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Fast MRI for All: Bridging Access Gaps by Training without Raw Data

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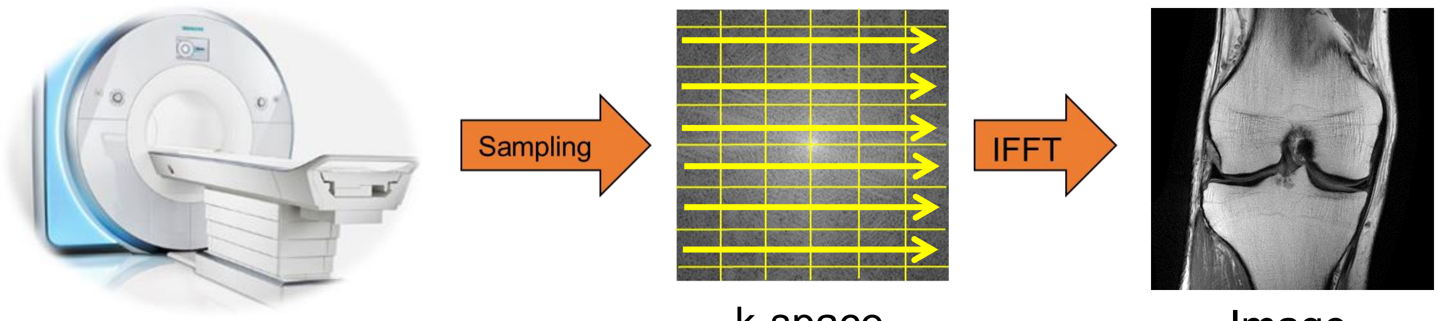
NEURAL INFORMATION PROCESSING SYSTEMS

Paper Code

MRI Reconstruction Problem

- MRI scanning procedure:



MRI Scanning

k-space
(Fourier domain)

Image

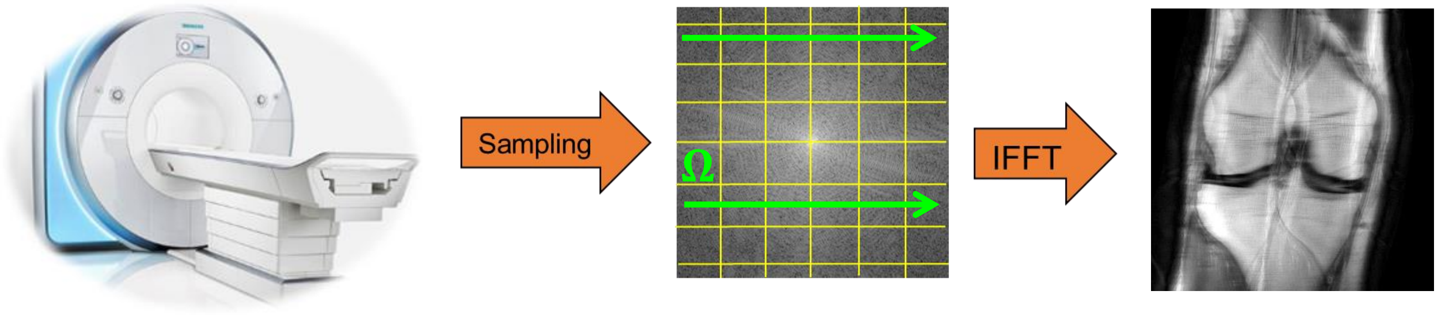
$$\mathbf{y} = \mathbf{E}_{\mathrm{full}}\mathbf{x} + \mathbf{n}$$

acquired measurements (k-space)

encoding matrix

measurement noise

- *Accelerated* MRI scanning procedure:



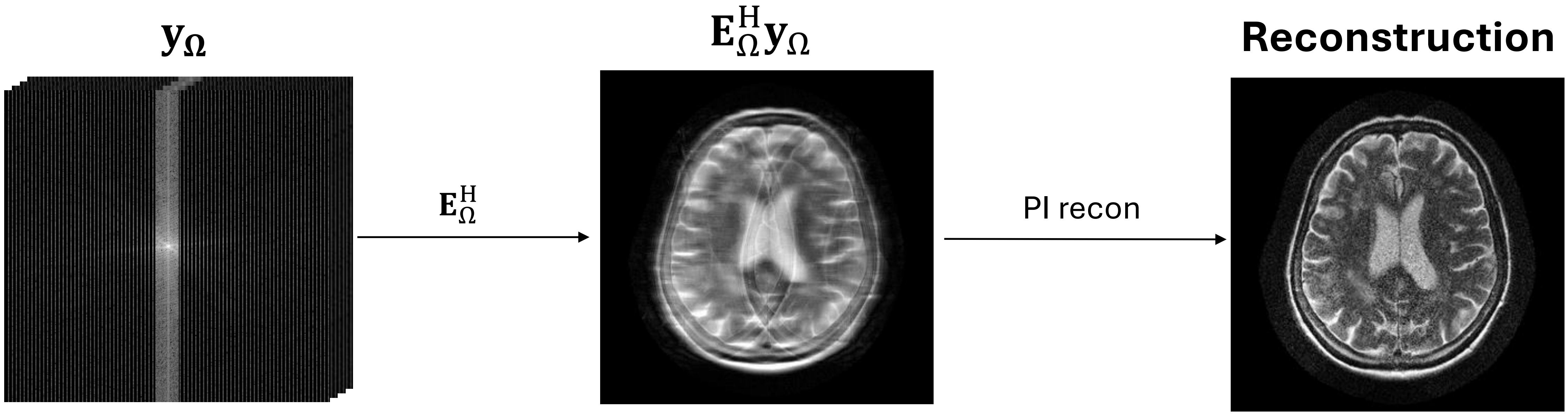
$$\mathbf{y}_{\Omega} = \mathbf{E}_{\Omega}\mathbf{x} + \mathbf{n}$$

$\mathbf{P}_{\Omega} \rightarrow m \times n$ masking operator
$\mathbf{E}_{\Omega} = \mathbf{P}_{\Omega}\mathbf{E}_{\mathrm{full}}$
$\mathbf{y}_{\Omega}^{\mathrm{k}} \in \mathbb{C}^{m}$, $\mathbf{x} \in \mathbb{C}^{n}$ with $m < n$

Clinical Methods (Parallel Imaging)

- Clinical “parallel imaging” methods use the redundancies among the receiver coils:

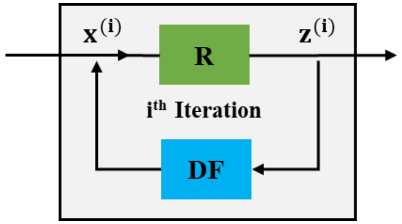
$$\mathbf{x}_{\mathrm{PI}} = \arg\min_{\mathbf{x}} \|\mathbf{y}_{\Omega} - \mathbf{E}_{\Omega}\mathbf{x}\|_2^2 = \left(\mathbf{E}_{\Omega}^{\mathrm{H}}\mathbf{E}_{\Omega}\right)^{-1}\mathbf{E}_{\Omega}^{\mathrm{H}}\mathbf{y}_{\Omega}$$



✓ They can work in a zero-shot manner without needing raw k-space data

✗ Performance degradation begins after $\times\, 2 - 3$ acceleration

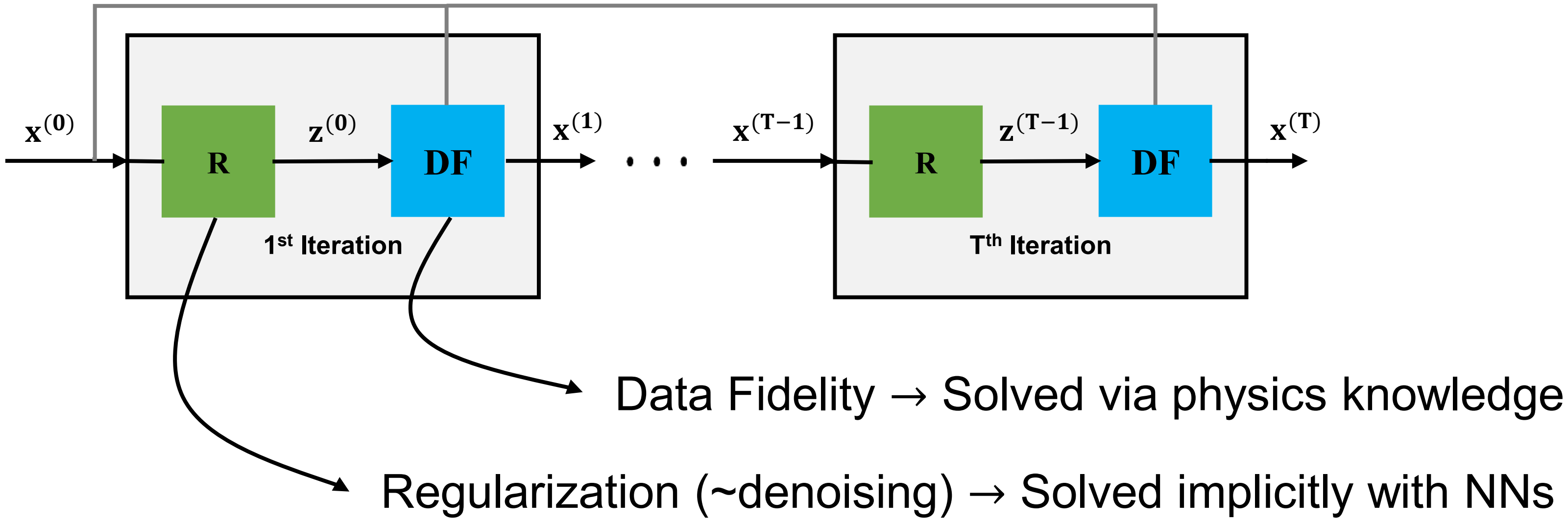
Physics-driven Deep Learning (PD-DL)



- In computational MRI, additional regularization is often incorporated:

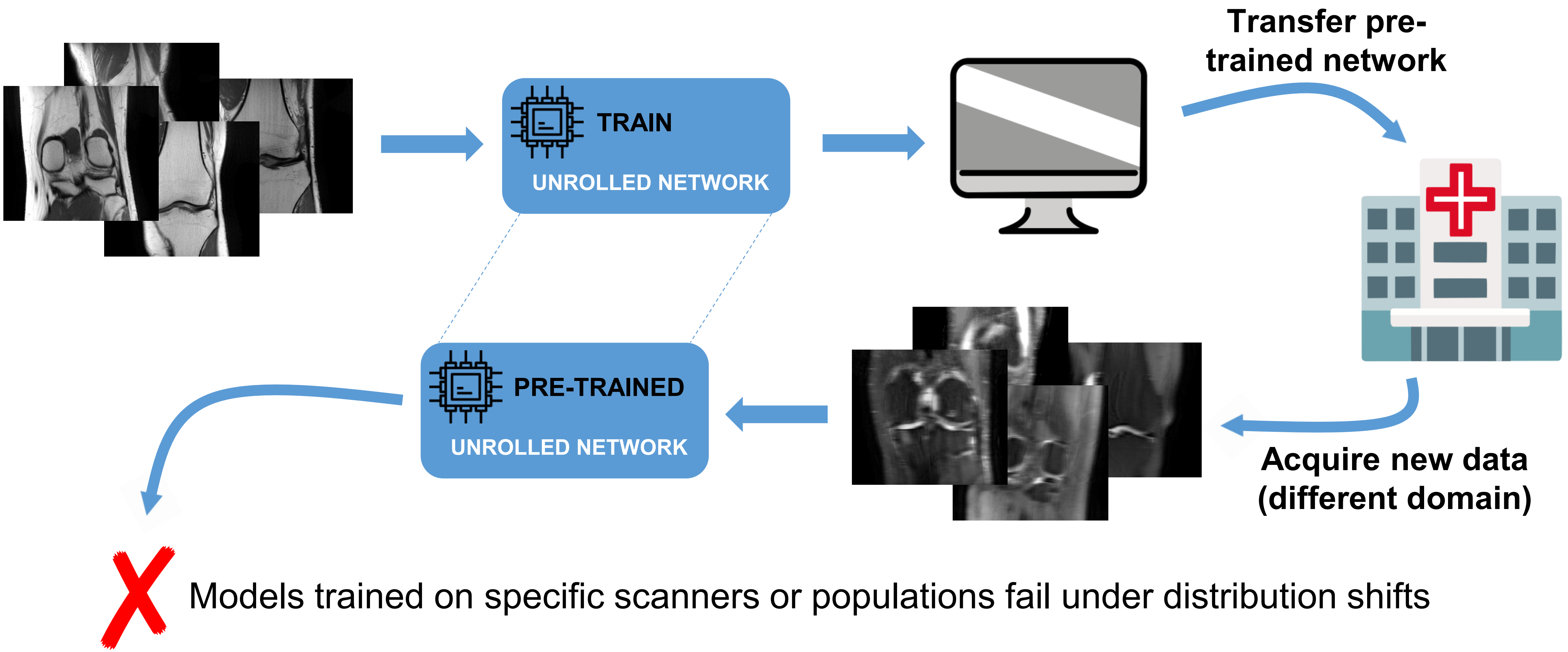
$$\arg\min_{\mathbf{x}} \underbrace{\|\mathbf{y}_\Omega - \mathbf{E}_\Omega \mathbf{x}\|_2^2}_{\text{Data Fidelity (DF)}} + \underbrace{\mathcal{R}(\mathbf{x})}_{\text{Regularizer (R)}}$$

- PD-DL methods learn the proximal operator of a regularizer
- One common PD-DL approach: Unrolled networks
  - Fix the number of iterations and "unroll" the optimization process



Need for Training without Raw Data

- Despite emerging AI methods, parallel imaging continues to define everyday MRI practice
- The main reason for this is the issue of **generalizability**

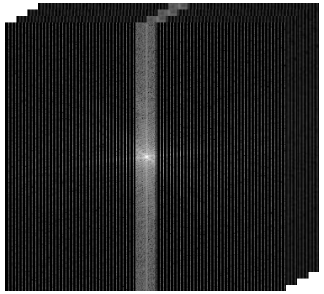


Models trained on specific scanners or populations fail under distribution shifts

Need for Training without Raw Data

- Fine-tuning models for specific domains is necessary to optimize performance
- **Caveat:** This fine-tuning requires access to raw k-space data

vendor restrictions

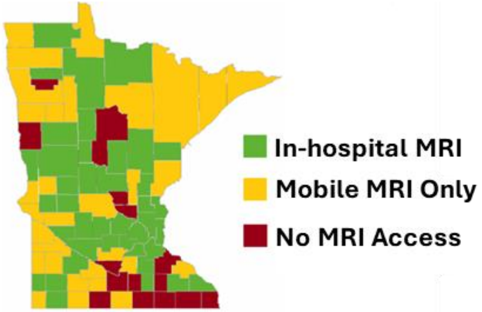


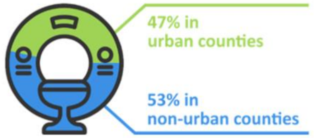
Raw kspace data

Vendor provided DICOM images

Majority of scanners outside specialized academic or research institutions:

- Local hospitals
- Mobile MRI units

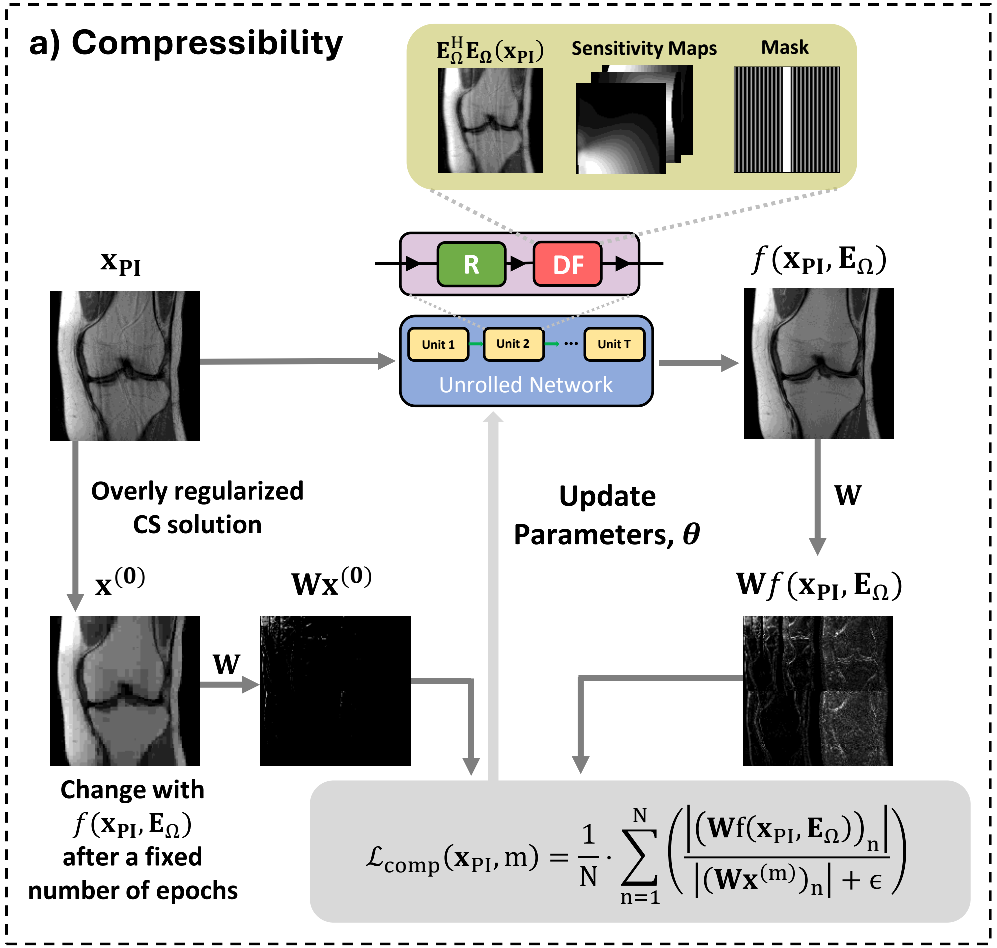




- Non-urban MRI scanners do not enjoy the specialized expertise in academic medical centers
- No vendor research agreements, needed for raw data access
- Cannot use or fine-tune fast MRI methods that require raw data

We need a training pipeline that does not require raw kspace data!

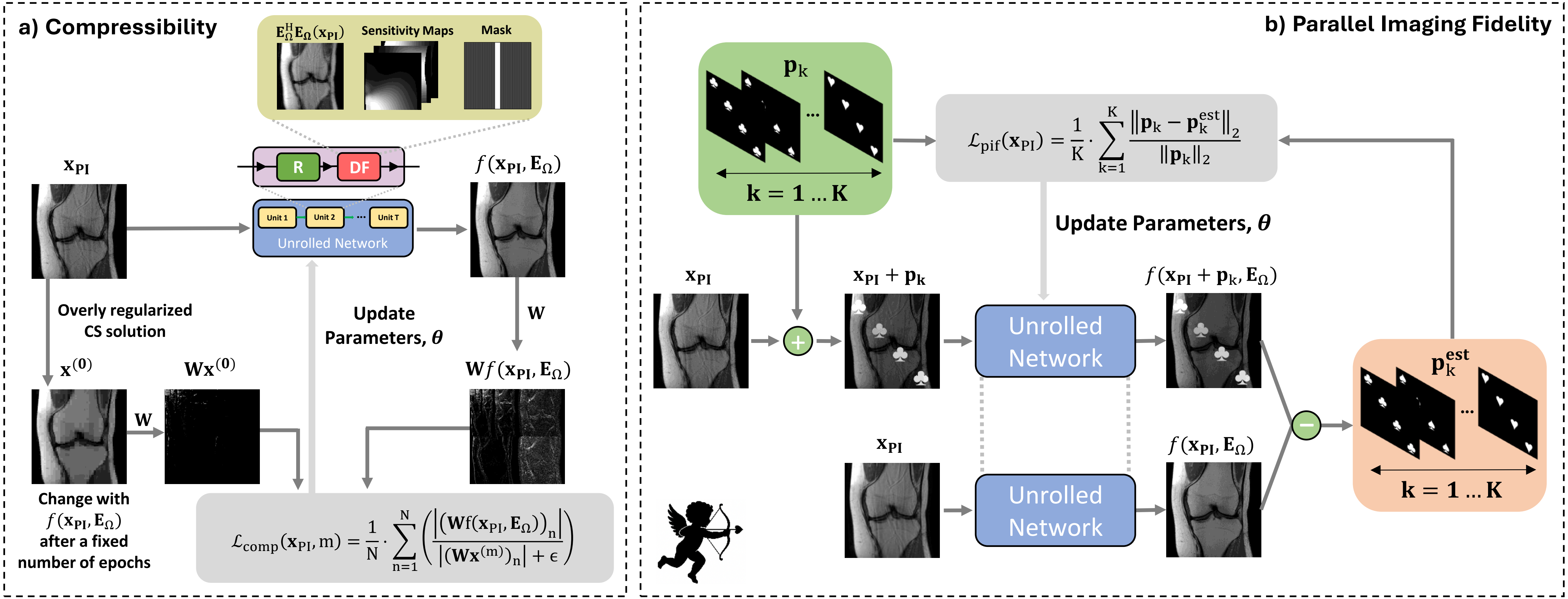
Pipeline of CUPID



b) Parallel Imaging Fidelity

$$\mathcal{L}_{CUPID} = \mathcal{L}_{comp} + \lambda \cdot \mathcal{L}_{pif}$$

Pipeline of CUPID



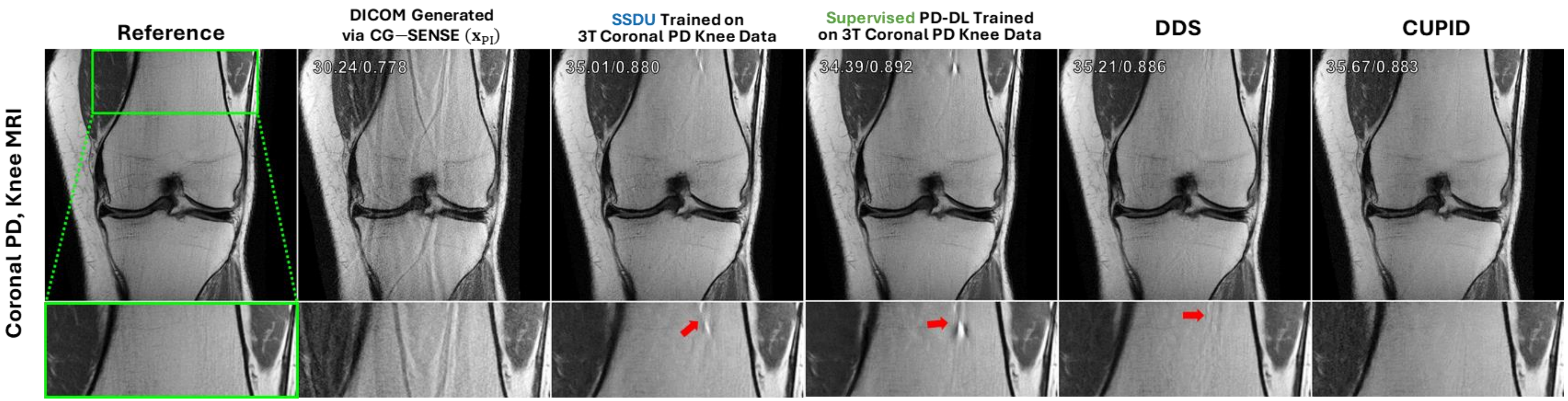
$$\mathcal{L}_{CUPID} = \mathcal{L}_{comp} + \lambda \cdot \mathcal{L}_{pif}$$

Contributions & Out-of-Distribution Illustration

🔥 **CUPID** is the **first** PD-DL framework **trainable solely from routine DICOM images acquired at target acceleration rates**

🔥 Operates in both **database-level unsupervised** and **zero-shot (subject-specific)**

🔥 Achieves **reconstruction quality matching** supervised and self-supervised methods **requiring raw k-space data**



- Supervised and SSDU models trained on 3T data fail to generalize to 1.5T scans
- DDS (trained on both 3T and 1.5T data) does a better job though some performance degradation persists

Links & Contact Information

- For all the results, ablation studies, technical details for perturbations, and radiologist readings please refer to our paper or publicly available code:

Paper

Code

Utku's Homepage

Spotlight Poster Session:

Date: Fri 5 Dec

Time: 4.30PM – 7.30PM

Place: Exhibit Hall C,D,E (San Diego)

Email: {**alcal029**,glle0001,akcakaya}@umn.edu