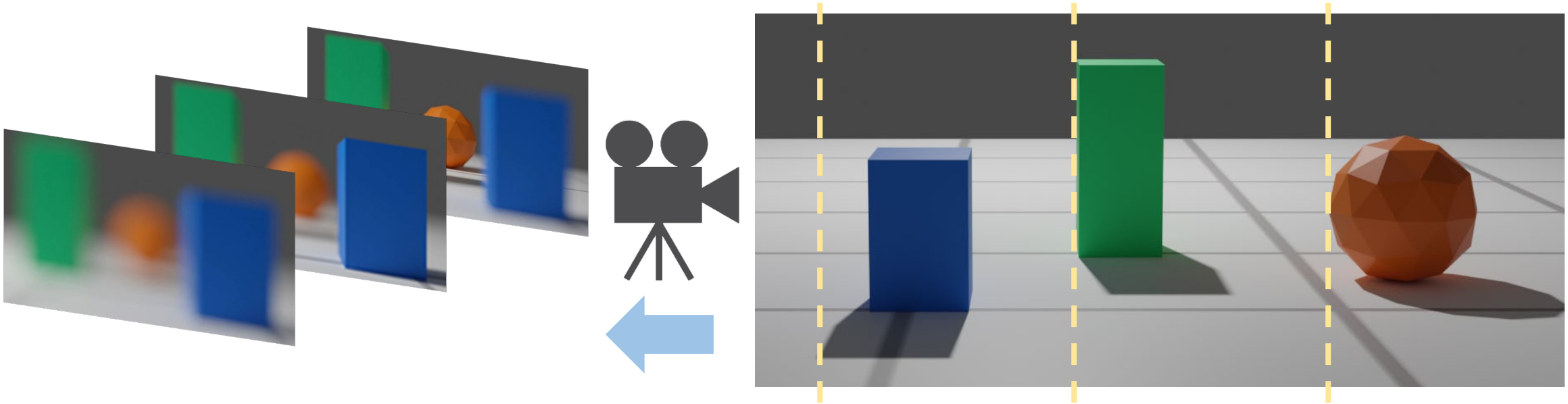
Image-based Methods: High frequency information cannot be recovered due to the ill-posed nature of single image defocus deblur.

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

Previous Works

Frame-based Focal Stack

Scene



Multiple depths in focus

Focal Depths

Previous Works

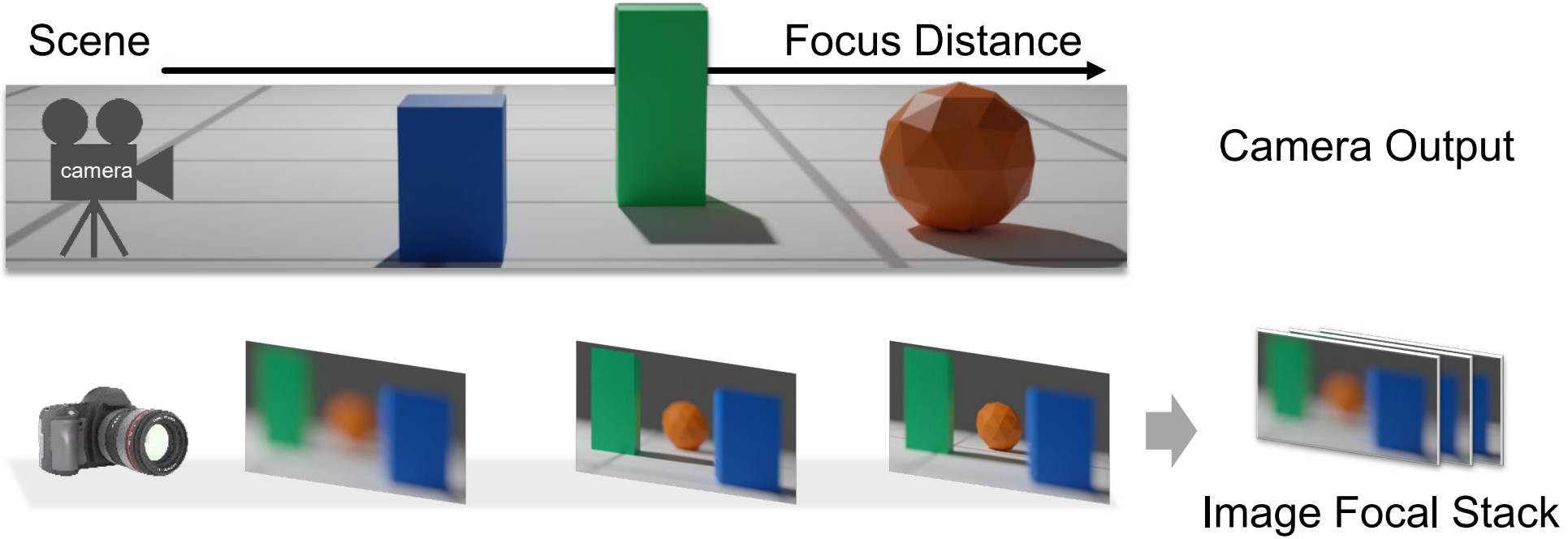
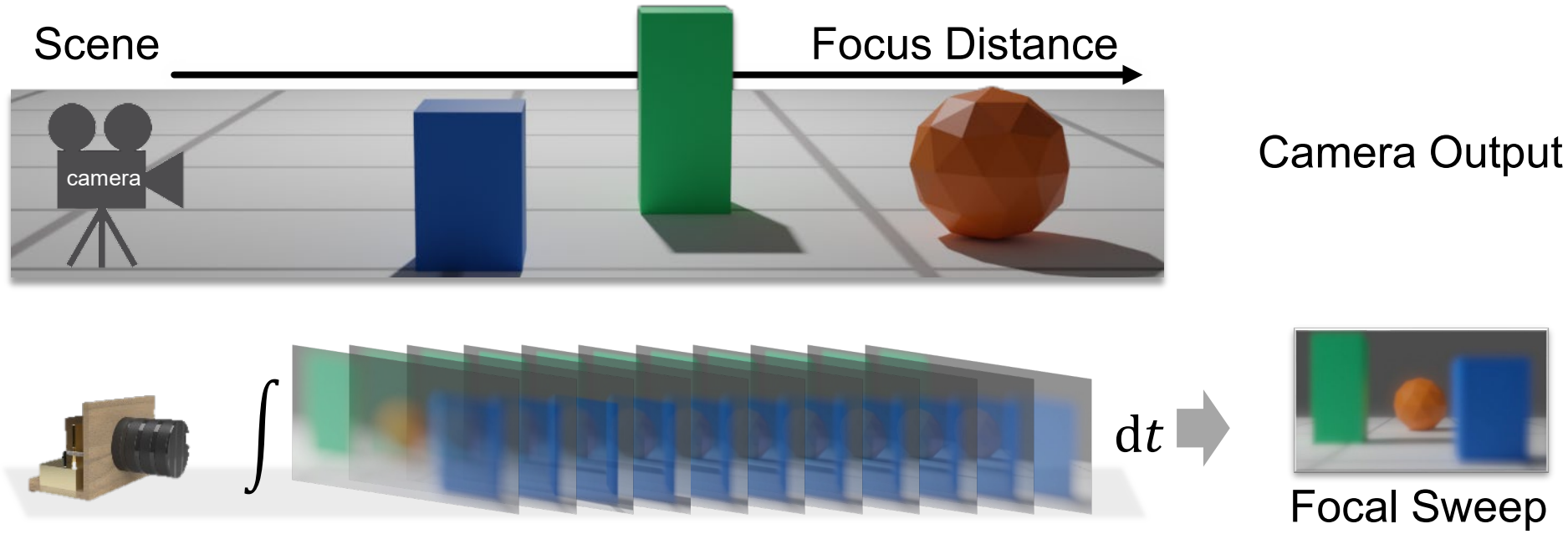


Image Focal Stack:
Requires careful operation & consumes long time;
Information is only collected at a discrete number of focal distances.

Previous Works

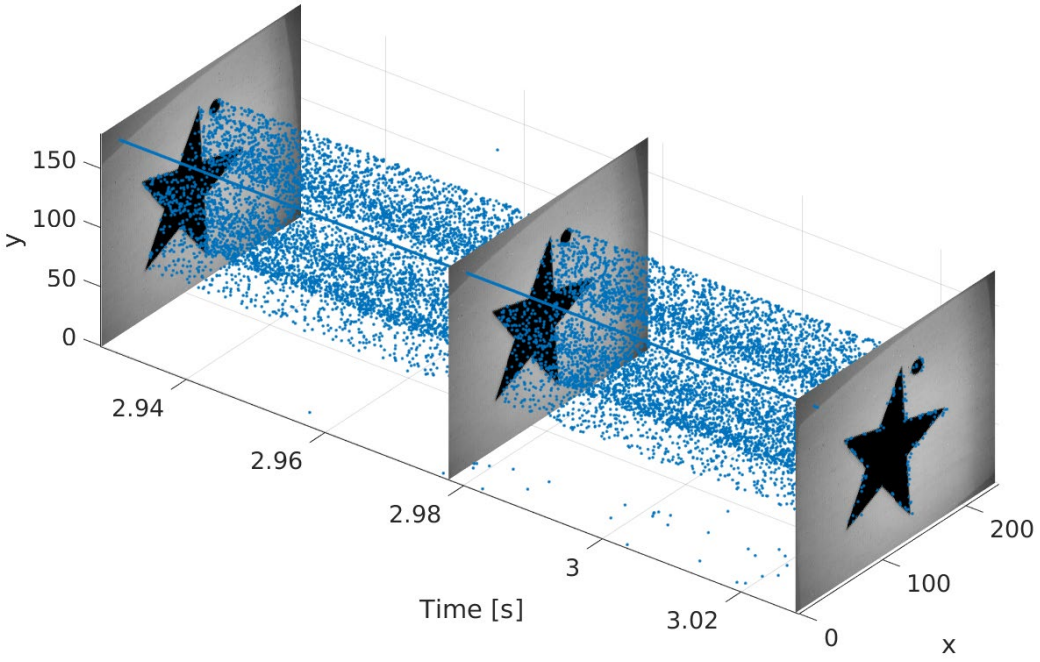


Focal sweep:
By sweeping the focal point in a single exposure, information is collected from all depths, but the depth information is lost.

Event Camera

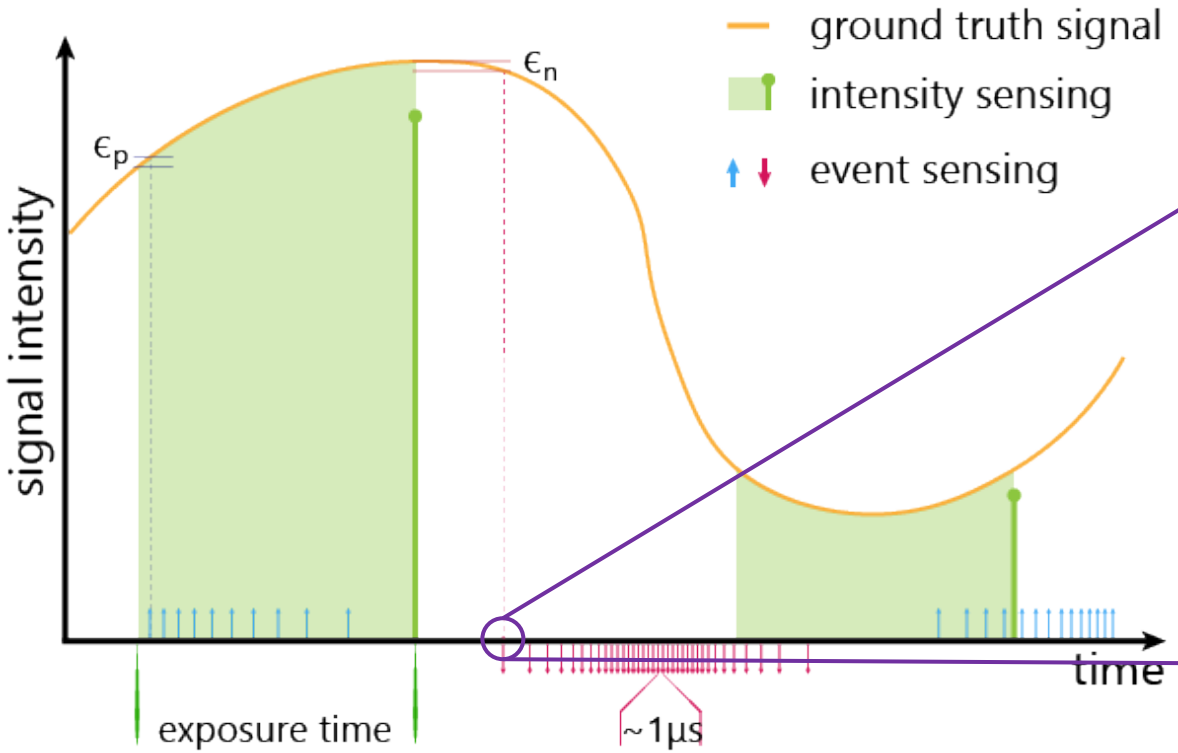
- Event cameras have novel sensors that measure only motion in the scene.

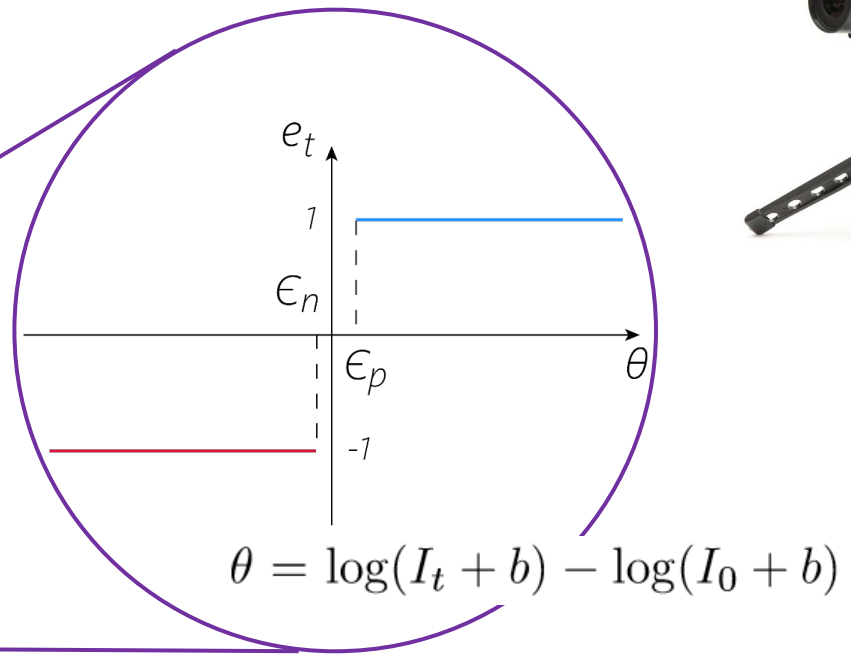
*Video courtesy of Elias Mueggler



Event Camera

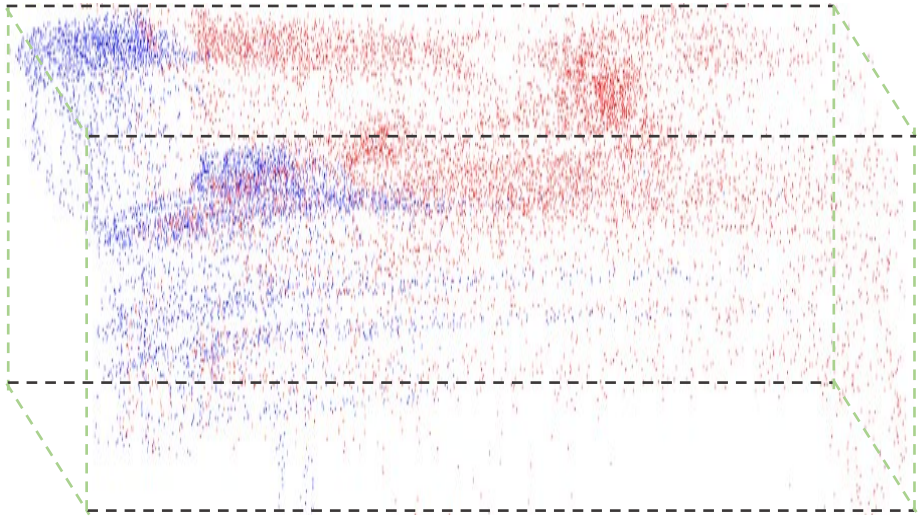
- Events are generated any time a single pixel sees a change in brightness larger than the threshold.



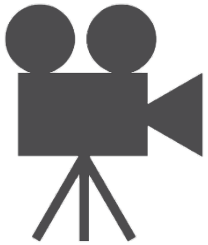


Problem Formulation

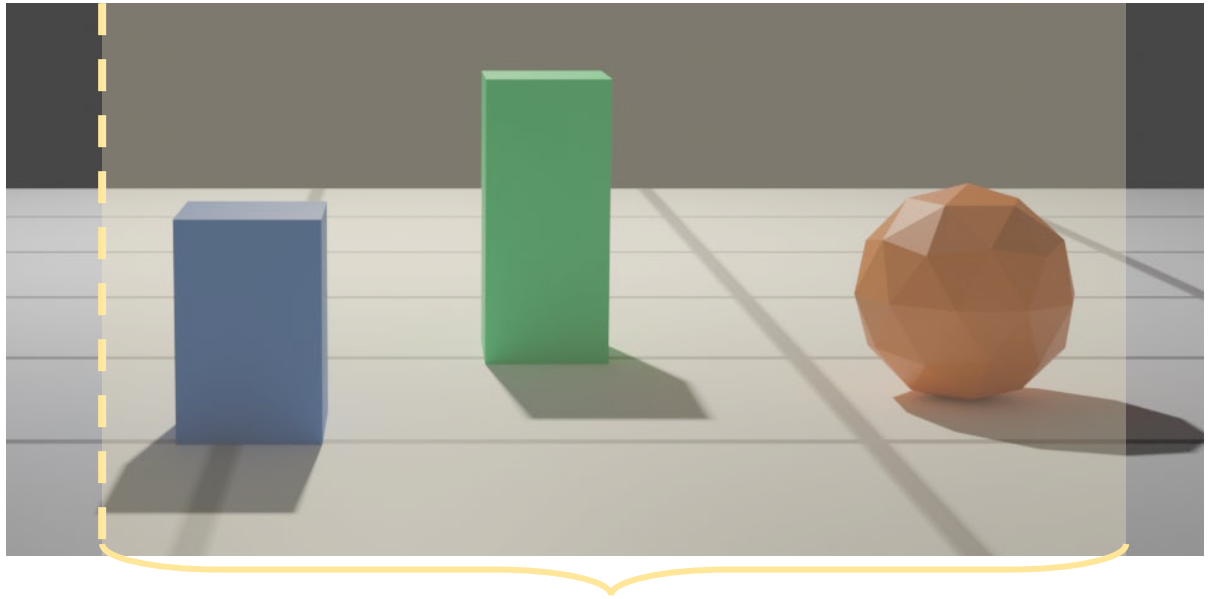
Event Focal Stack



All depths in focus



Scene

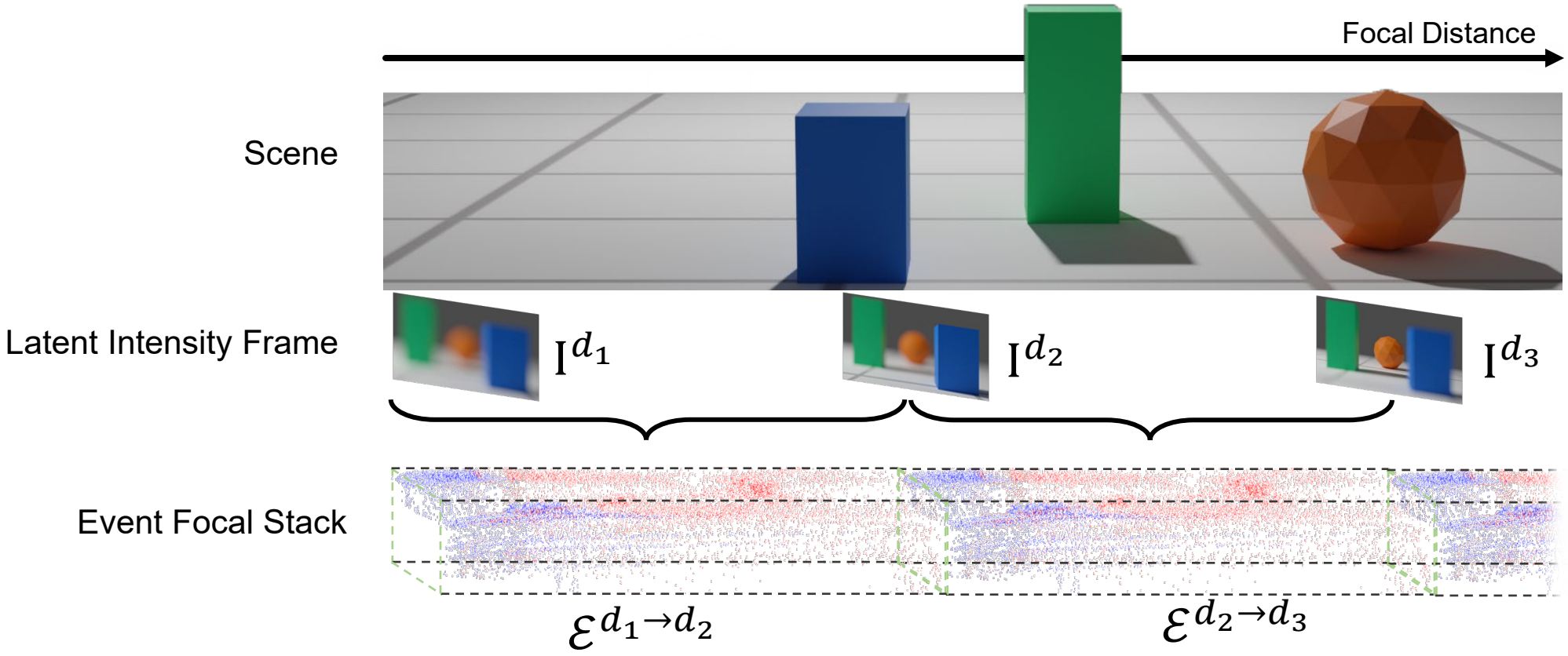


Focal Depths

Problem Formulation

$$\log(\mathrm{I}^{d_j}) = \log(\mathrm{I}^{d_i}) + \sum \mathcal{E}^{d_i \to d_j}$$

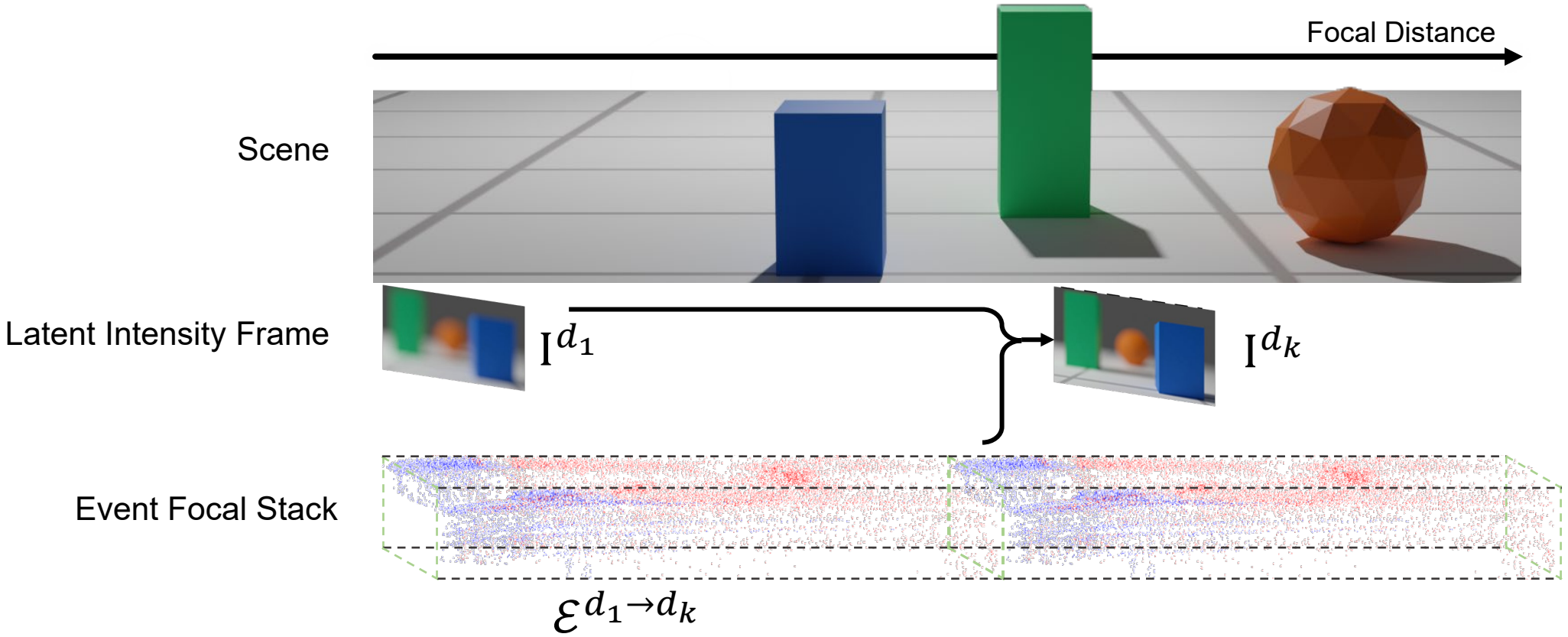
The latent intensity frame changes as the focal point moves.
Events encode the logarithm change of latent intensity.



Problem Formulation

$$\log(\mathrm{I}^{d_j}) = \log(\mathrm{I}^{d_i}) + \sum \mathcal{E}^{d_i \to d_j}$$

Given a defocused image and the EFS, we can reconstruct the latent image focused at any distance.



Method

Single image + EFS

↓ Golden search

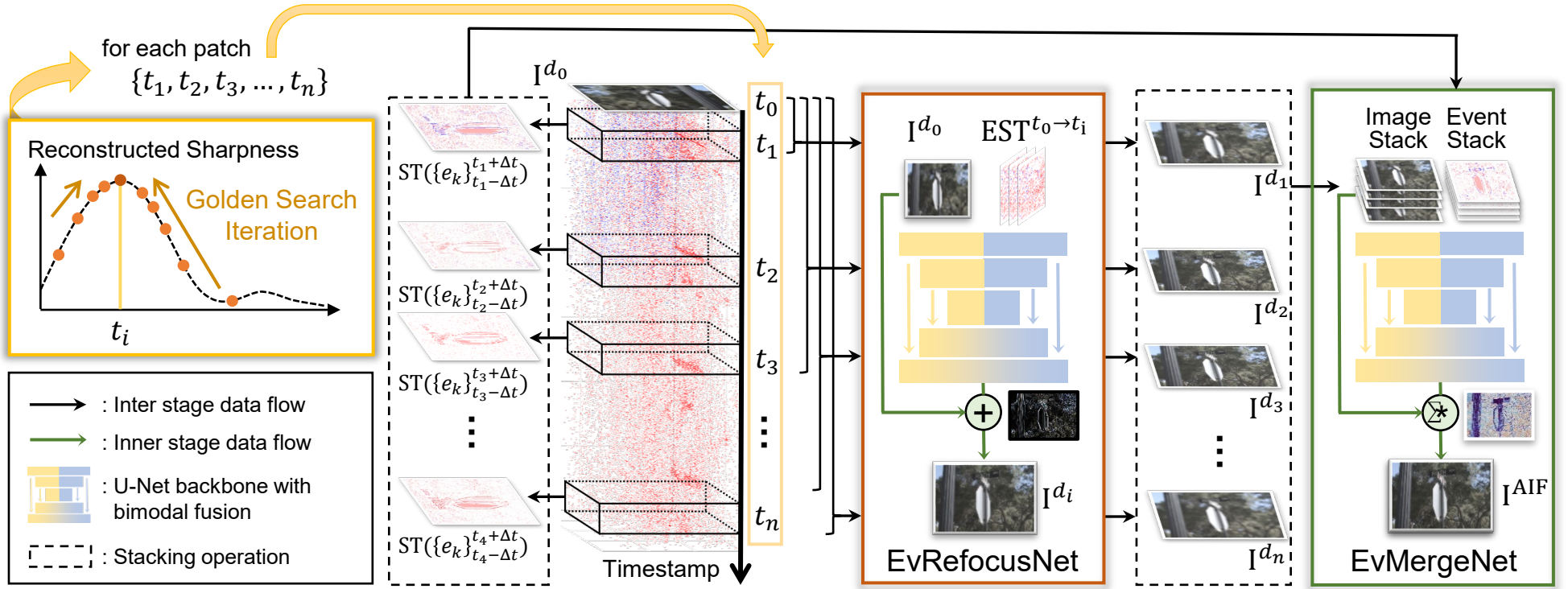
Refocus timestamps

↓ Reconstruction

Image focal stack

↓ Merge

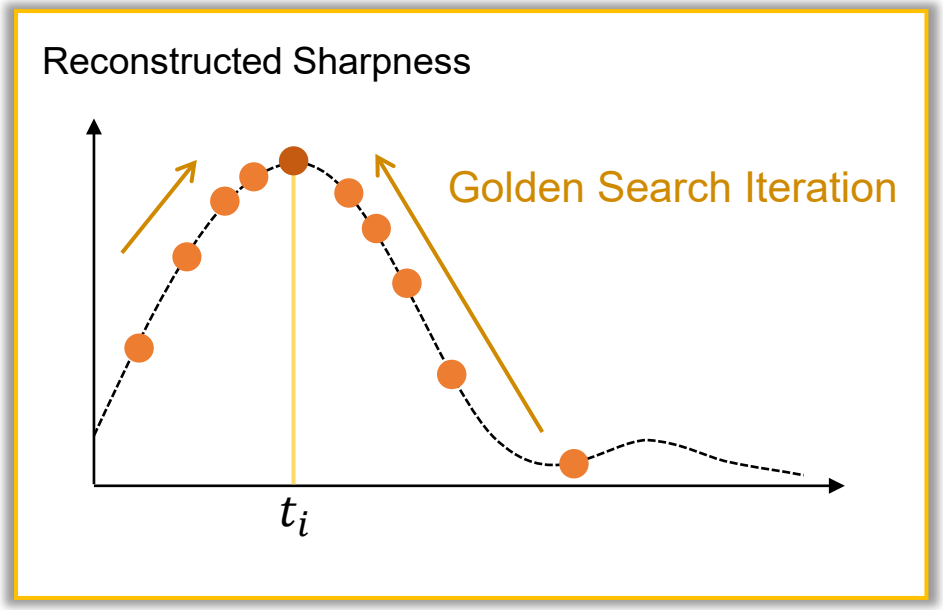
All-in-focus Image



Golden Search for Refocus Timestamps

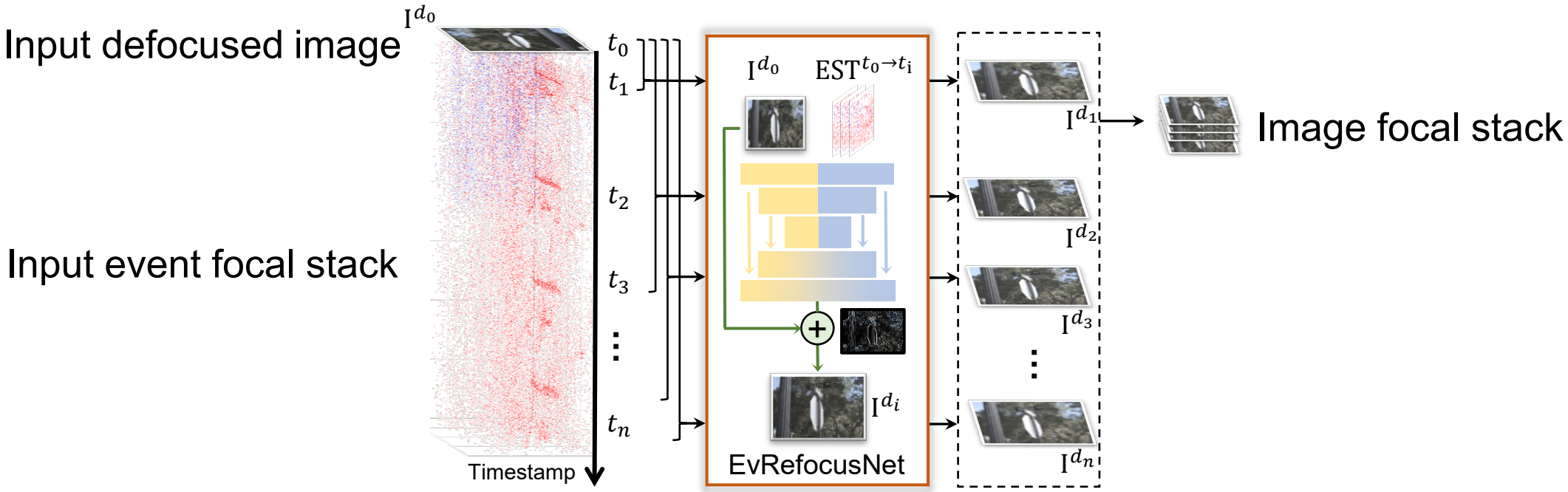
Algorithm 1 Refocusing time selection with EFS

Data: threshold μ, golden ratio $\varphi = 1.618$
Input: EFS $\mathcal{E}$ and an RGB image $\mathbf{I}^d$
Result: Refocusing timestamp t_r
$L \leftarrow 0, R \leftarrow N_e$
while $R - L > \mu$ **do**
  $t_1, t_2 \leftarrow R - (R-L)/\varphi, L + (R-L)/\varphi$
  Reconstruct $\mathbf{I}^{d_1}, \mathbf{I}^{d_2}$ with Equation (5)
  if $\mathbb{D}(\mathbf{I}^{d_1}) > \mathbb{D}(\mathbf{I}^{d_2})$ **then** $R \leftarrow t_2$
  else $L \leftarrow t_1$
  end if
  $t_r \leftarrow (L + R)/2$
end while



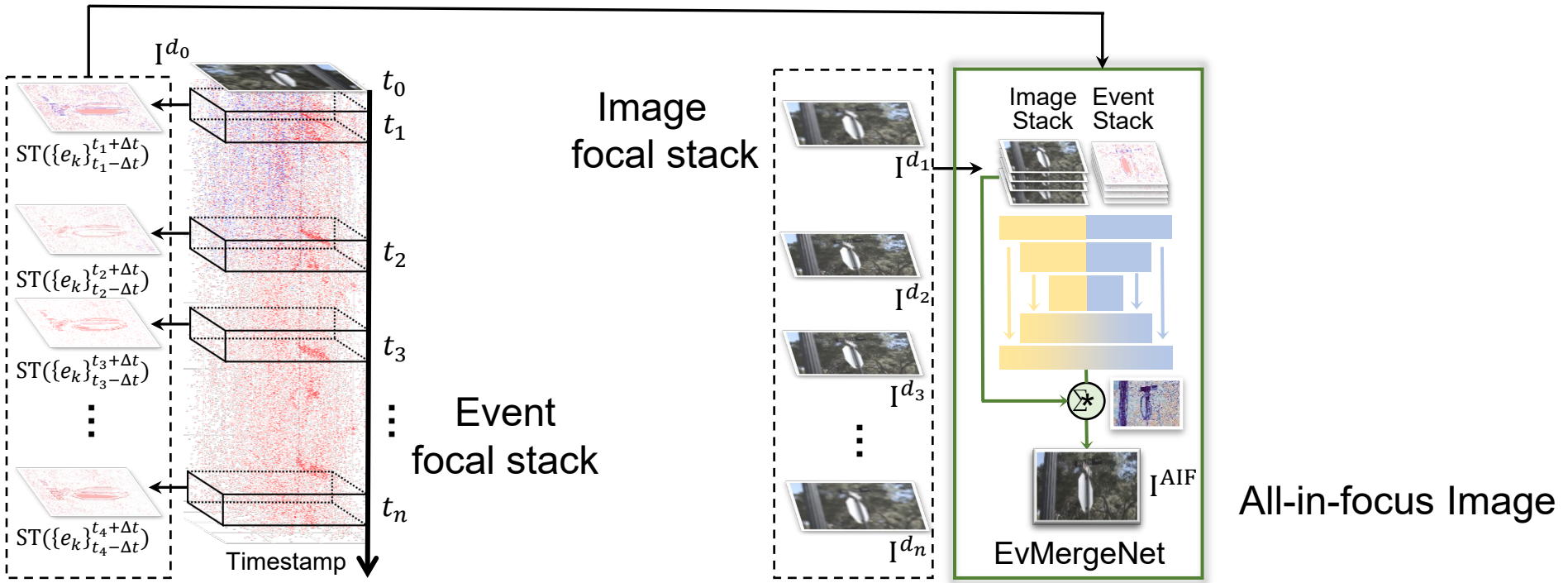
Step 1： For each patch of the image, we use the Golden Rate Search Algorithm to find the moment when it was in focus, getting N×N refocus timestamps(one for each patch).

Image Refocusing



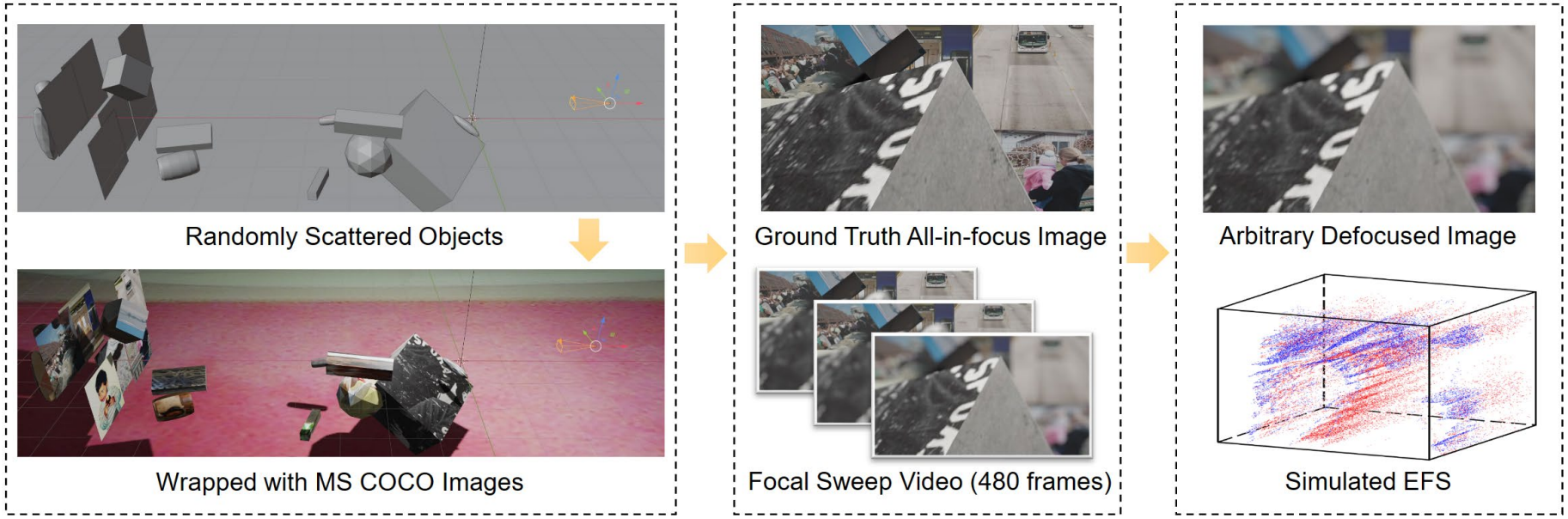
Step 2： For each refocus timestamp, we use EvRefocusNet to reconstruct a refocused image from the input image + event focal stack, forming an image focal stack.

Merging Focal Stack



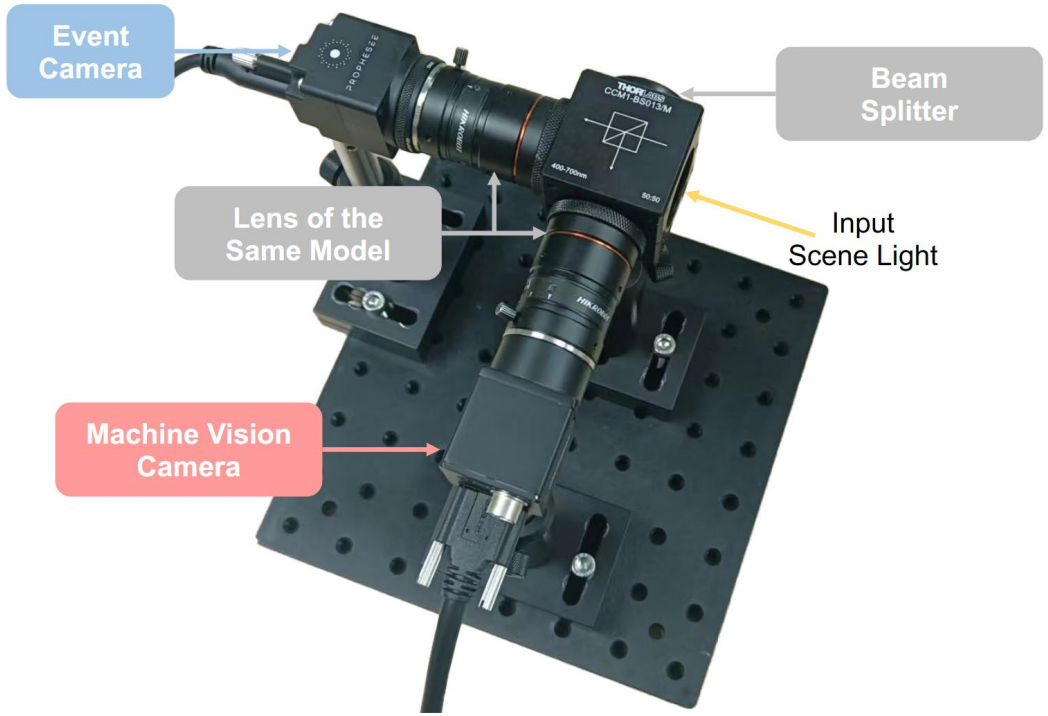
Step 3： We predict merging weights with EvMergeNet, using image focal stack and events as input. We merge the focal stack with weights to get all-in-focus result.

Training Dataset



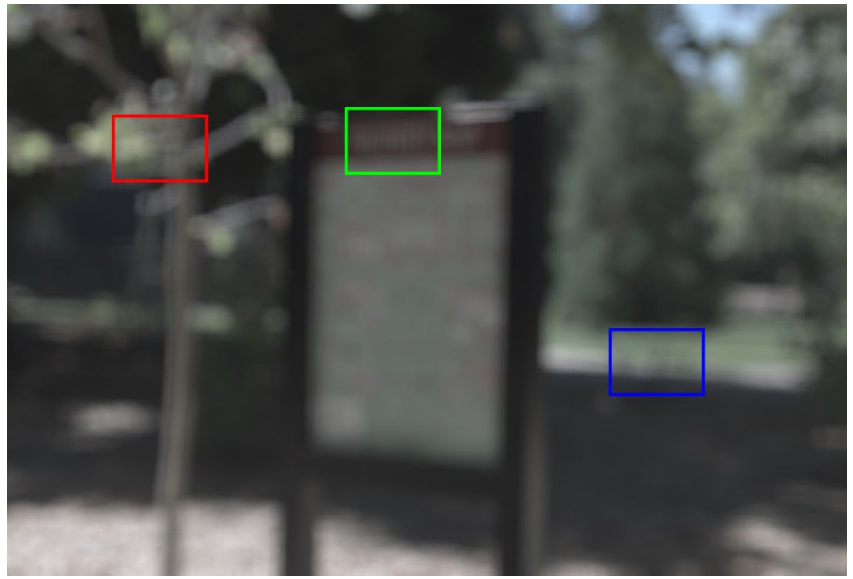
- We use Blender to render high-frame-rate focal sweep videos & ground truth all-in-focus images.
- We use MS COCO dataset images to enrich object textures.
- We use DVS-Voltmeter to simulate events from focal sweep videos. To prevent overfitting, we use random simulator parameters in each video.

Test Dataset

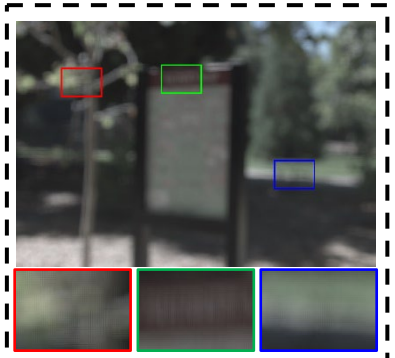


- We use a hybrid camera system to capture real test data.

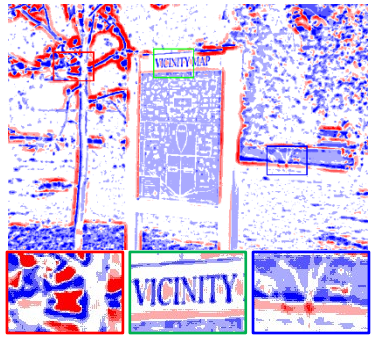
Results on Synthetic Data



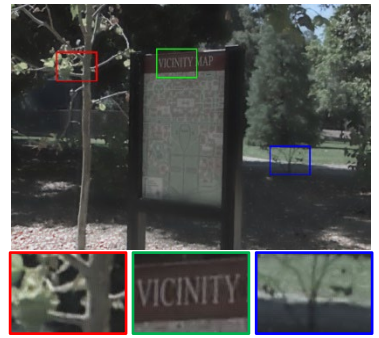
Defocused Image



Defocused Image



Events



Ours

Ground Truth

DRBNet

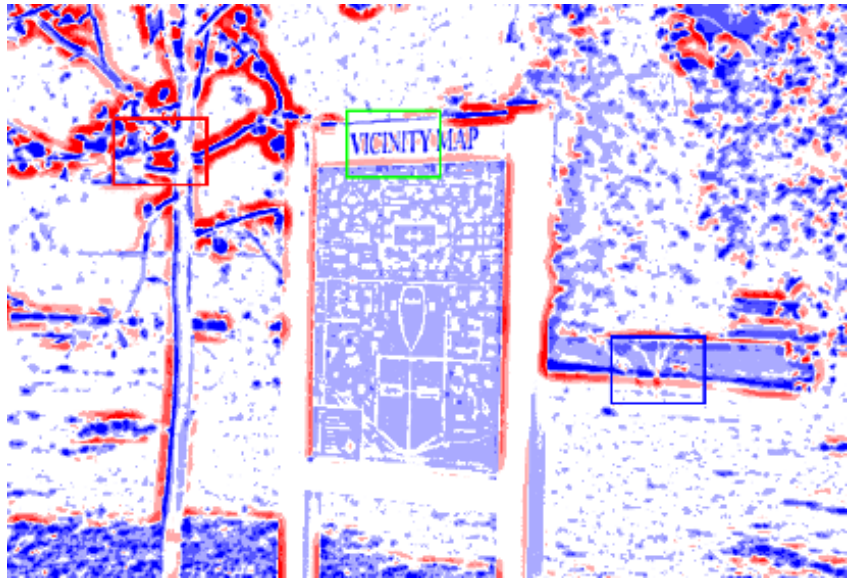
IFAN

KPAC

APL

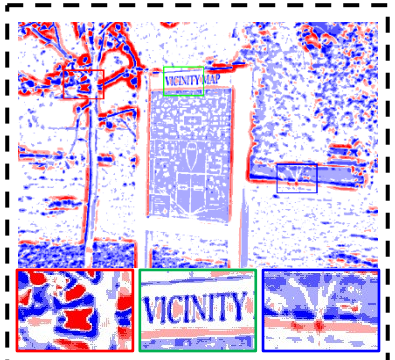
Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

Results on Synthetic Data



Events

Defocused Image



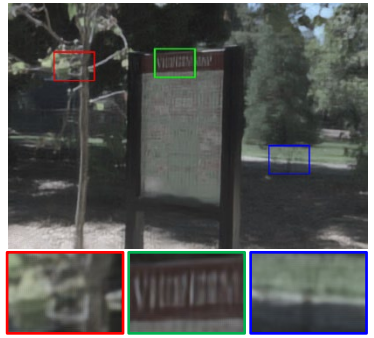
Events

Ours

Ground Truth

DRBNet

IFAN



KPAC

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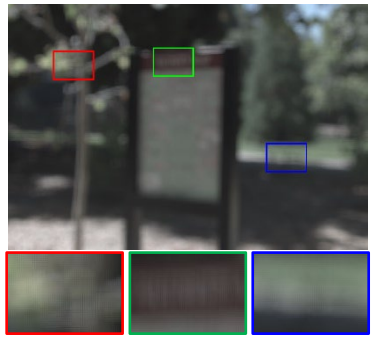
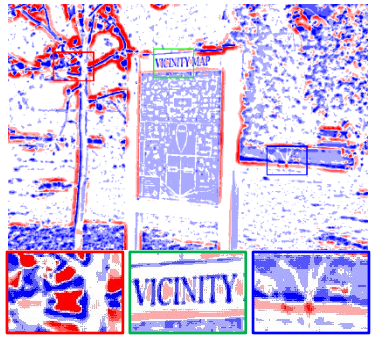
Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

Results on Synthetic Data

Ours



Defocused Image



Events

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Ground Truth

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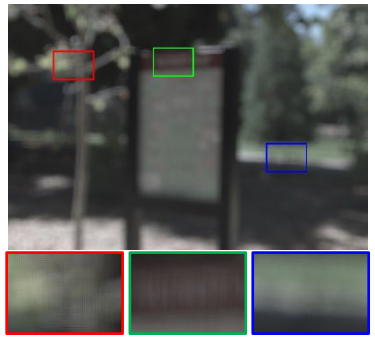
Results on Synthetic Data

Ground Truth



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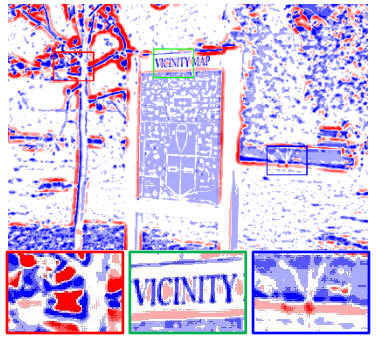
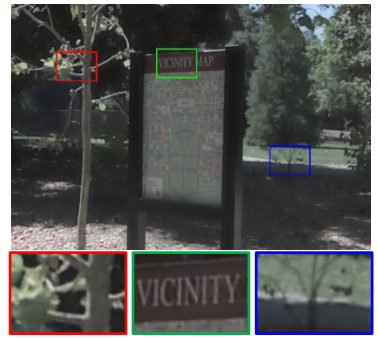


Events



Ours

Ground Truth

DRBNet

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Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

Results on Synthetic Data

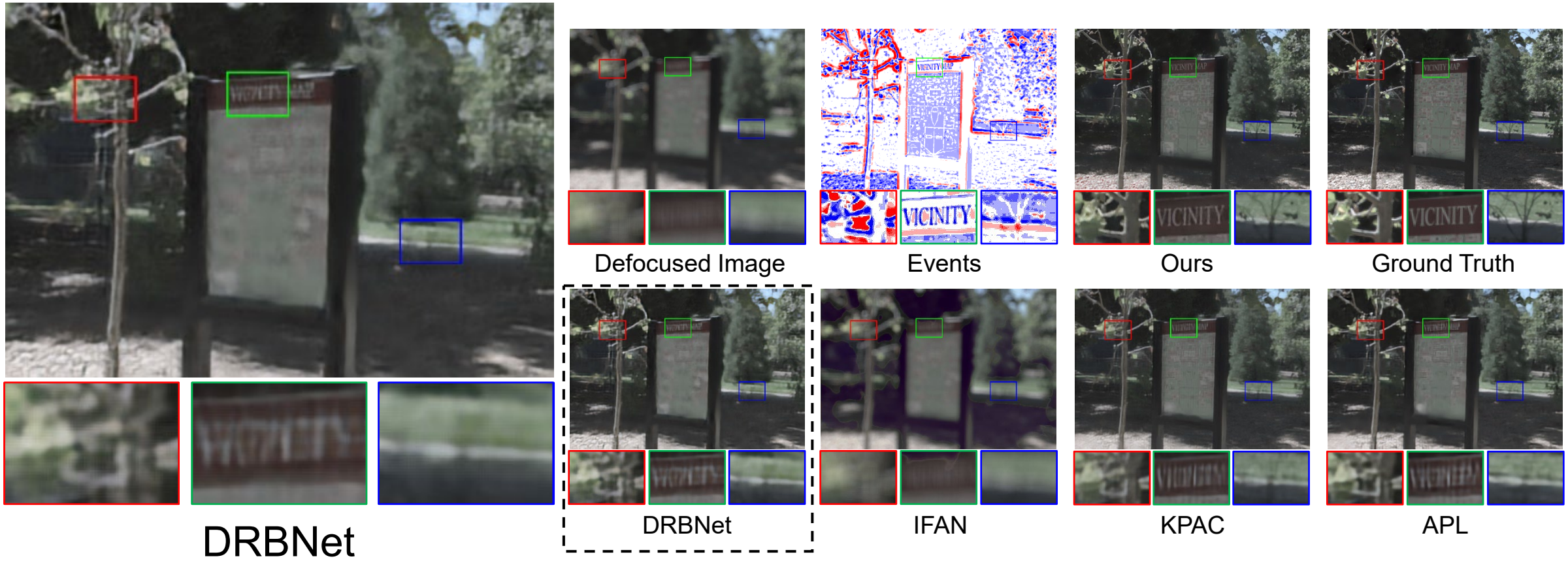
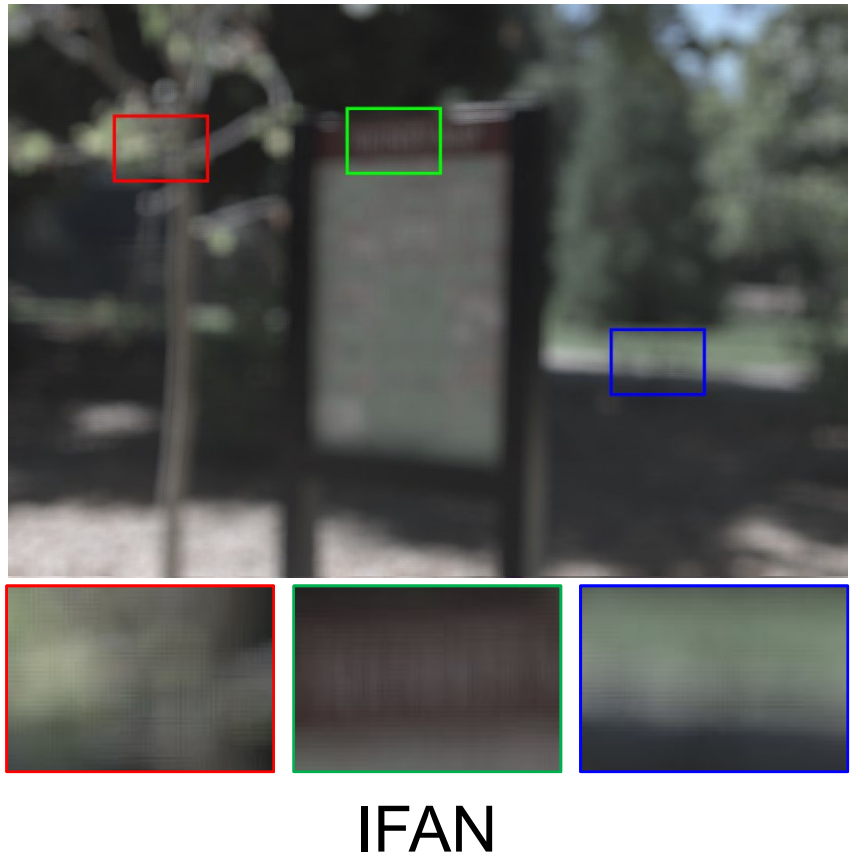
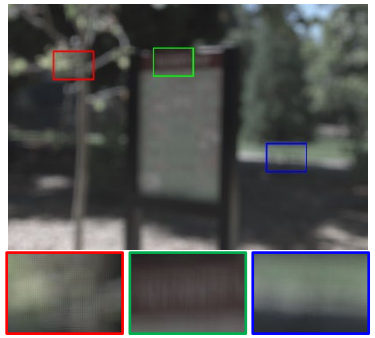


Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

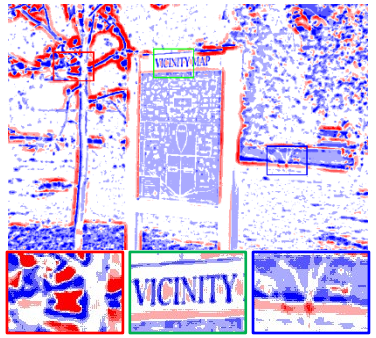
Results on Synthetic Data



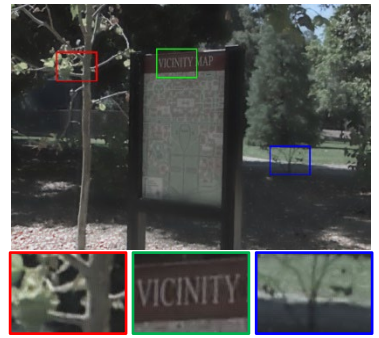
IFAN



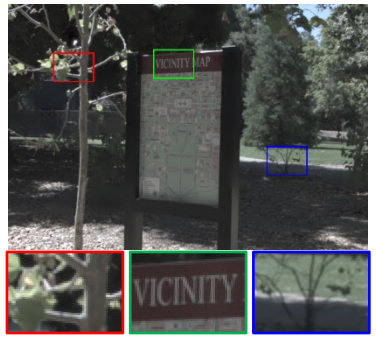
Defocused Image



Events

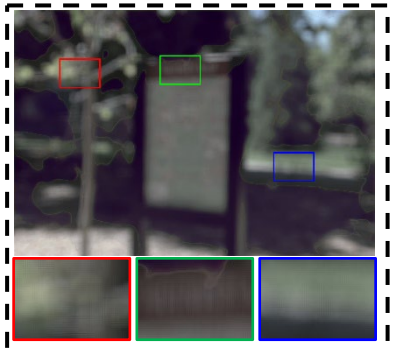


Ours



Ground Truth

DRBNet



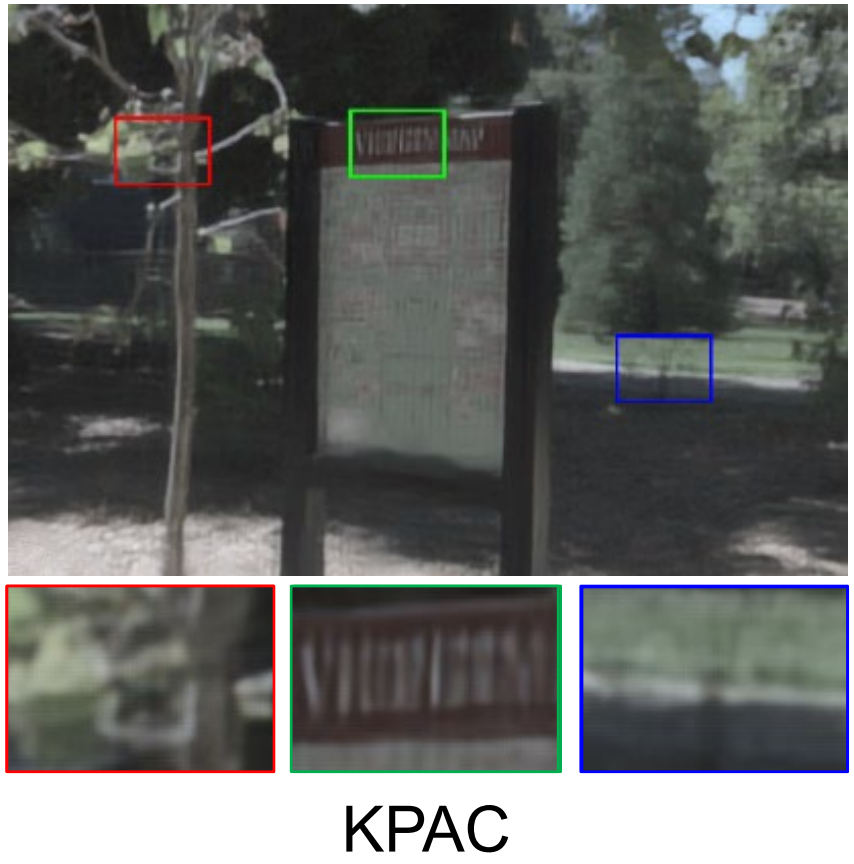
IFAN

KPAC

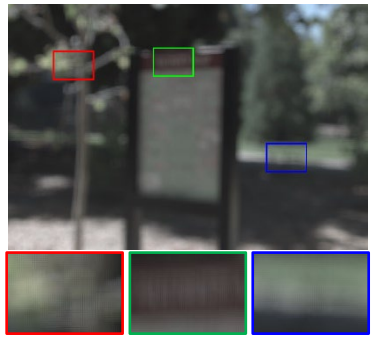
APL

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

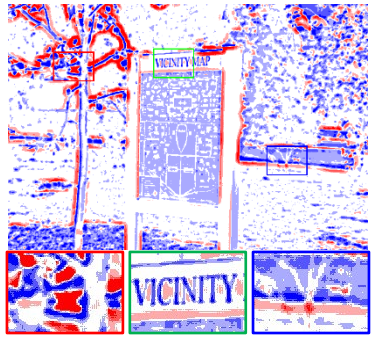
Results on Synthetic Data



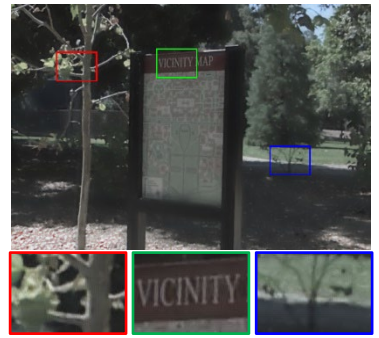
KPAC



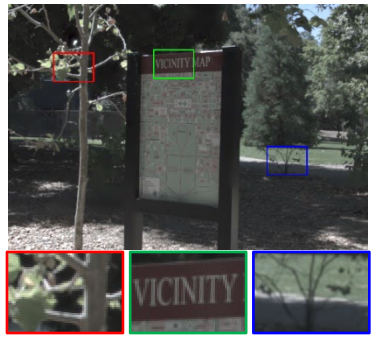
Defocused Image



Events



Ours



Ground Truth

DRBNet

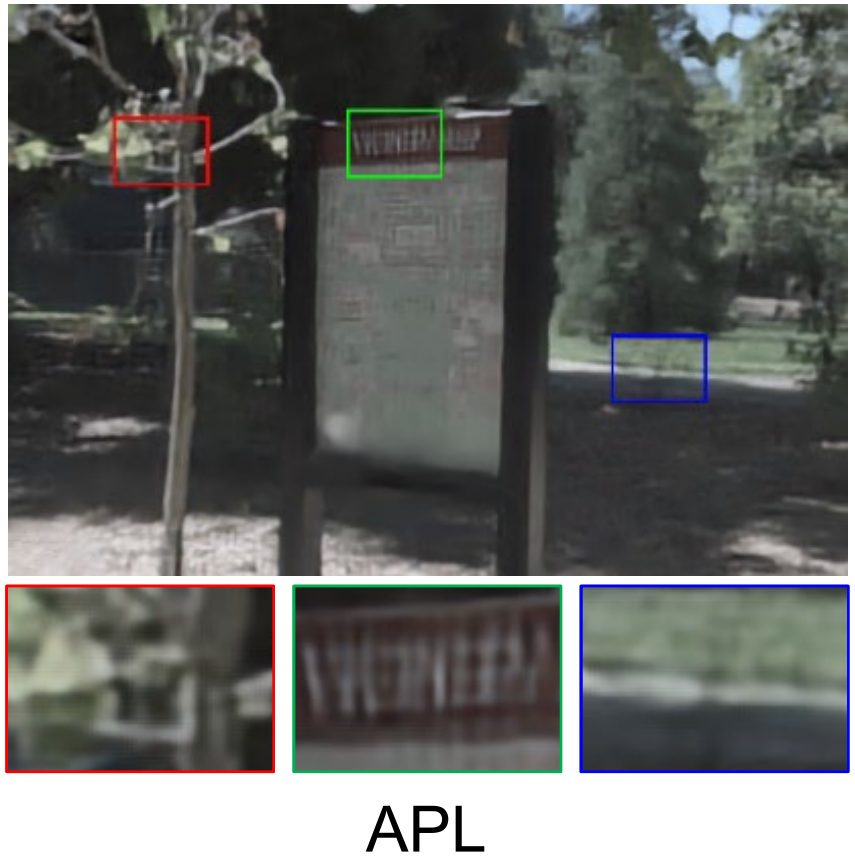
IFAN

KPAC

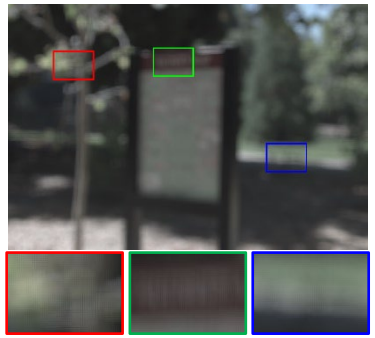
APL

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

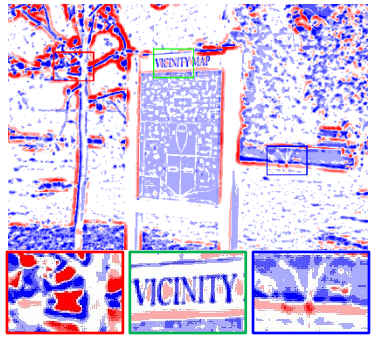
Results on Synthetic Data



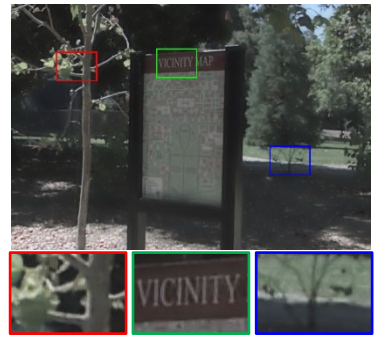
APL



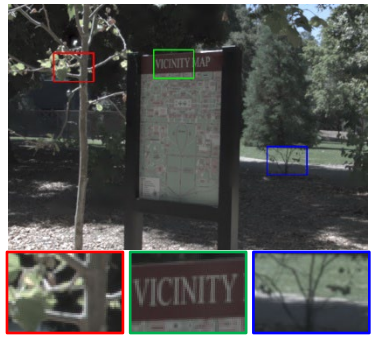
Defocused Image



Events



Ours



Ground Truth

DRBNet

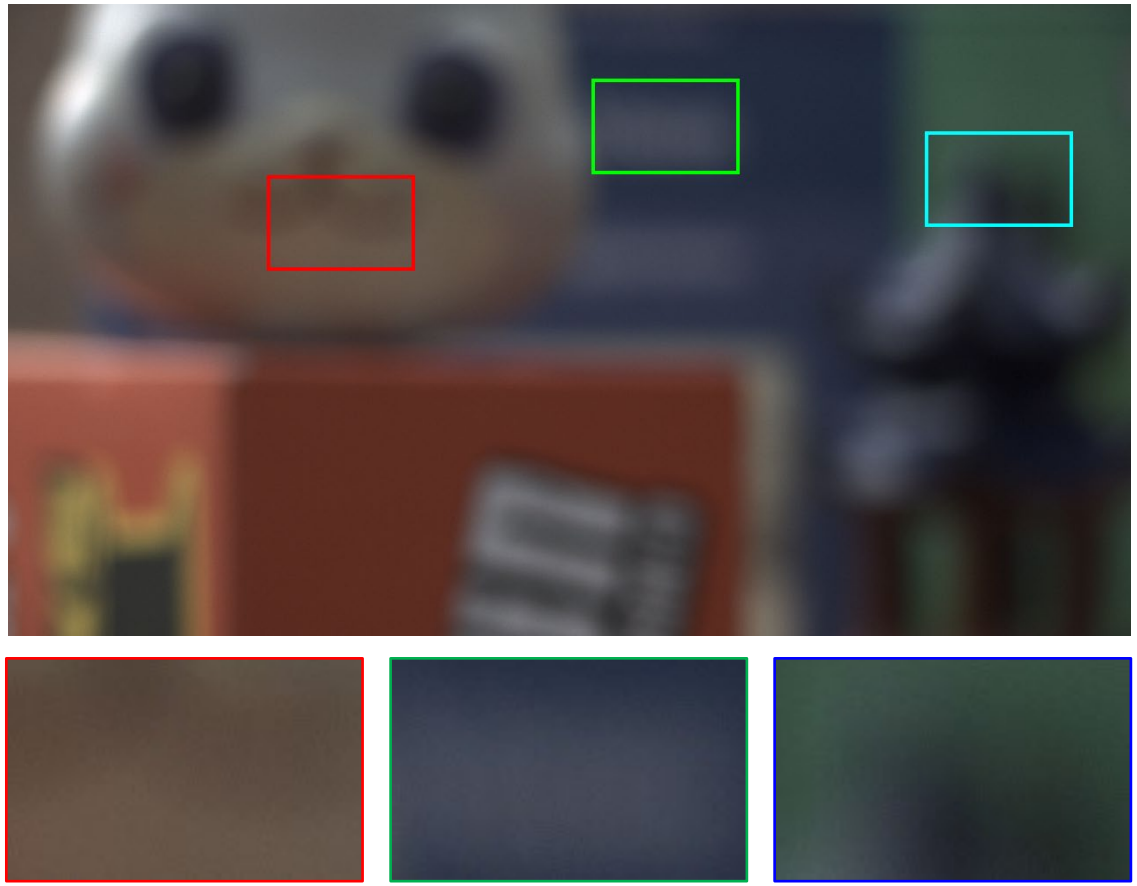
IFAN

KPAC

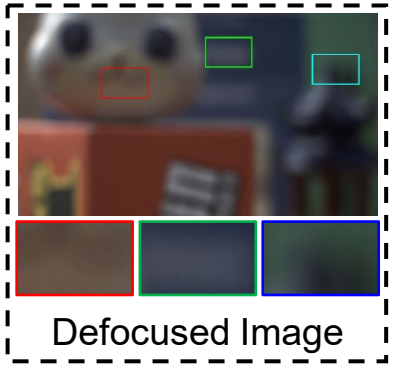
APL

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

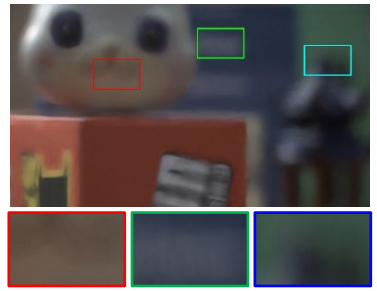
Results on Real Data



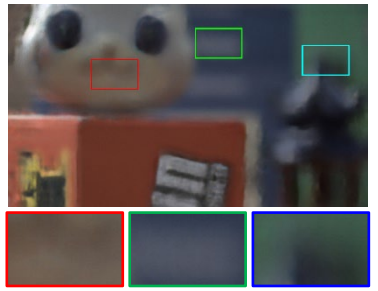
Defocused Image



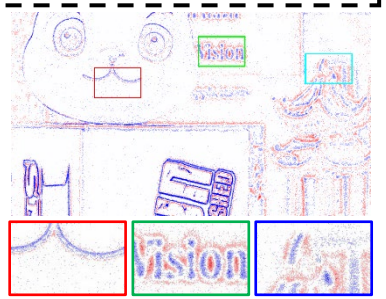
Defocused Image



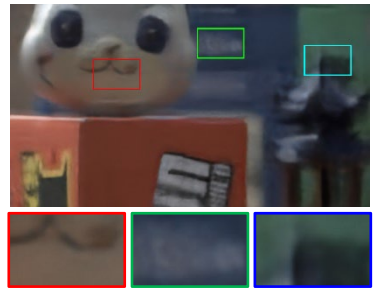
DRBNet



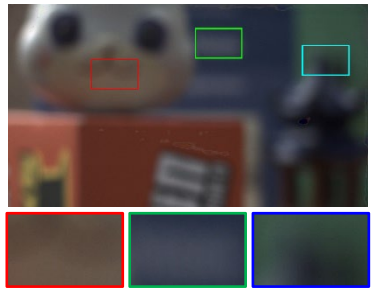
KPAC



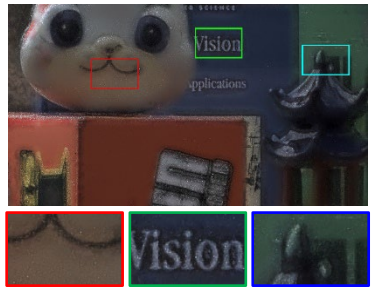
Events



IFAN



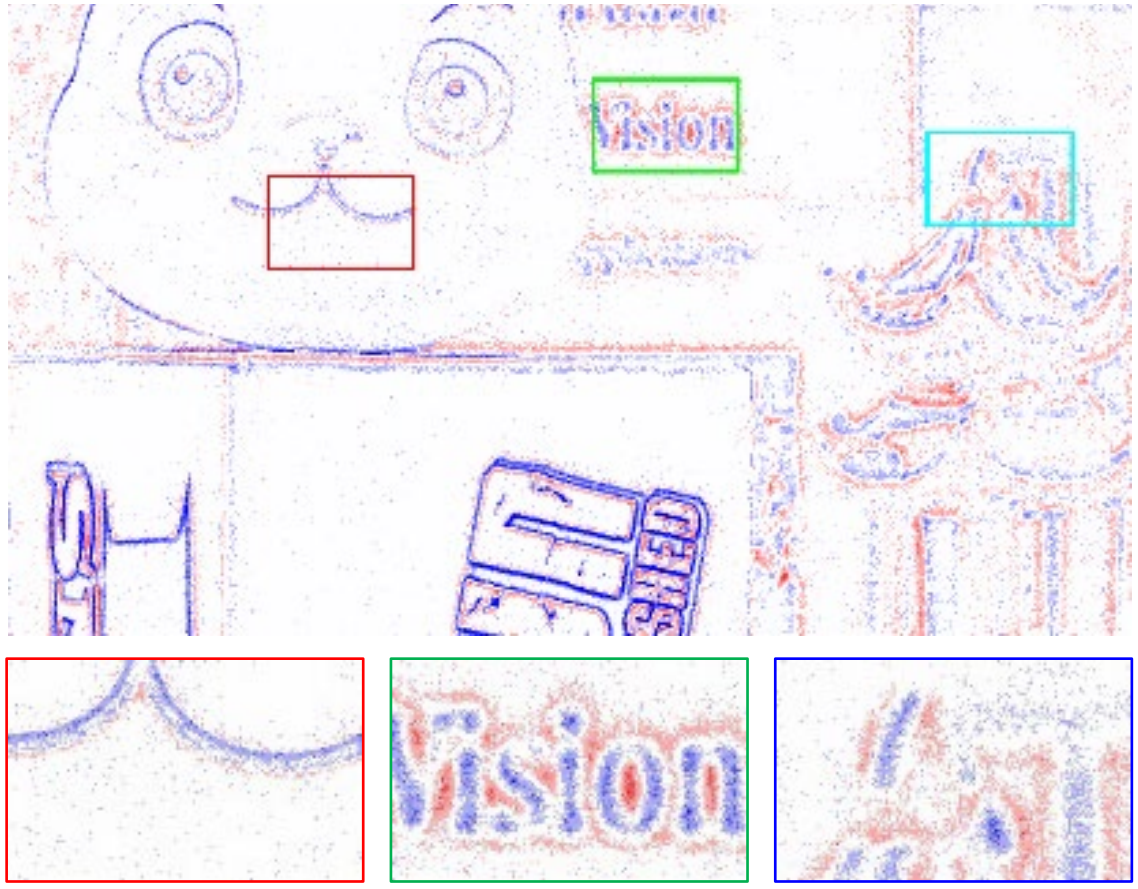
APL



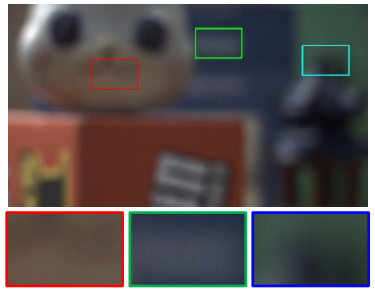
Ours

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

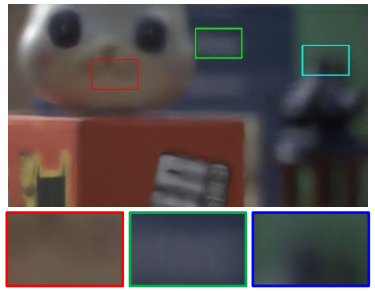
Results on Real Data



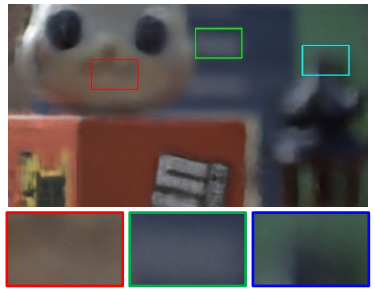
Events



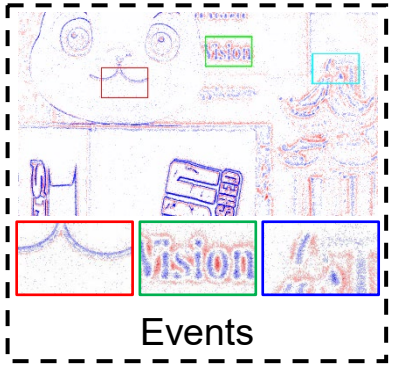
Defocused Image



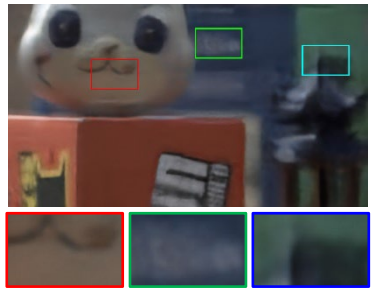
DRBNet



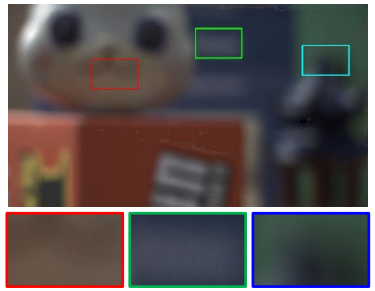
KPAC



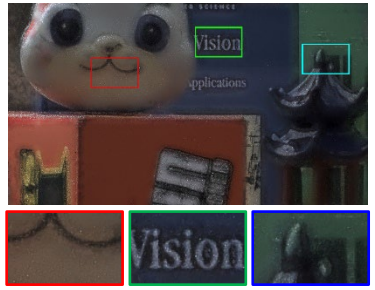
Events



IFAN



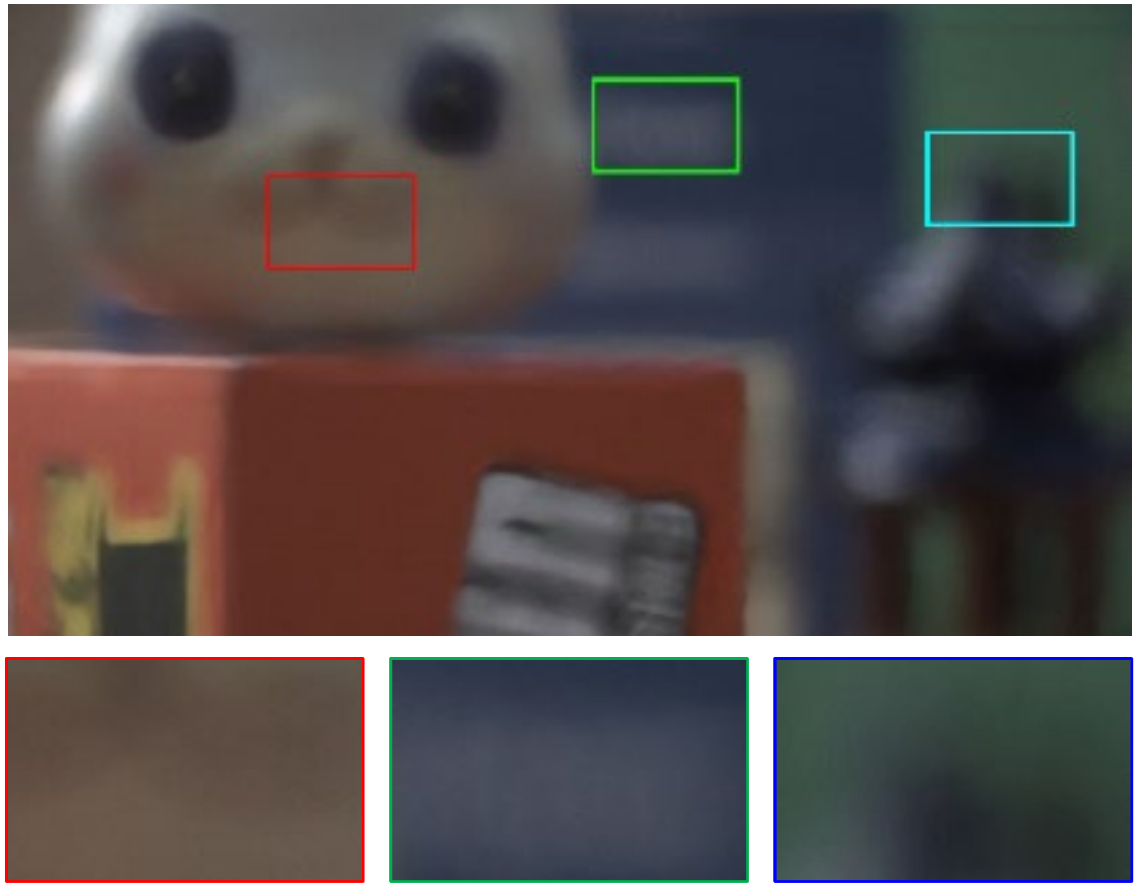
APL



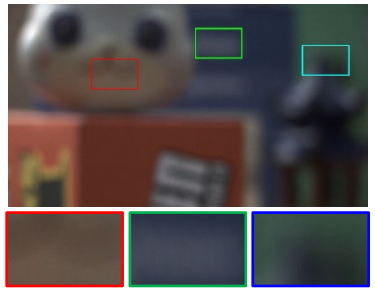
Ours

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

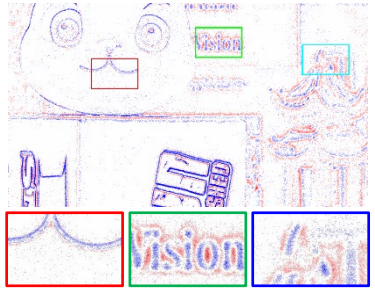
Results on Real Data



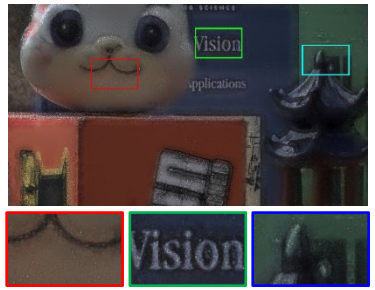
DRBNet



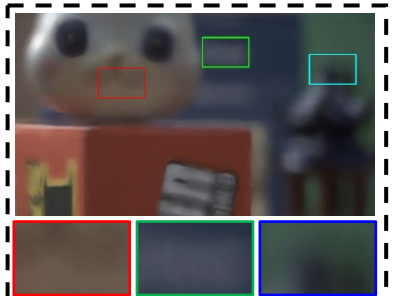
Defocused Image



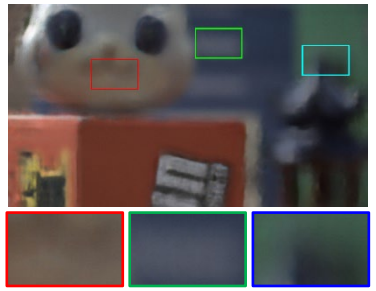
Events



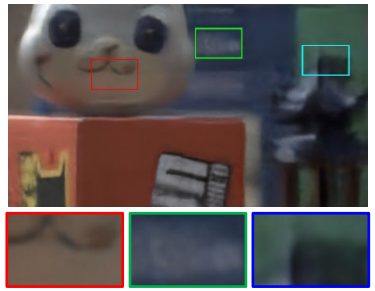
Ours



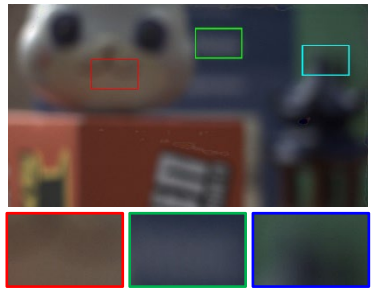
DRBNet



KPAC



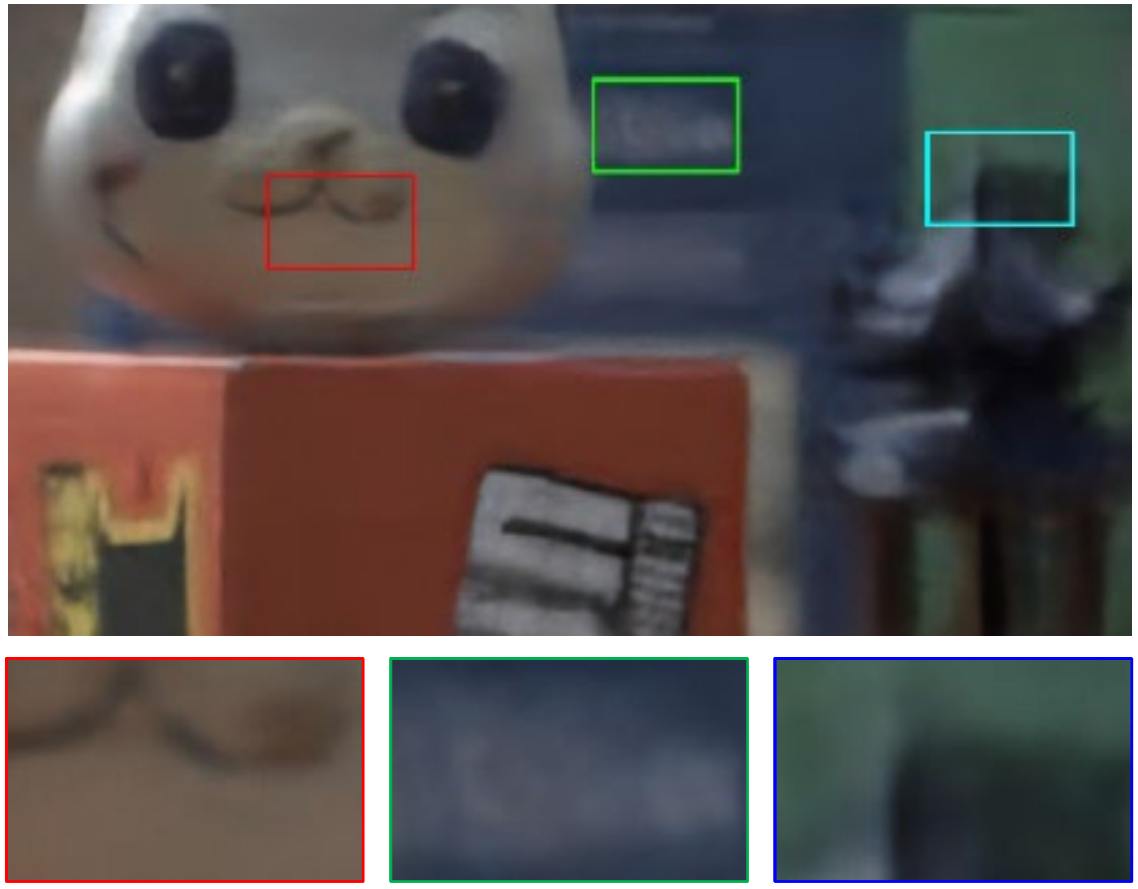
IFAN



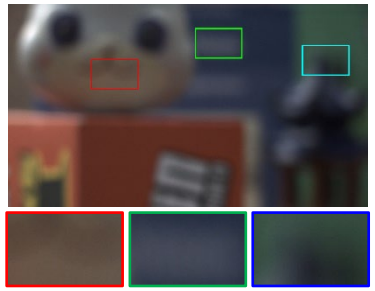
APL

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

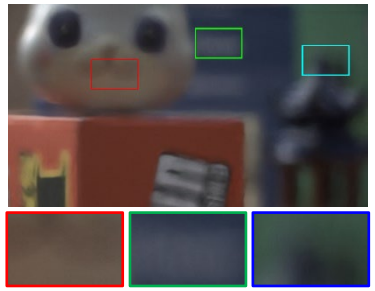
Results on Real Data



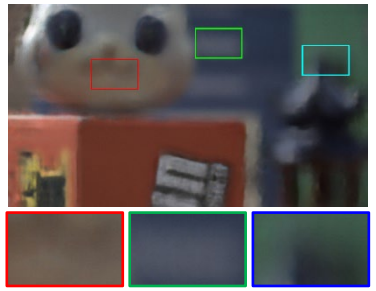
IFAN



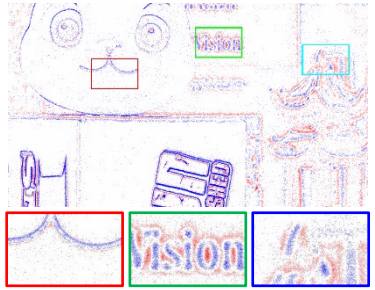
Defocused Image



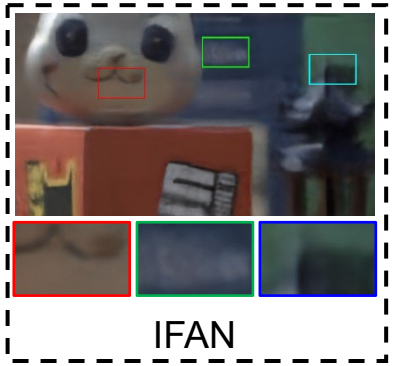
DRBNet



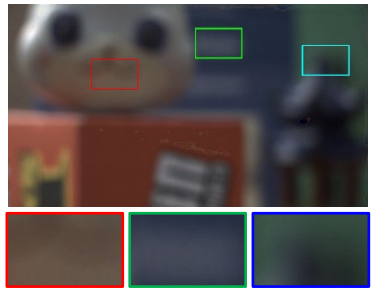
KPAC



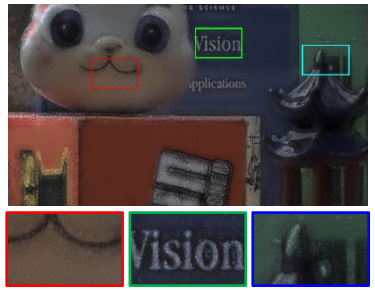
Events



IFAN



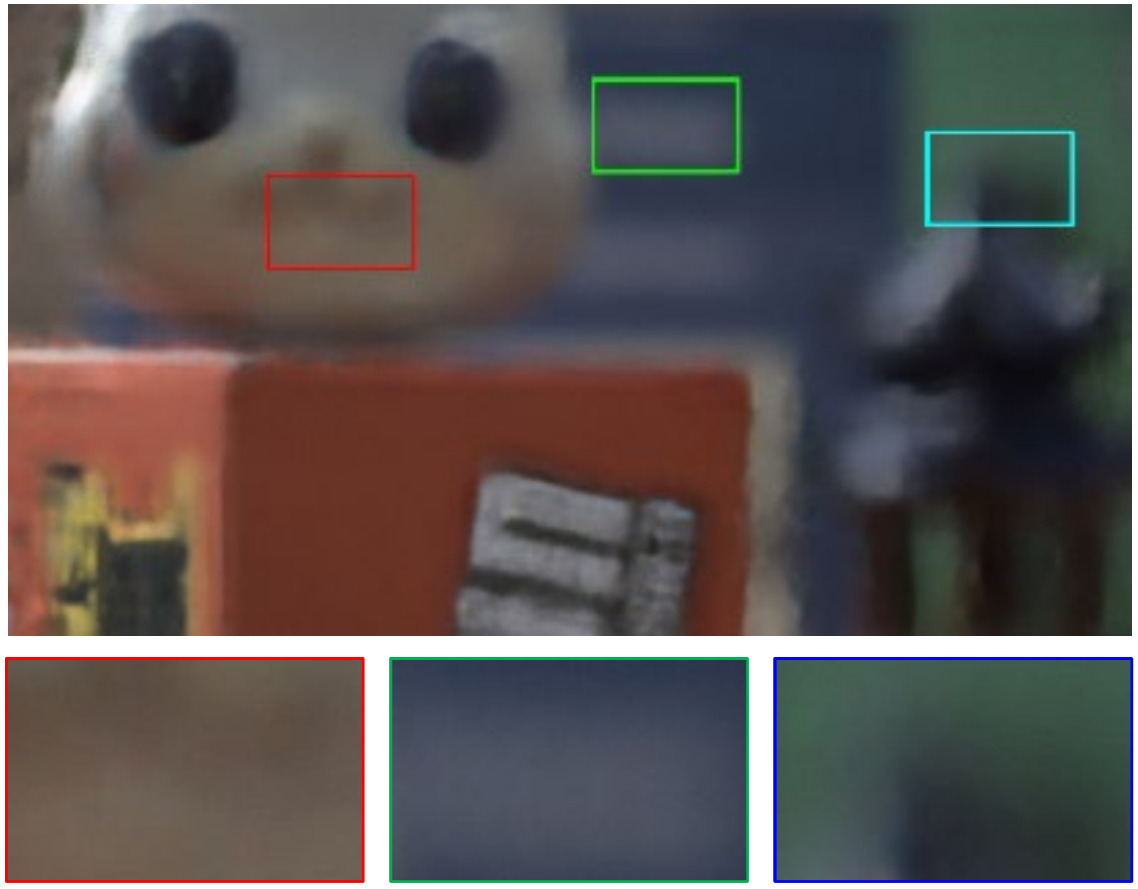
APL



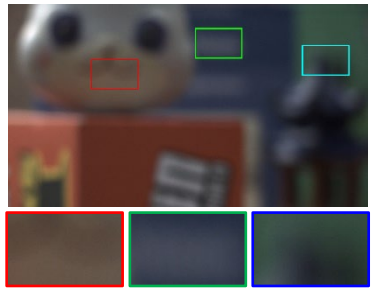
Ours

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

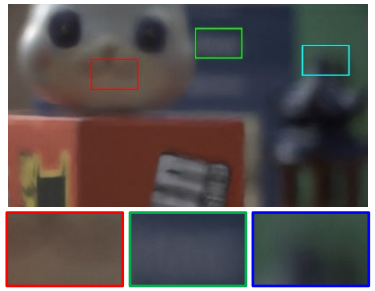
Results on Real Data



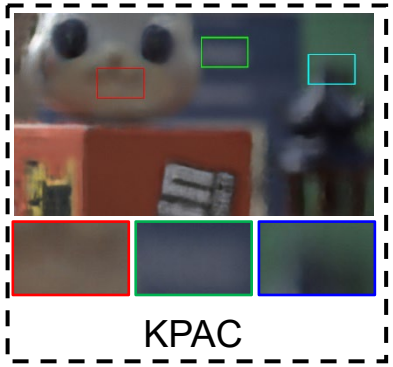
KPAC



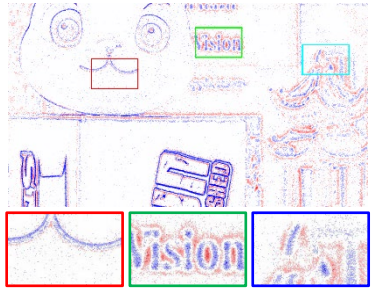
Defocused Image



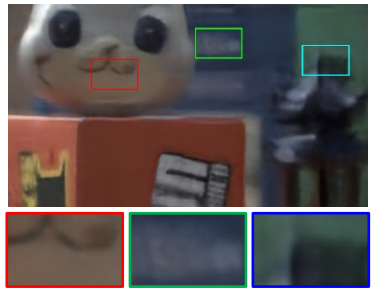
DRBNet



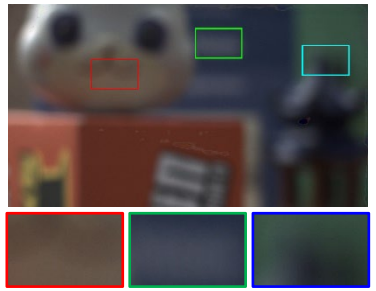
KPAC



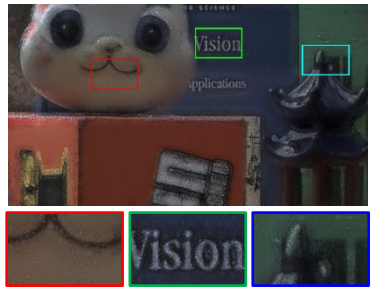
Events



IFAN



APL

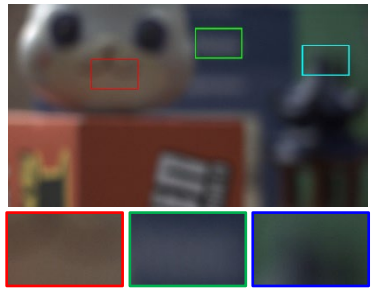


Ours

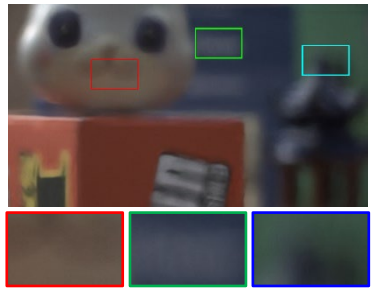
Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

Results on Real Data

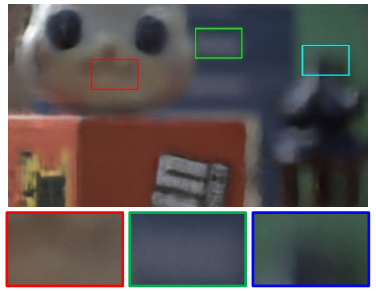
APL



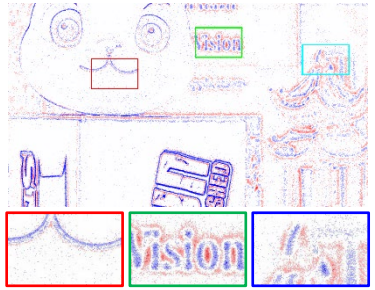
Defocused Image



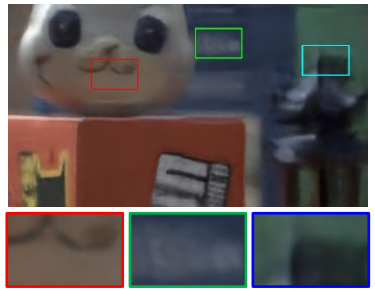
DRBNet



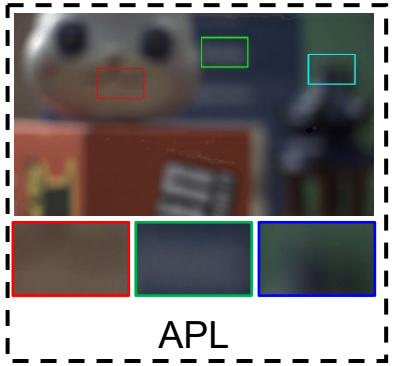
KPAC



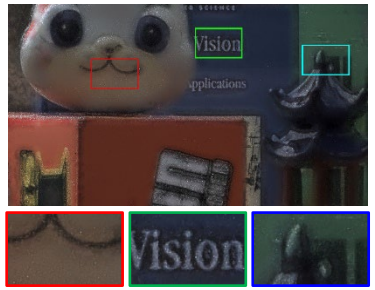
Events



IFAN



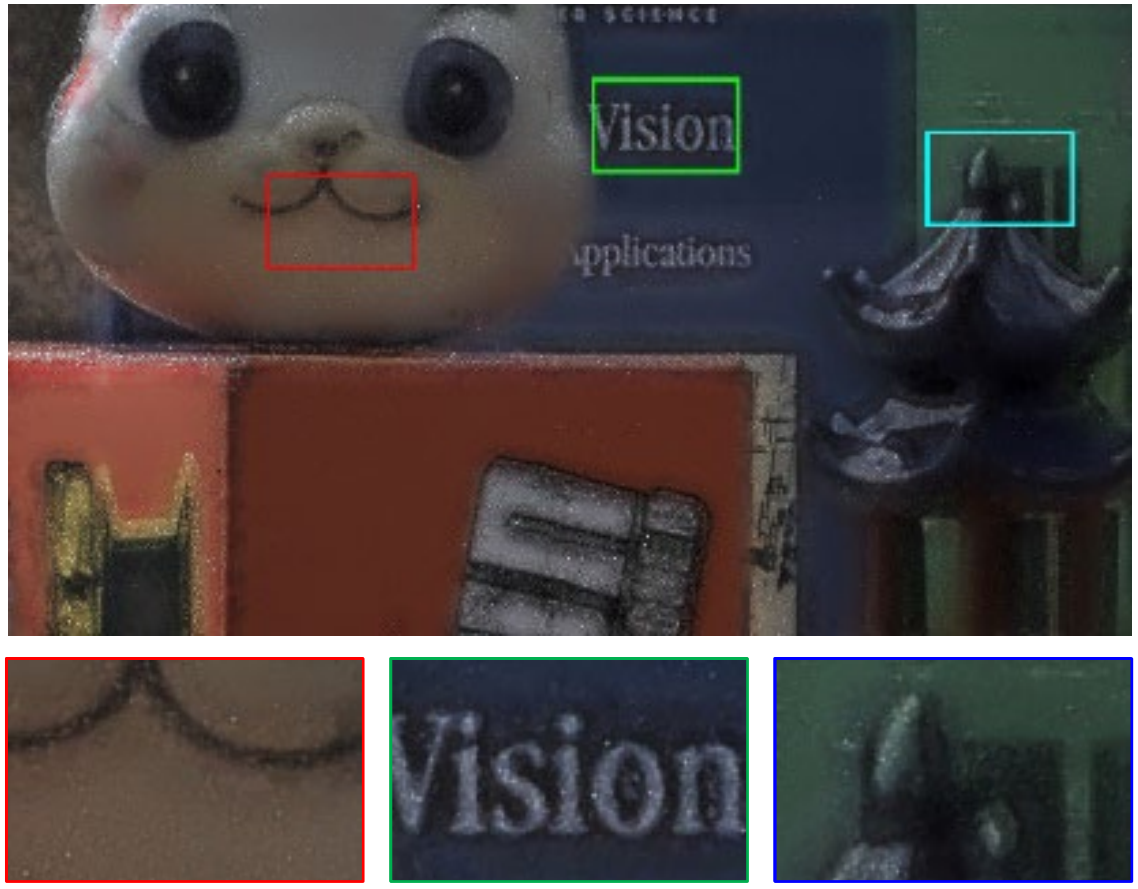
APL



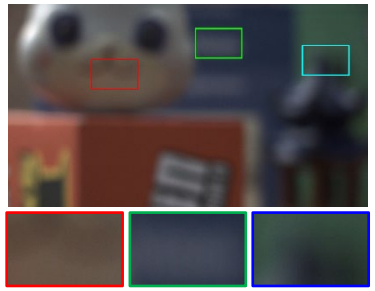
Ours

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

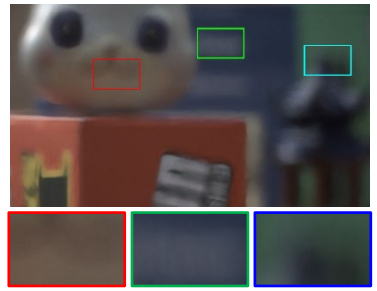
Results on Real Data



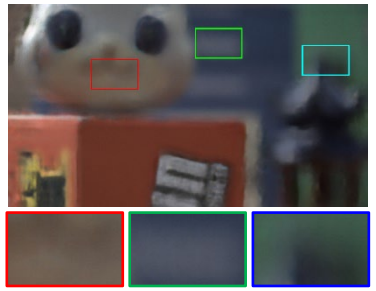
Ours



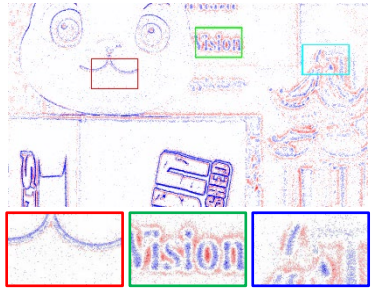
Defocused Image



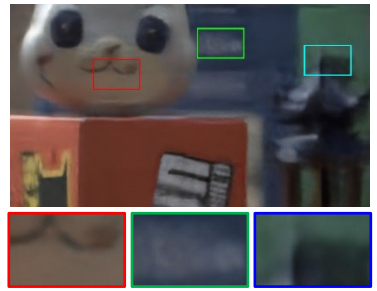
DRBNet



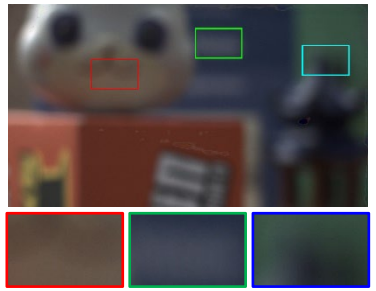
KPAC



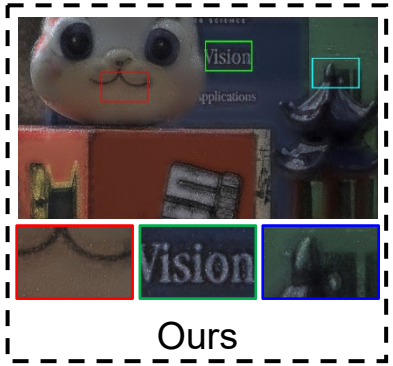
Events



IFAN



APL

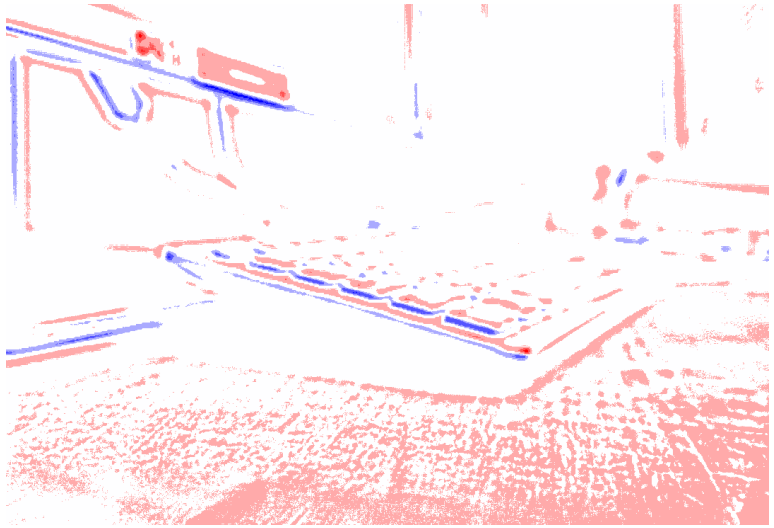


Ours

Image-based defocus: [DRBNet, CVPR 2022], [IFAN, CVPR 2021], [KPAC, ICCV 2021], [APL, ECCV 2022]

Refocusing on Synthetic Data

Input Events

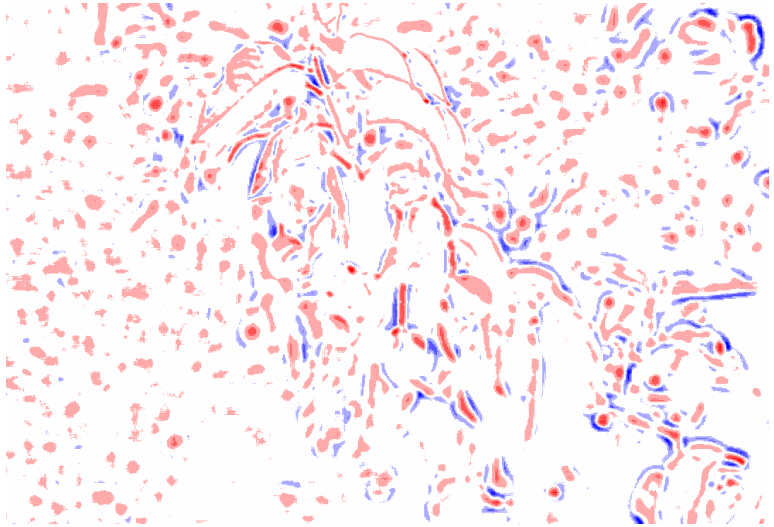


Input Image

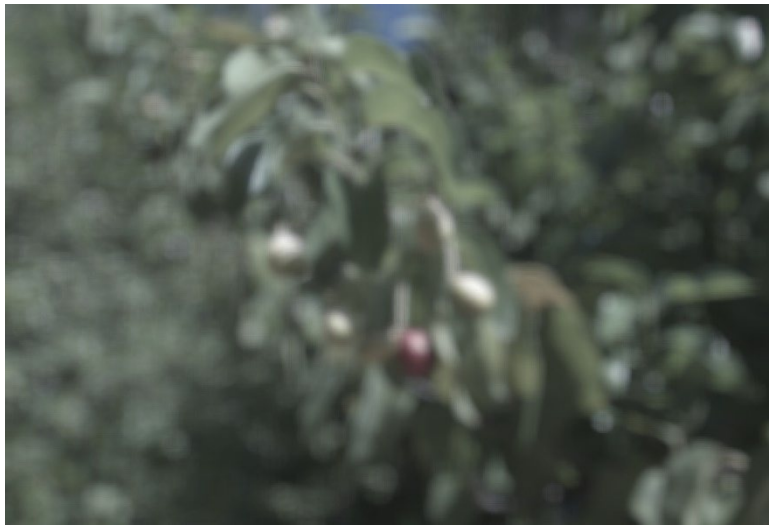
Refocus Results

Refocusing on Synthetic Data

Input Events



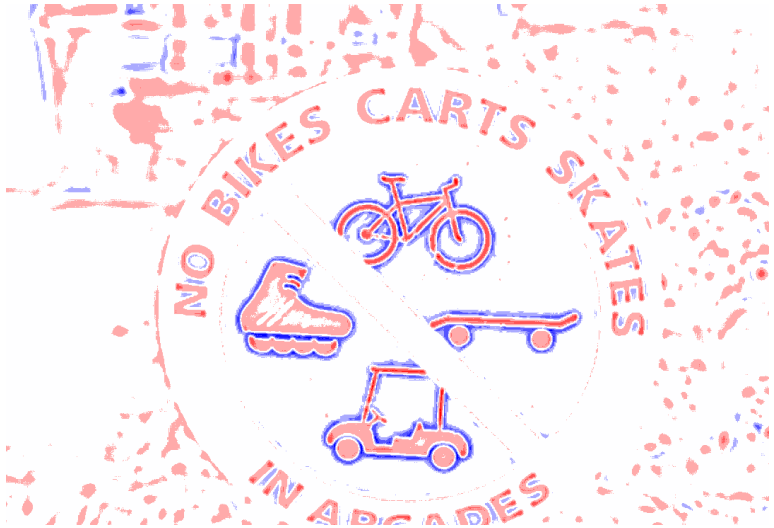
Input Image



Refocus Results

Refocusing on Synthetic Data

Input Events

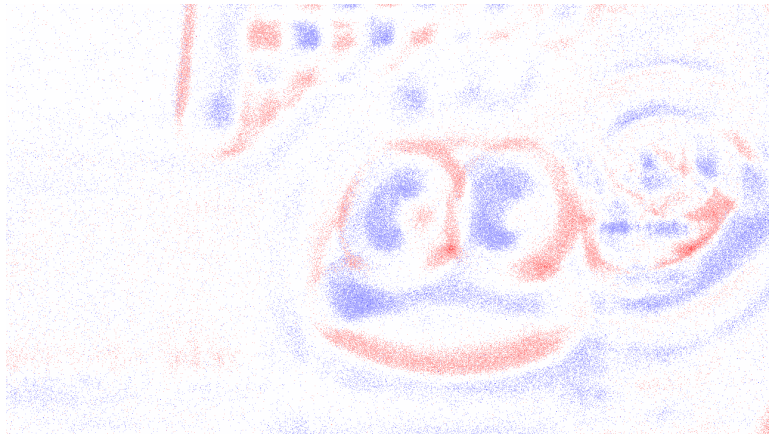


Input Image

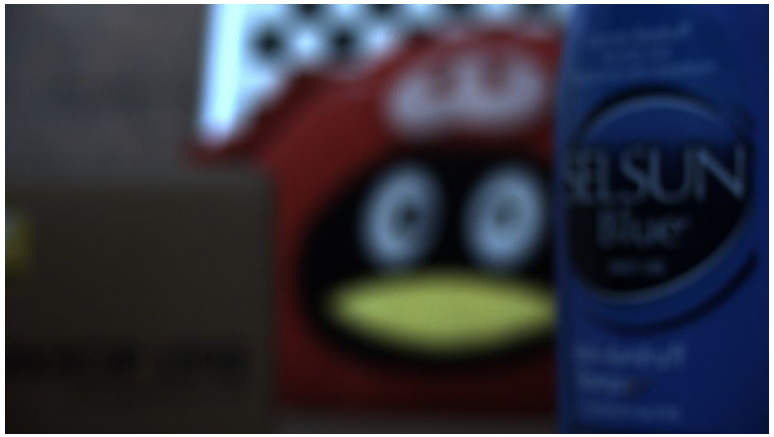
Refocus Results

Refocusing on Real Data

Input Events



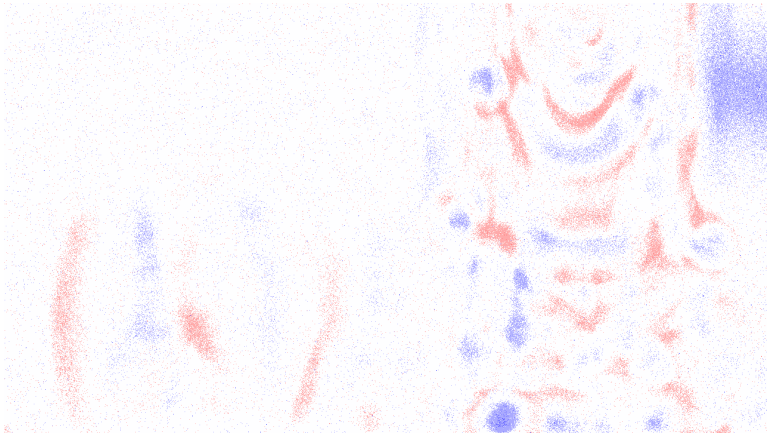
Input Image



Refocus Results

Refocusing on Real Data

Input Events

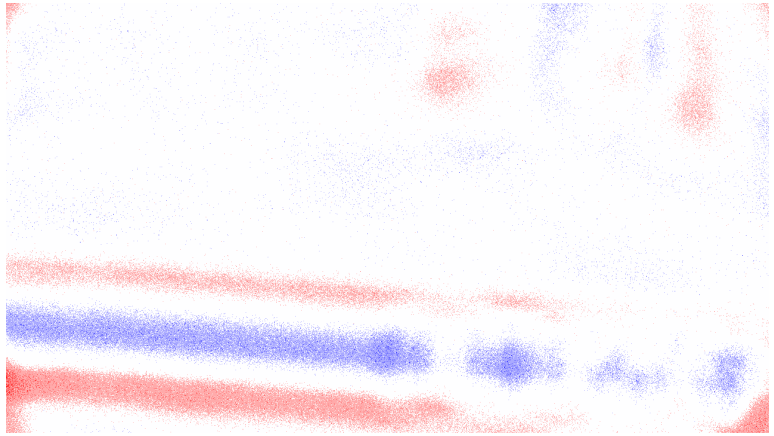


Input Image

Refocus Results

Refocusing on Real Data

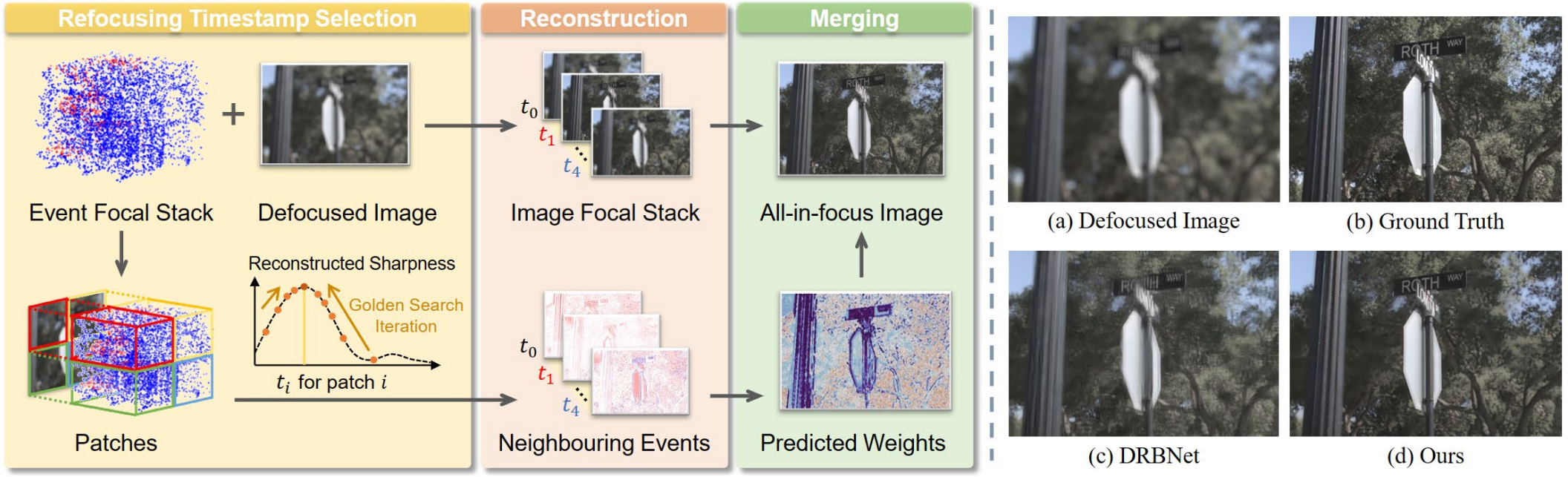
Input Events



Input Image

Refocus Results

Conclusion



- We propose recording Event Focal Stacks (EFS) for high quality all-in-focus imaging.
- We design a three-stage algorithm to exploit the continuous information encoded in event focal stacks.

Thanks for your time!

Project Page

Lab Page