A Unified Model for Compressed Sensing MRI Across Undersampling Patterns

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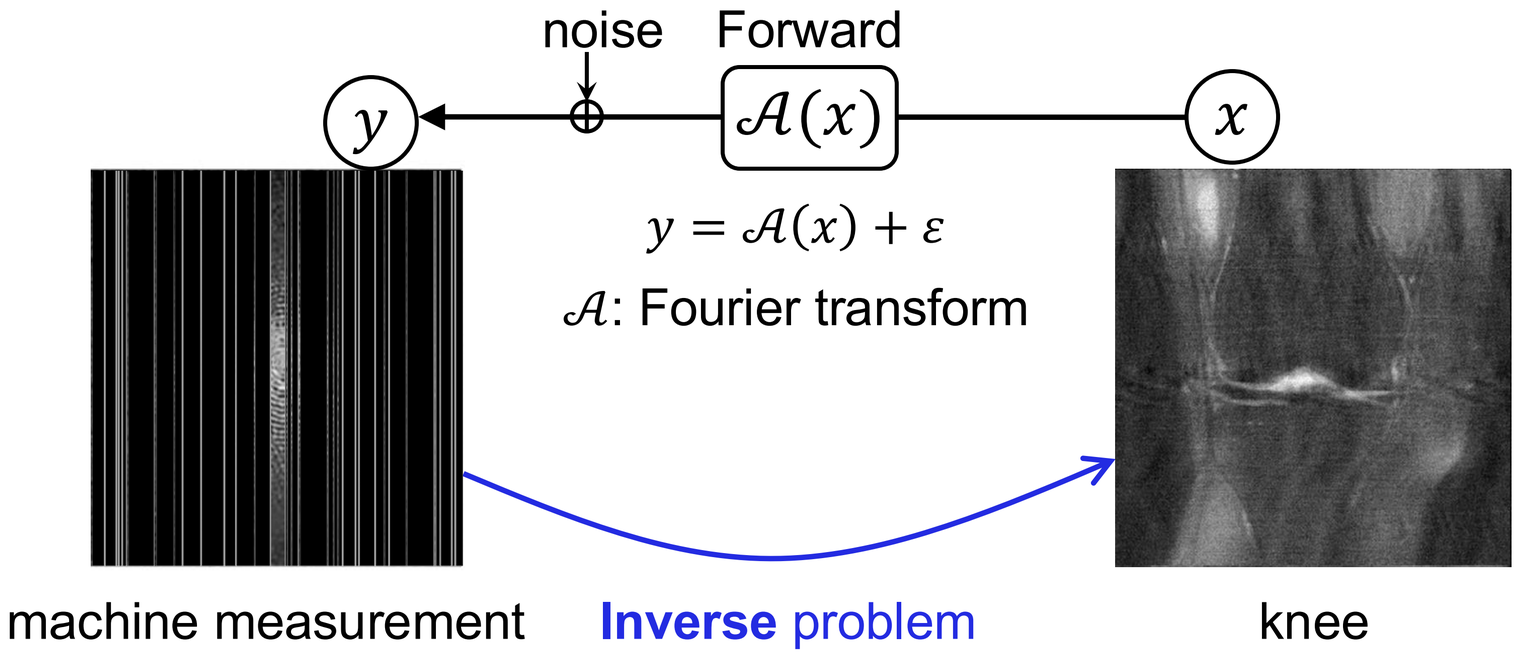
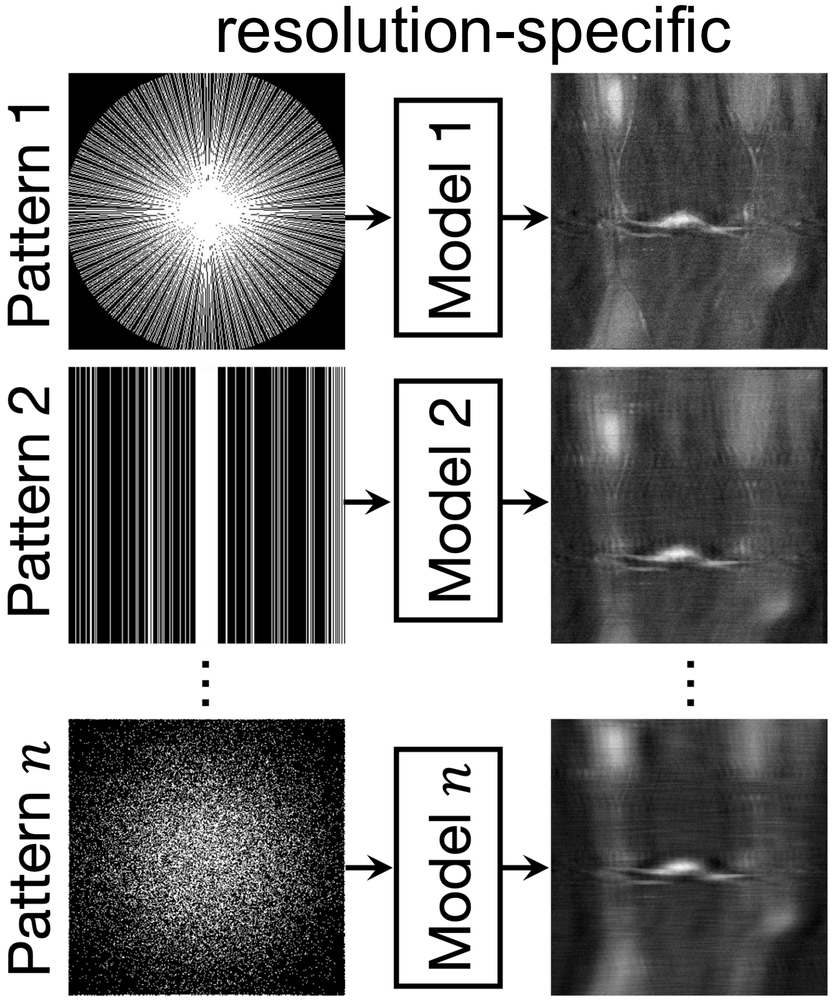
Caltech

CVPR Nashville JUNE 11-15, 2025

Task: MRI reconstruction



Neural network for MRI reconstruction



Improves diagnostic performance for brain, knee and pelvic MRI.[1]

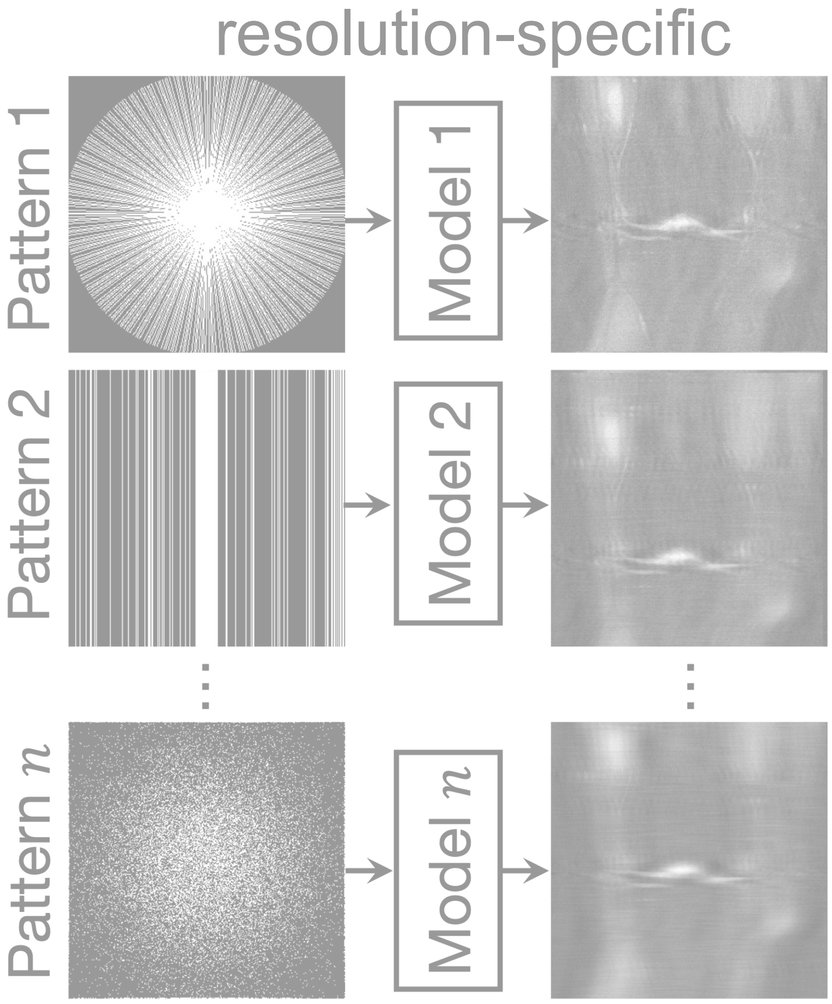
Robust on unseen scanners.[2]

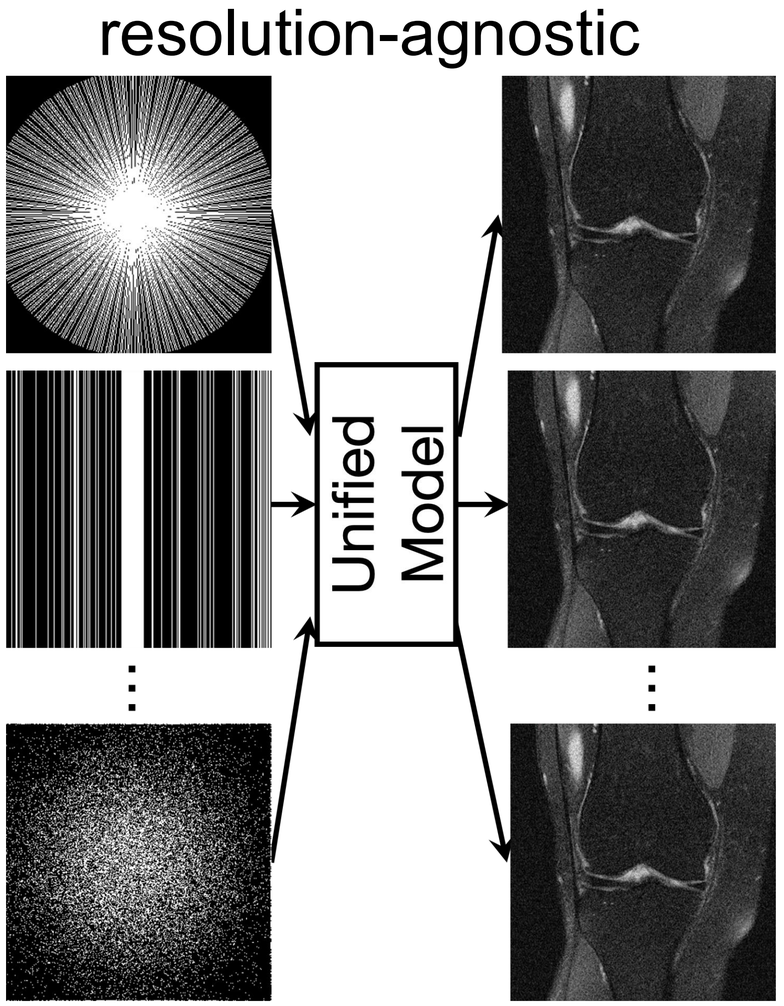
Undersampling pattern changes in clinics…

→ **Specific network needed** for a specific measurement pattern.

1 [Kiryu et al., ‘23]
2 [Wood et al., ‘22]

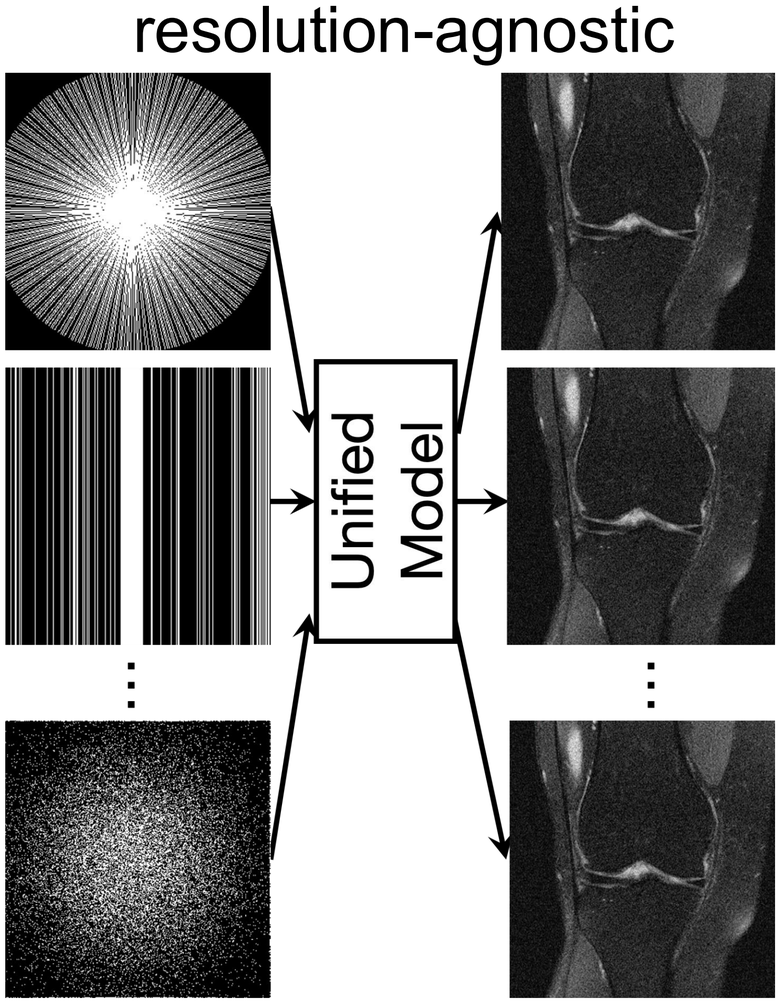
Neural network vs neural operator





[Wang* et al., CVPR ’25]

Neural operator: resolution-agnostic architecture



Neural operator: deep learning <u>architectures</u> that learn mapping between function spaces (infinite-resolution)

works for diffusion/iterative methods [Kerrigan et al,. AISTATS '24]

- **Approximate*** physics operator (learn in function space)
- **Training** with multi-resolution
- **Inference** on any-resolution

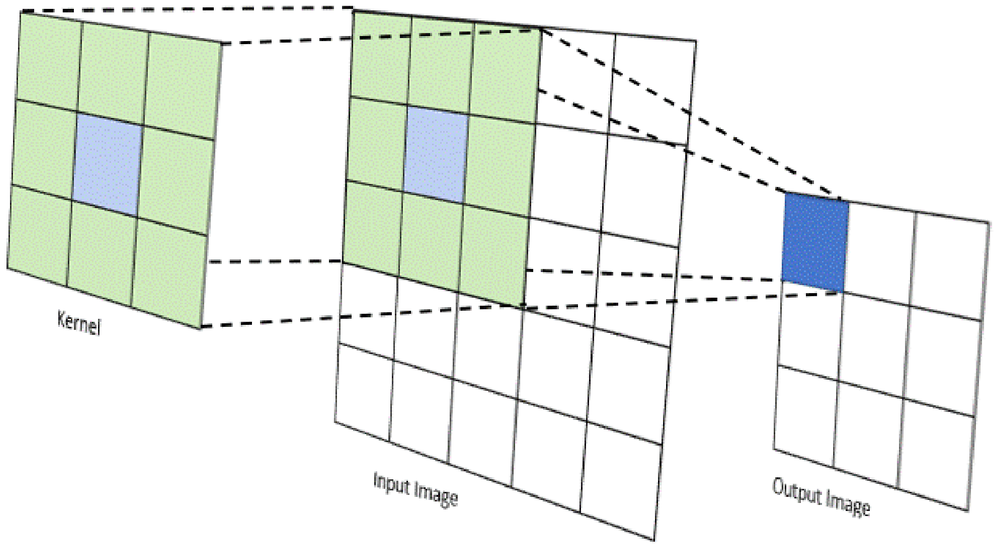
* Neural operator can approximate any continuous operator with nonlocality and nonlinearity. [Kovachki et al., JMLR '23] [Lanthaler et al,. arXiv '23] [Wang* et al., CVPR '25]

knee MRI

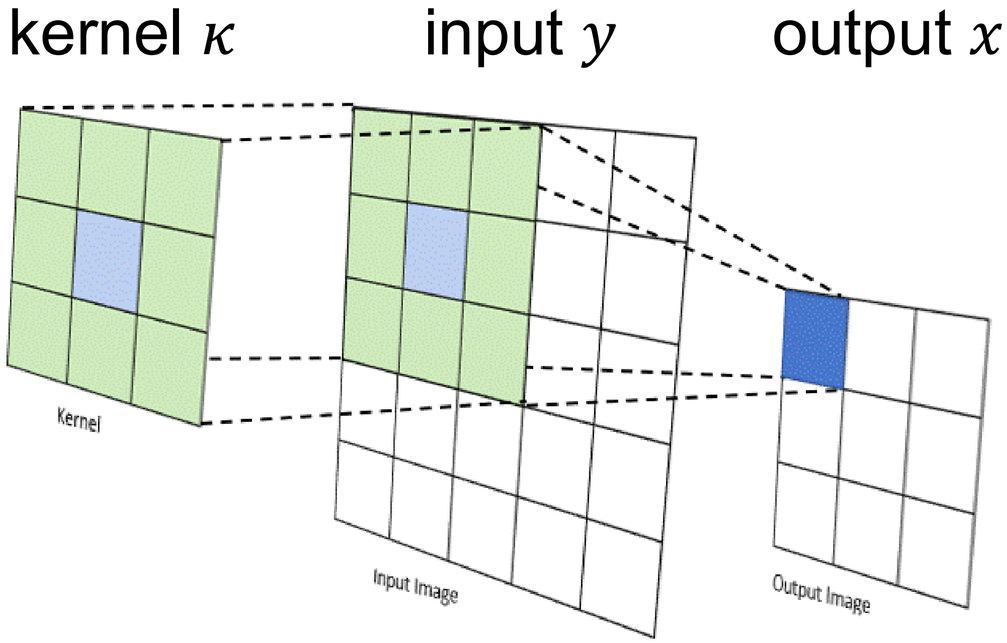
Convolutional
neural **network**

knee MRI

kernel κ input y output x

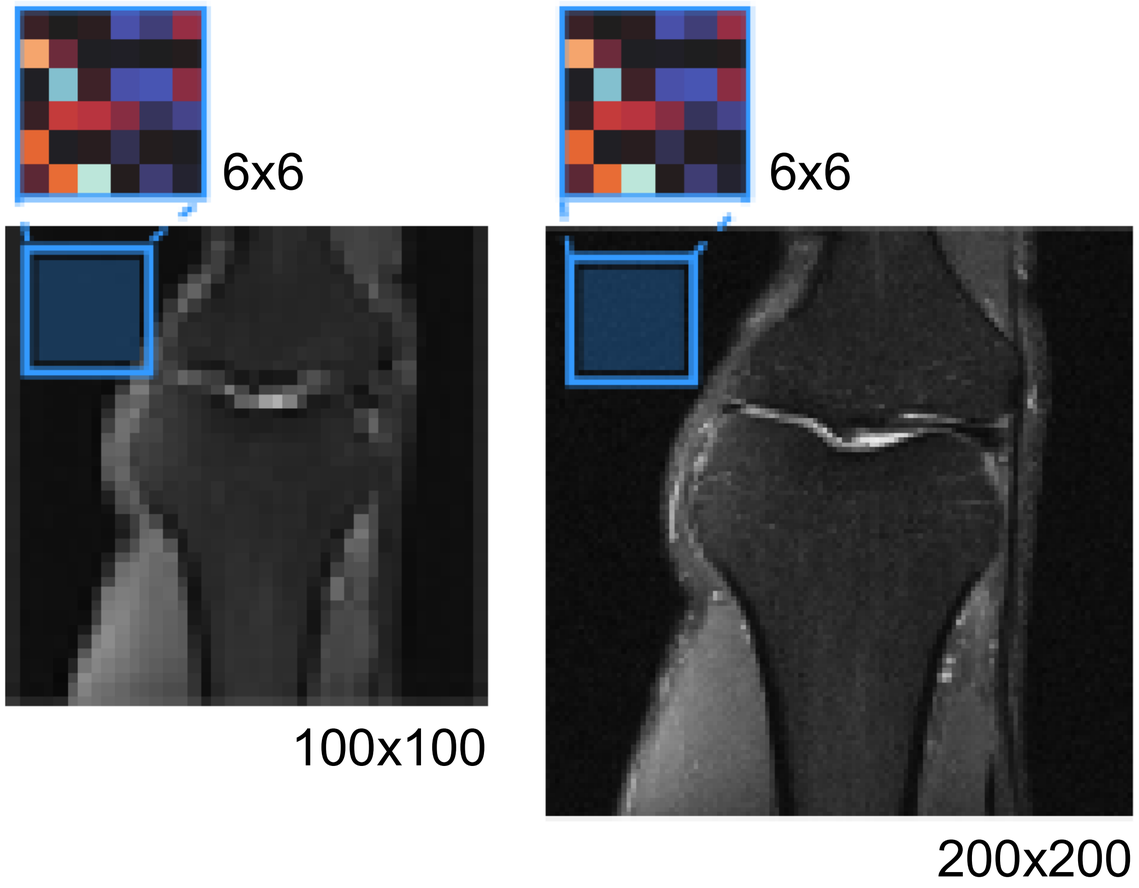


Convolutional
neural **network**



$$\mathrm{ReLU}\left(\sum_j \sum_i \kappa[i,j] \cdot y[m-i, n-j]\right) = \mathrm{ReLU}(x[m,n])$$

Convolutional
neural **network**

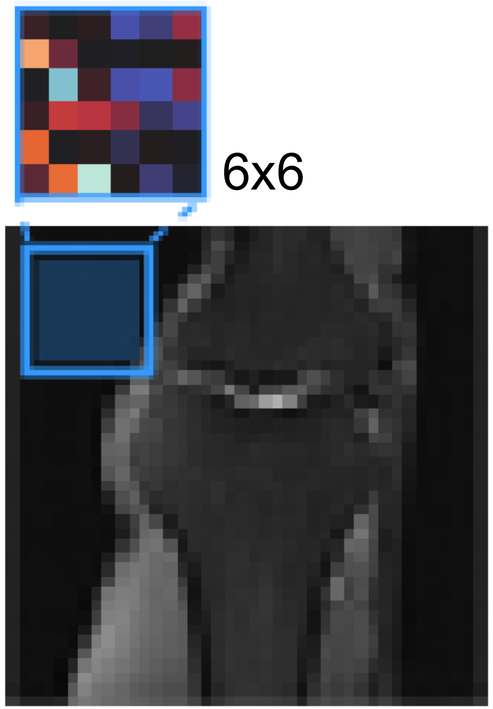


Receptive field: a restricted input area received by neuron

Convolutional
neural **network**

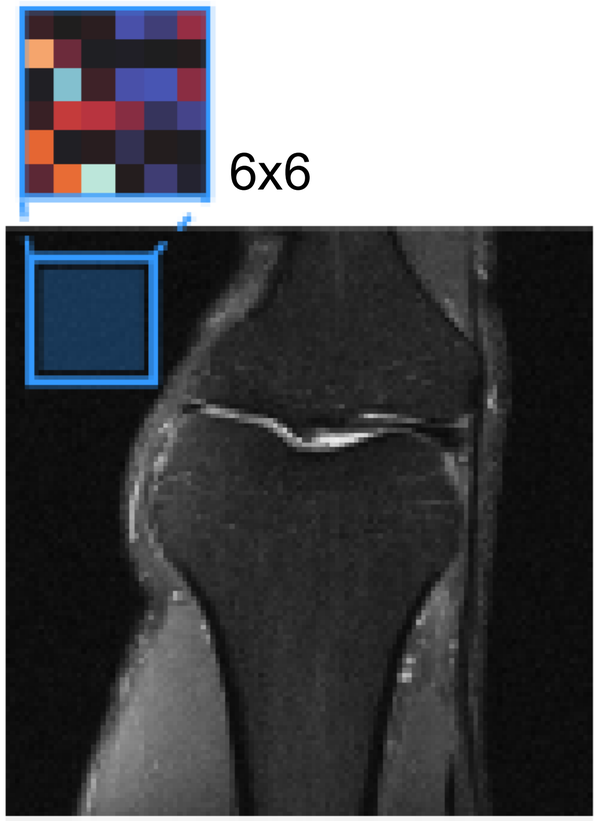
6x6

50x50



6x6

100x100

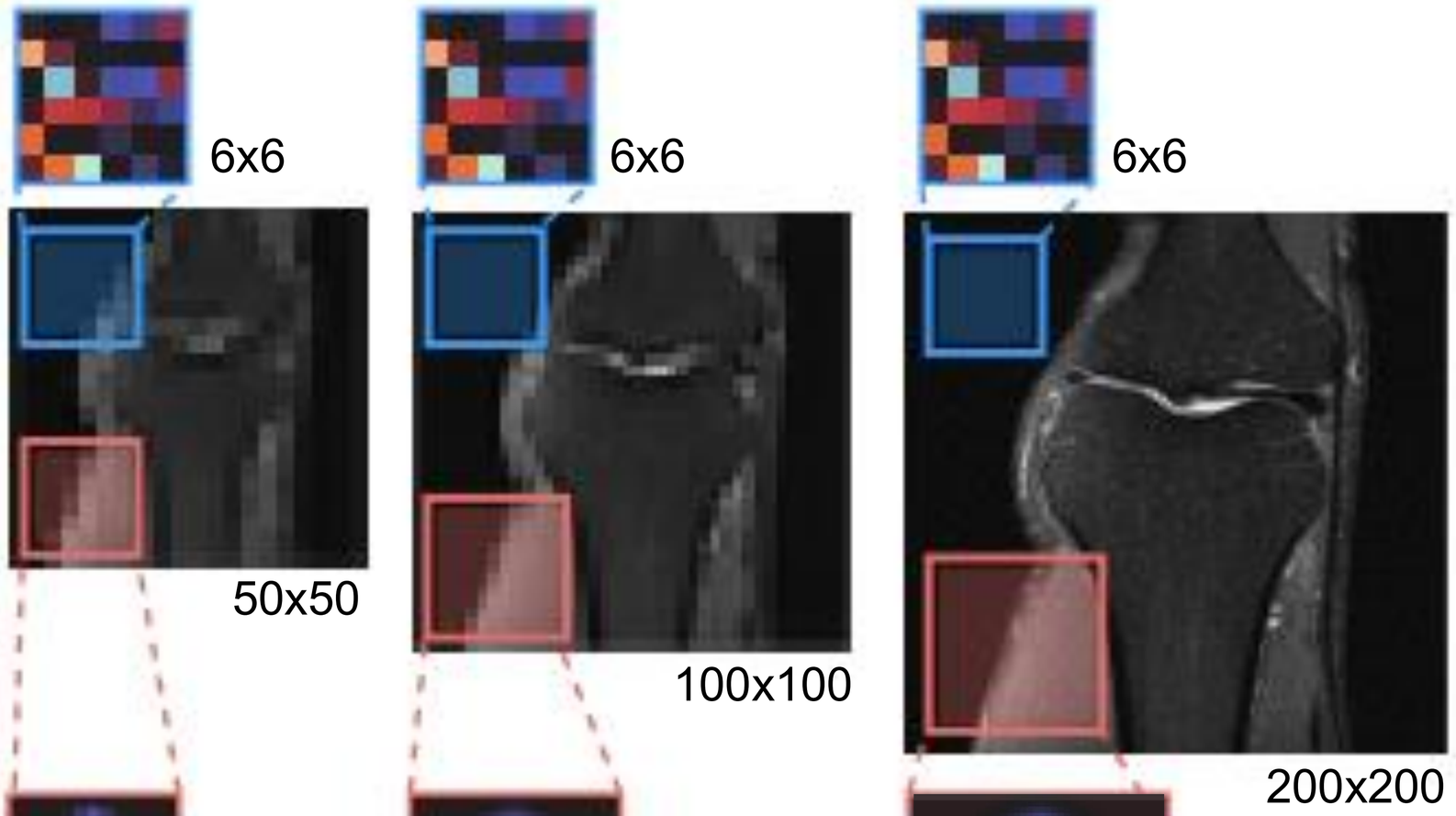


6x6

200x200

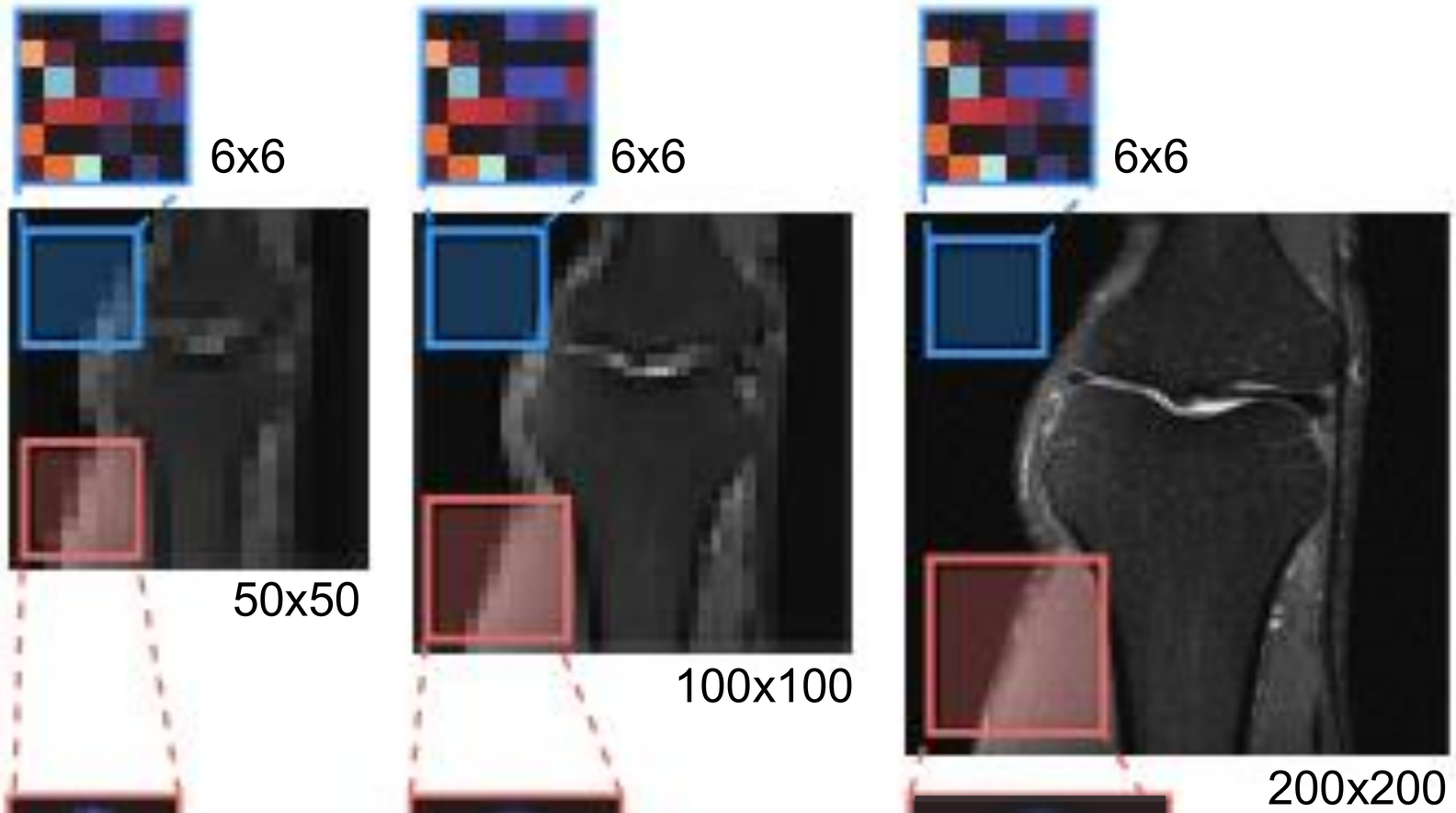
Convolutional
neural **operator**

Convolutional neural **network**



Convolutional neural **operator**

Convolutional neural **network**

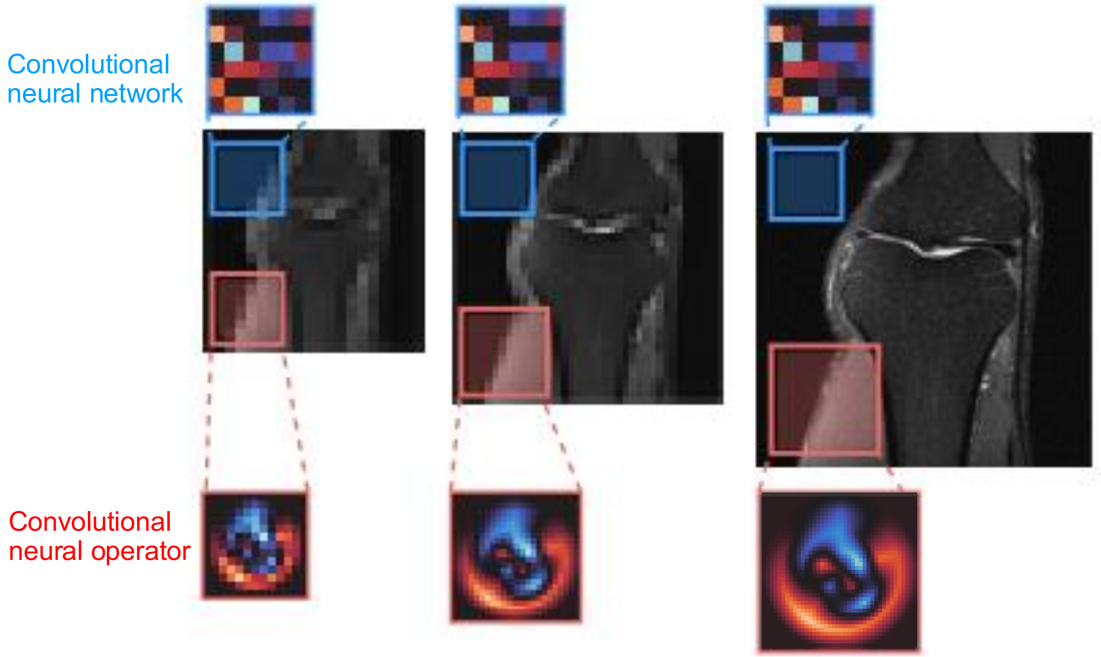


Convolutional neural **operator**

? Learn infinite-resolution kernel?

[**Wang*** et al., CVPR '25]

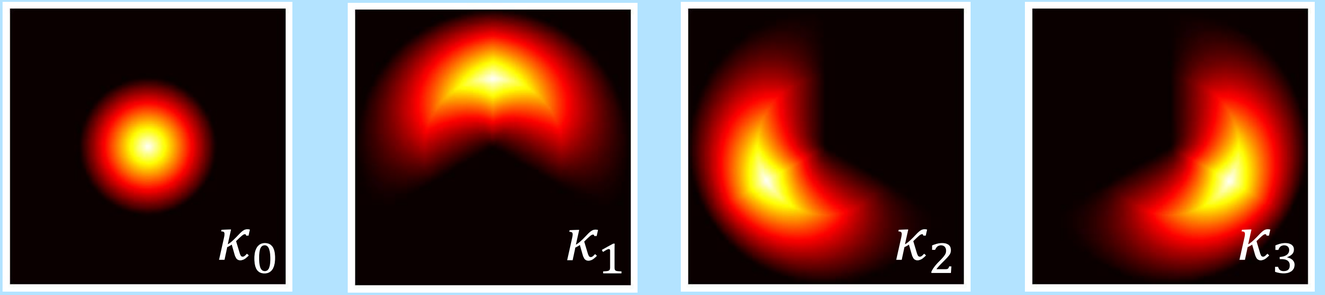
Resolution-agnostic architecture



Convolution kernel is a weighted sum of pre-defined basis functions
→ learn strength parameter θ via gradient descent

$$\kappa = \sum_i \theta_i \kappa_i$$

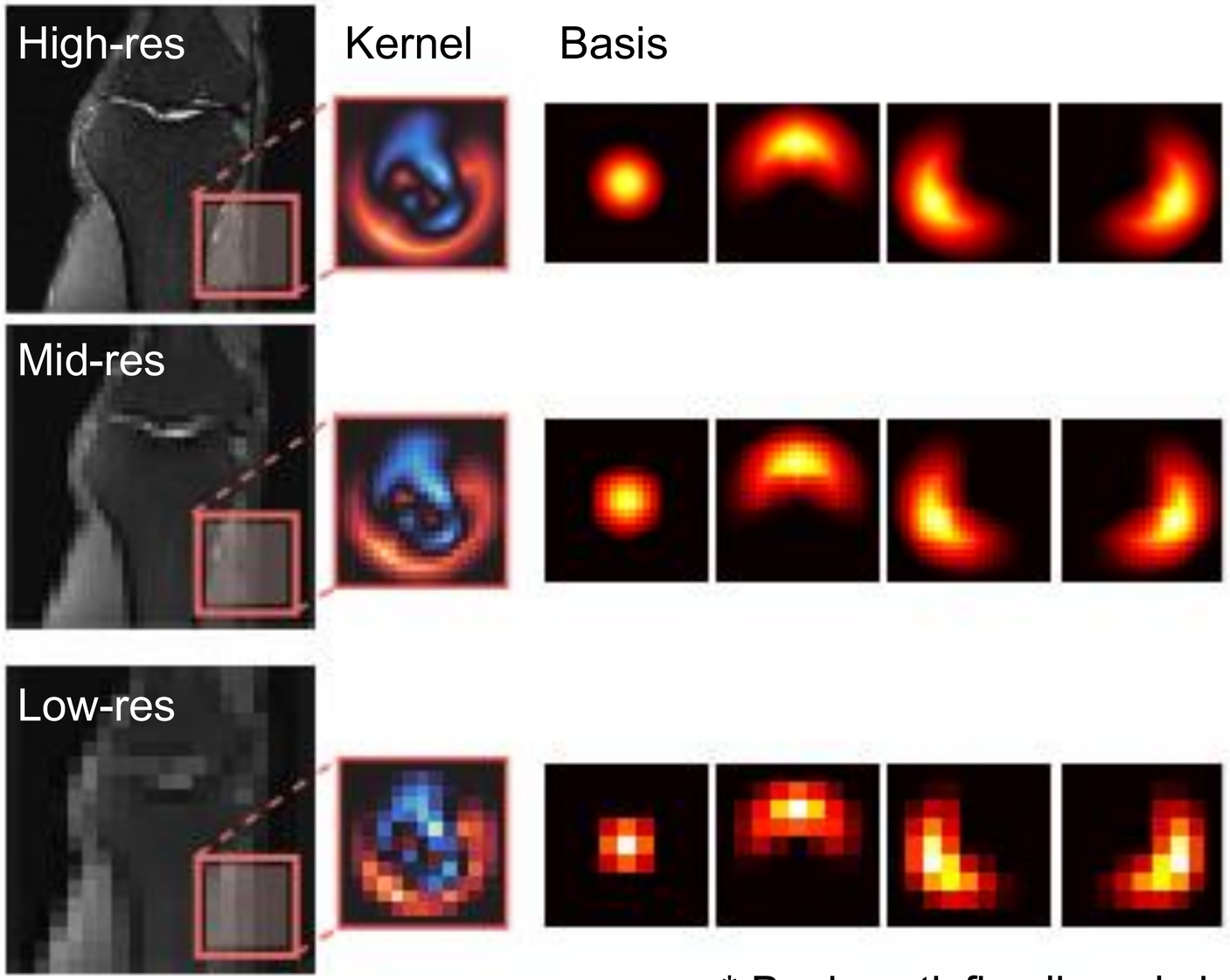
Basis functions (continuous, first 4)



Other layers: same as CNNs

[**Wang*** et al., CVPR ’25]
[Ocampo et al., ICLR ’23]

Resolution-agnostic architecture



Learn kernel function (infinite-resolution)

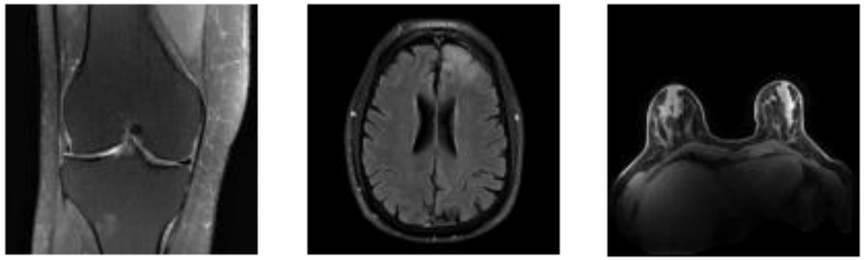
Train & Inference @ any discretization

* Basis satisfies linearly independence and spanning property

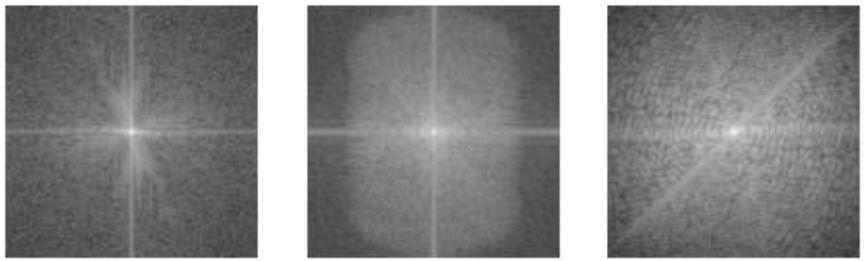
[Wang* et al., CVPR '25]

Network design:
U-Shaped architecture in image and frequency space

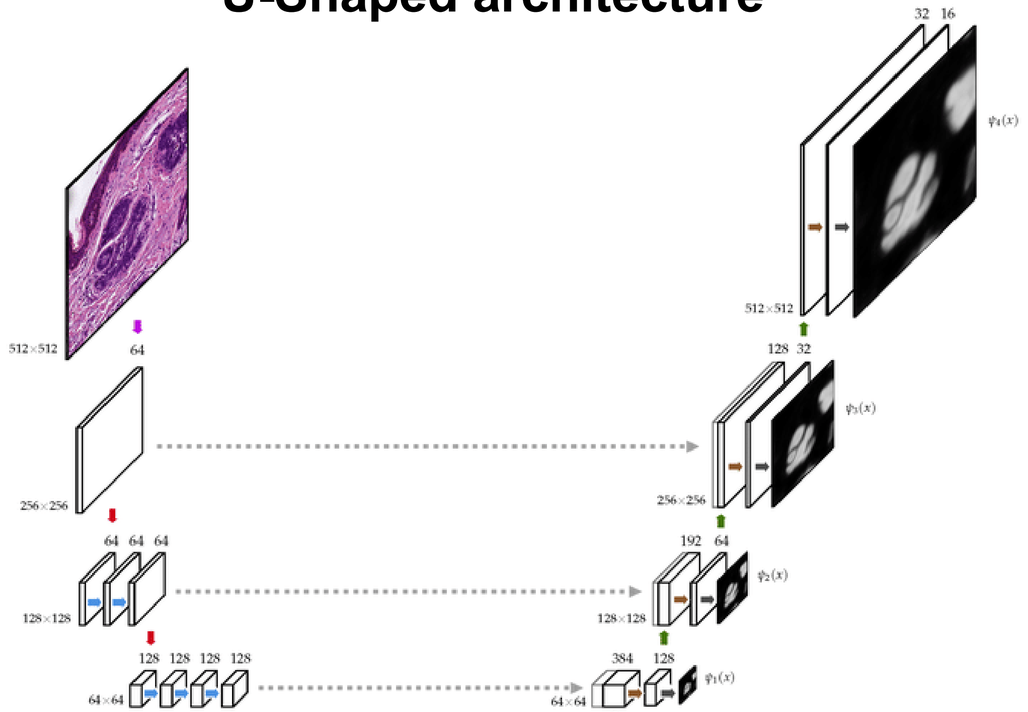
image space
(local features)



frequency space
(global features)



U-Shaped architecture



- Convolution: GPU-optimized
- Global and local features (duality)
- **Multi-scale** features

Neural operator for image

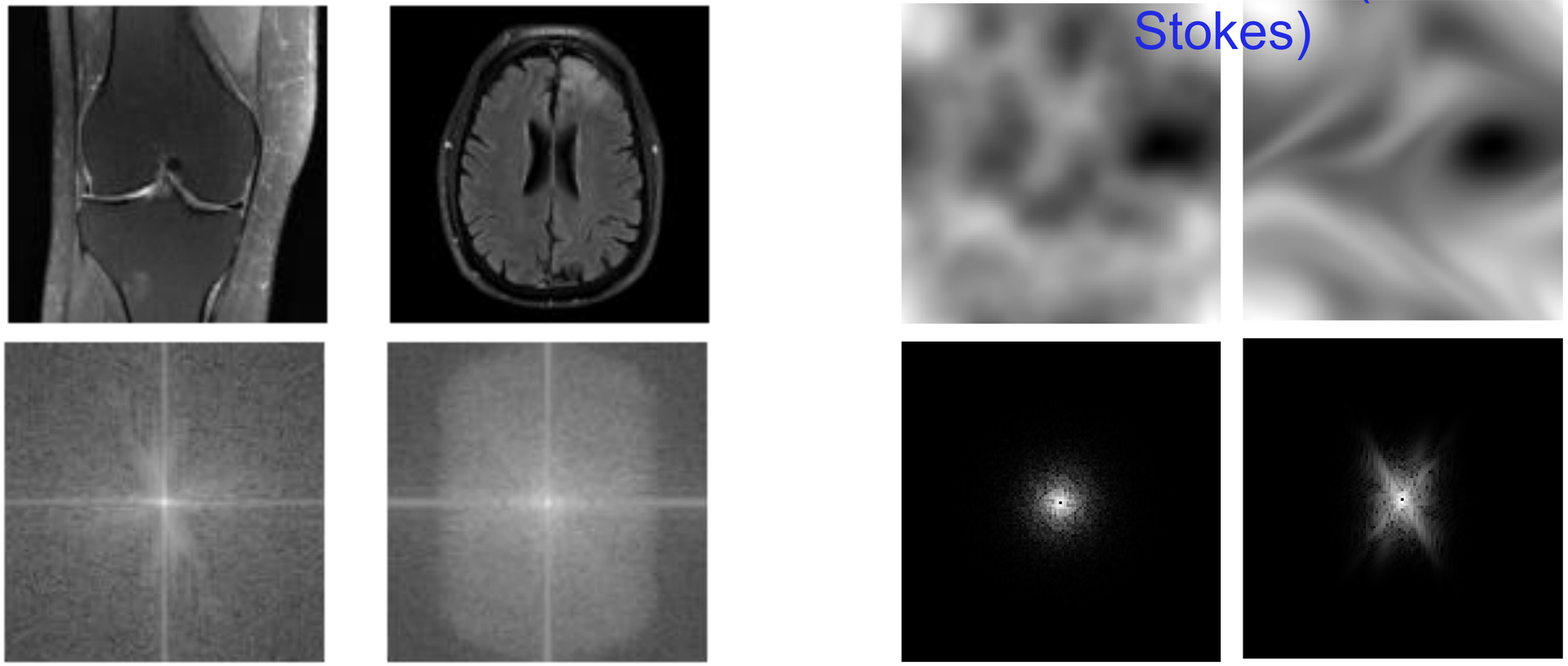
Comparison to FNO (Fourier neural operator, popular PDE learner)

Ours: MRI dataset

FNO: PDE dataset (Navier-Stokes)

image space

frequency space



[FNO. Li et al., arXiv '20]

Neural operator for image

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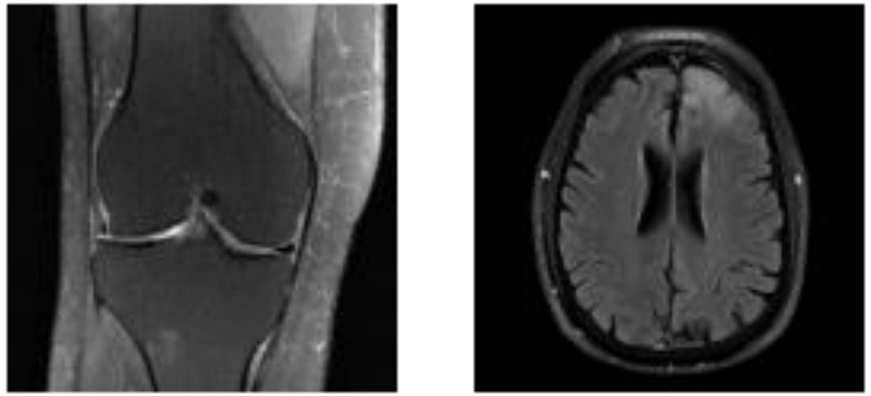
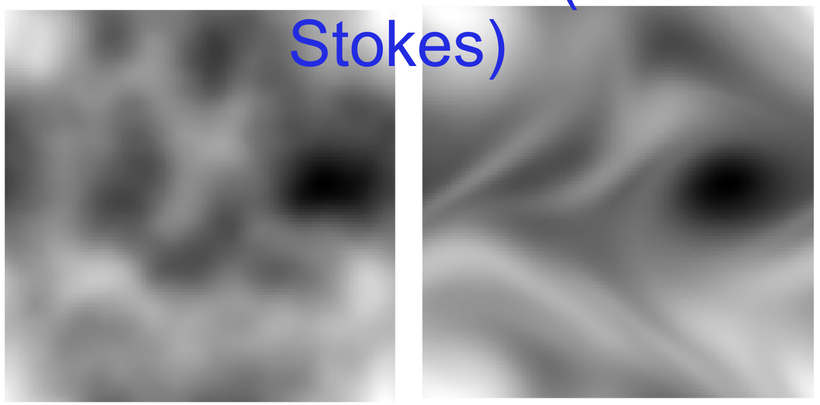
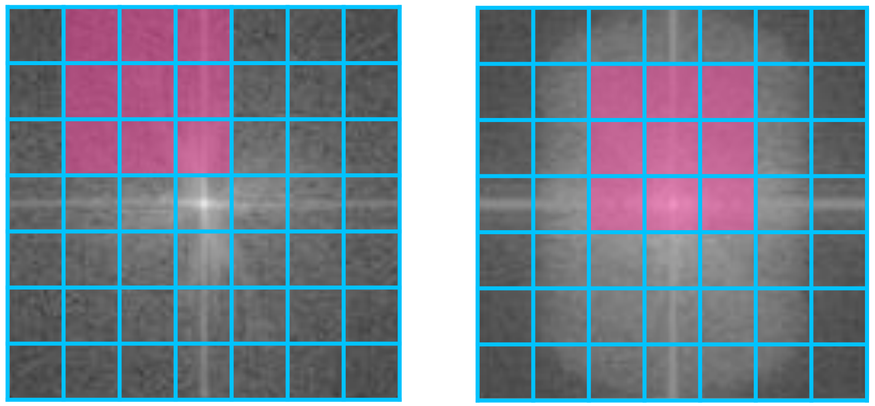




frequency space



- No frequency cutting
- Local integral kernels ($k \times k$)

- Frequency cutting
- Point-wise operator (1×1)

[FNO. Li et al., arXiv '20]

Neural operator for image

Comparison to FNO (Fourier neural operator, popular PDE learner)

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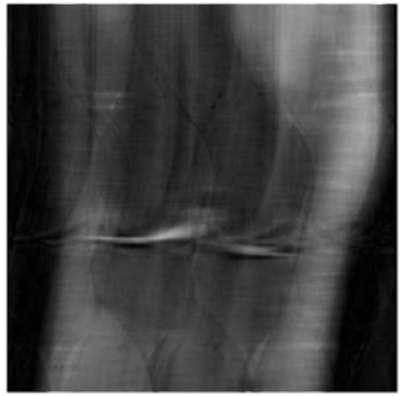
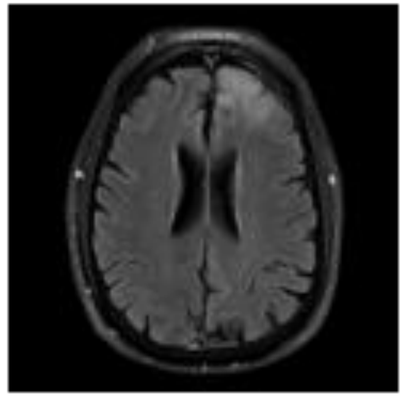
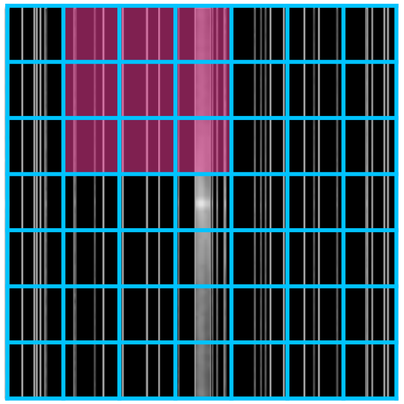
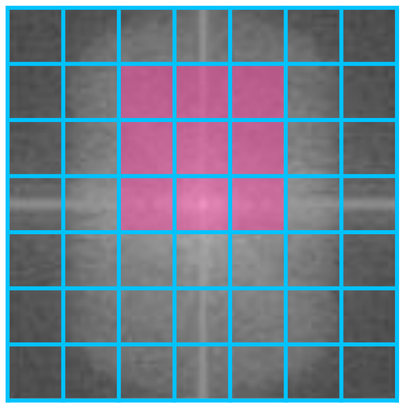
image space





frequency space





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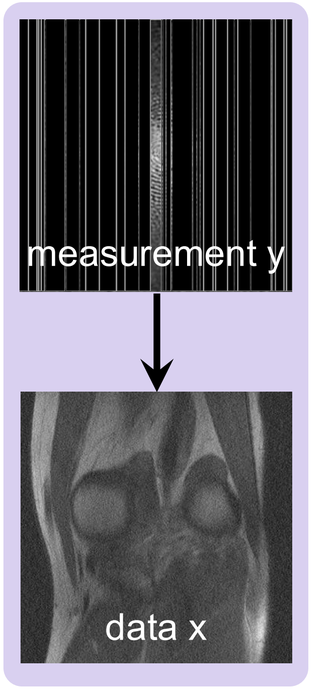
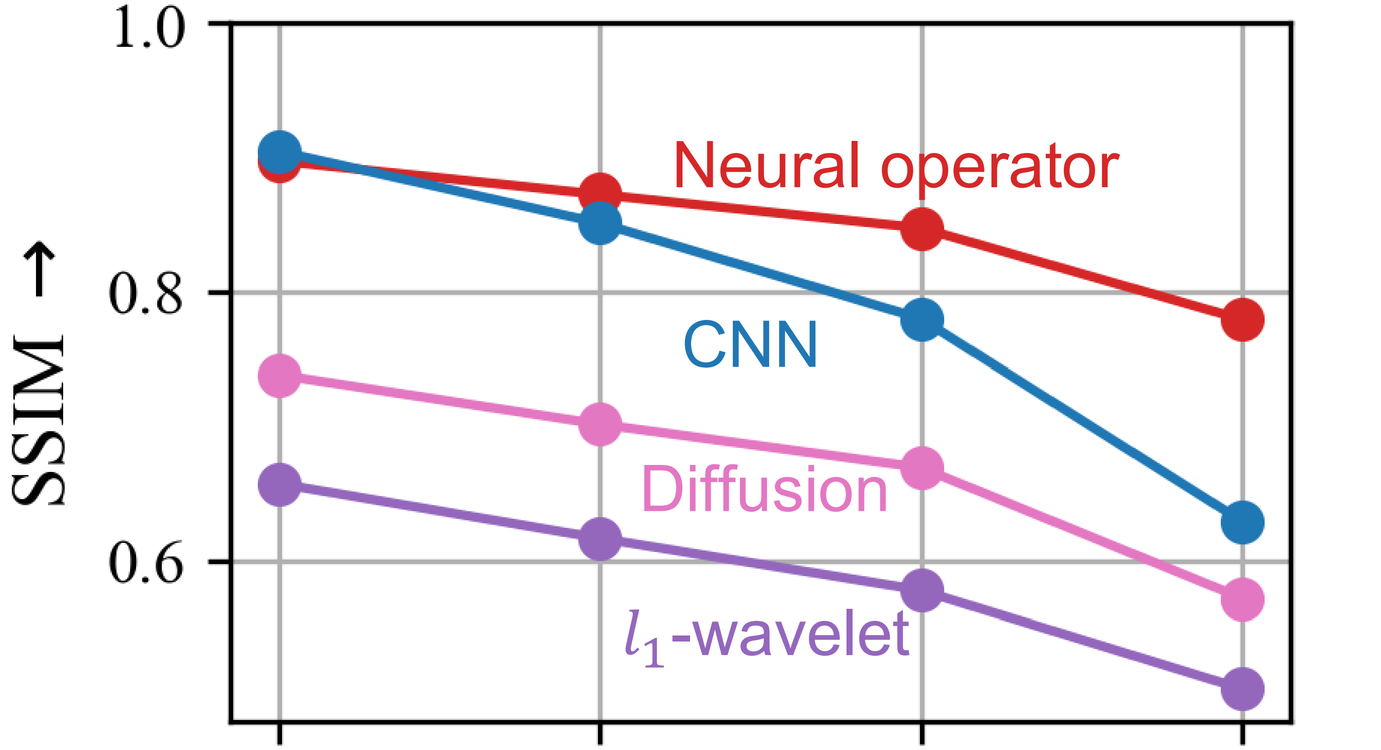
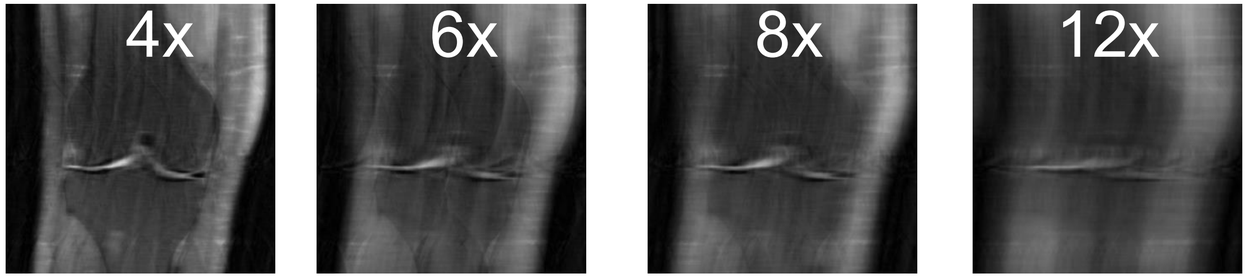
[FNO. Li et al., arXiv '20]

Results: Undersampling inputs





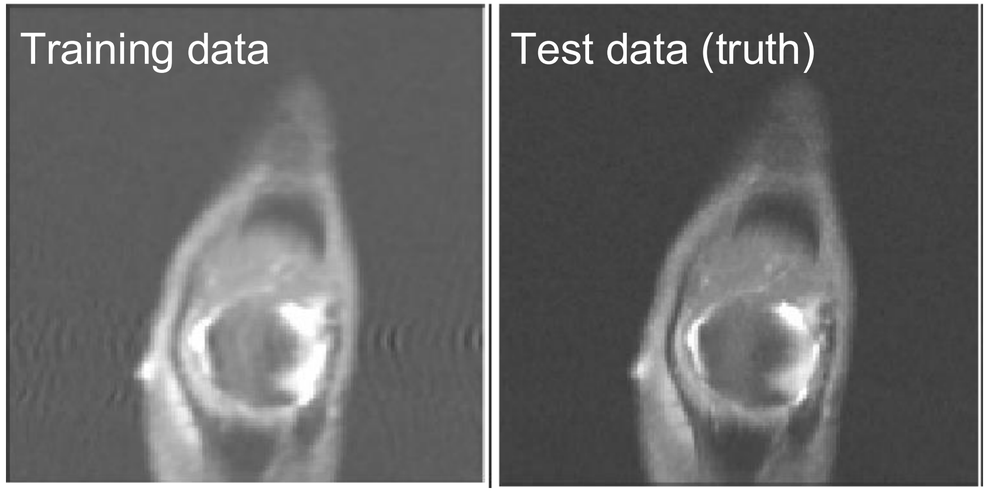
Undersampling rate



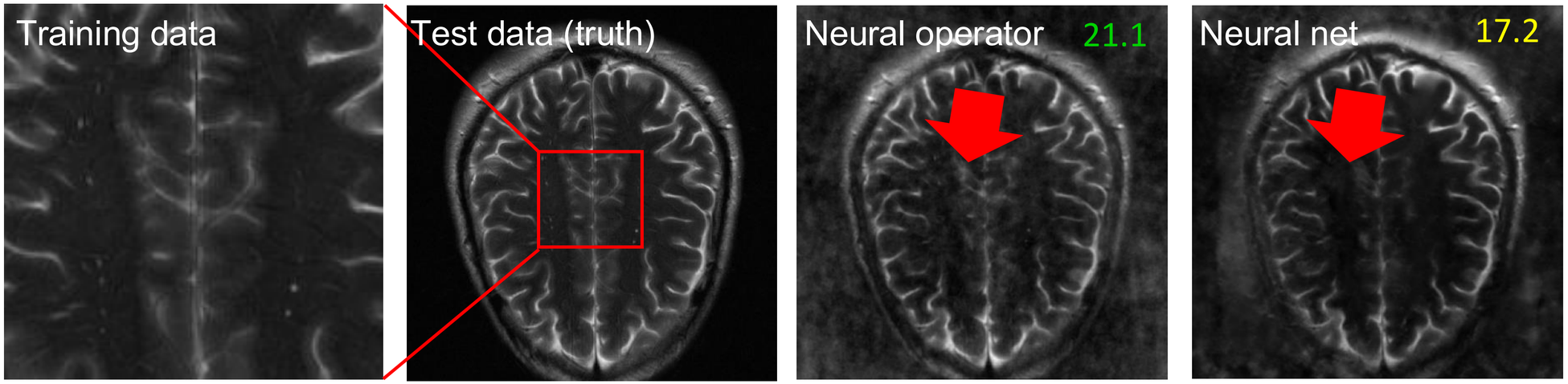
Results: Upsampling outputs (zero-shot)

Knee: image super-resolution

Metric: PSNR (↑)



Brain: image extended field of view (frequency super-resolution)



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Thank you!

Please come to our poster: #477
ExHall D, Sun Jun 15 (morning)

Paper/code/data: