Exploiting Connection-Switching U-Net for Enhancing Surface Anomaly Detection

YeongHyeon Park [1,2], Sungho Kang [1], Myung Jin Kim [2], Yeonho Lee[1], Juneho Yi [1]
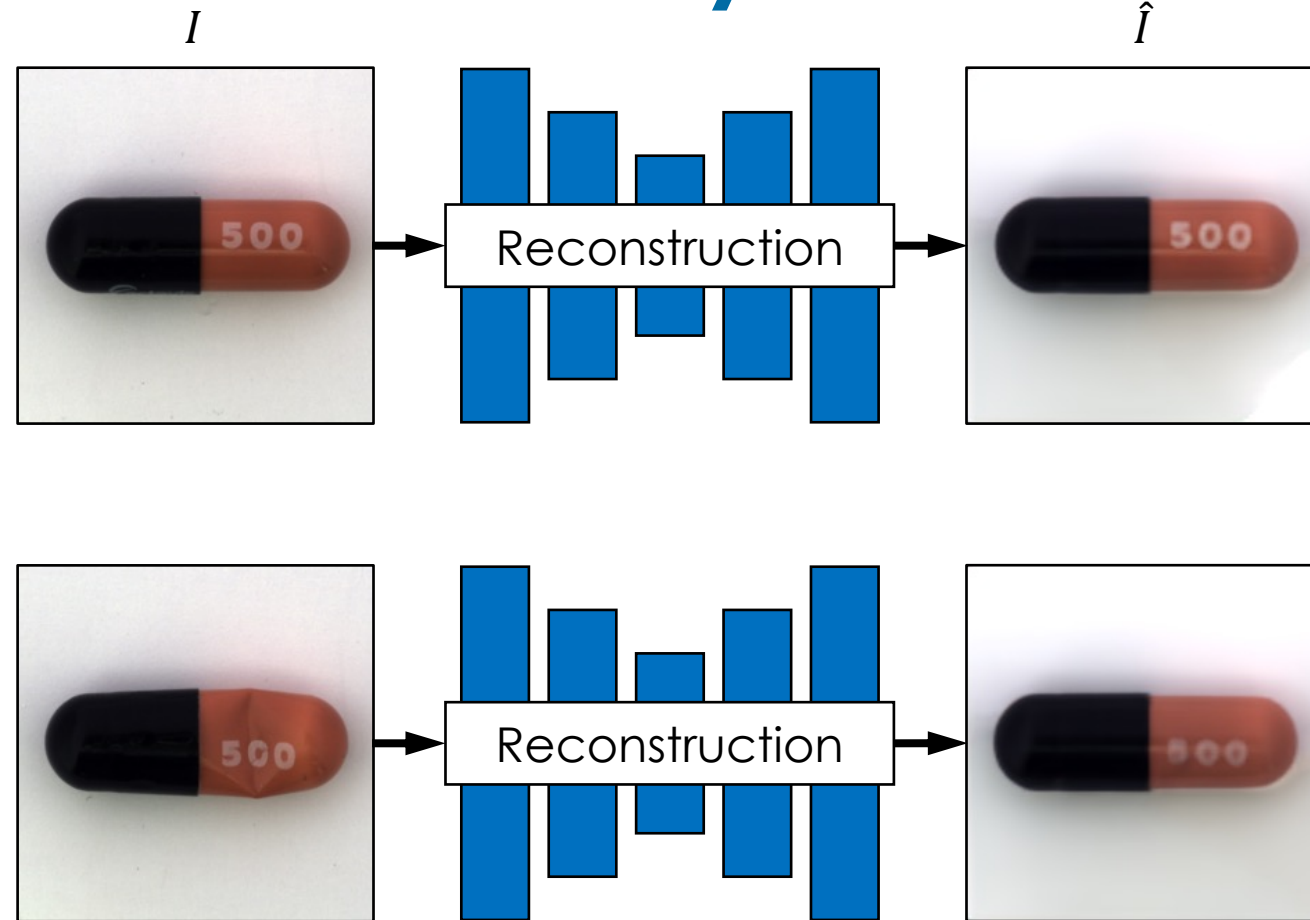
Department of ECE, Sungkyunkwan University [1]

SK Planet Co., Ltd. [2]

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Unsupervised anomaly detection (UAD)

I

Reconstruction

$\hat{I}$

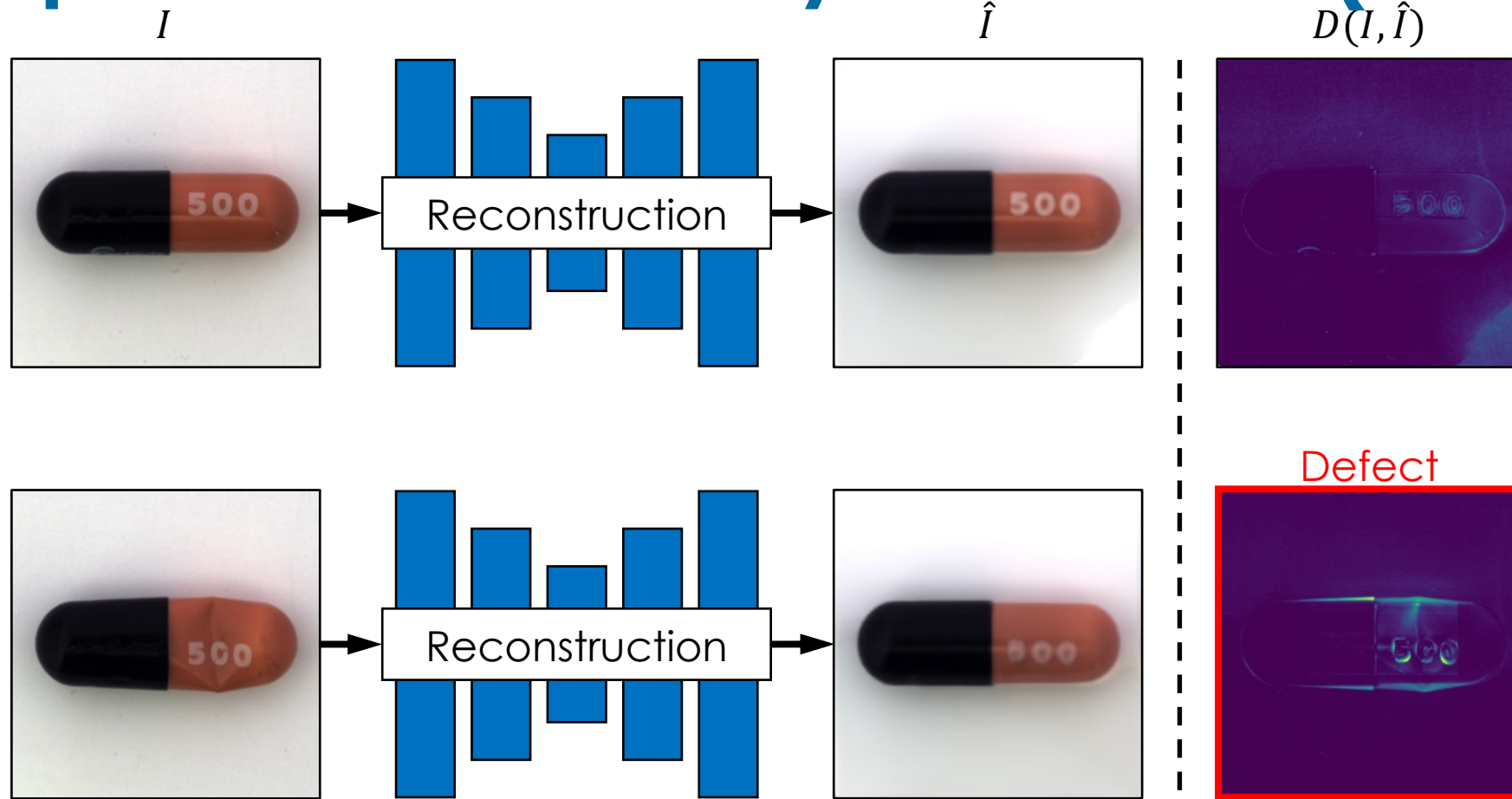Reconstruction

[1] Park et al., "Visual Defect Obfuscation Based Self-Supervised Anomaly Detection Strategy." *Scientific Reports*, 2024

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Unsupervised anomaly detection (UAD)

I $\hat{I}$ $D(I,\hat{I})$

Reconstruction

Defect

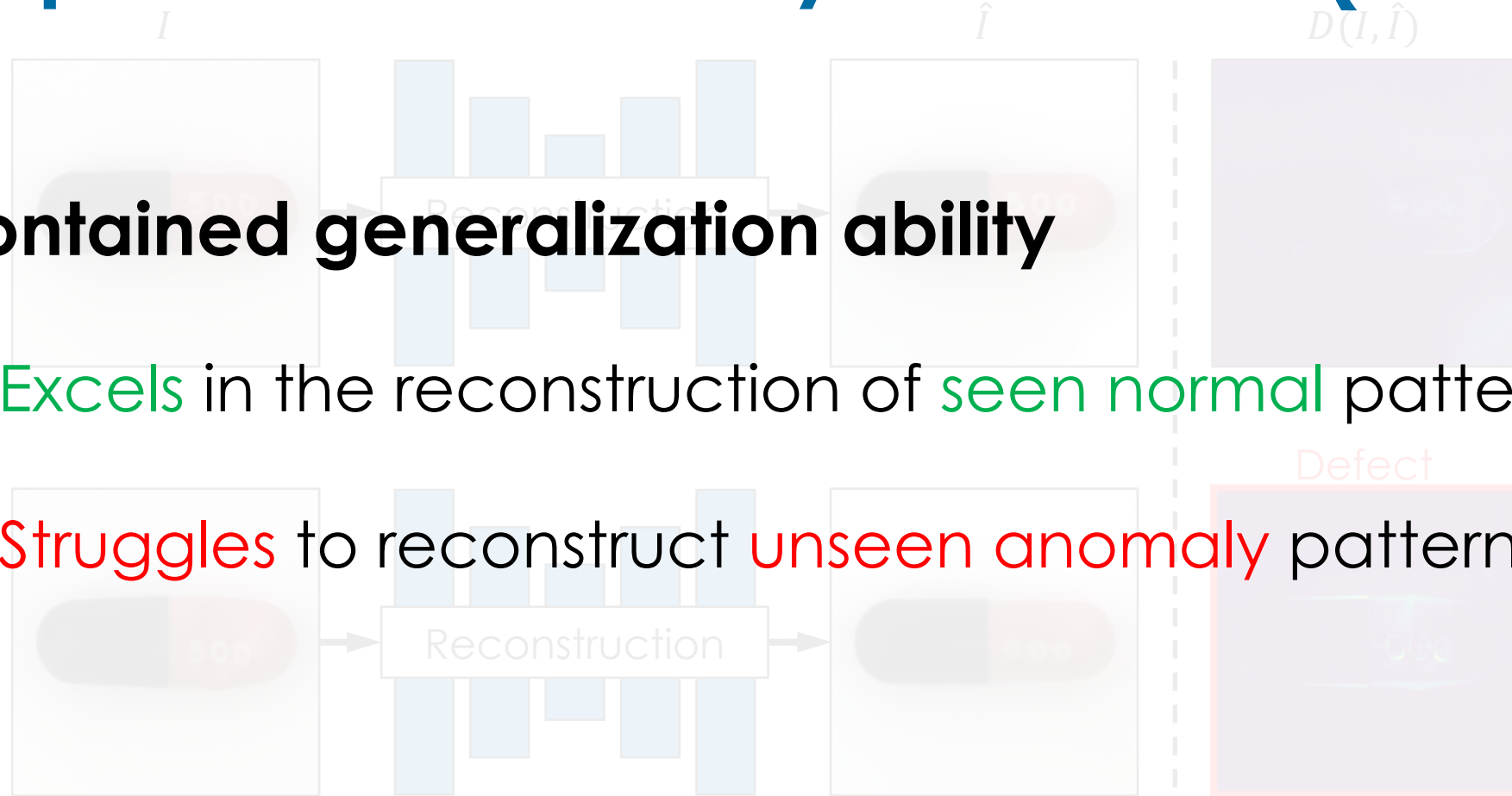[1] Park et al., "Visual Defect Obfuscation Based Self-Supervised Anomaly Detection Strategy." *Scientific Reports*, 2024

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Unsupervised anomaly detection (UAD)

Contained generalization ability

- Excels in the reconstruction of seen normal patterns

- Struggles to reconstruct unseen anomaly patterns

[1] Park et al., "Visual Defect Obfuscation Based Self-Supervised Anomaly Detection Strategy." *Scientific Reports*, 2024
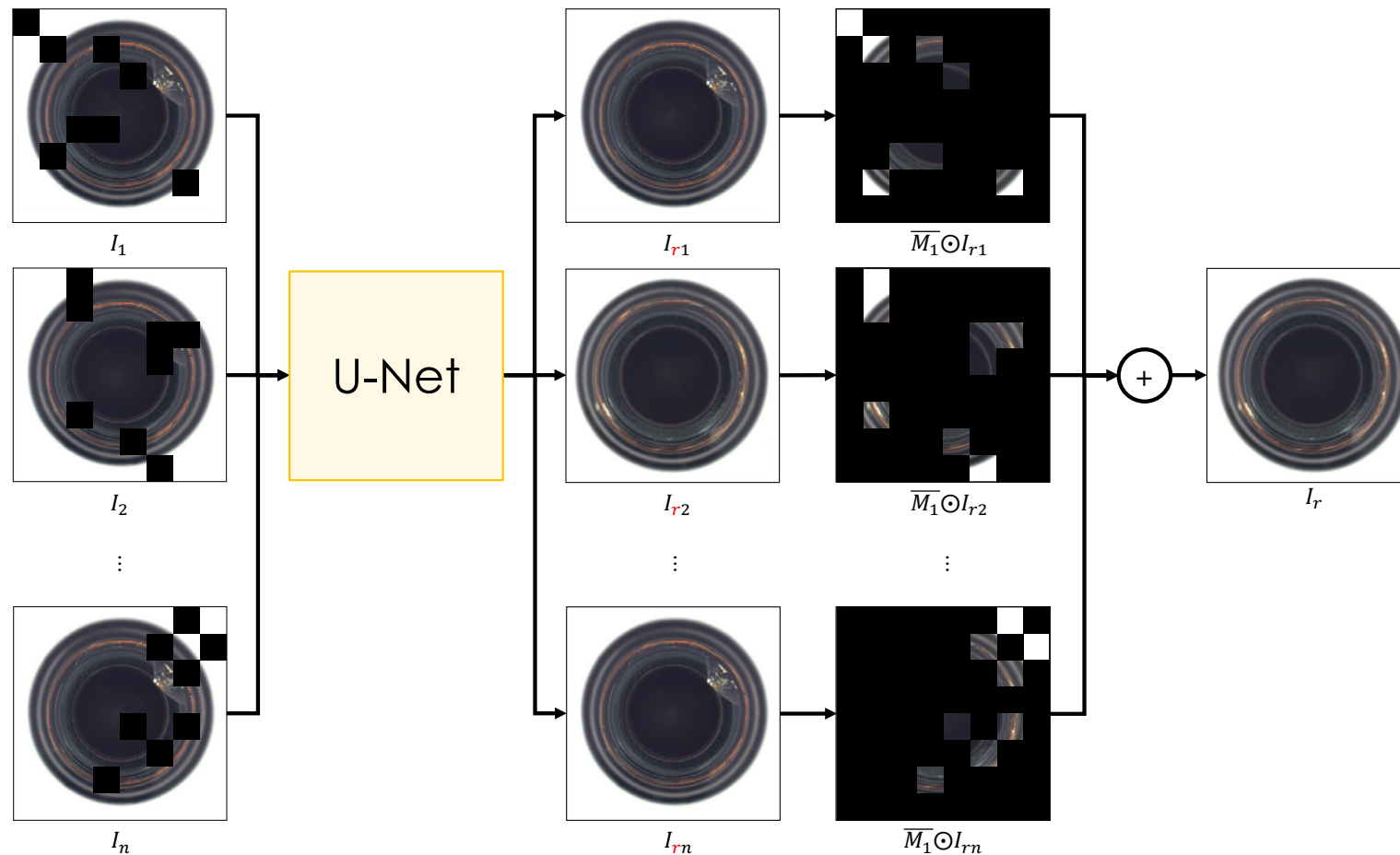
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Motivations

❑ Excel the accurate reconstruction of normal patterns
- For judging normal as normal
- Skip connections of U-Net excels accurate reconstruction of input image
- Skipping connections also allows fast loss convergence in the training process

❑ Avoid the Identity shortcut (IS) issue of U-Net
- For judging defect as defect
- Skip connections can excessively transmit defect features to the decoder

❑ Explore potential performance enhancement of deployed UAD models
- Control generalization ability of U-Net by connection switching
- Minimize test time false alarms without additional training

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Reconstruction-by-inpainting

[2] Vitjan et al., "Reconstruction by inpainting for visual anomaly detection." *Pattern Recognition,* 2021

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Reconstruction-by-inpainting

Issues of multiple random masking

1) <u>Inference latency</u> issue of multiple masking

2) <u>Output inconsistency</u> issue of random masking

I_n I_{rn} $\overline{M_1} \odot I_{rn}$

[2] Vitjan et al., "Reconstruction by inpainting for visual anomaly detection." *Pattern Recognition,* 2021
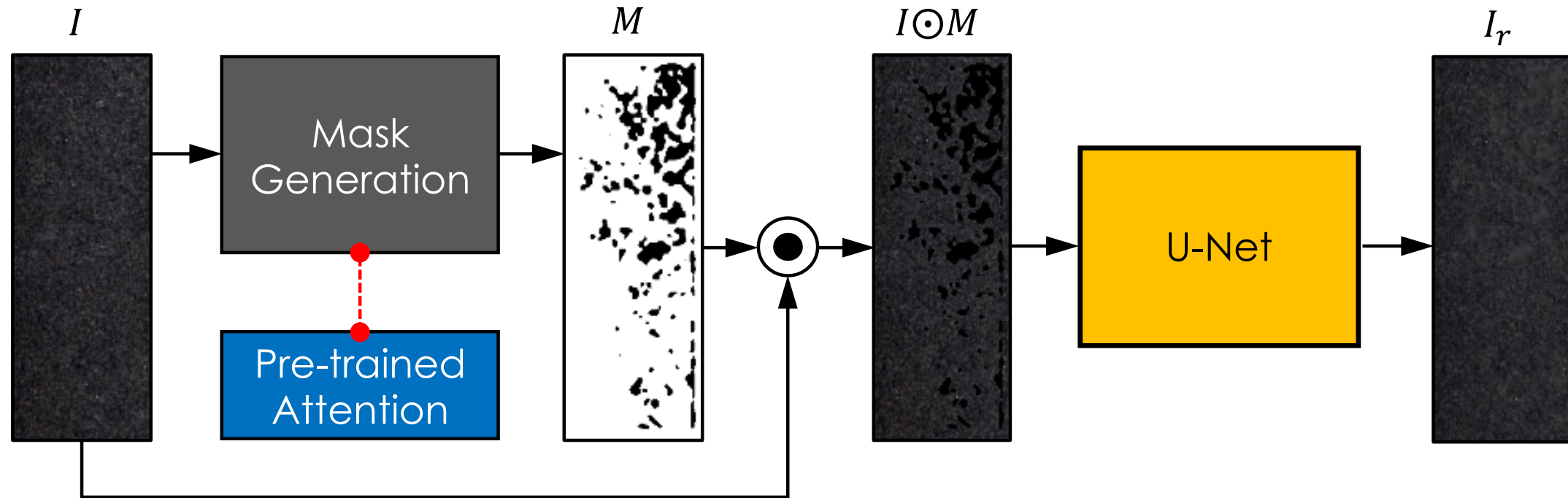
Single deterministic masking scheme
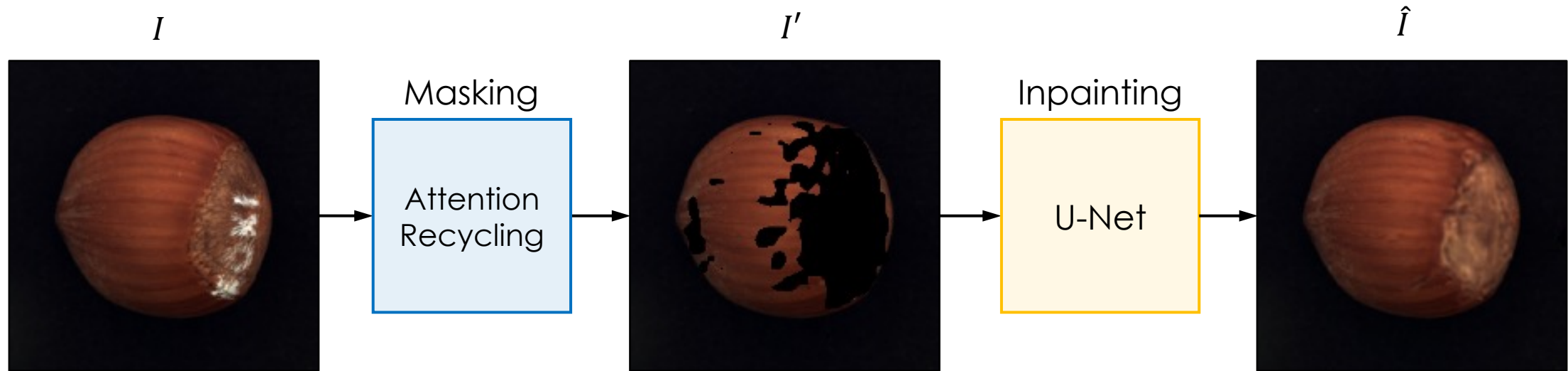
Recycling of a <u>pre-trained attention mechanism</u>
to generate single deterministic mask

[1] Park et al., "Visual Defect Obfuscation Based Self-Supervised Anomaly Detection Strategy." *Scientific Reports*, 2024
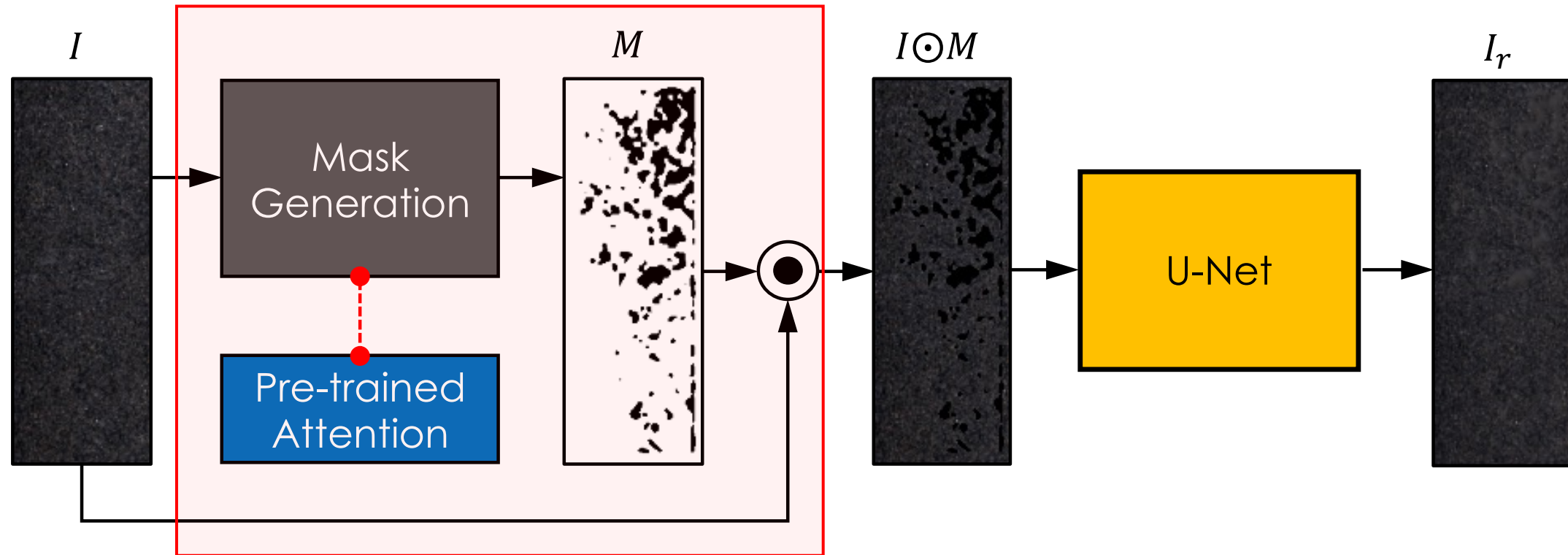[3] Caron et al., "Emerging properties in self-supervised vision transformers." ICCV 2021

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U-Net for anomaly detection

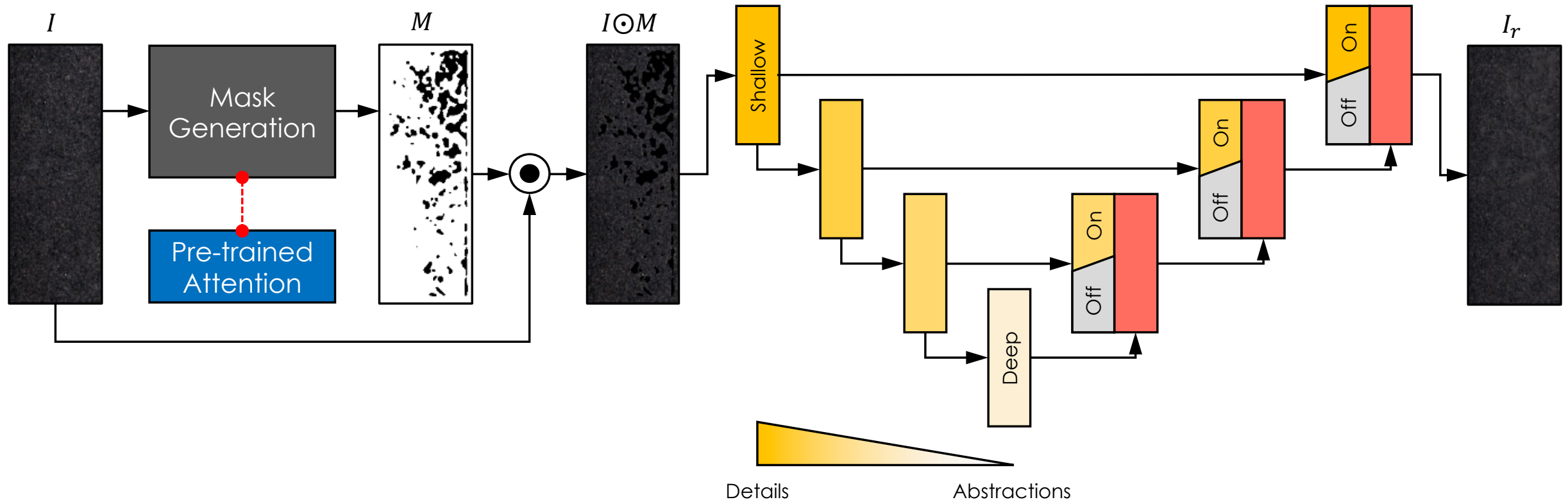# U-Net for anomaly detection

Cut out <u>suspected</u> defectives
by MNIST pre-trained attention

[4] Park et al., "Boost-up Efficiency of Defective Solar Panel Detection with Pre-trained Attention Recycling." *IEEE Trans. Industrial Applications*, 2023

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U-Net for anomaly detection

Connection Switch on skip connection
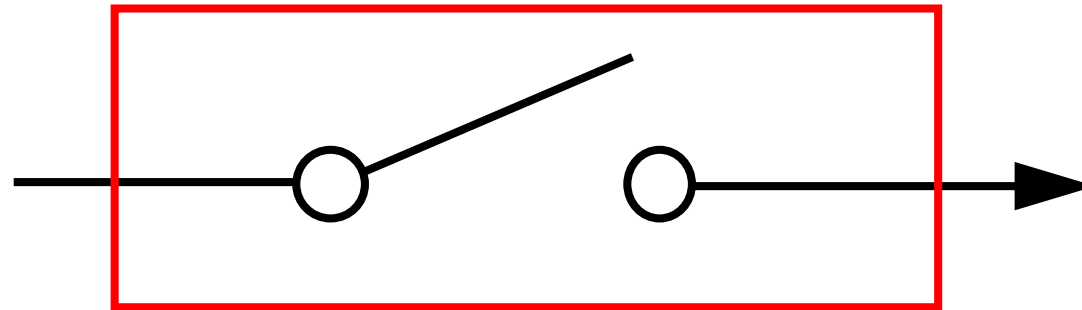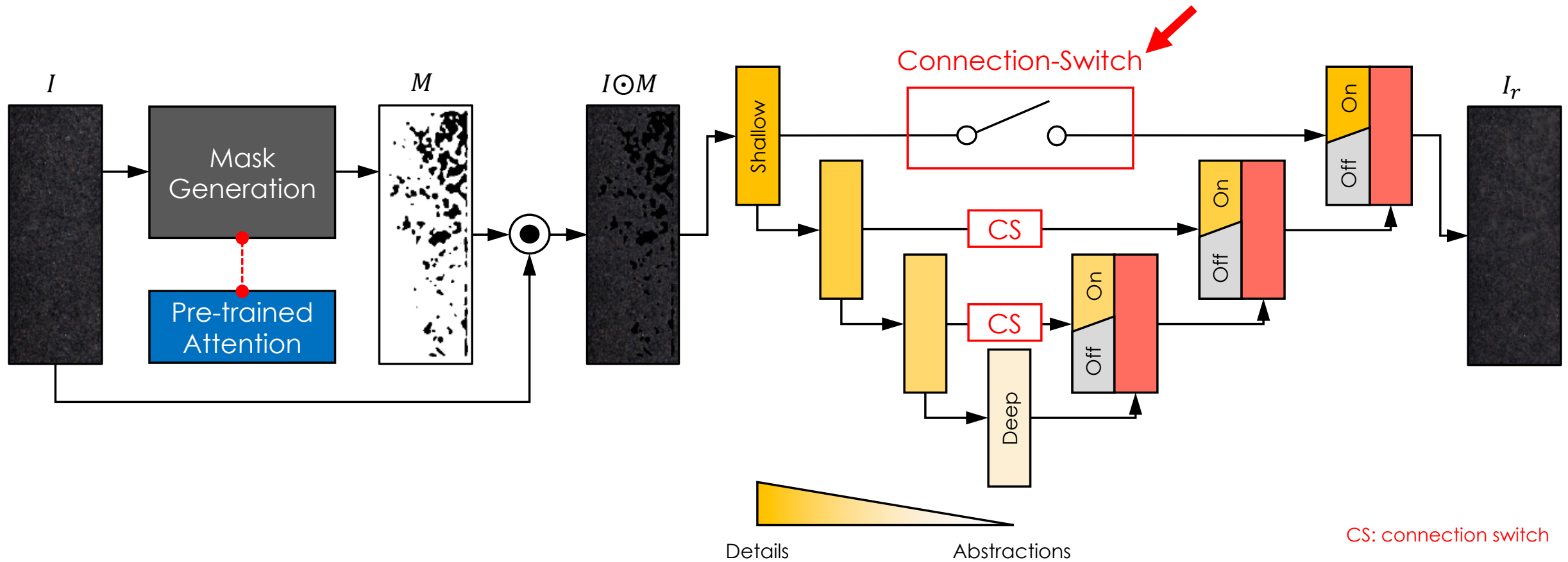

To block transmitting details of defective features
(Prevent reconstruction of defect image)

Add Connection Switches on U-Net

Connection Switching U-Net

Connection-Switch

Shallow

CS

CS

Deep

On

Off

On

Off

Shallow layer
Detailed features
Easy for decoding

Deep layer
Abstract features
Hard for decoding
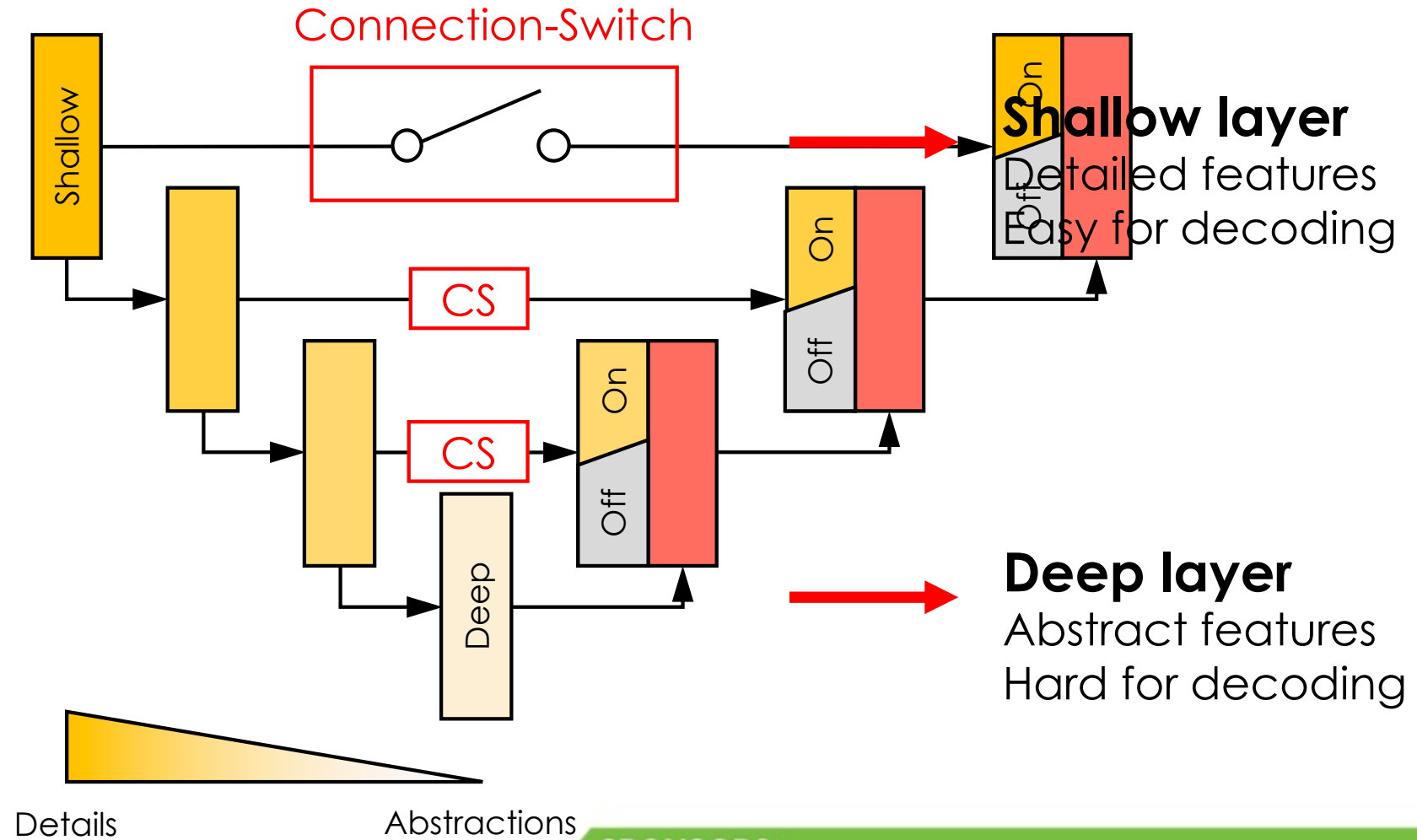
Details   Abstractions

Training

Training on fully activated skip connections

- I: Input image
- I_r: Reconstructed image
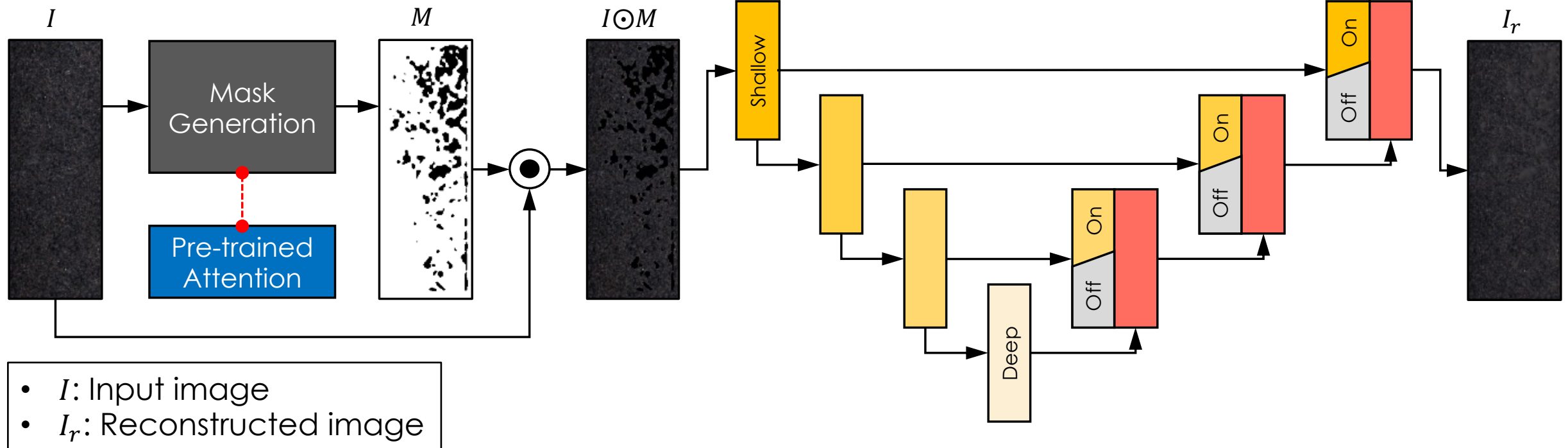
$$\mathcal{L}_{total} = \lambda_2 \mathcal{L}_2(I, I_r) + \lambda_{ssim} \mathcal{L}_{ssim}(I, I_r) + \lambda_{msgms} \mathcal{L}_{msgms}(I, I_r)$$

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Inference

Connection-Switch

Inference after deactivating some of the connections

Quantitative results

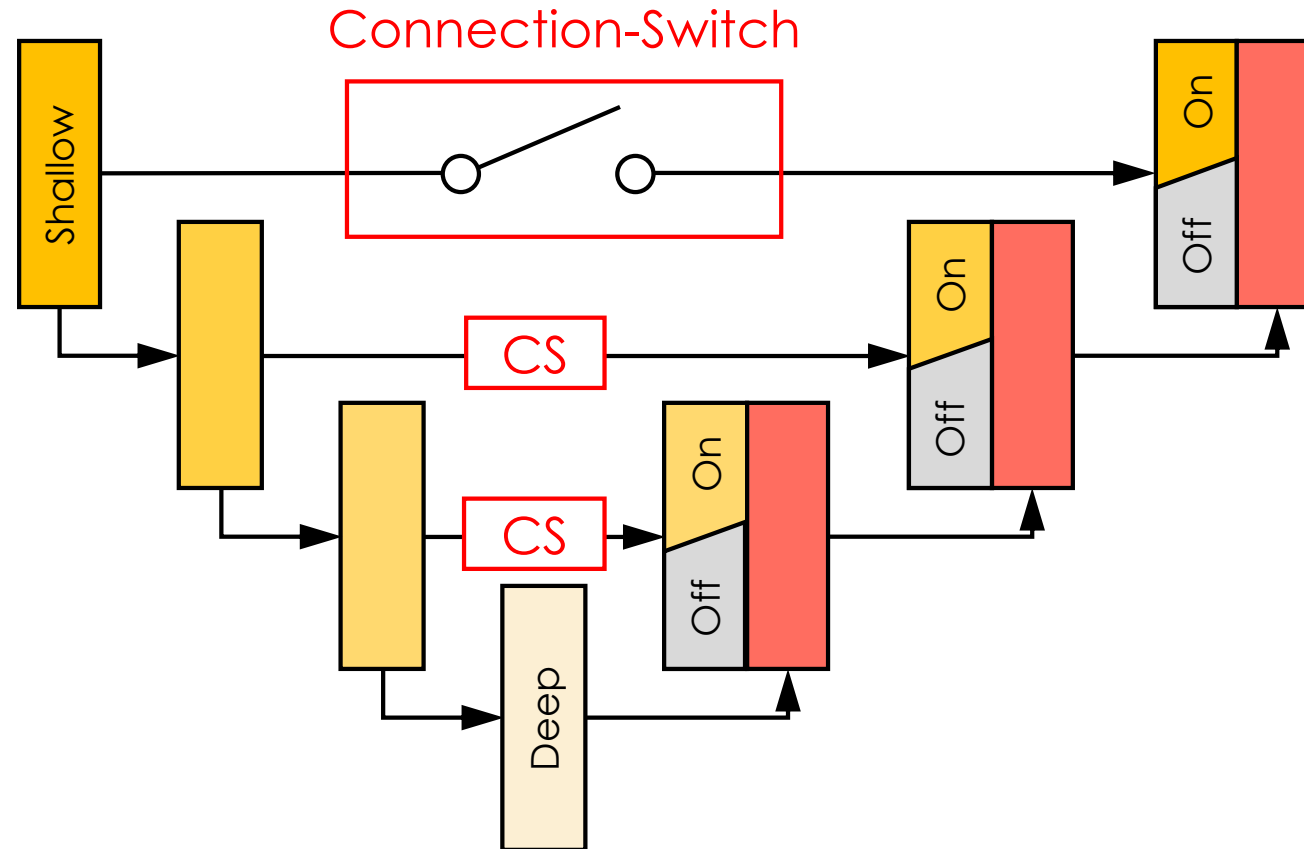| Model		Skip connection			AUROC ↑	Time (seconds) ↓	
		Shallow	Middle	Deep		Training	Inference
AE		✗	✗	✗	0.752	**11,173**	**0.017**
RIAD [2]		✓	✓	✓	0.703	198,429	0.246
Attention Mask	$CS\text{-}U\text{-}Net_A$	✓	✓	✓	0.829	24,325	0.043
	$CS\text{-}U\text{-}Net_D$	✓	✓	✗	0.832		
	$CS\text{-}U\text{-}Net_M$	✓	✗	✓	0.838	-	0.043
	$CS\text{-}U\text{-}Net_S$	✗	✓	✓	**0.858**		

- **CS-U-Net$_A$** : All skip connections on
- **CS-U-Net$_D$** : Deep CS off

- **CS-U-Net$_M$** : Middle CS off
- **CS-U-Net$_S$** : Shallow CS off

[2] Vitjan et al., "Reconstruction by inpainting for visual anomaly detection." *Pattern Recognition,* 2021

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Quantitative results

Model		Skip connection			AUROC ↑	Time (seconds) ↓	
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[2] Vitjan et al., "Reconstruction by inpainting for visual anomaly detection." *Pattern Recognition,* 2021

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[2] Vitjan et al., "Reconstruction by inpainting for visual anomaly detection." *Pattern Recognition*, 2021
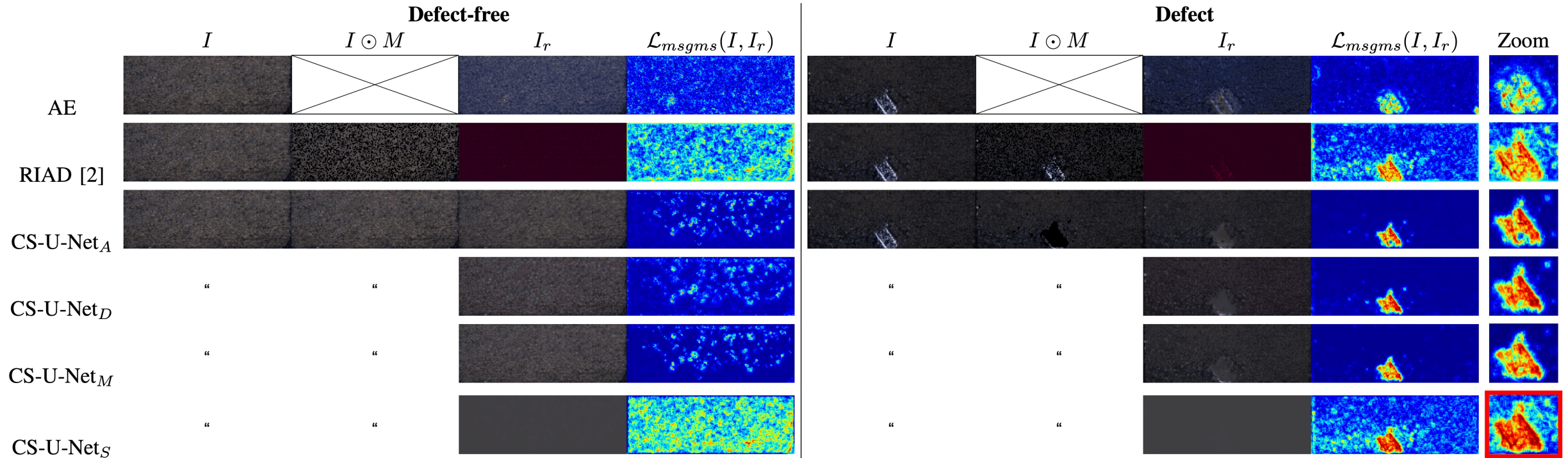
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Qualitative results

	Defect-free				**Defect**				
	I	$I \odot M$	I_r	$\mathcal{L}_{msgms}(I, I_r)$	I	$I \odot M$	I_r	$\mathcal{L}_{msgms}(I, I_r)$	Zoom
AE									
RIAD [2]									
CS-U-Net$_A$									
CS-U-Net$_D$									
CS-U-Net$_M$									
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[2] Vitjan et al., "Reconstruction by inpainting for visual anomaly detection." *Pattern Recognition*, 2021

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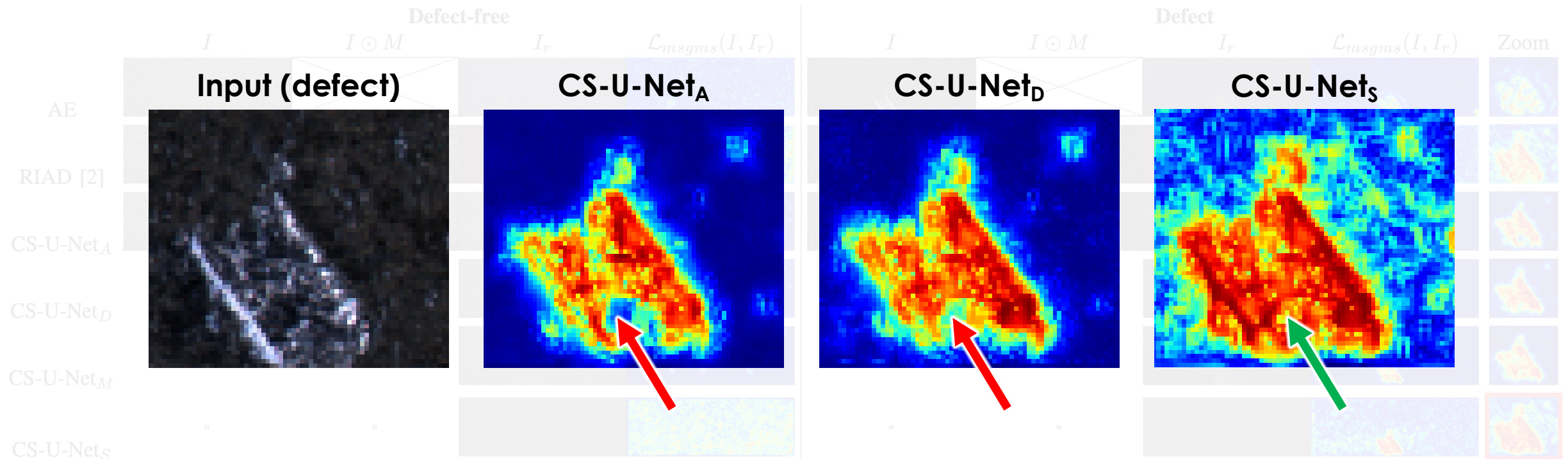
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Qualitative results

- **CS-U-Net$_A$** : All skip connections on

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[2] Vitjan et al., "Reconstruction by inpainting for visual anomaly detection." *Pattern Recognition,* 2021

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Conclusions

❑ Enhance performance of deployed UAD models via CS module
- Without additional training process
- Prevents accurate reconstruction of defective patterns

❑ Demonstrate the effect of CS on/off for each depth of layers
- CS off helps to block the transmission of defect feature to the decoder
- Detailed features are passed by shallow skip connection

Future plans

❑ Investigate into the optimal connection switching
- Combinations of cutting off skip connections
- Learnable connection switching method

❑ Develop a method to block the transmission of defect feature
- Detect and block missing mask region of defect feature

Input	Attention case1	Attention case2	Attention case3

Missing mask regions

Potential missing mask regions
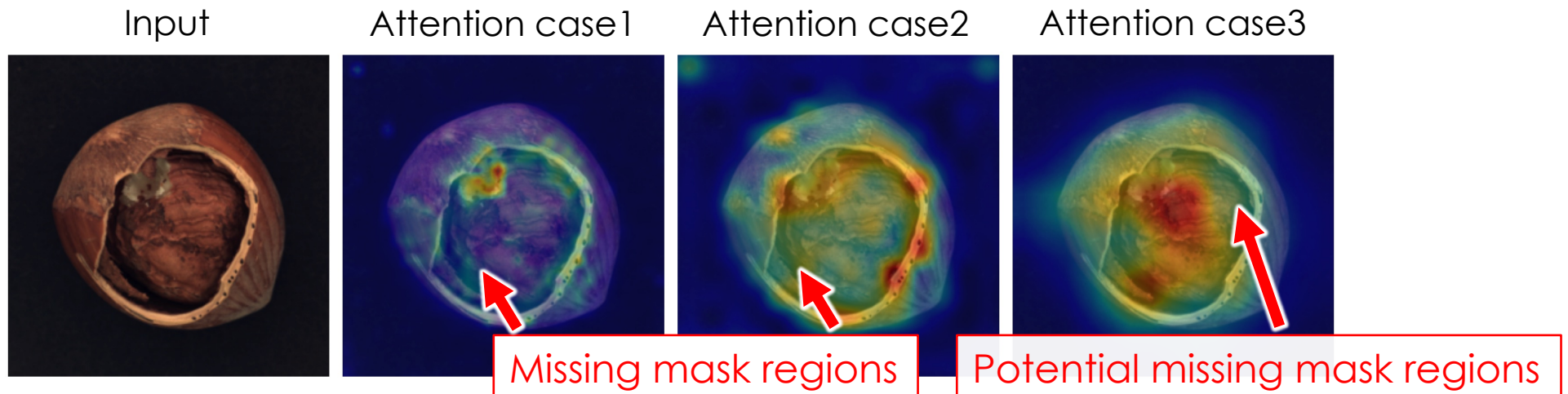
[5] Park et al., "Feature Attenuation of Defective Representation Can Resolve Incomplete Masking on Anomaly Detection." arXiv, 2024

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Thank you

YeongHyeon Park