



Federated Learning

MONAI Bootcamp | Sep 2021



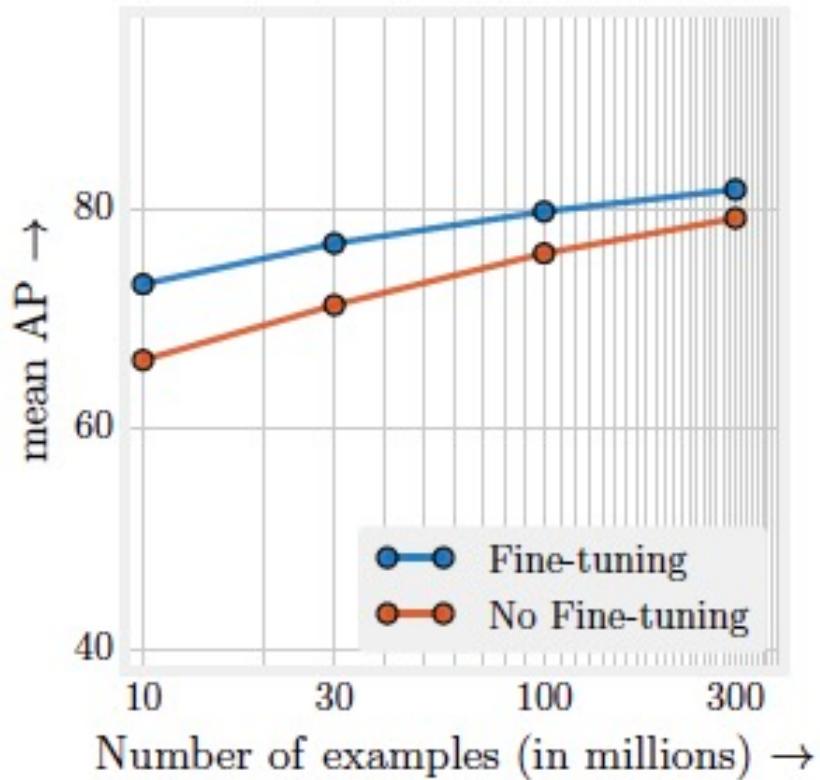
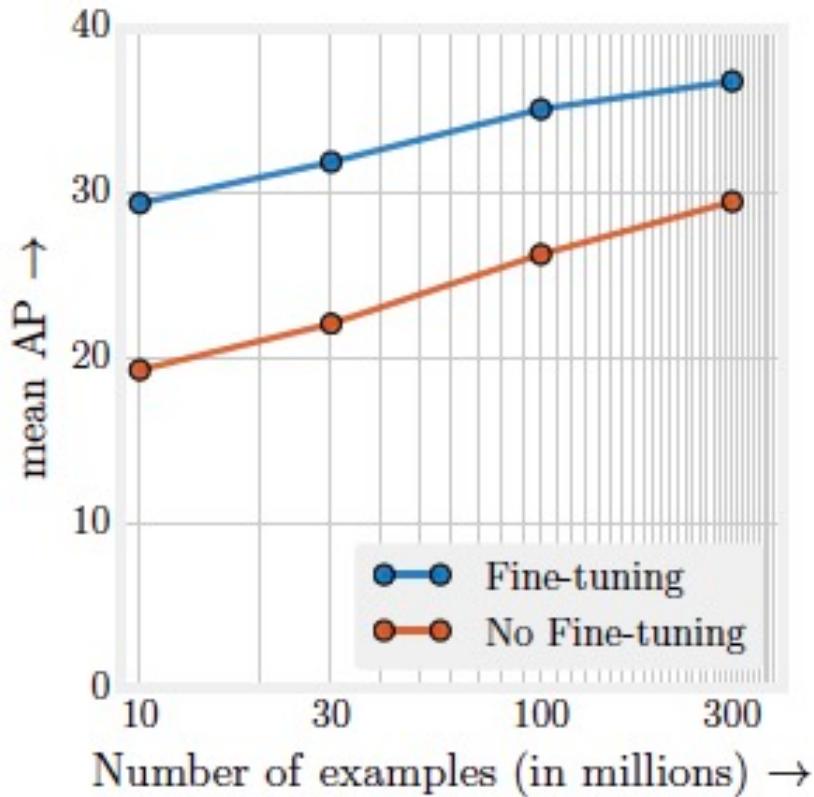
Holger Roth <hroth@nvidia.com>

Federated Learning

- Machine/Deep learning/Computation on decentralized data
- Enable (edge) devices to do **state-of-the-art** machine/deep learning **without the need to centralize data** and **with privacy by design**
- Assumption: **more data usually results in better models**

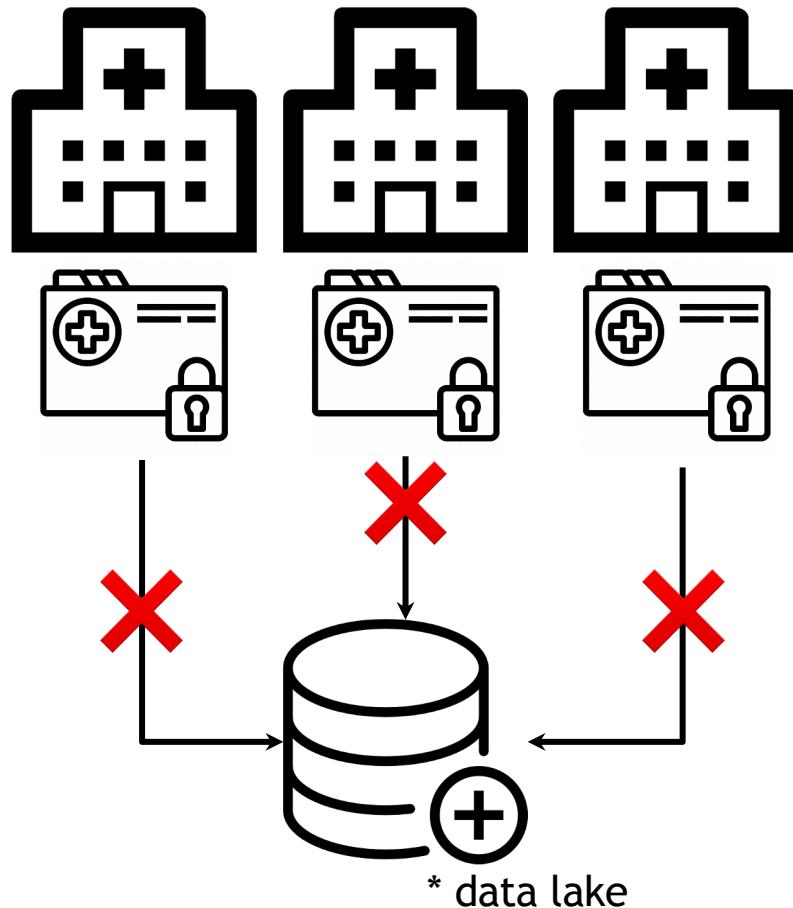
NEED FOR LARGE DATASETS

Logarithmic relationship between the dataset size and accuracy



LARGE SCALE TRAINING

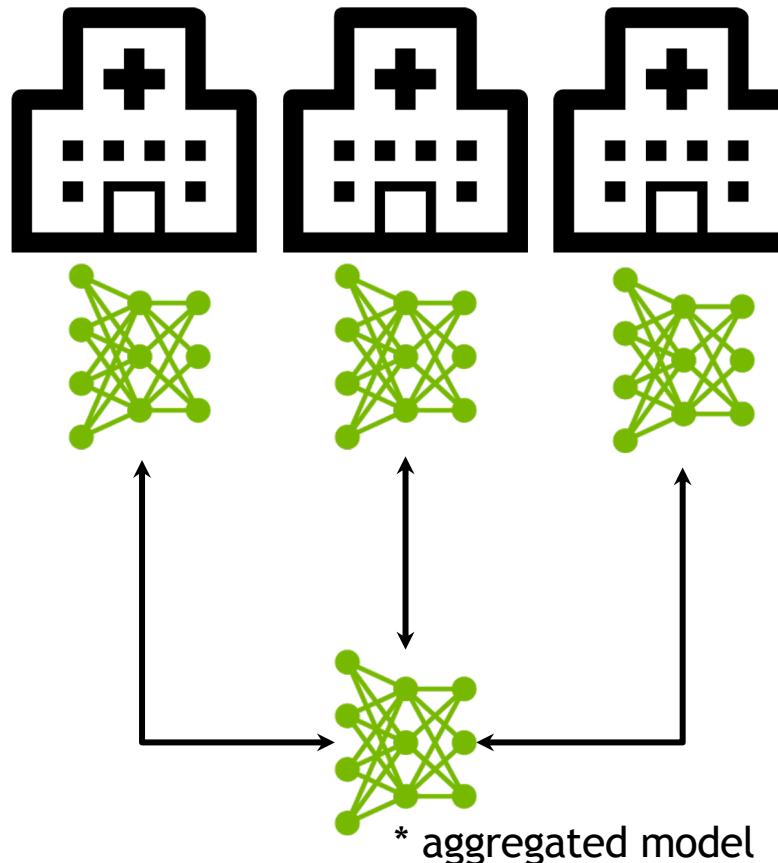
Creating large, centralized medical dataset is challenging



- Private data can't be shared
- Anonymization is not truly effective
- Data annotation is costly - Data is an asset
- Bureaucracy of data sharing is complex

LARGE SCALE TRAINING

Collaborative learning solves crucial issues in healthcare



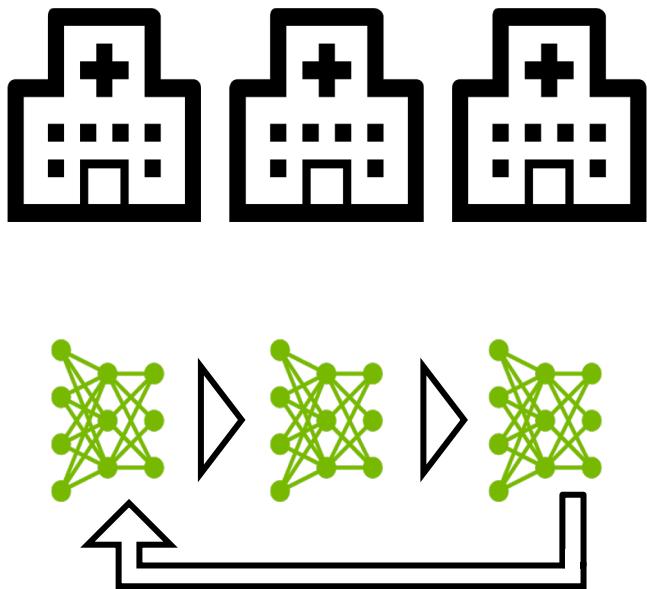
- Private data can't be shared
- Anonymization is not truly effective
- Data annotation is costly. Data is an asset
- Bureaucracy of data sharing is complex
- Share models, not data!

McMahan, Brendan, and Daniel Ramage. "Federated learning: Collaborative machine learning without centralized training data." *Google Research Blog* 3 (2017).

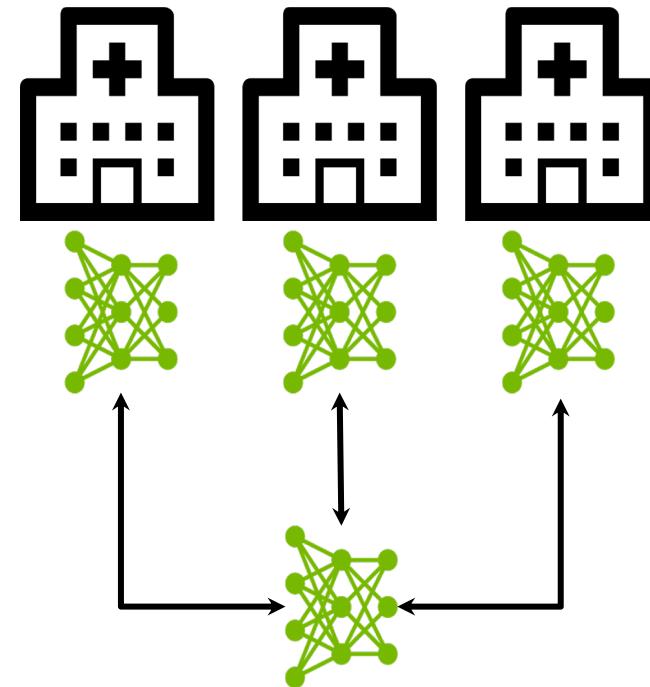
COLLABORATIVE TRAINING METHODS

Obtaining strong models without pooling data

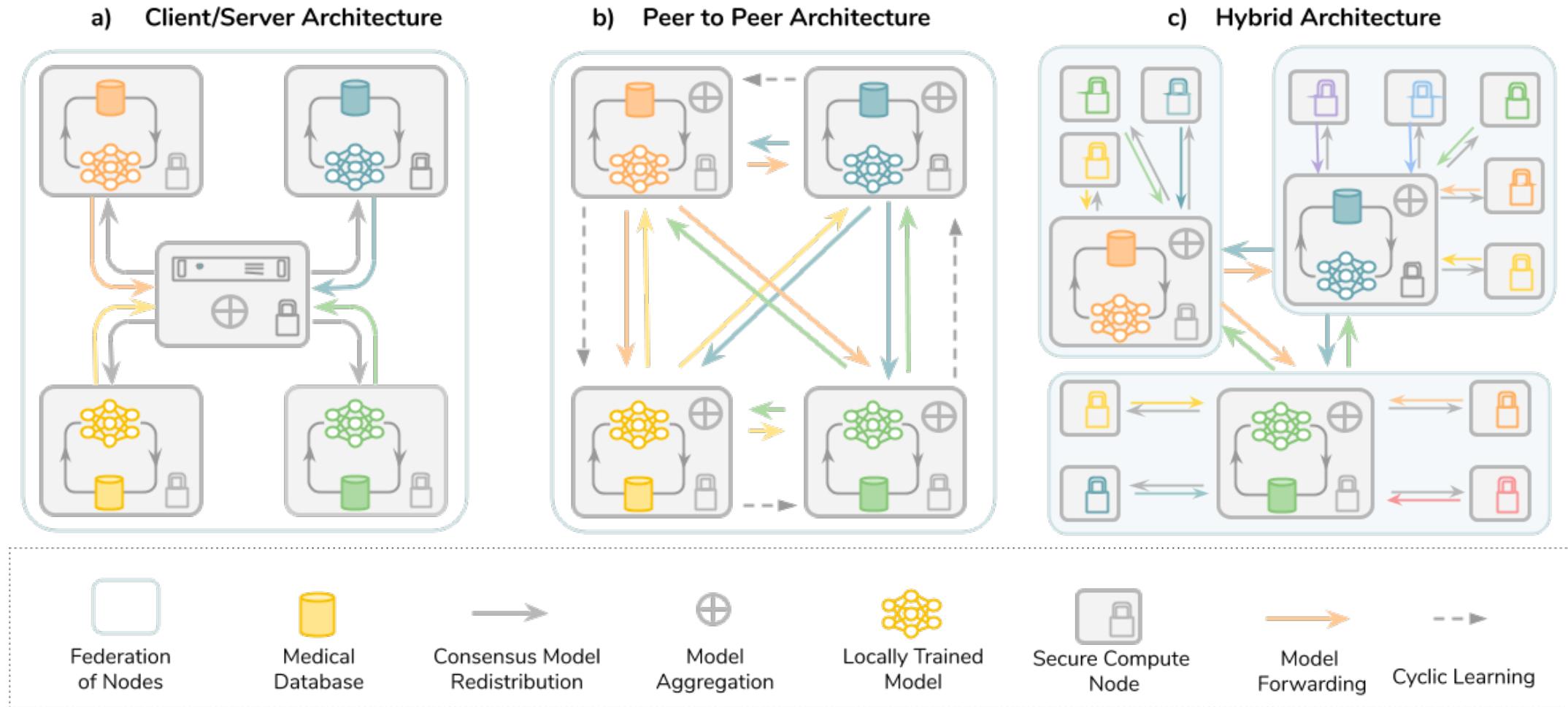
CYCLICAL LEARNING



FEDERATED LEARNING



FEDERATED LEARNING ARCHITECTURES



<https://arxiv.org/abs/2003.08119>

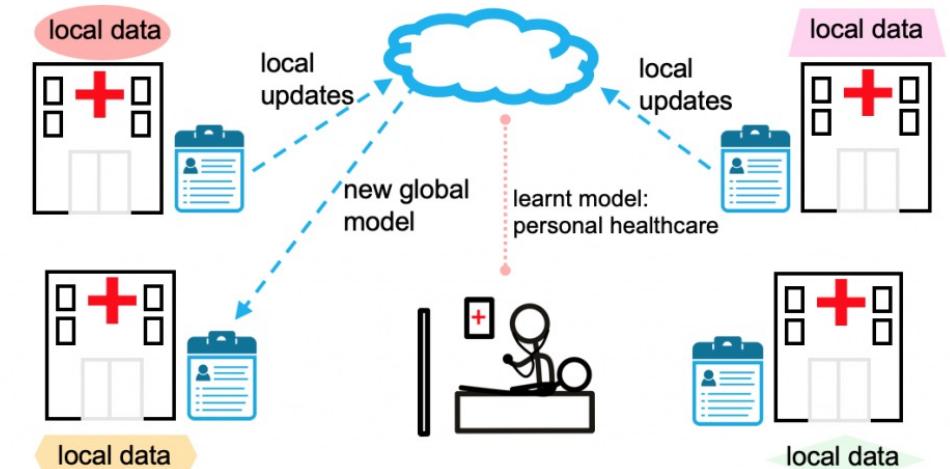
Healthcare vs. Mobile sector

Mobile (cross-device):

- Large number of user (millions), unknown to each other
- Intermittent user/data availability (select from a pool)
 - user/data for each FL round could be different
- Massively distributed
- Low computation power

Healthcare (cross-silo):

- Usually comes from a trusted collaboration, small number (10s-100s)
- Relatively stable user/data and connection
- High computation power, usually dedicated
- Regional/global scale



IMPACT OF FEDERATED LEARNING

Increasing the value of AI for all healthcare stakeholders



Clinicians

Accurate assistance tools,
Standardization

Patients

Accurate and unbiased AI,
Data donor

Researchers

Access to large datasets,
Clinical relevant problems

Hospital and Practices

Full control of patient data,
Infrastructure

Manufacturers

Continuous improvement
of ML-based systems

Rieke, N., Hancox, J., Li, W., Milletari, F., Roth, H., Albarqouni, S., Bakas, S., Galtier, M. N., Landman, B., Maier-Hein, K., Ourselin, S., Sheller, M., Summers, R. M., Trask, A., Xu, D., Baust, M. & Cardoso, M. J.; [The Future of Digital Health with Federated Learning](#). NPJ digital medicine (2020).

FL APPLICATIONS

1. Horizontal FL

- aka “Homogenous Federated Learning”
- Data Split by Examples
- E.g., hospitals have different patients’ data but the same features

2. Vertical FL

- aka “Heterogeneous Federated Learning”
- Data Split by Features
- E.g., image data of a patient reside in hospital while its blood test data reside in Pharmacy

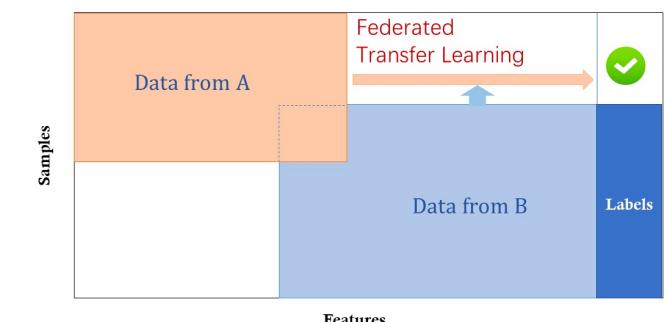
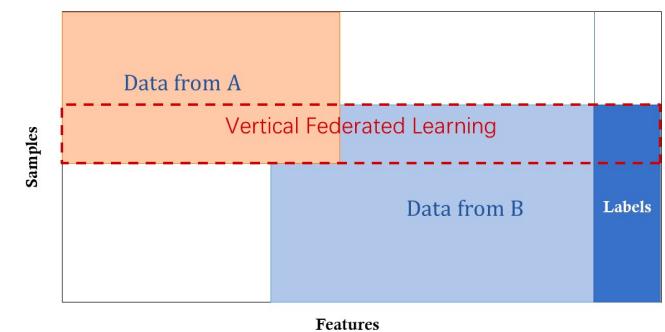
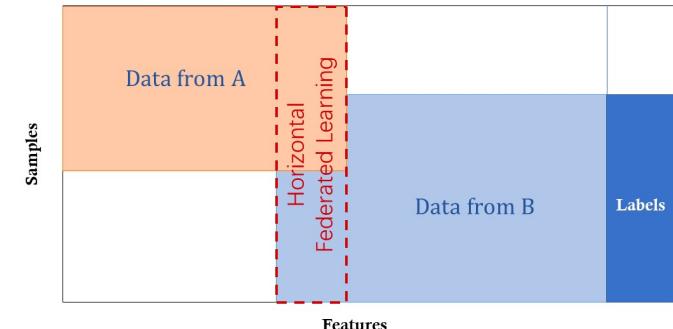
3. Federated Transfer Learning:

- Use small amount of common data to train FL model
- Finetune the model using large amount of local data

4. Multi-task Federated Learning:

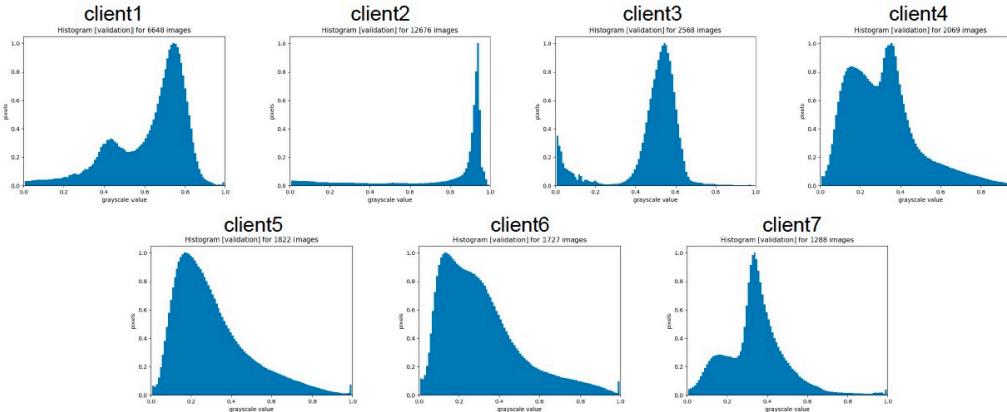
- Each client could work on its own task (segment a different organ)
- Different network used for each client
- Client-specific hardware considerations

5. Federated evaluation

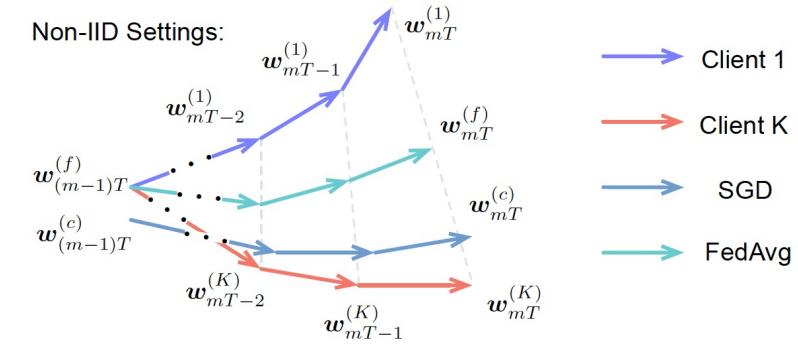
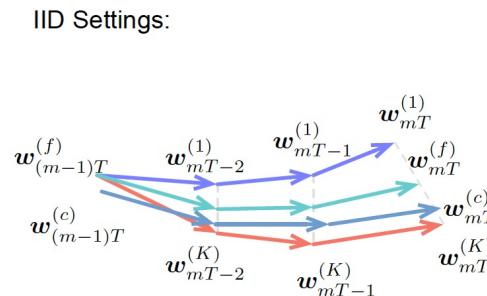


DATA/COMPUTE CHALLENGES IN FL

- Globally vs. Locally optimized (Personalized) models
- Disparity across sites:
 - Data number, appearance could be different due to scanner, imaging protocol, patient population, etc.
 - Data annotation number, class, and protocol
 - Some sites has only healthy patient, and/or no annotation
 - Non-IID data can cause severe performance drop
 - Ongoing research direction
 - E.g., FedProx, FedMA, FedOpt, etc.
 - Client regularization, more robust aggregation functions
 - Hardware:
 - Some sites has a GPU cluster while some only has one low end GPU
 - Straggler problem: most clients are waiting for the slowest one



Intensity distribution of Mammography images across sites, Roth et al. DCL 2020

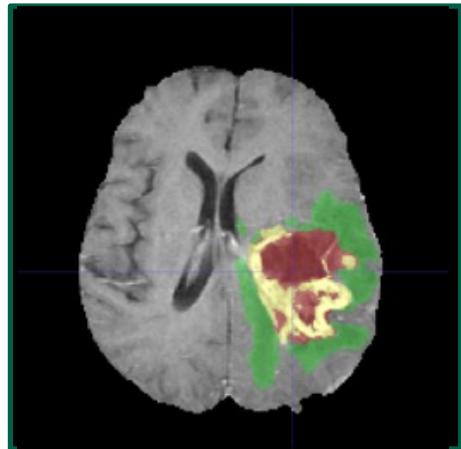


Zhao, et. al, Federated Learning with Non-IID Data, 2018

FEDERATED LEARNING

USE CASES

MICCAI 2019



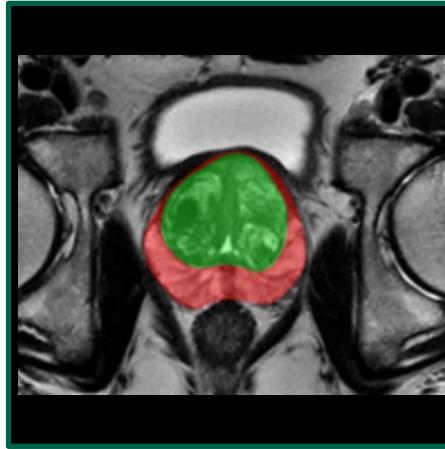
Brain Tumor
Segmentation
KCL

MICCAI 2020



Mammography
Classification
ACR/DASA/OSU/MGB/Stanford

JAMIA 2021



Prostate Segmentation
SUNY/UCLA/NIH

MICCAI 2020



Pancreas Segmentation
NTU/Nagoya

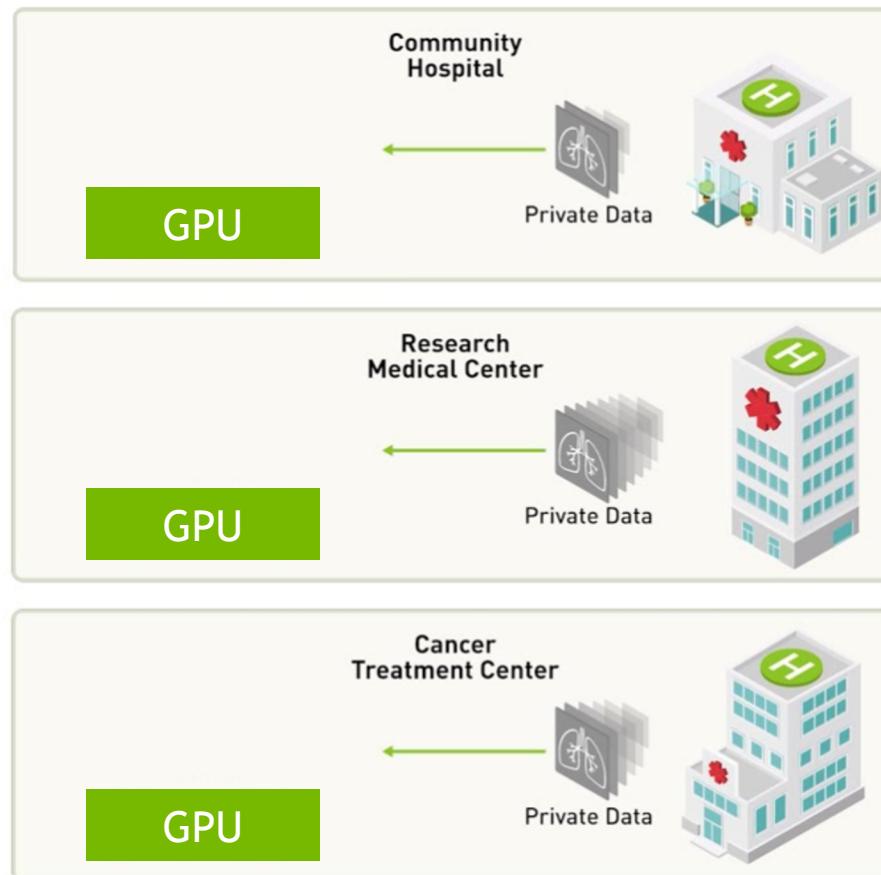
Nature Medicine 2021



CXR/EMR Classification
20 Global Collaborators

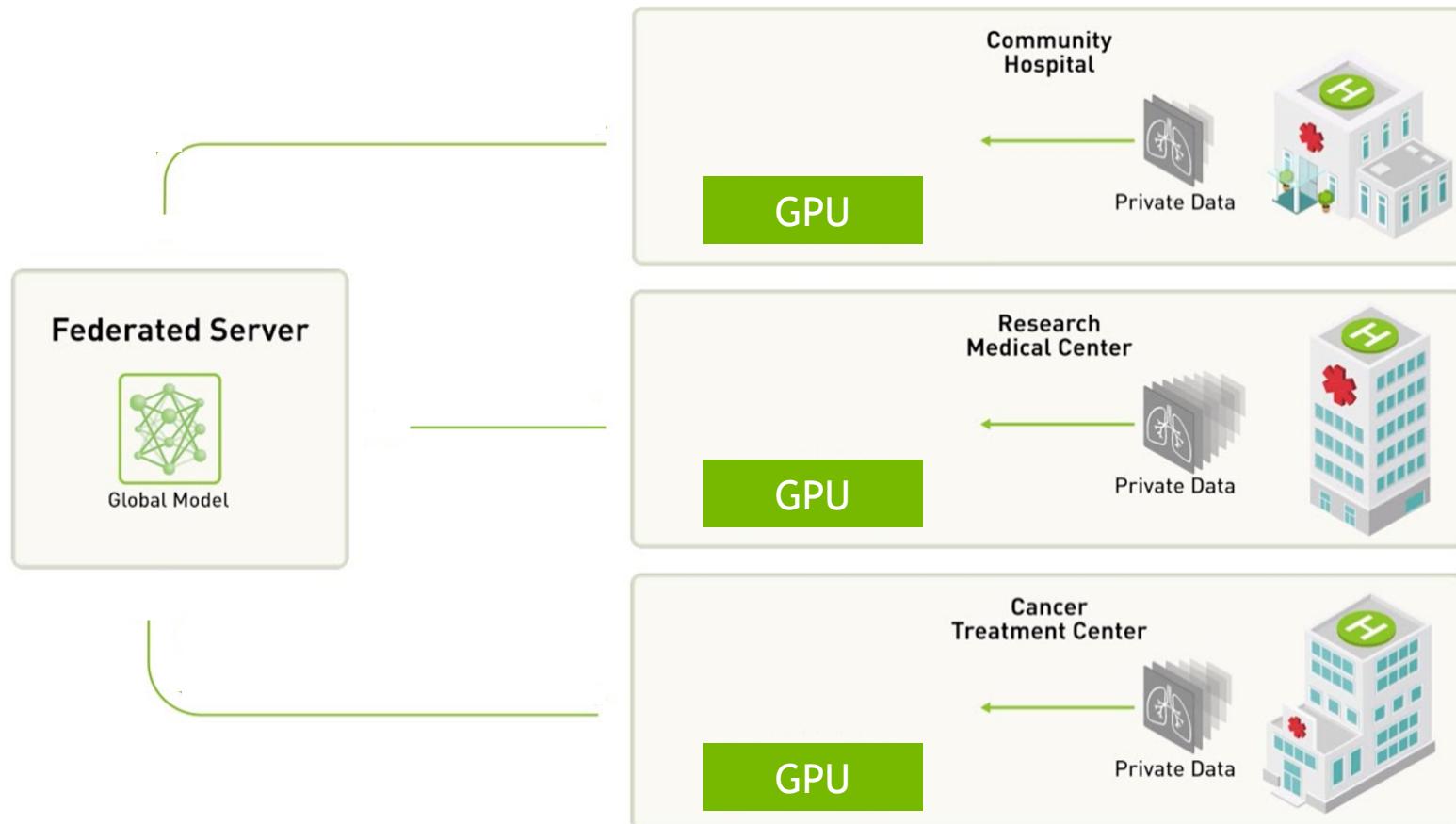
SERVER-CLIENT FEDERATED LEARNING

Changing the way AI algorithms are trained



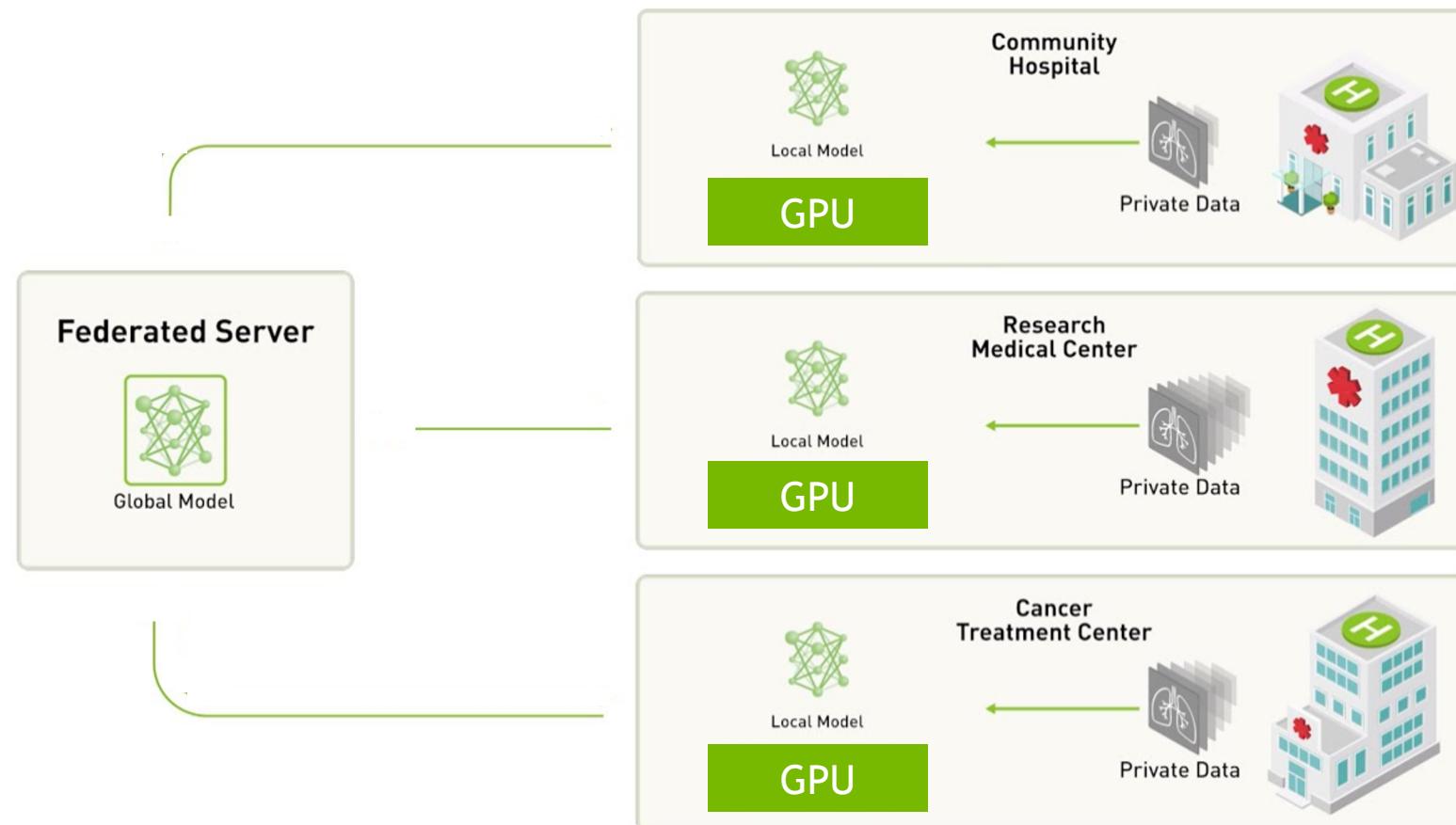
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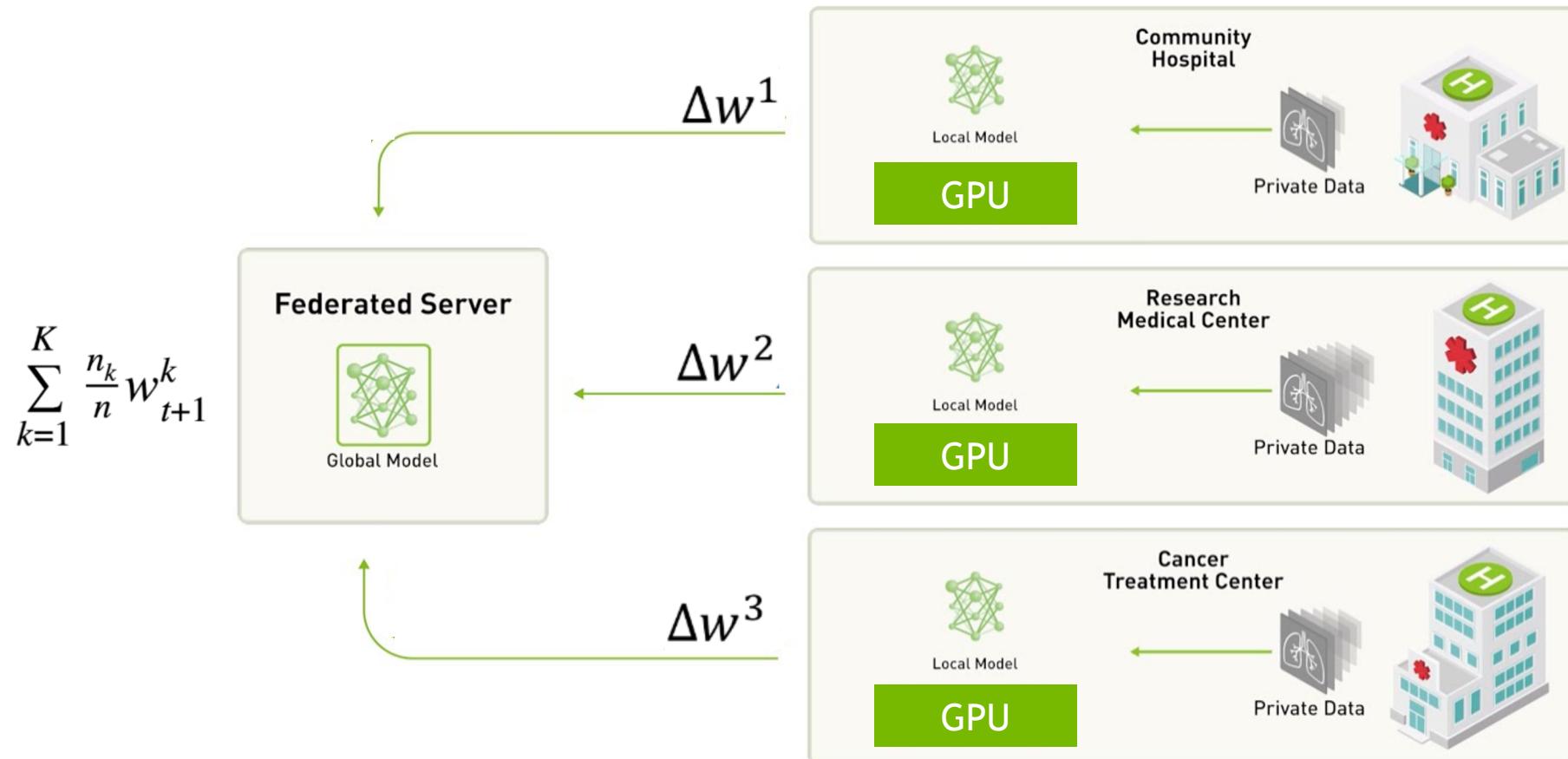
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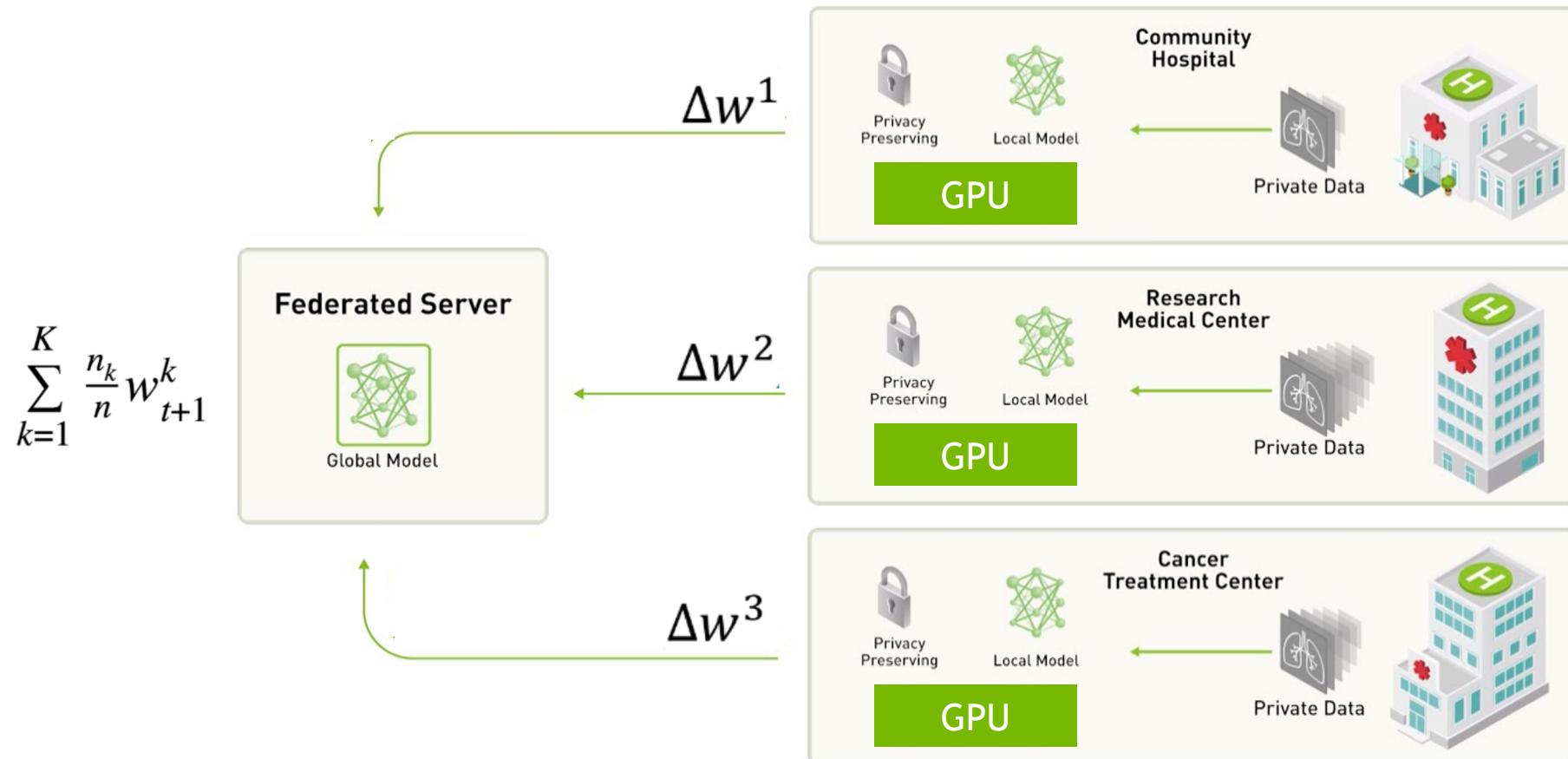
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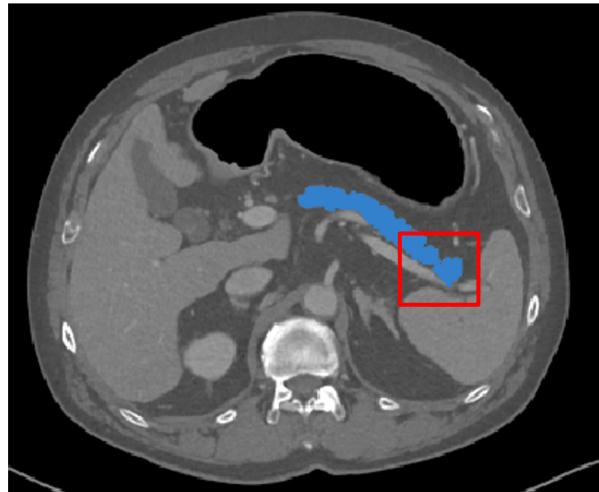
SERVER-CLIENT FEDERATED LEARNING

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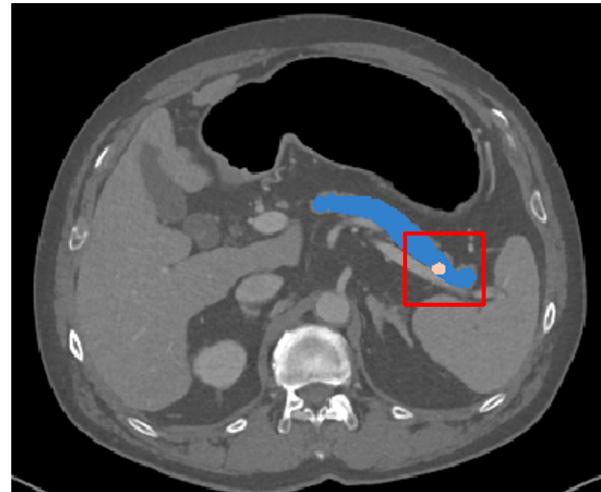


FEDERATED LEARNING

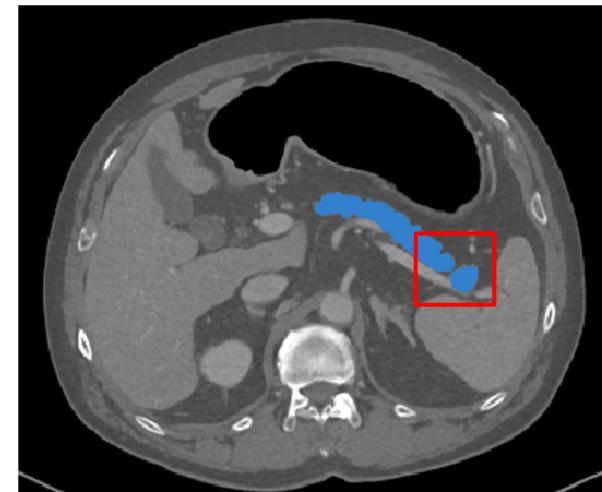
Global vs. Local



Ground truth



C2 (local)
Trained on
pancreas & tumor

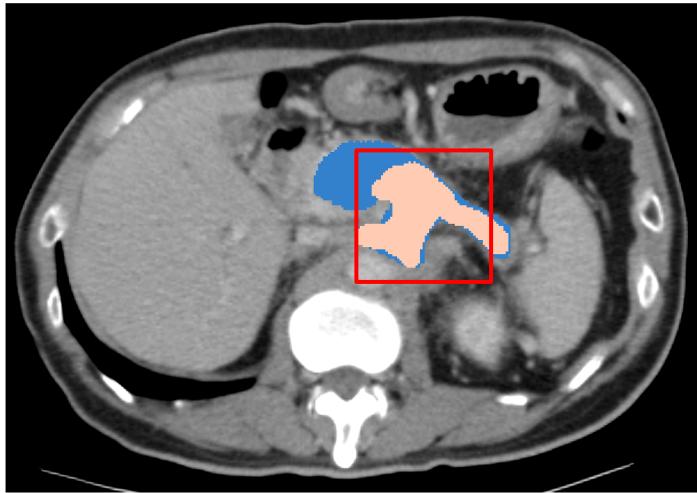


FL (global)

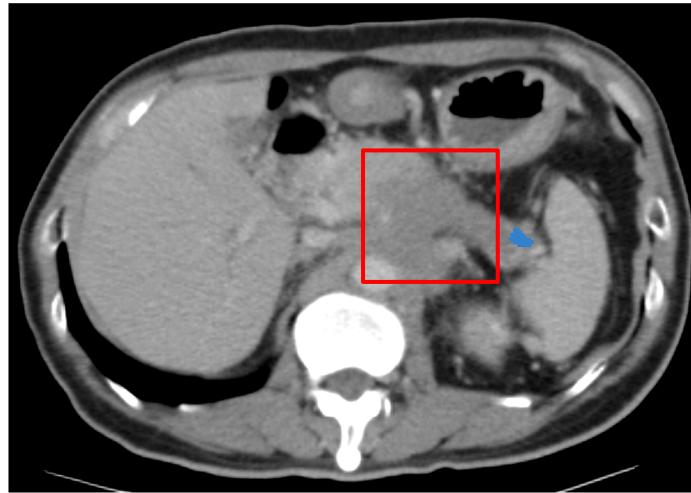
Dataset	Client 1	Client 2
Cases	420	486
Label	2 class (background, pancreas)	3 classes (background, pancreas, tumor)

FEDERATED LEARNING

Global vs. Local



Ground truth



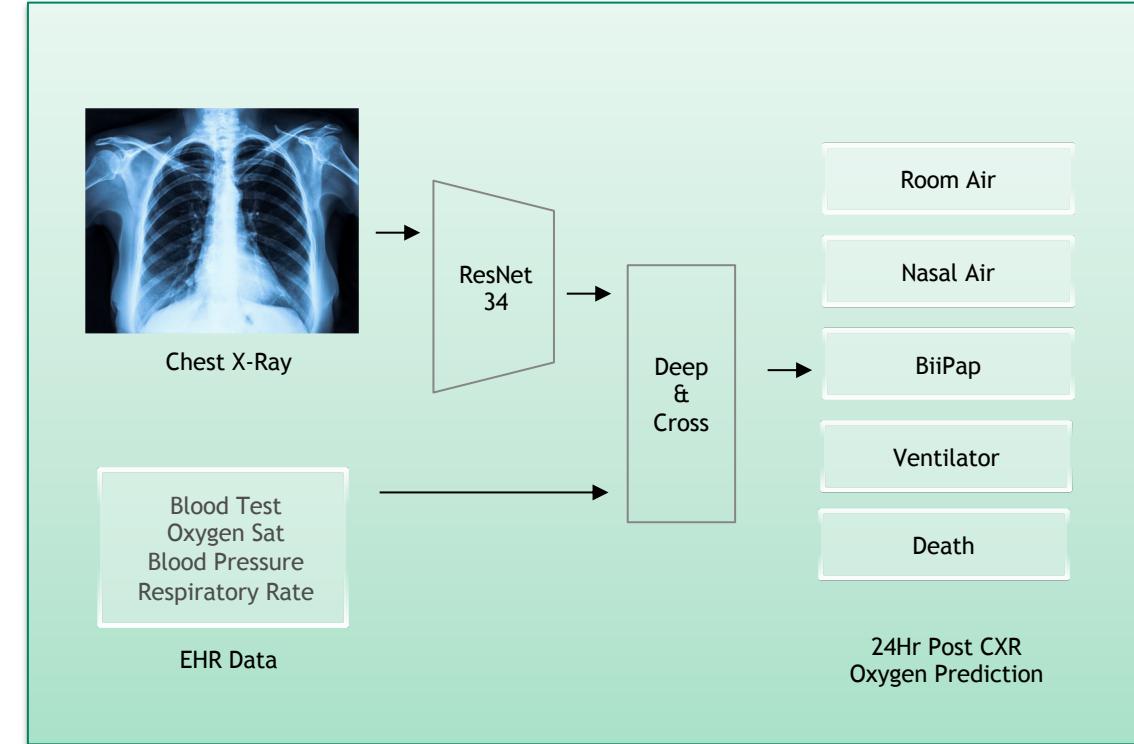
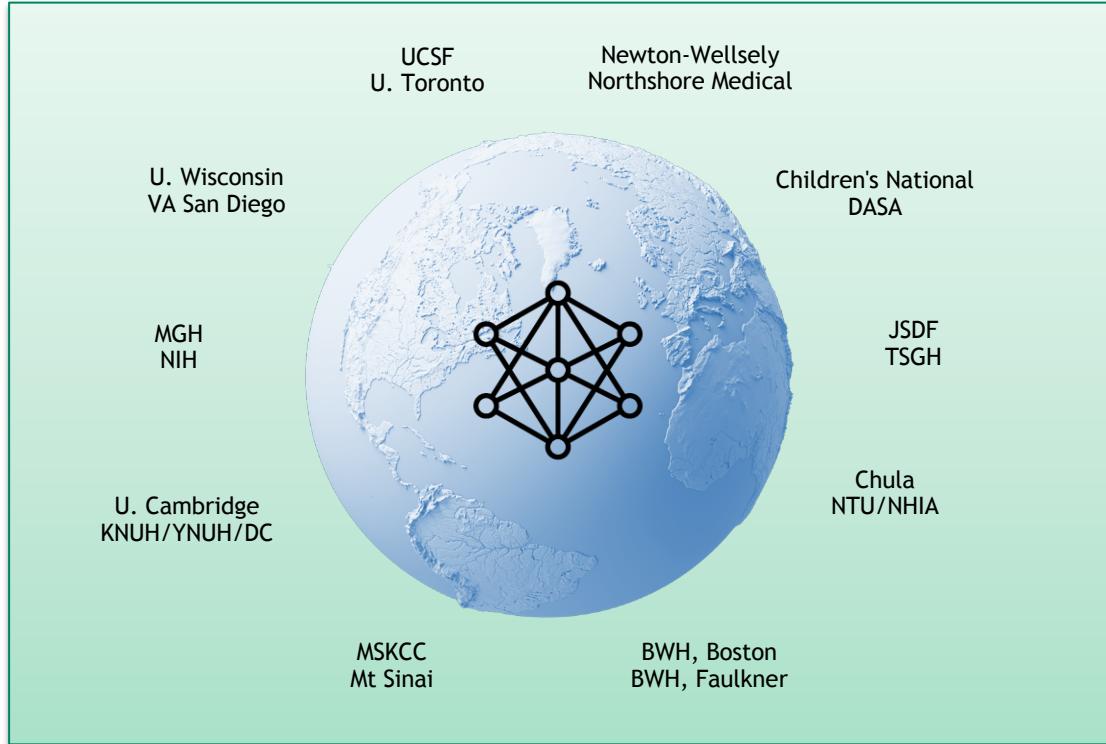
C1 (local)
Trained on
healthy pancreas



FL (global)

Dataset	Client 1	Client 2
Cases	420	486
Label	2 class (background, pancreas)	3 classes (background, pancreas, tumor)

FEDERATED LEARNING FOR COVID-19 PATIENT CARE



Clara Federated Learning
20 Sites | 8 Countries
COVID-19 Oxygen Prediction

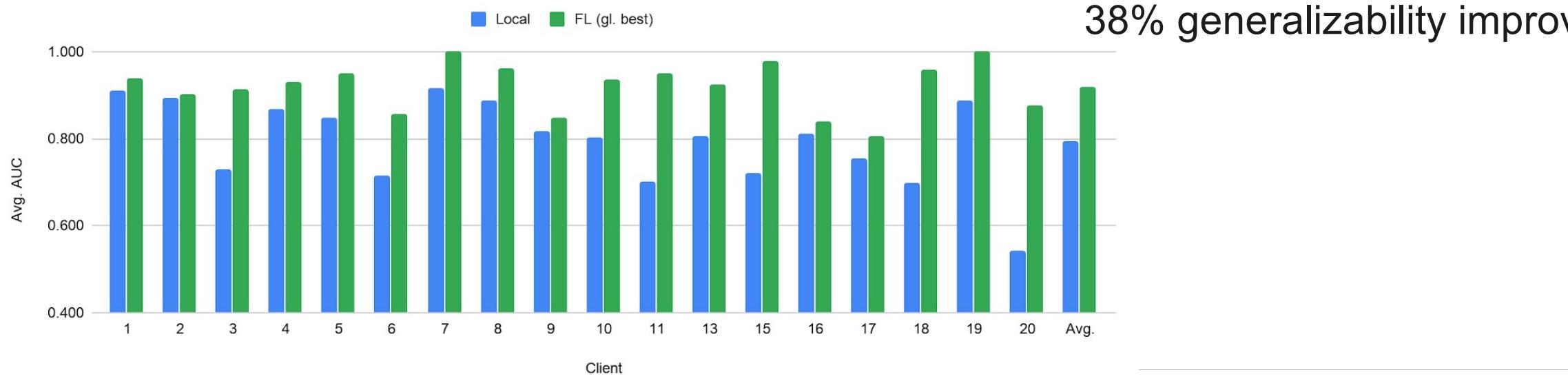
Global Model Achieved .93AUC
>25% Relative Improvement
Every Site Benefited Regardless of Dataset Size

Dayan et al. Nature Medicine, Sep 15, 2021:
<https://www.nature.com/articles/s41591-021-01506-3>

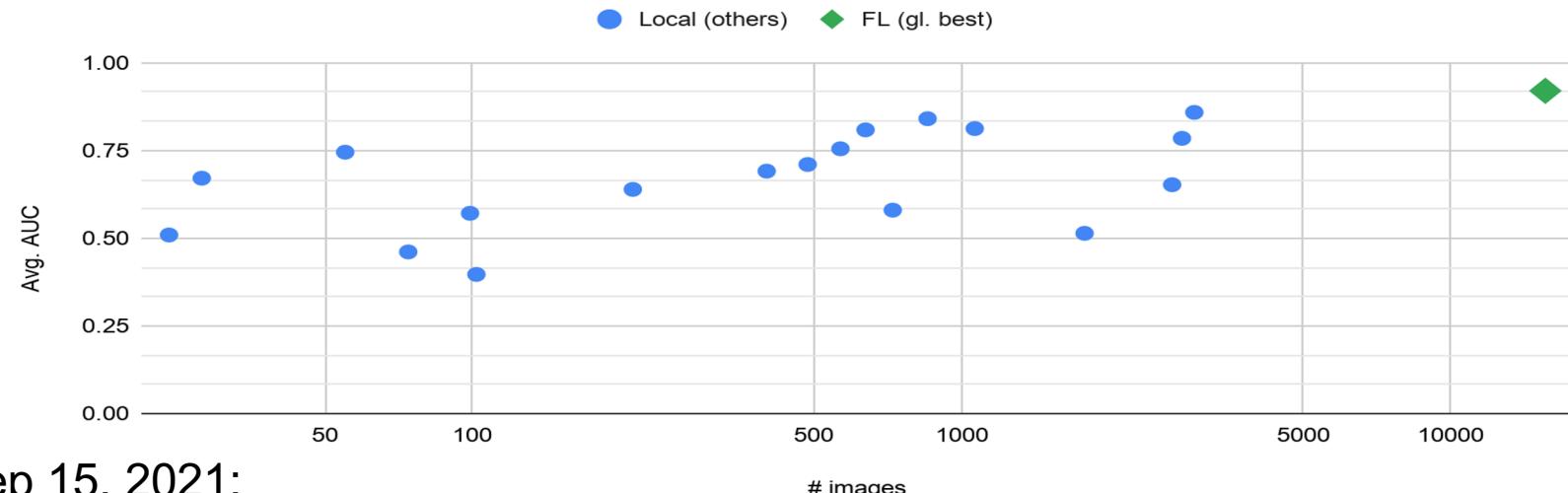
FL FOR COVID-19

size-based ordering

FL resulted on average in
16% performance improvement
38% generalizability improvement



Size vs. generalizability

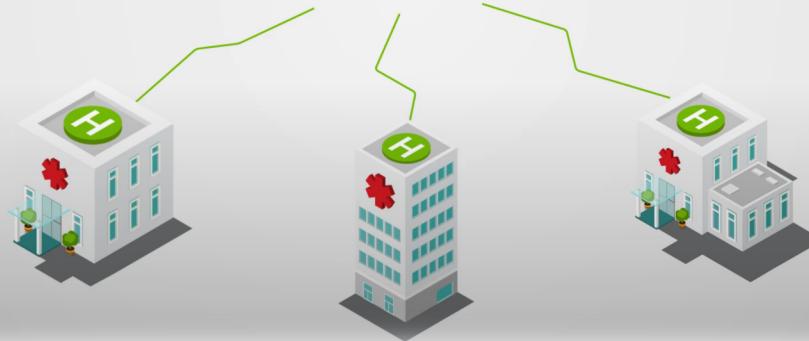


FL FOR COVID-19: EXTERNAL VALIDATION

95 %
Sensitivity



88 %
Specificity



Predicting need for mechanical ventilation

**EXAM Model Released
on NGC:**

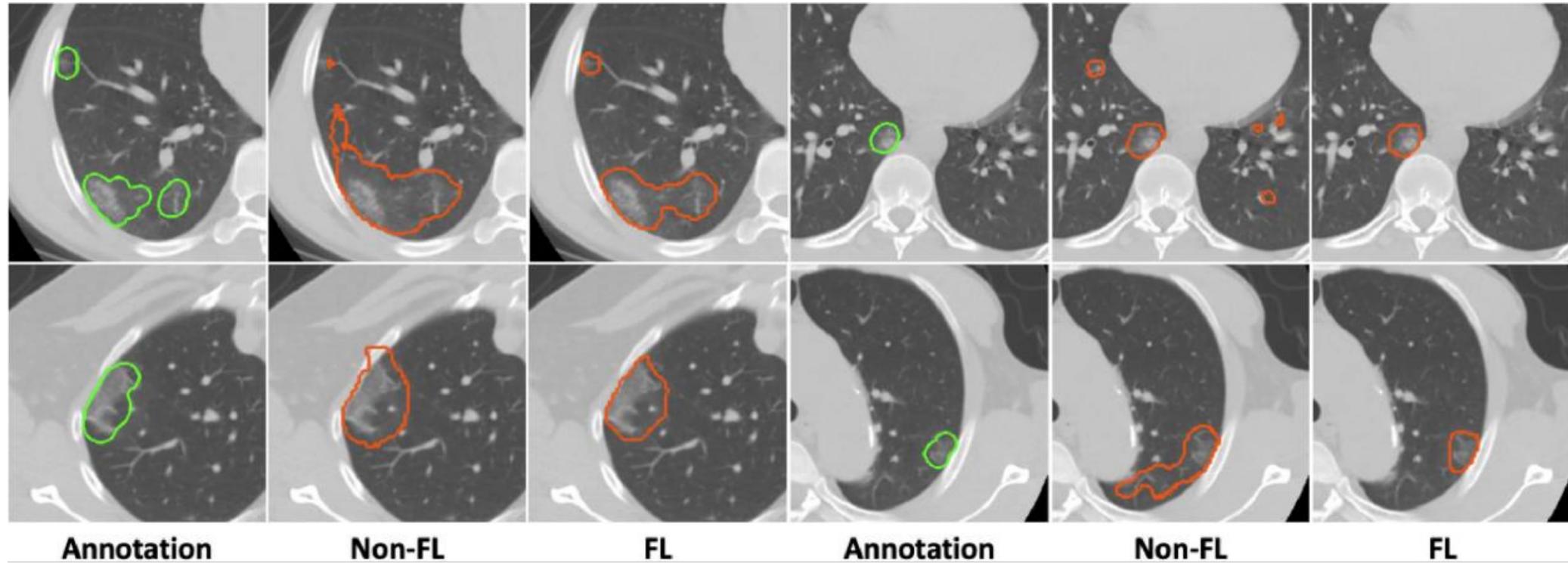
24h avg. AUC: **0.94**

72h avg. AUC: **0.91**

[https://ngc.nvidia.com/catalog/models/nvidia:med:
clara_train_covid19_exam_ehr_xray](https://ngc.nvidia.com/catalog/models/nvidia:med:clara_train_covid19_exam_ehr_xray)

YouTube: <https://youtu.be/cOXVrtkv6FE>

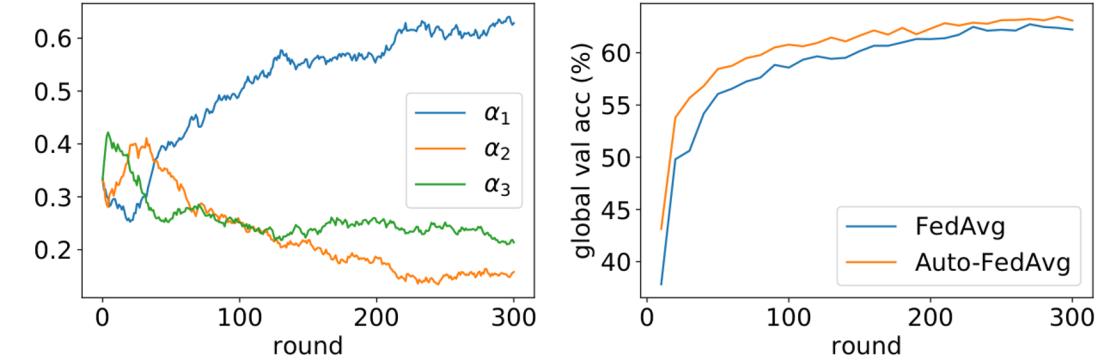
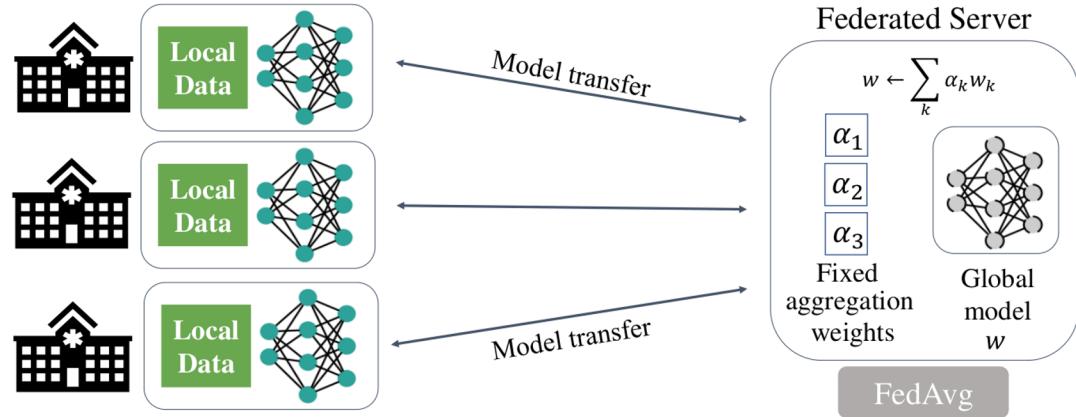
FEDERATED SEMI-SUPERVISED LEARNING



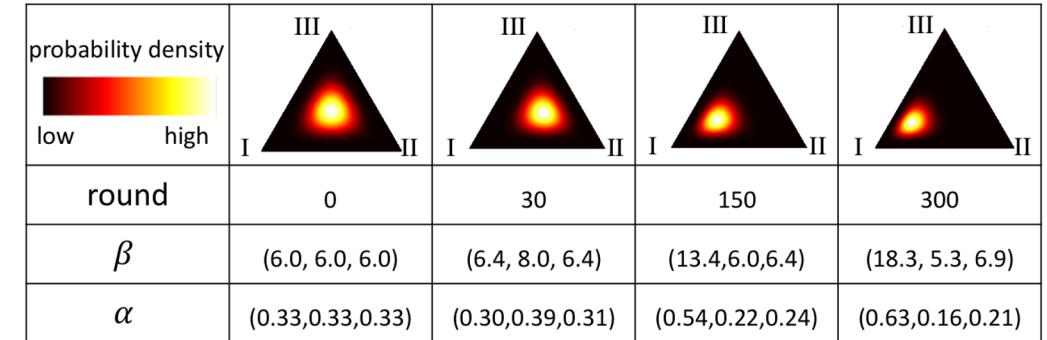
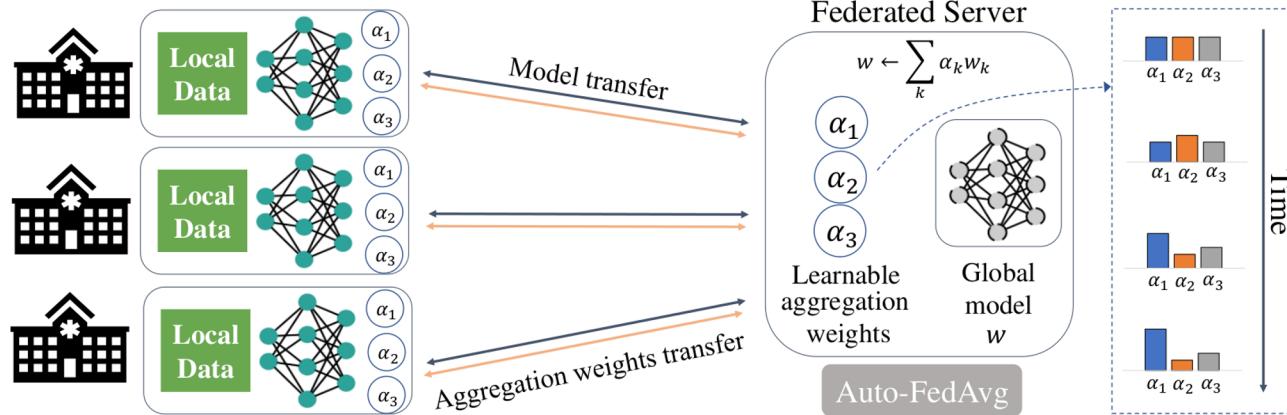
Non-FL: model trained with client 1 alone

FL: model trained with federated semi-supervised learning on client 1 and client 2

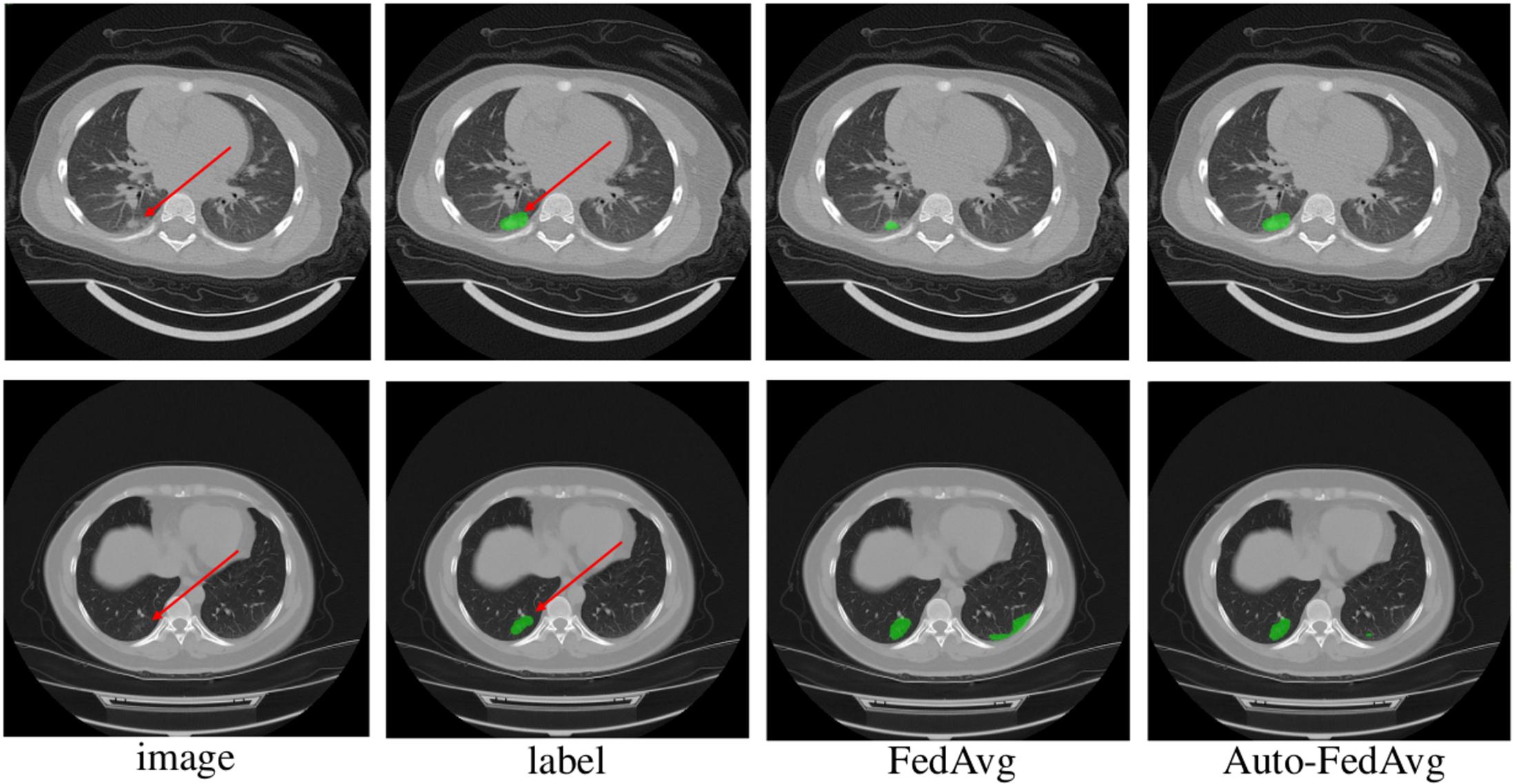
AUTO-FEDAVG: LEARNABLE FEDERATED AVERAGING FOR MULTI-INSTITUTIONAL MEDICAL IMAGE SEGMENTATION



Auto-FedAvg:

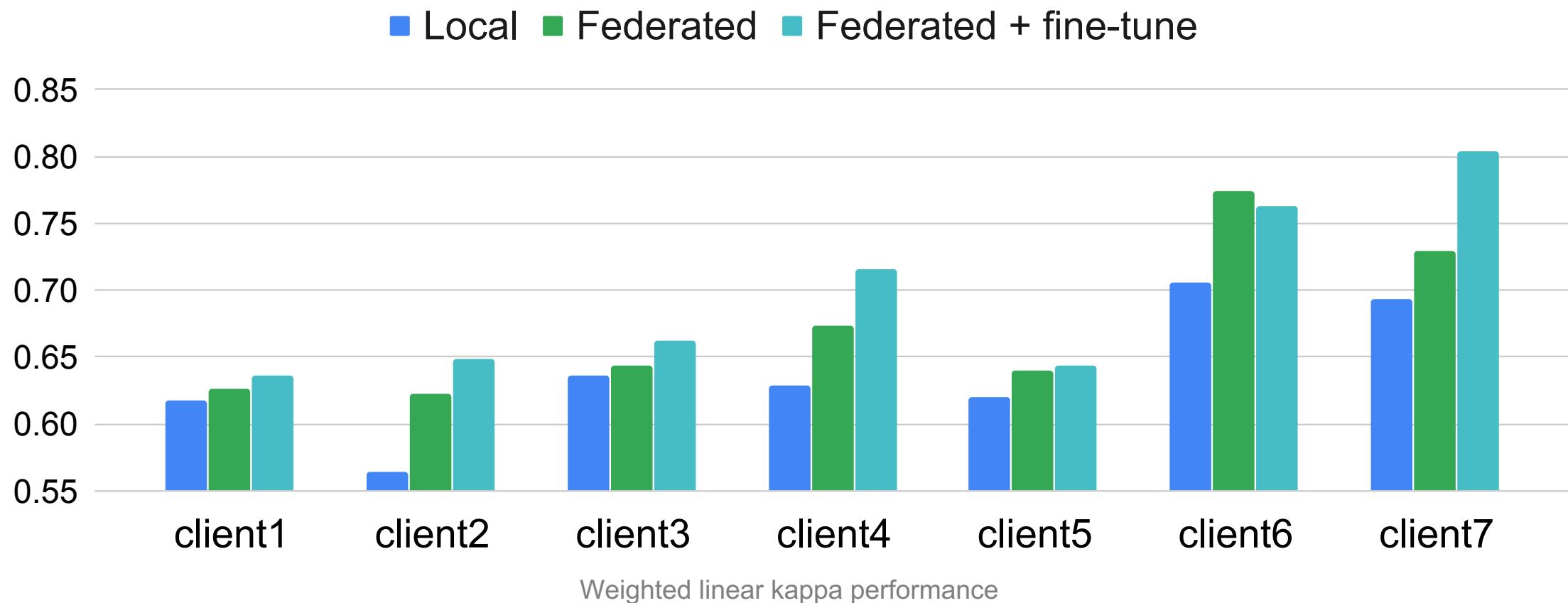


GLOBAL MODEL PERFORMANCE

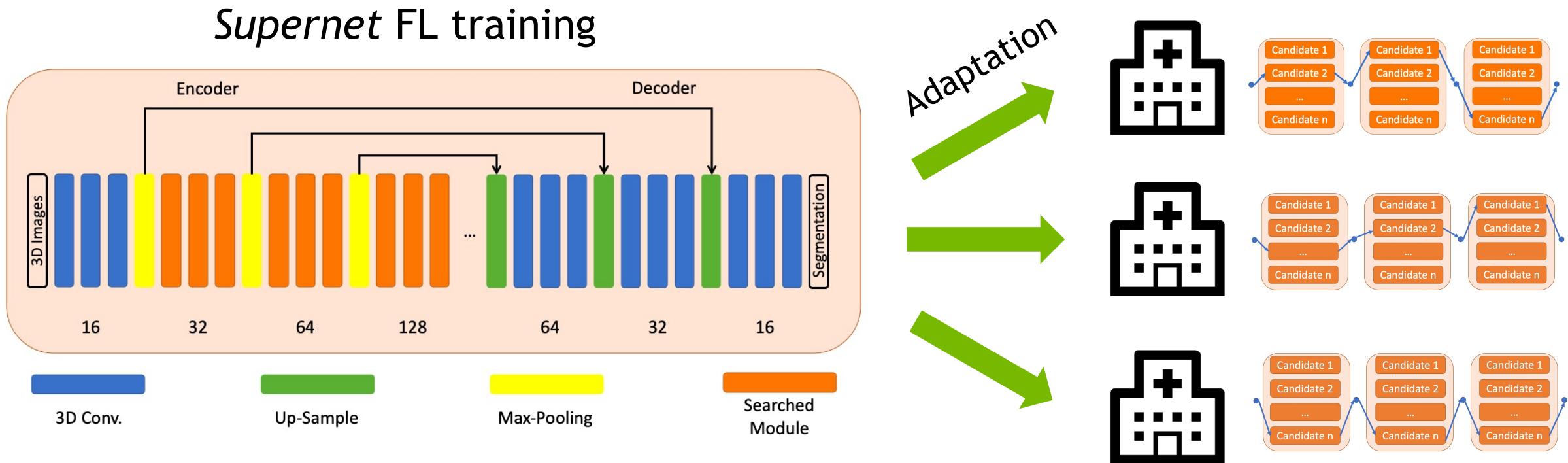


PERSONALIZATION

Additional fine-tuning

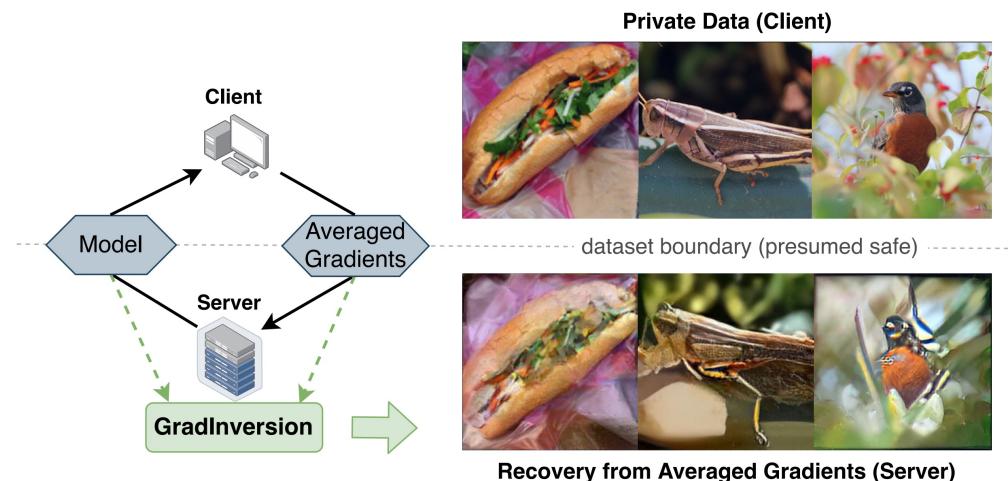


PERSONALIZATION



PRIVACY

- Could happen during training and trained model
- Any part of the model may leak privacy



Model inversion

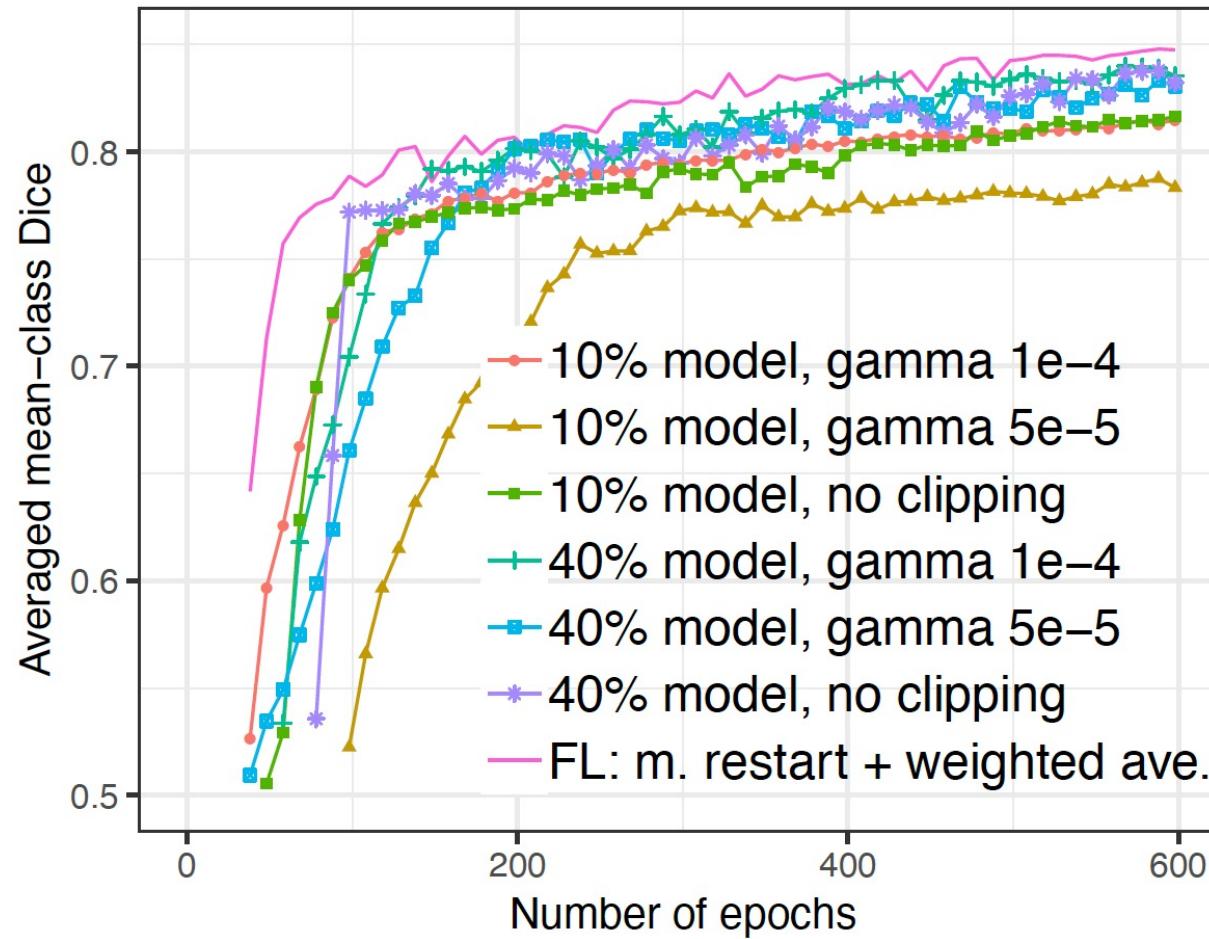
Reconstruction from only
gradients and batchnorm

Actual Image	MIA	DCGAN
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		

“hacker” using GAN

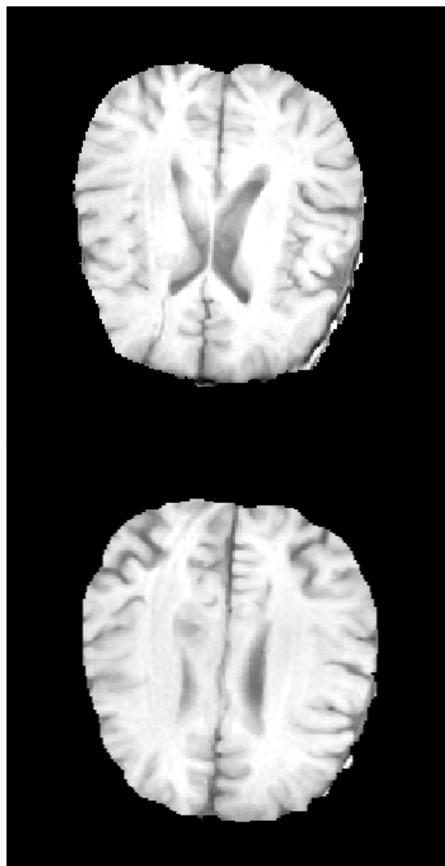
PRIVACY PRESERVING FL

Federated Brain Tumor Segmentation

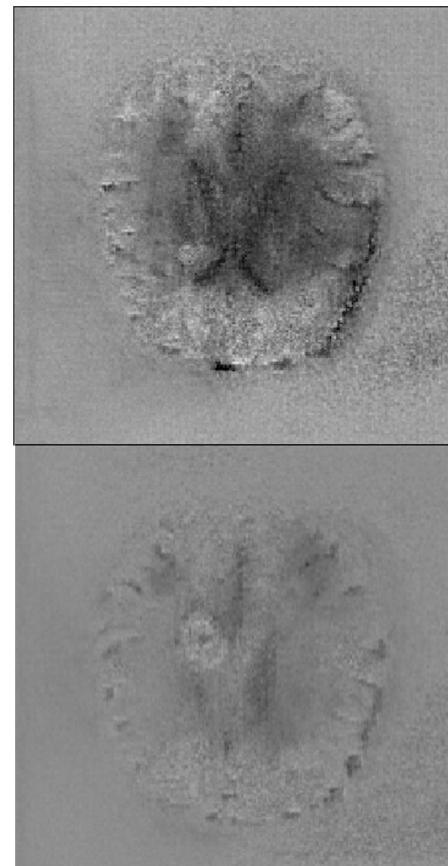


MODEL INVERSION CASE STUDY

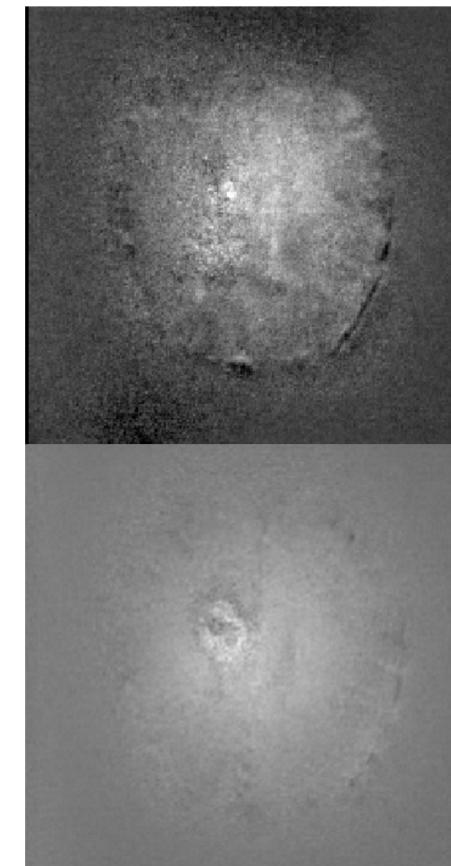
Training
volumes



Reconstructions from
FL model after
training



Reconstructions from FL
model trained with privacy-
preserving module



FL SECURITY

Multi Layered



Identity Security
Public Key Infrastructure



Communication Security
(SSL)



Differential Privacy
Homomorphic Encryption
Secure Multi-Party
Computation

MONAI FL WORKING GROUP

Federated Learning and Applications



Group Leads: [Jayashree Kalpathy-Cramer](#) & [Daniel Rubin](#) & [Holger Roth](#)

FL examples, reusable components, standardization, etc.

FL TUTORIALS IN MONAI

Project-MONAI / **tutorials** Public

Watch 16 Star 302 Fork 160

<> Code Issues 22 Pull requests 9 Discussions Actions ...

master tutorials / federated_learning / Go to file Add file ...

 **Borda** and wyli rename n_classes (#322) ... ✓ 13 days ago ⏪ History

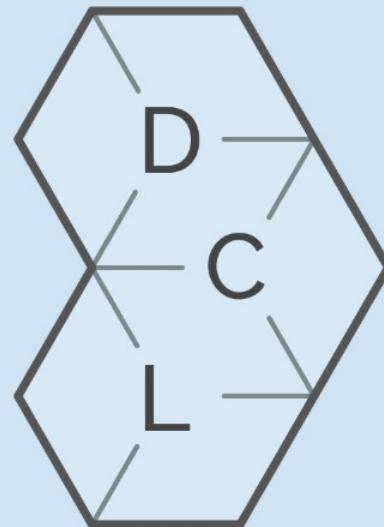
..

 nvflare rename n_classes (#322) 13 days ago

 substrा 299 add inference script (#338) 19 days ago

Source: https://github.com/Project-MONAI/tutorials/tree/master/federated_learning

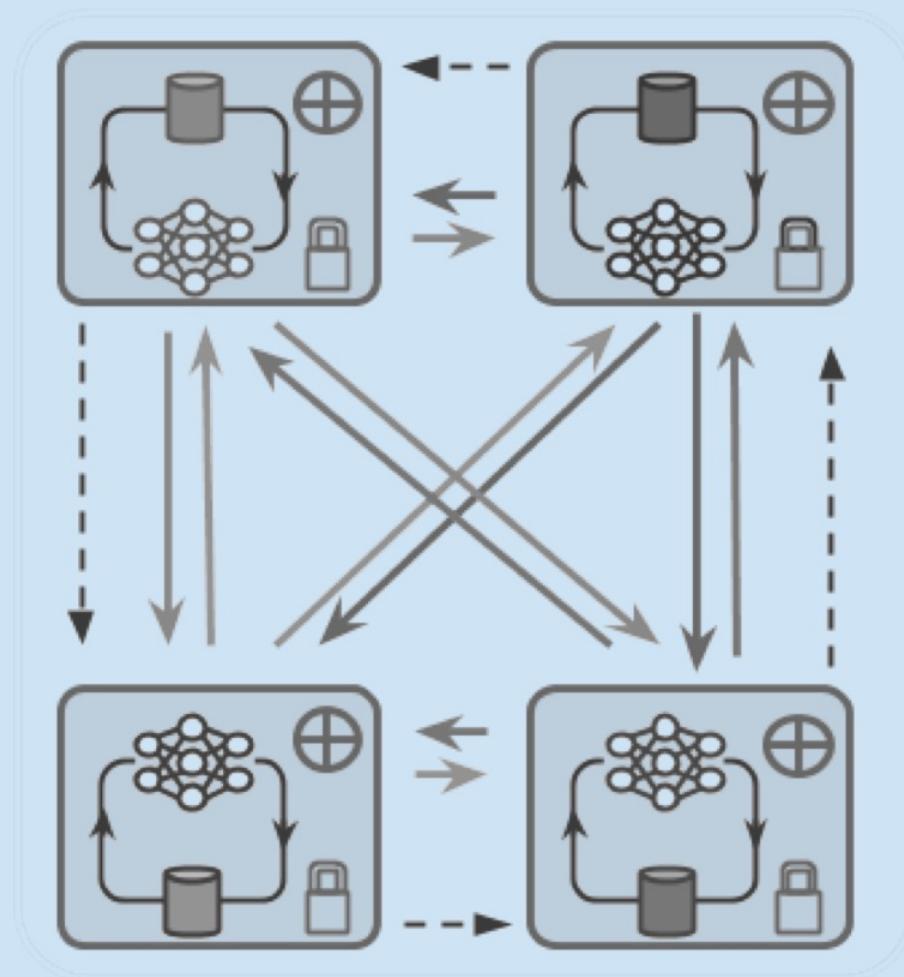
Website: <https://dcl-workshop.github.io>



Distributed &
Collaborative
Learning

2nd MICCAI Workshop on
“Distributed And Collaborative Learning”

Oct 1, 2021 / 9:00-13:00 (UTC)



Thank you!