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CAreFL: Contribution-Aware Federated Learning for Smart Healthcare

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About Me

Liu Zelei

- 2019/10-2022/10, **Research Fellow @ SCSE, NTU**
- 2019: **PhD** in CS from CCST, JLU

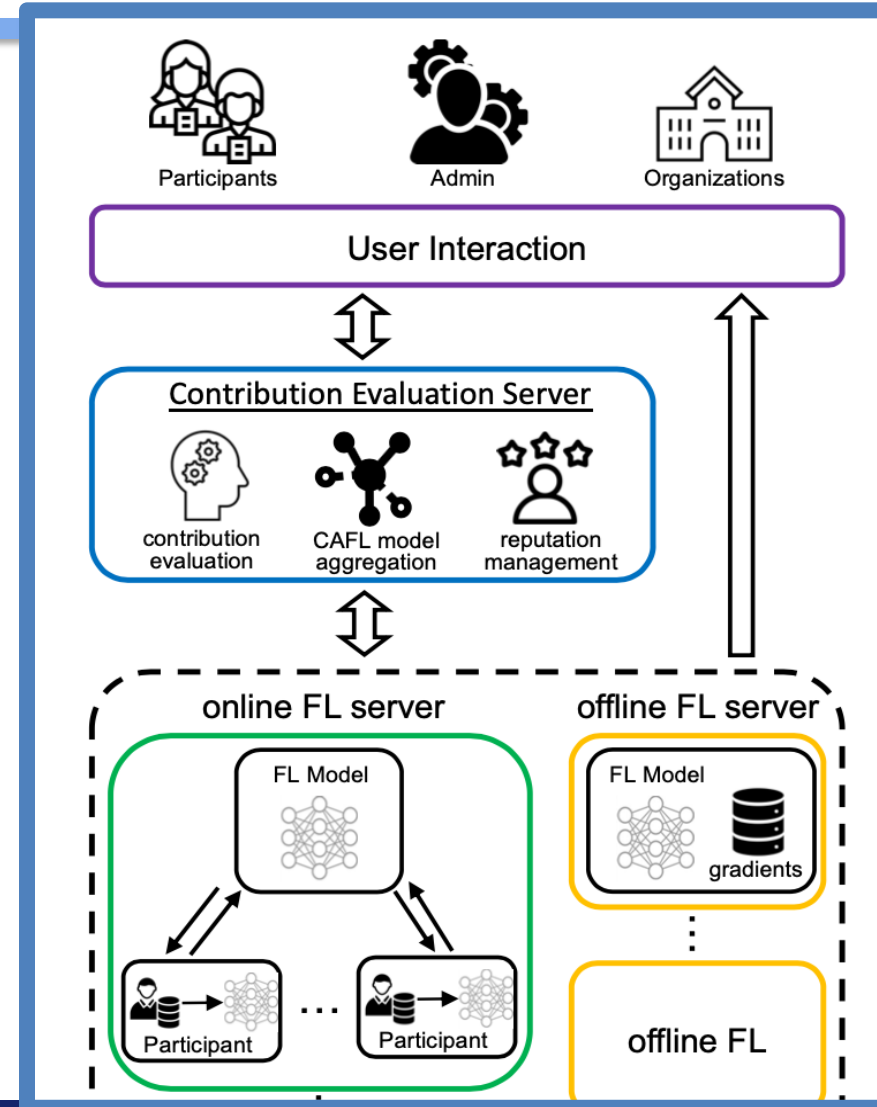
Research Interest:

- Incentive Mechanism Design for FL
- Fairness in Ethical AI



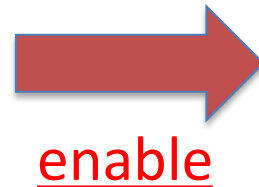
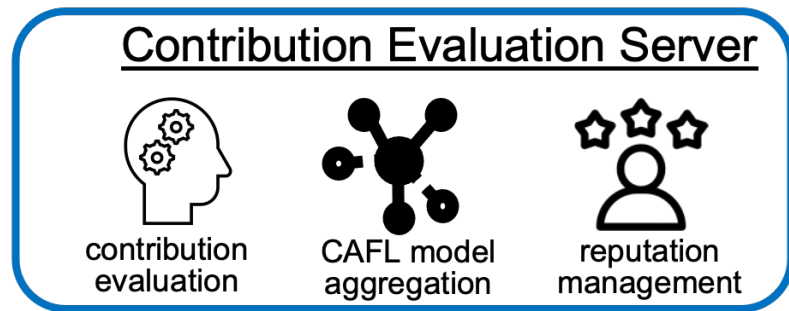
CAreFL Overview

1. FL infrastructure
2. Contribution Evaluation
3. User Interaction

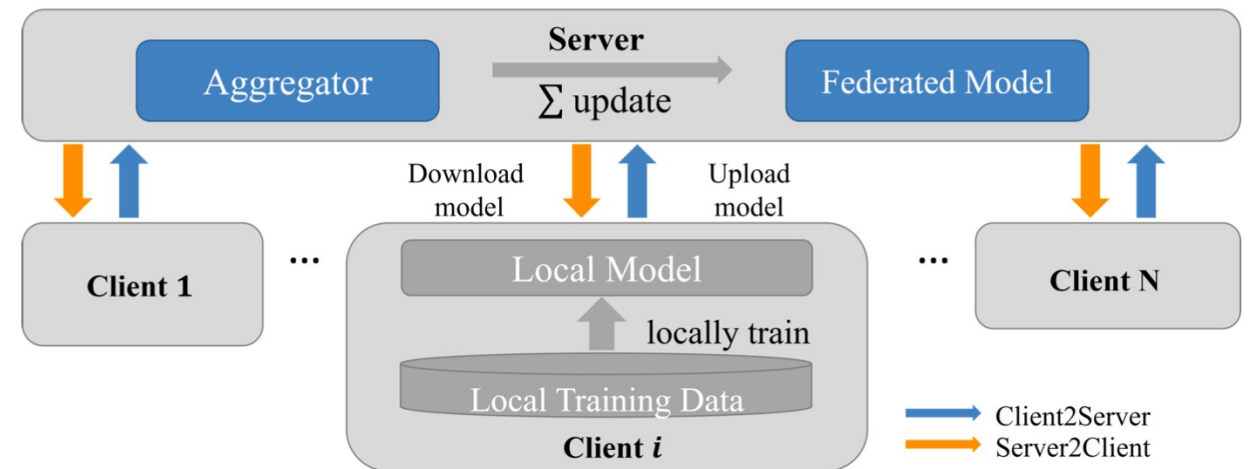


CAreFL Overview

- CAreFL: a HFL framework focusing on Contribution in FL.



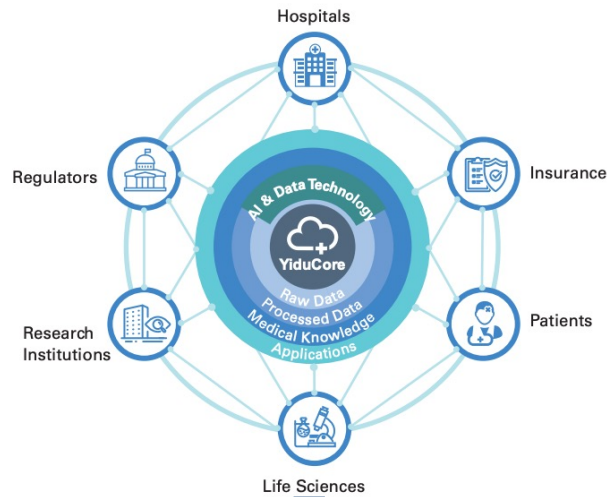
Traditional HFL framework



New Solution for Smart Healthcare

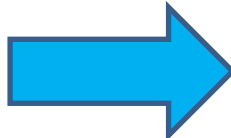
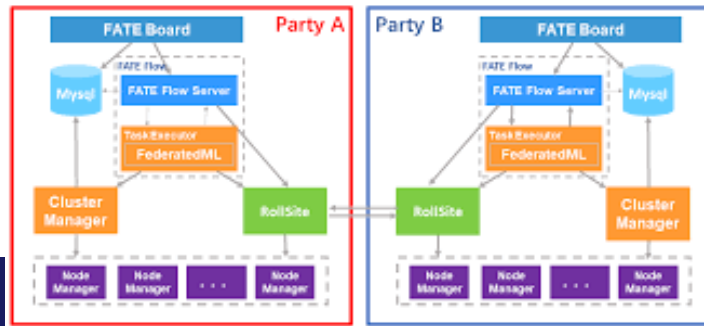


Healthcare Big Data Platform



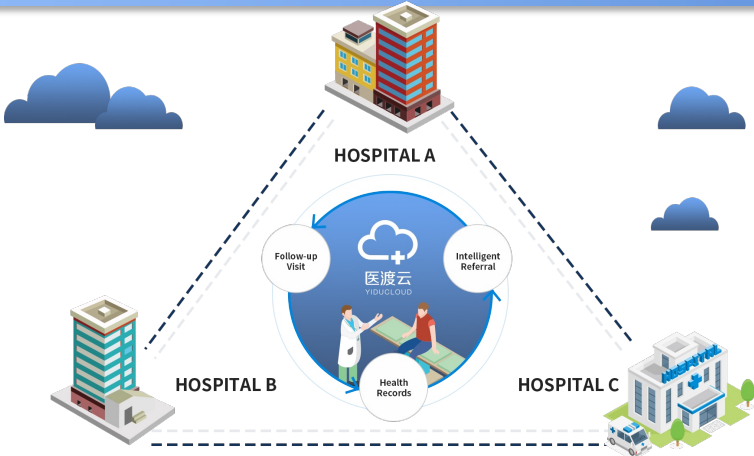
FATE

Federated Learning framework



New Collaboration Solution

Diverse Collaborations



light-weight collaboration



collaboration between hospitals



collaboration with third party

Key Concerns - Contribution



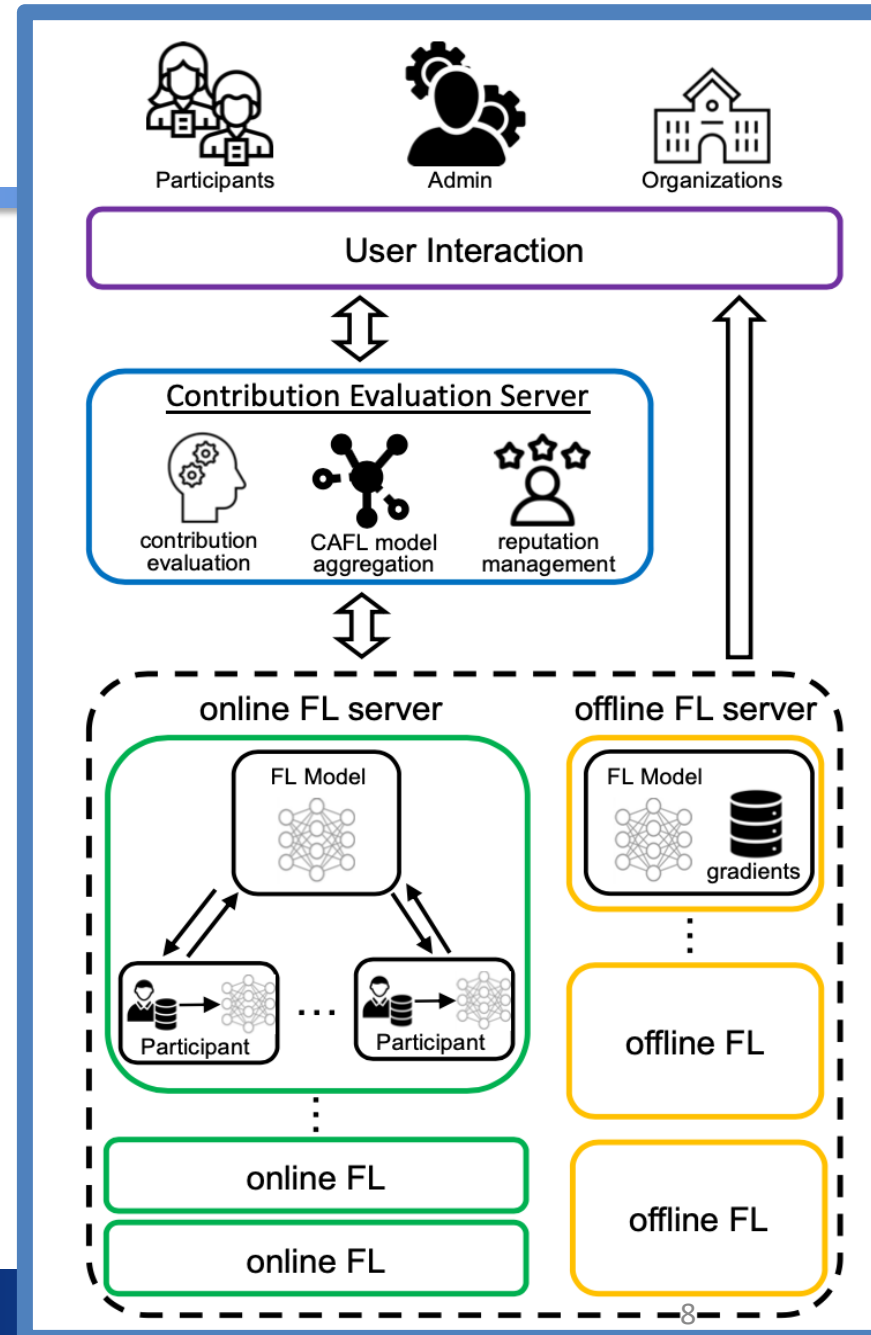
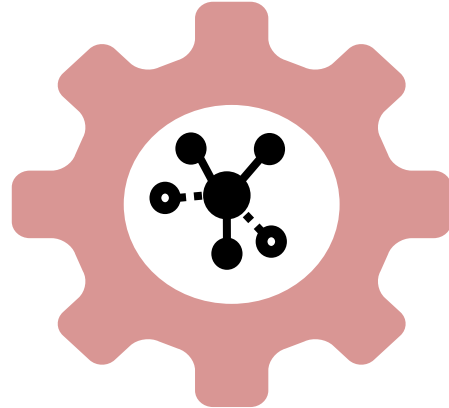
For example, a **pharmaceutical** company may wish to build a model to facilitate drug research by leveraging data from **multiple hospitals** through FL. In order to **compensate** the **participating hospitals**, the pharmaceutical company may need to offer **incentive payouts**. **How to fairly allocate the compensation?**



Fair Contribution Evaluation.

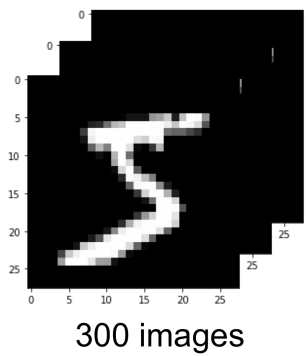
AI in CAreFL

- Focus on Contribution Evaluation

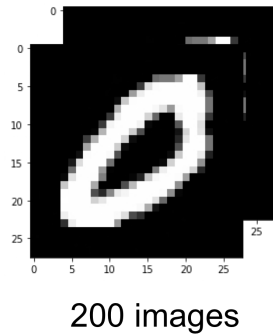


Contribution Evaluation Obstacle

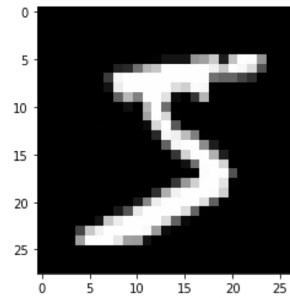
- Quantity, Quality, Label Quality



V.S.



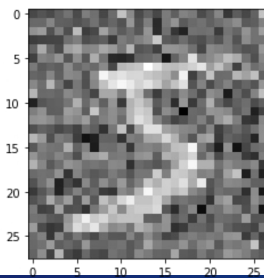
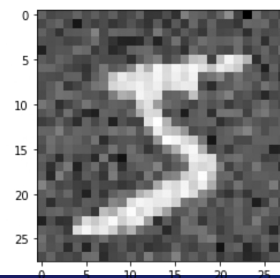
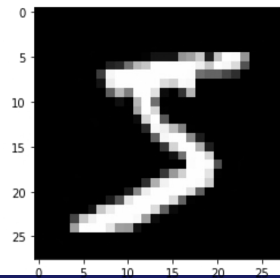
“Quantity”



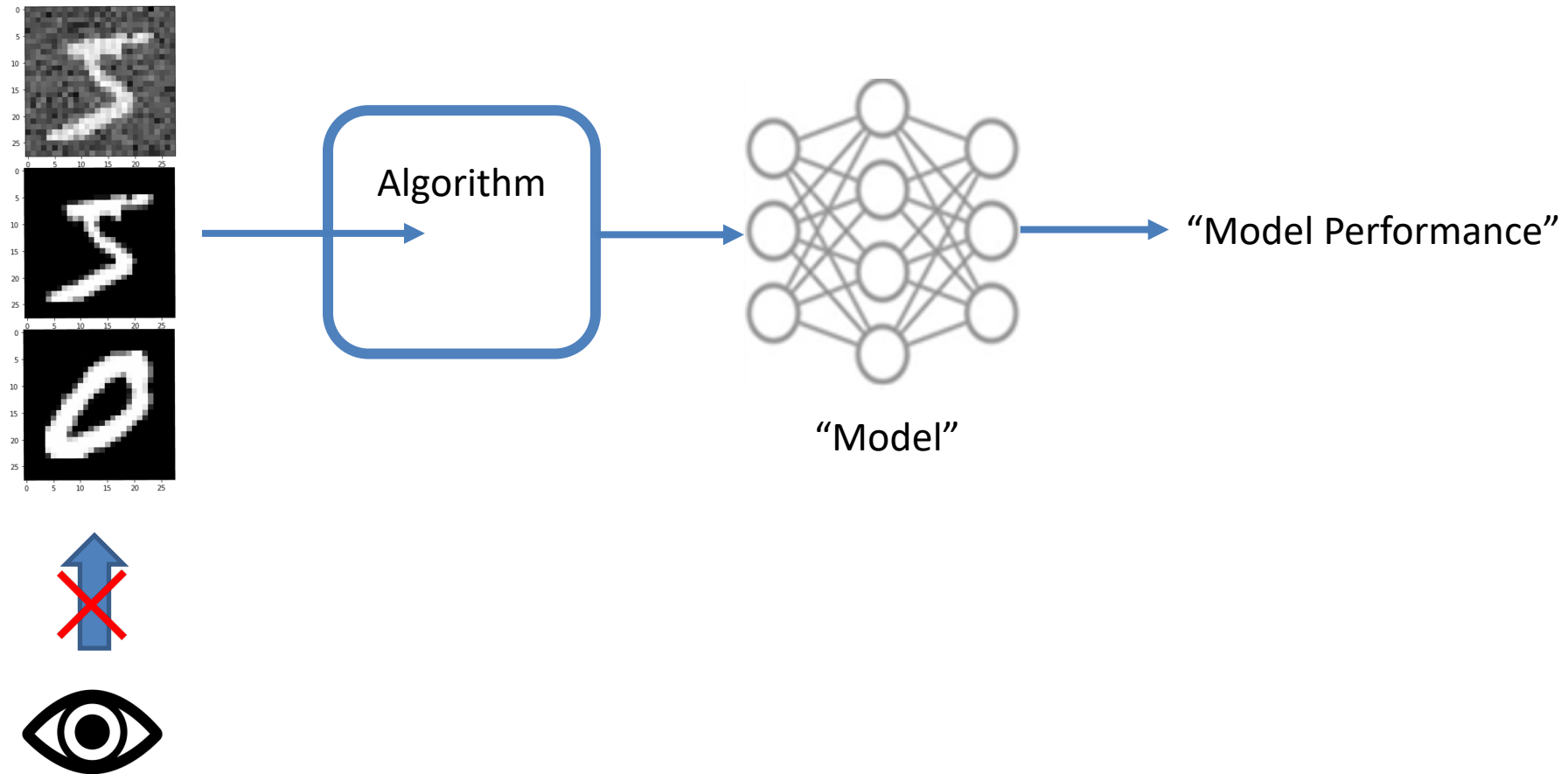
wrong label “1”

“Label Quality”

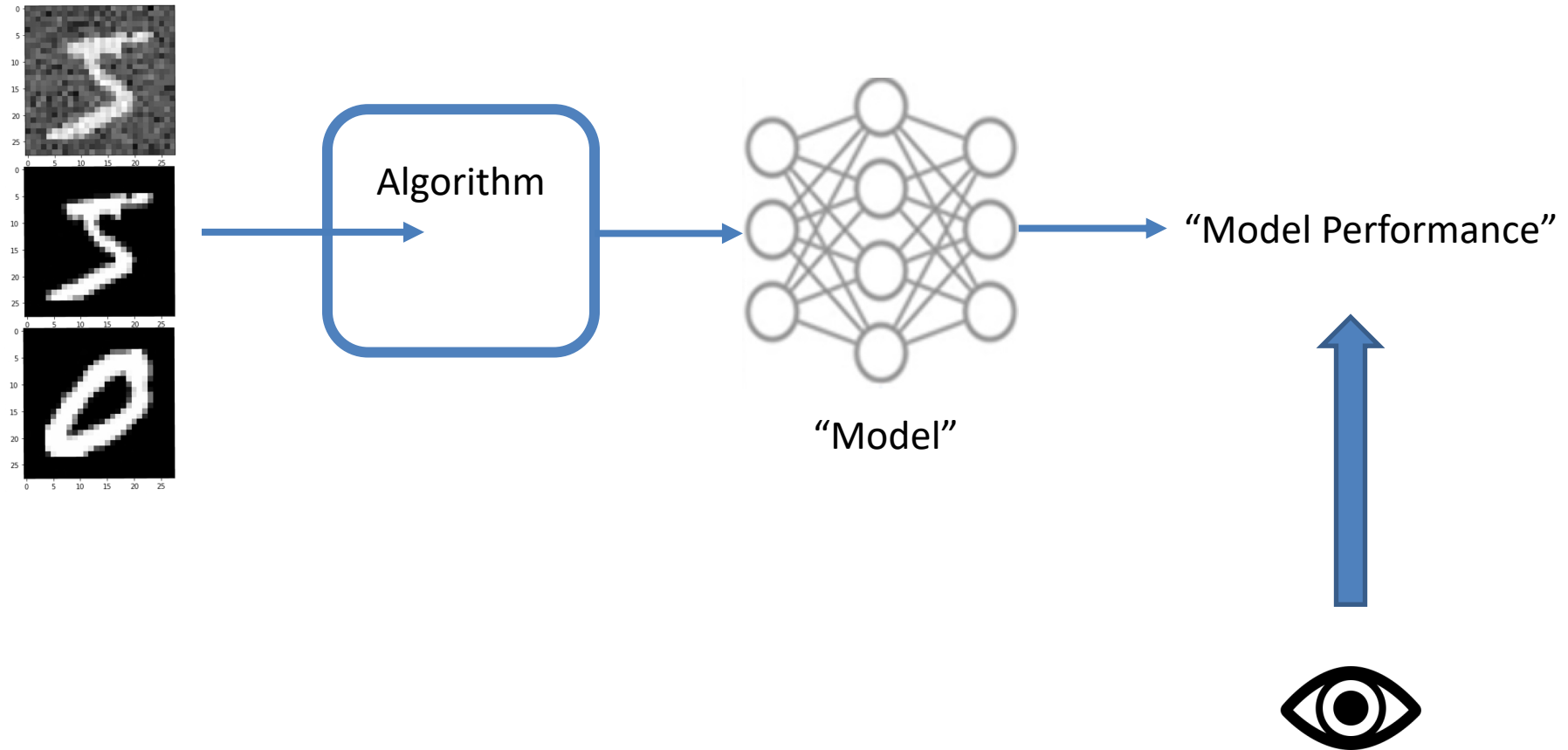
“Quality”



Contribution Evaluation Obstacle

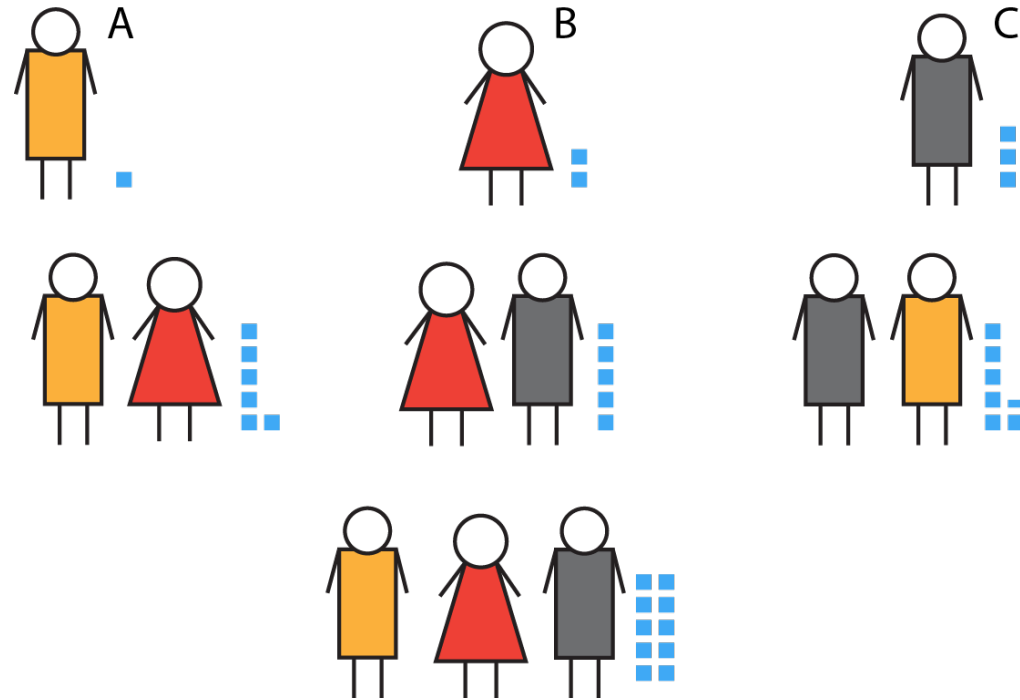


Contribution Evaluation Obstacle



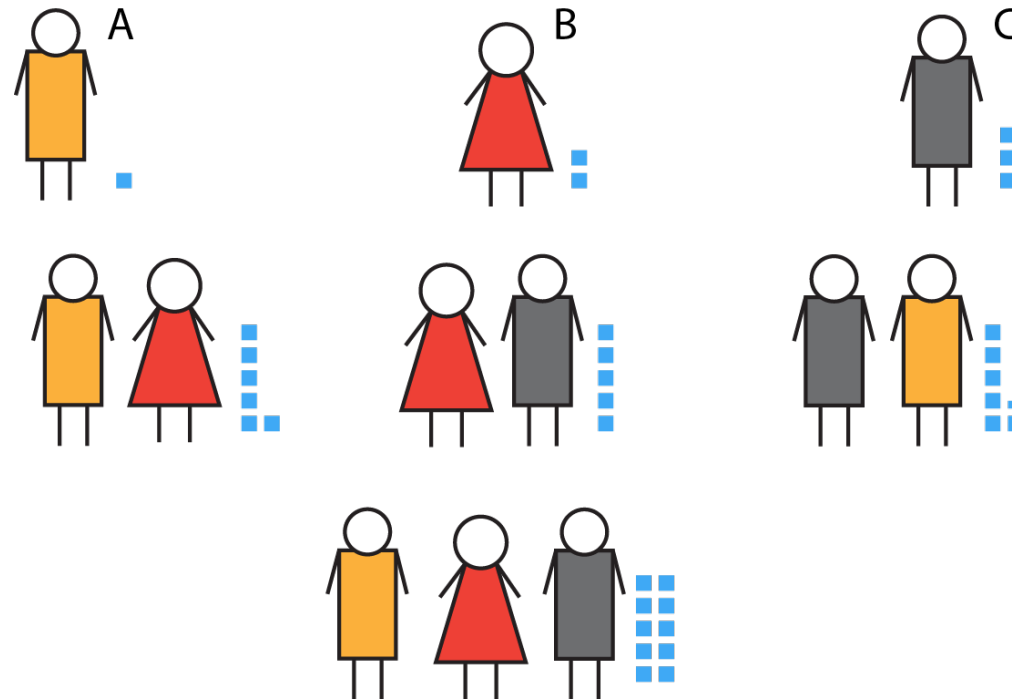
Shapley Value – An Example

- Example: A, B, C works together in a project worth of 100 points. How many points should each of them get?



Shapley Value – An Example

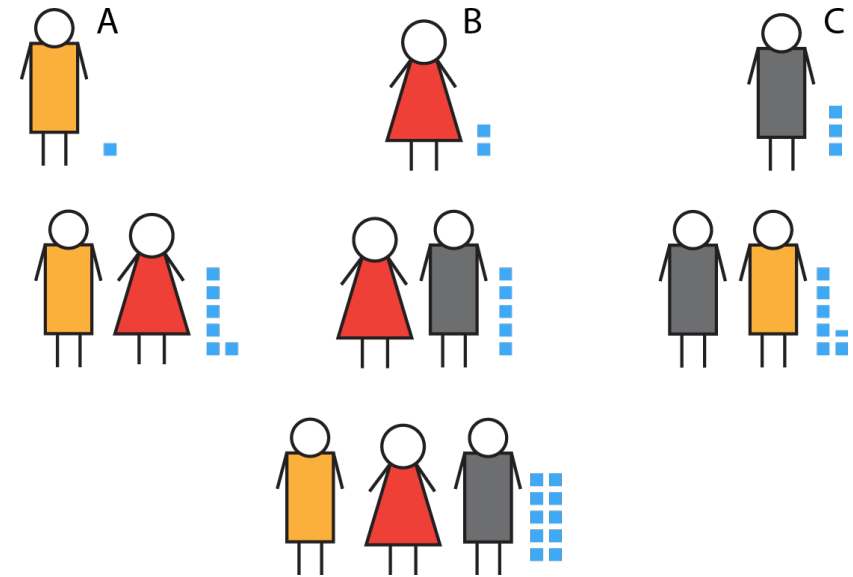
- $V(A)=10$, $V(B)=20$, $V(C)=30$
- $V(AB)=60$, $V(BC)=50$, $V(AC)=65$, $V(ABC)=100$



Shapley Value – An Example

- $V(A)=10, V(B)=20, V(C)=30$
- $V(AB)=60, V(BC)=50, V(AC)=65, V(ABC)=100$

- **B-C-A**: $(A,B,C)=(50,20,30)$
- **C-A-B**: $(A,B,C)=(35,35,30)$
- **A-C-B**: $(A,B,C)=(10,35,55)$
- **C-B-A**: $(A,B,C)=(50,20,30)$
- **B-A-C**: $(A,B,C)=(40,20,40)$

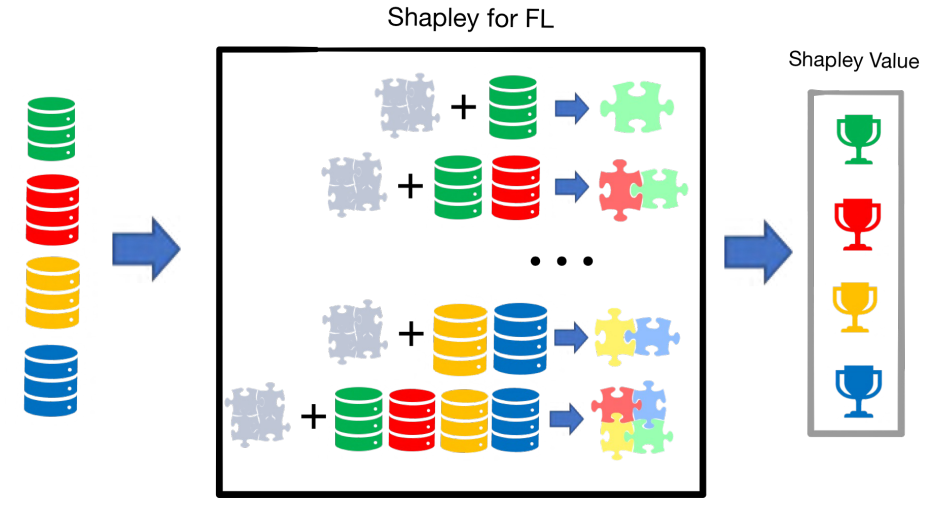
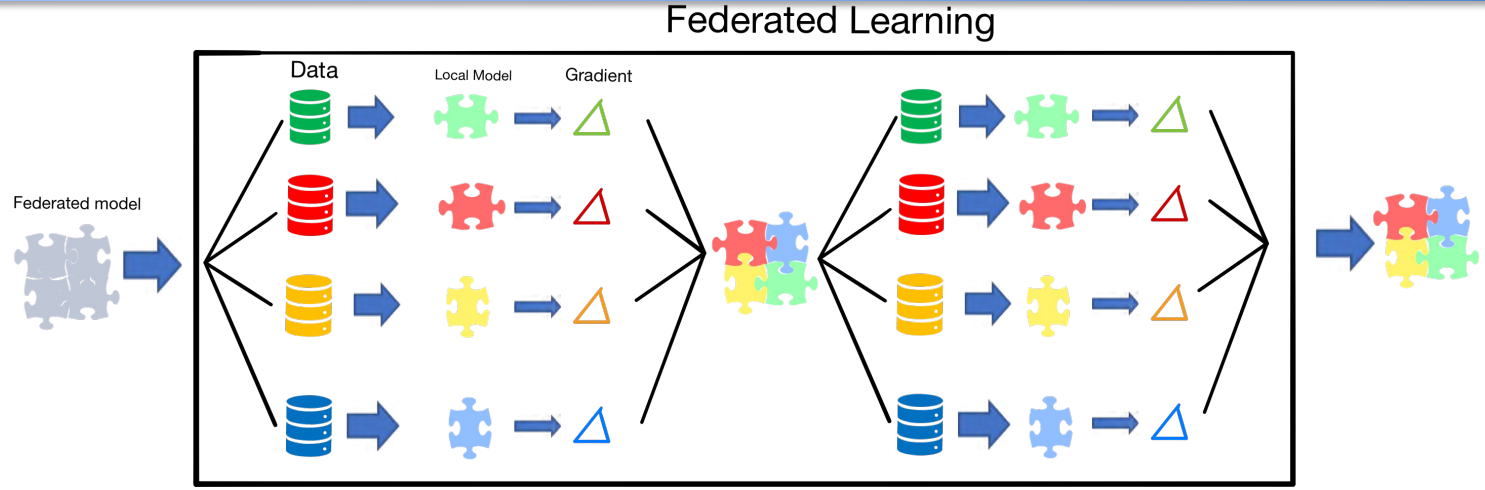


Shapley Value – An Example

- $A = (10 + 50 + 35 + 10 + 50 + 40) / 6 = 195 / 6 = 32.5$
- $B = (50 + 20 + 35 + 35 + 20 + 20) / 6 = 180 / 6 = 30$
- $C = (40 + 30 + 30 + 55 + 30 + 40) / 6 = 225 / 6 = 37.5$



Adopting Shapley Value in FL



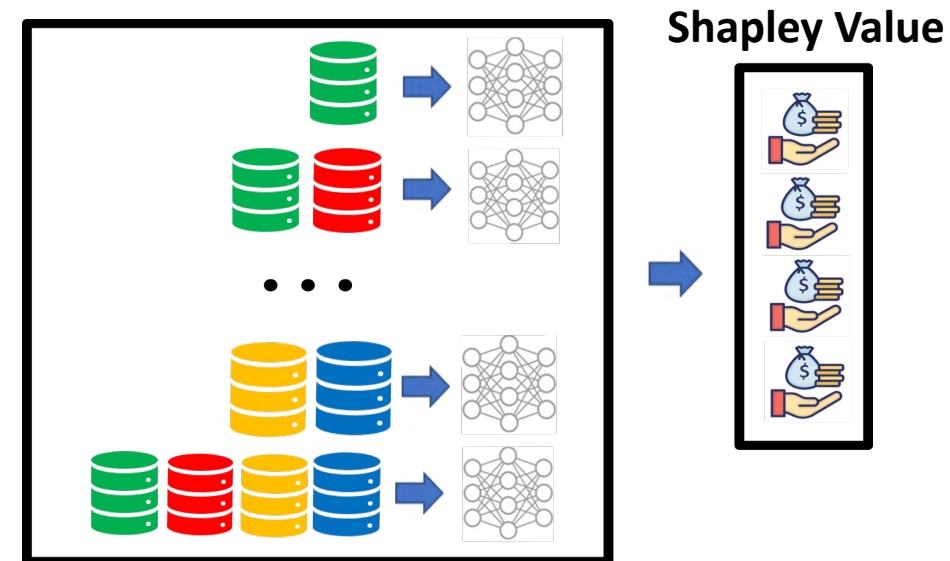
Drawbacks of Shapley Value

Problem:

1. Traditional Shapley requires **retraining** FL sub-models.

$$V(S) = V(M_S) = V(\mathcal{A}(M^{(0)}, D_S))$$

2. **2^N** FL sub-models' utility evaluations **$V(S)$** lead to computation overhead.



Solution: GTG-Shapley

- Guided Truncation Gradient Shapley (GTG-Shapley) : Fair, Efficient, and Privacy-preserving.

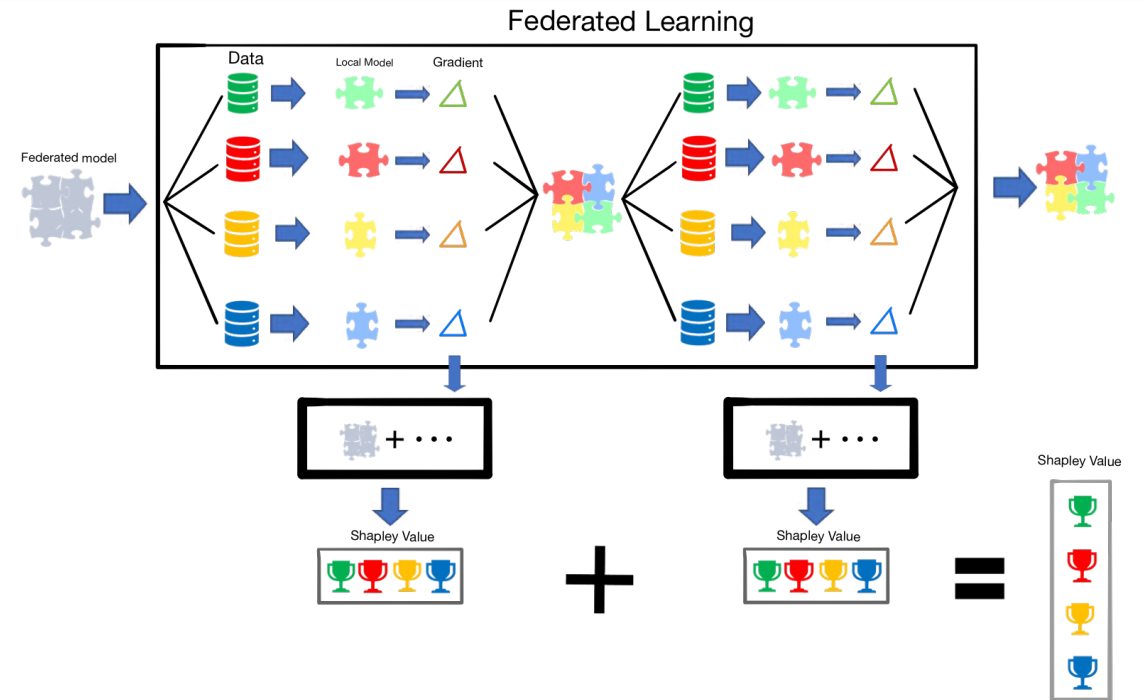
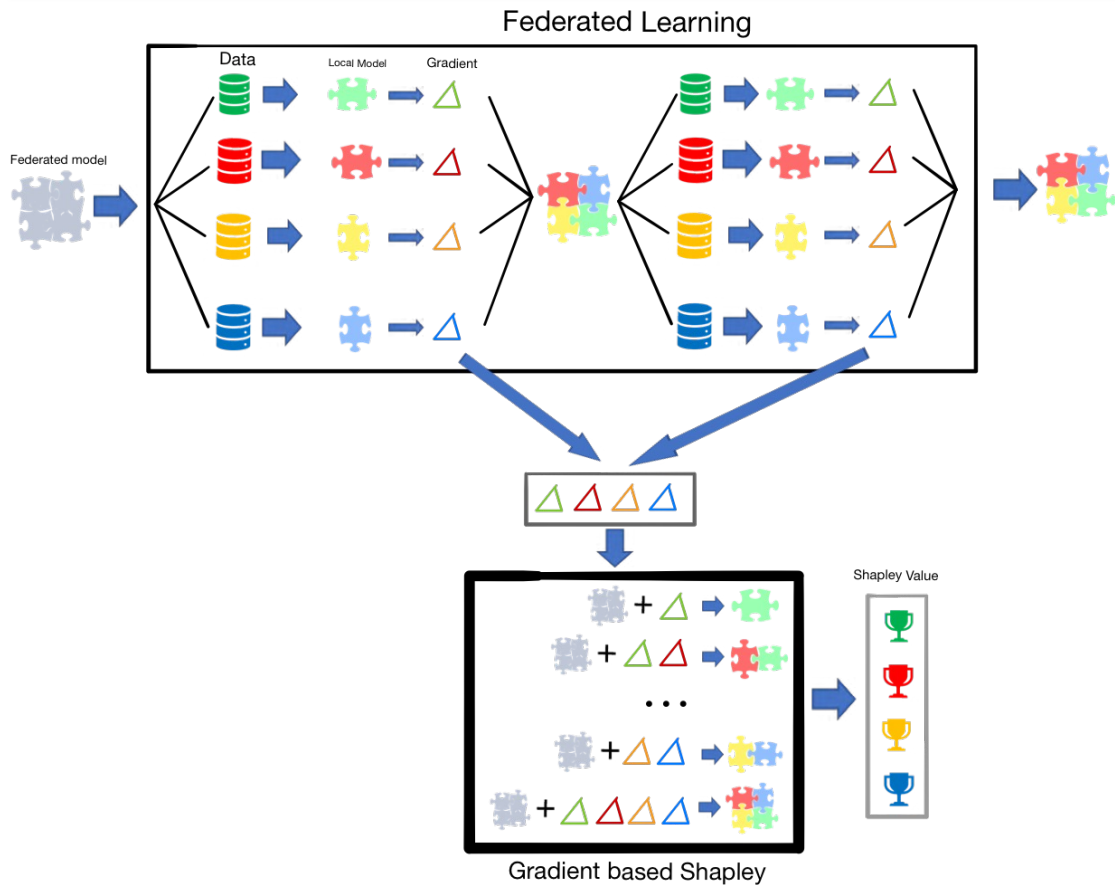
Key Idea:

1. Model Reconstruction, instead of Model Retraining

$$V(S) = V(M_S) = V\left(M + \sum_{i \in S} \frac{|D_i|}{|D_S|} \Delta_i\right) \\ \neq V(\mathcal{A}(M^{(0)}, D_S))$$



GTG-Shapley: Model Reconstruction



Solution: GTG-Shapley

- Guided Truncation Gradient Shapley (GTG-Shapley) : Fair, Efficient, and Privacy-preserving.

Key Idea:

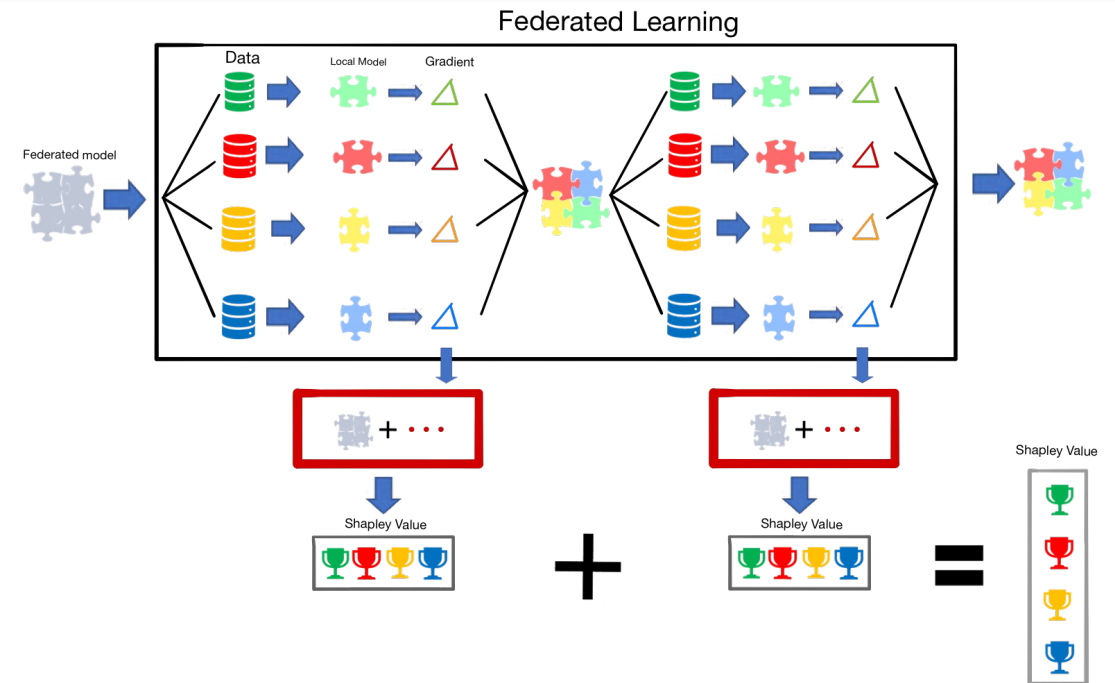
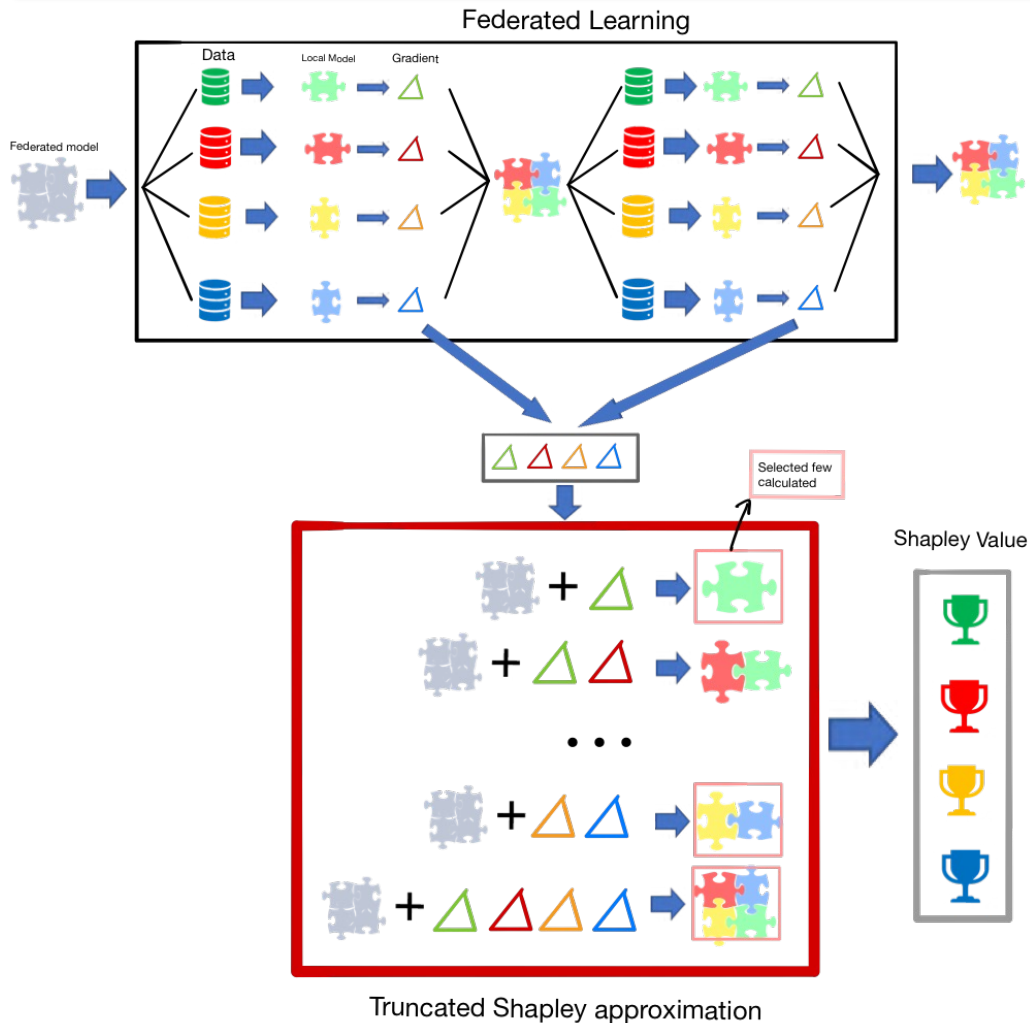
1. Model Reconstruction, instead of Model Retraining

$$V(S) = V(M_S) = V\left(M + \sum_{i \in S} \frac{|D_i|}{|D_S|} \Delta_i\right) \\ \neq V(\mathcal{A}(M^{(0)}, D_S))$$

2. Truncating unnecessary sub-model, instead of 2^N sub-models.



GTG-Shapley: Monte-Carlo Truncation



GTG-Shapley Performance

Empirical studies on 7 existing **SV-based** FL participant contribution evaluation approaches under **i.i.d.** and **non-i.i.d.** settings.

GTG-Shapley consistently achieves the **highest efficiency** and **accuracy** under both i.i.d. and non- i.i.d. settings.

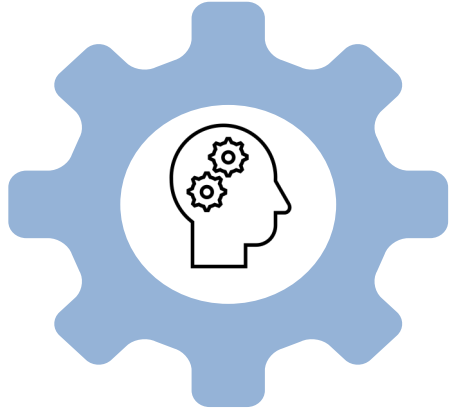
	i.i.d		non-i.i.d	
	Duration	ED	Duration	ED
Canonical SV	4.615	-	4.615	-
MR	3.833	-2.35	3.733	-2.148
TMC	4.168	-1.687	4.213	-1.369
TMR	3.531	-2.353	3.678	-2.27
GroupTesting	4.583	-0.894	4.557	-0.667
Fed-SV	3.784	-0.757	3.711	-0.789
GTG-Shapley	2.662	-2.427	2.733	-2.323

present in \log_{10} scale

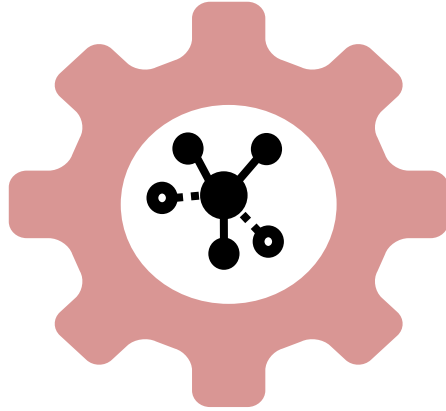


AI in CAreFL

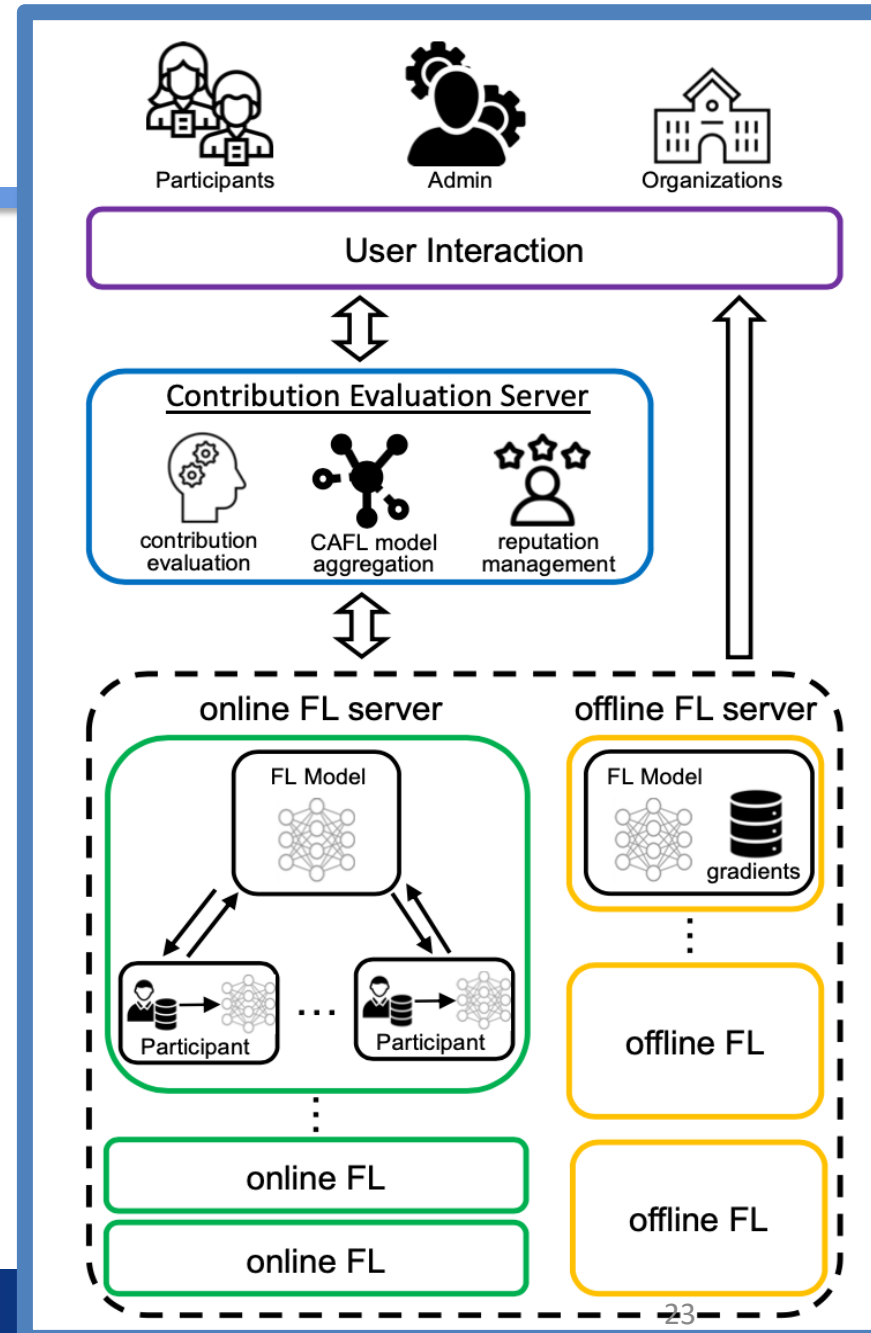
- Focus on Contribution Evaluation



Fast and Accurate Contribution Evaluation

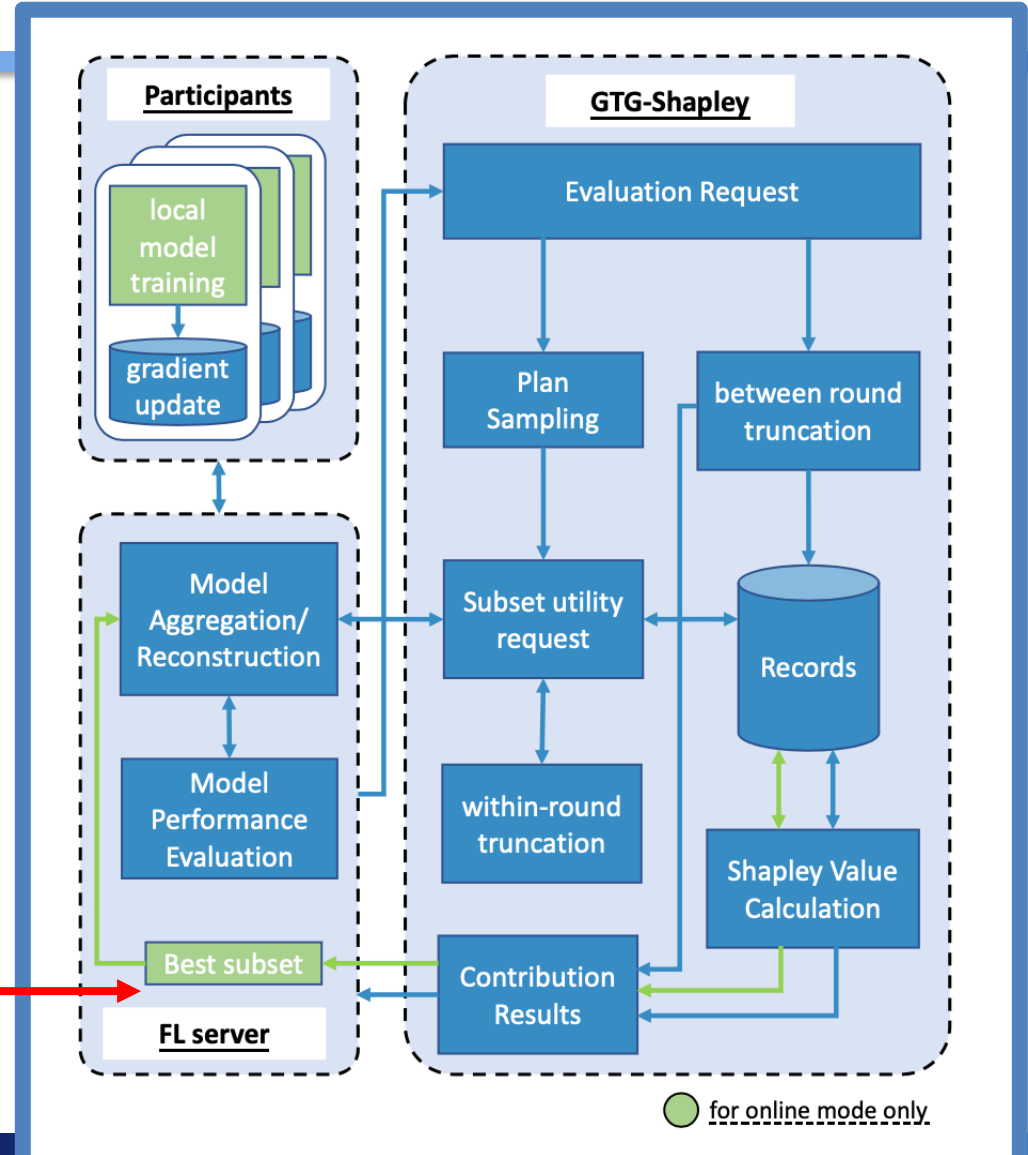
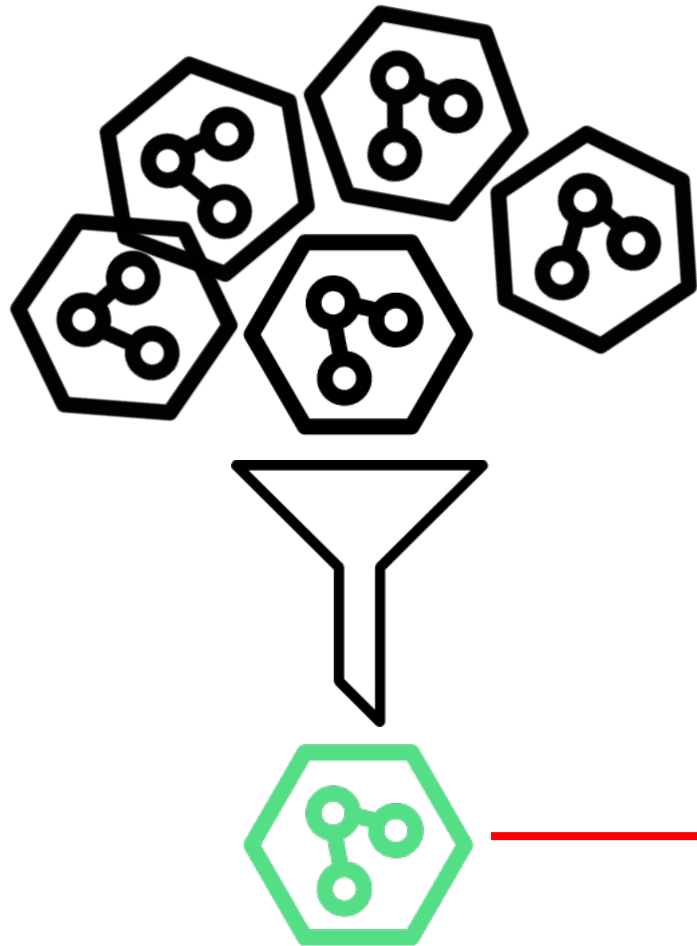


Contribution-Aware FL Model Aggregation



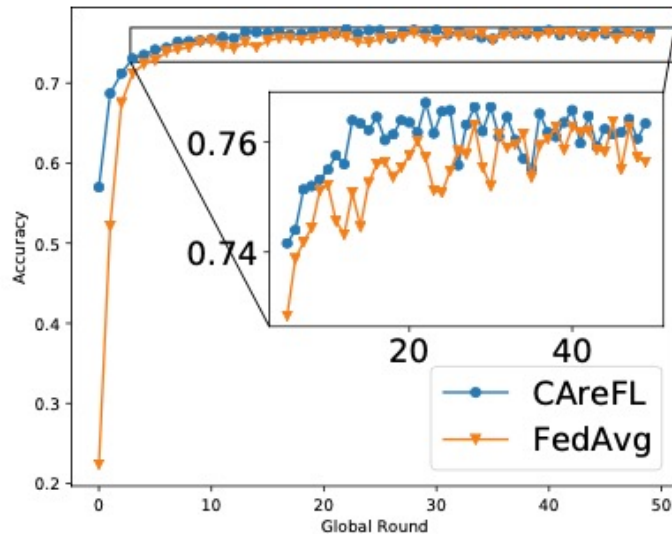
CAreFL model aggregation

FL sub-models

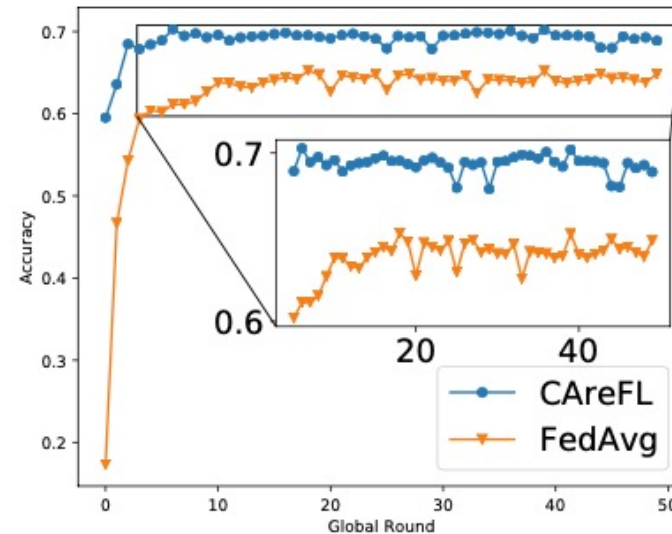


Results on public benchmark

- Empirical Studies on CAreFL model aggregation with FedAvg under i.i.d and non-i.i.d settings (CIFAR-10 dataset).



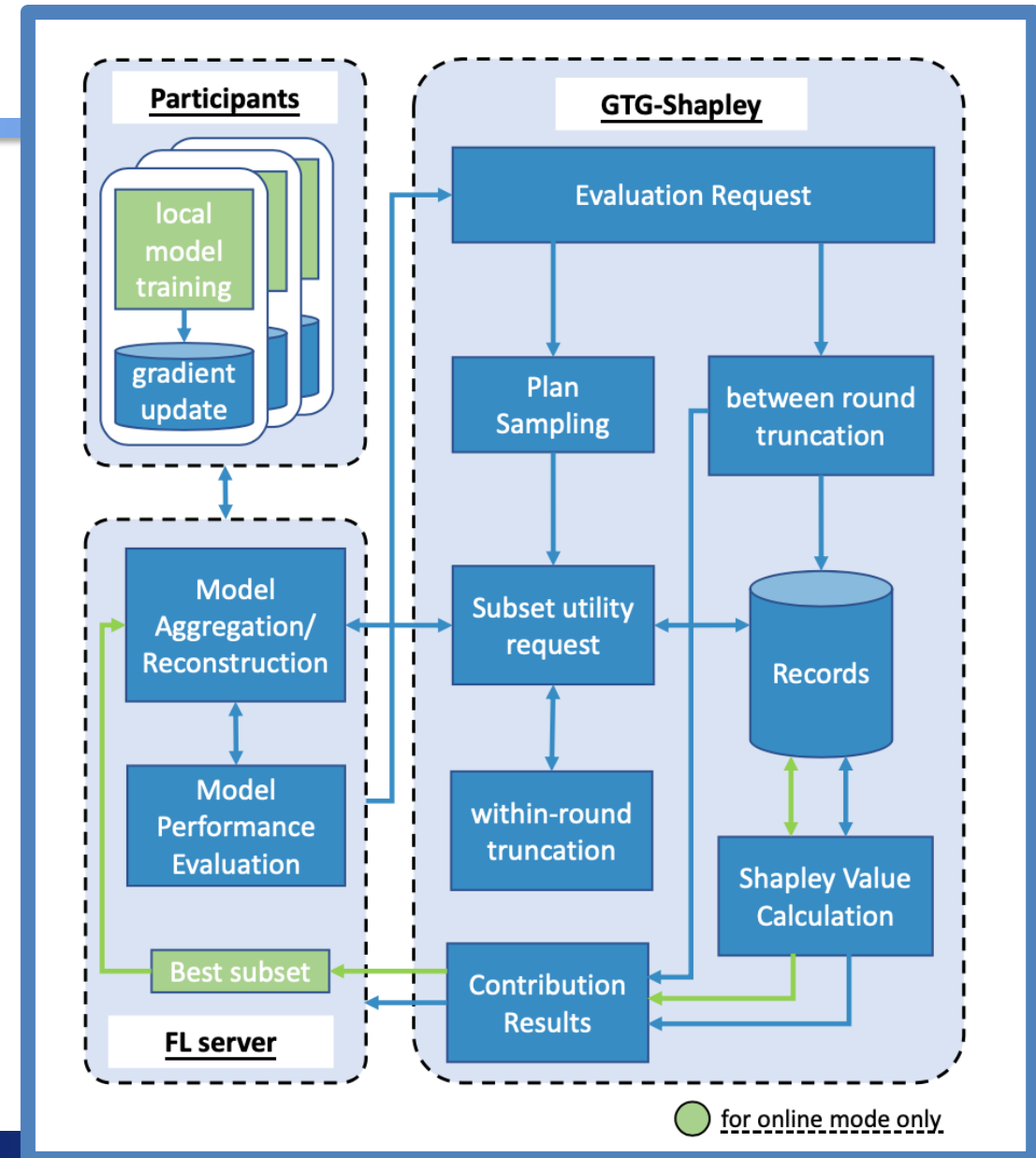
(a) i.i.d. case



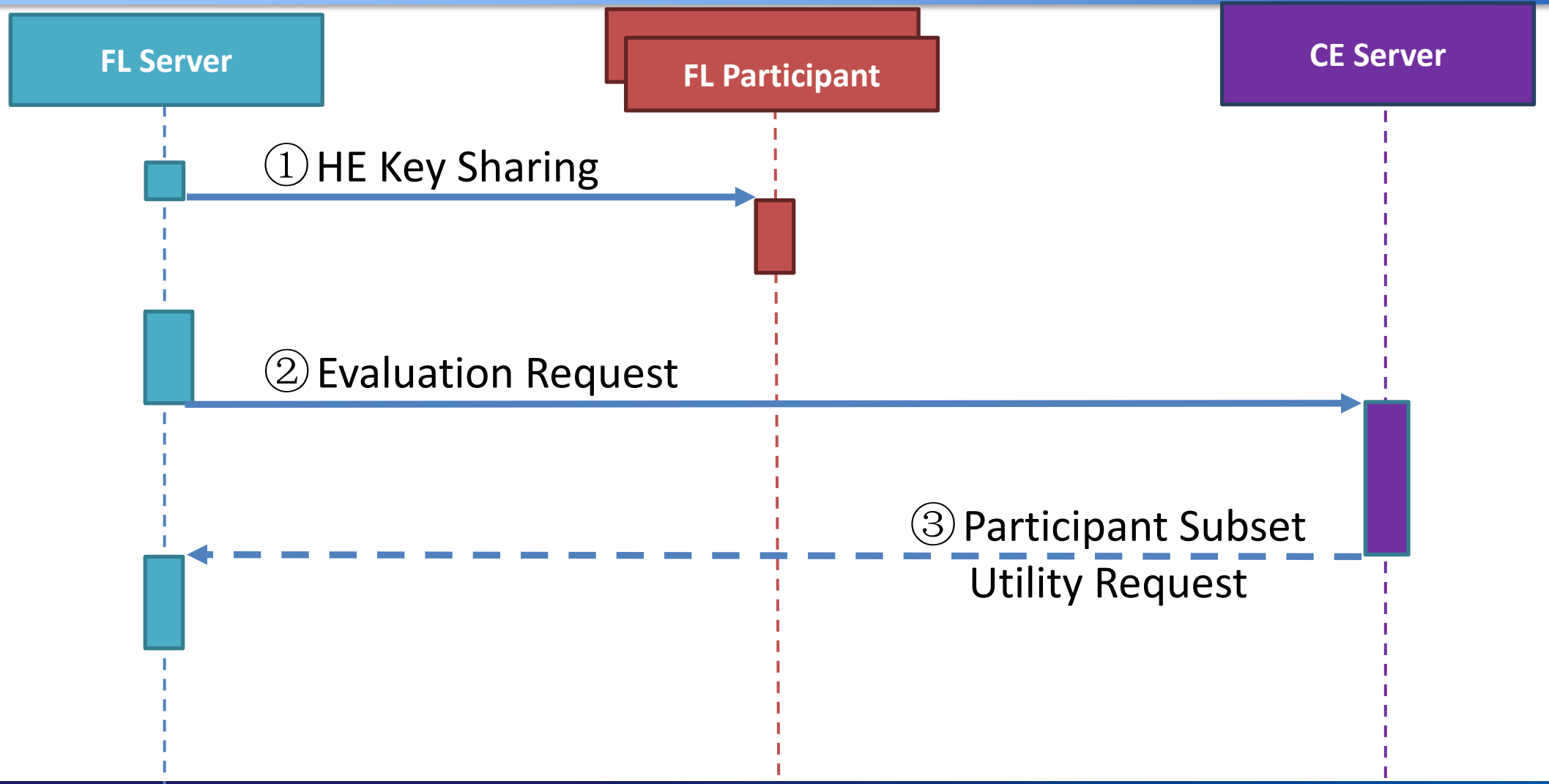
(b) non-i.i.d. case

CAreFL in details

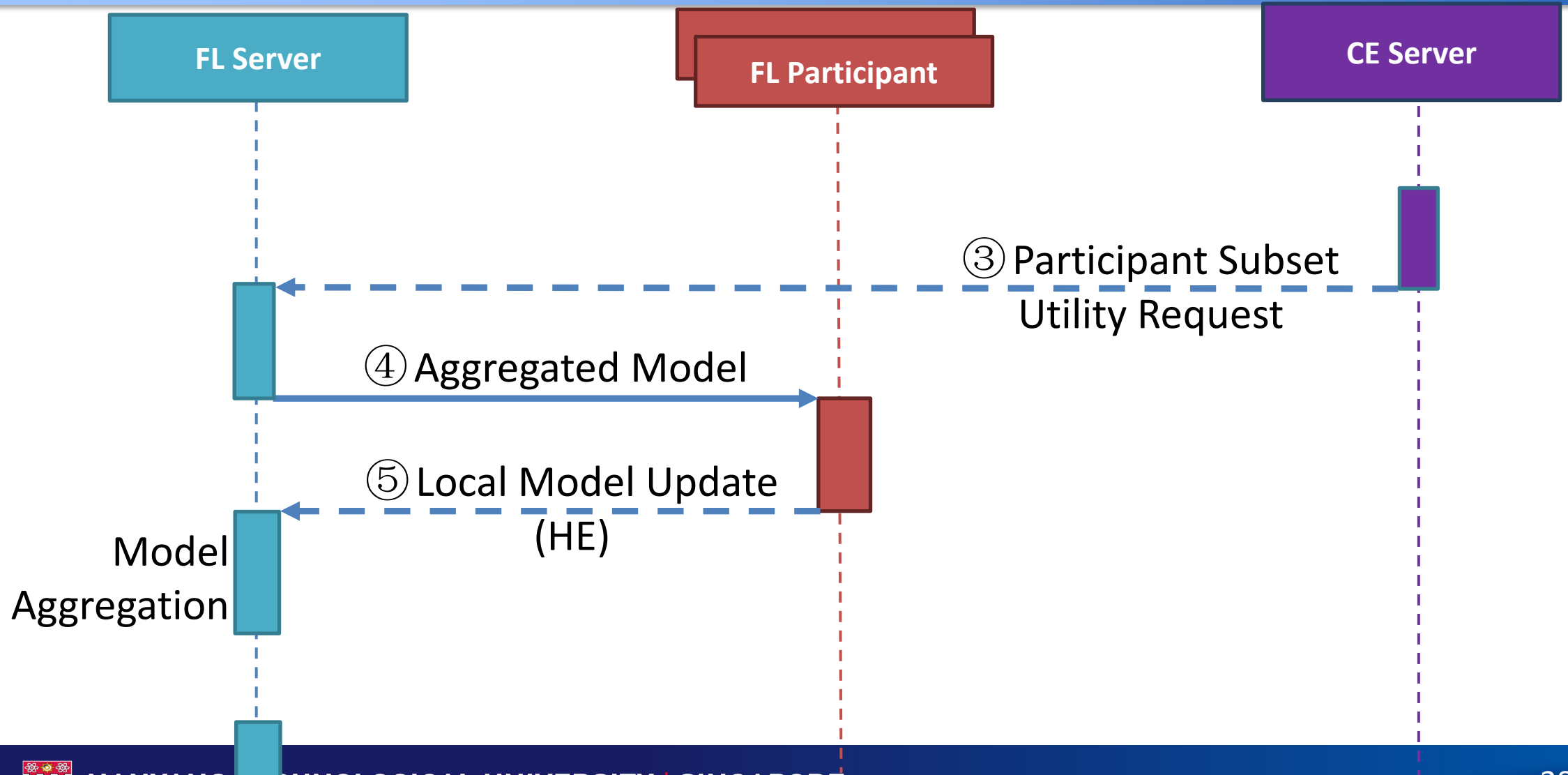
- GTG-Shapley **only requires** a list of unique participants' IDs and **computes** the participants' contributions in an efficient manner and **returns the results to the FL server**.
- In addition, it also identifies the **“best subset”** and passes this information to the FL server to improve model **aggregation**.
- The aggregation function is only relevant for **online** FL training during which the global FL model is still in the process of being established.



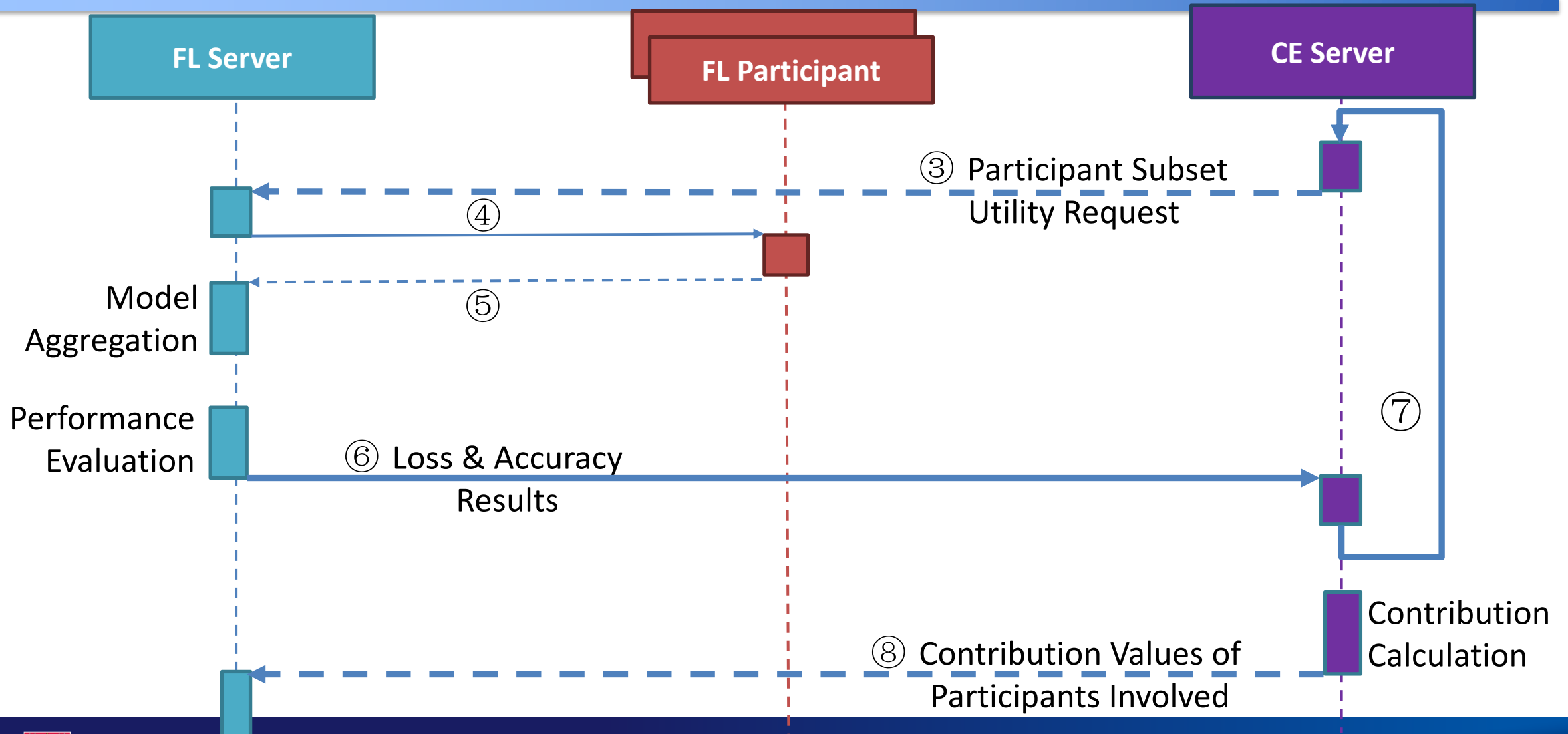
Contribution Evaluation workflow



Contribution Evaluation workflow



Contribution Evaluation workflow



Deployment and Payoff

- The **CAreFL** framework has been **deployed** in Yidu Cloud Technology Inc. **since March 2021** in two lines of their business: 1) **clinical research services**, and 2) **real-world trial research services**.

Leukemia

- **Clinical research.**
- A total of **62,000 patients**.

Biopsy

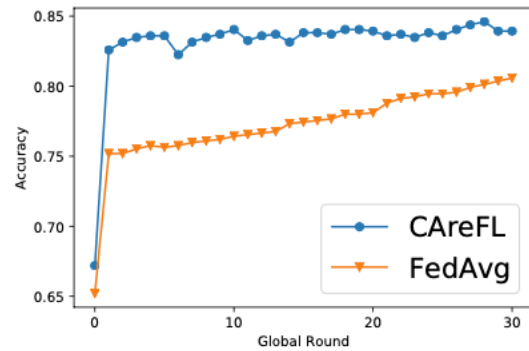
- **Real-world trial.**
- A total of **5,978 patients** screened, and 2,426 patients selected.

Pneumonia

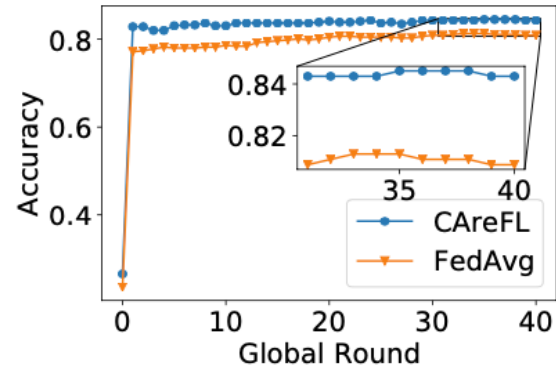
- **Real-world trial.**
- A total of **103,455** sample data.



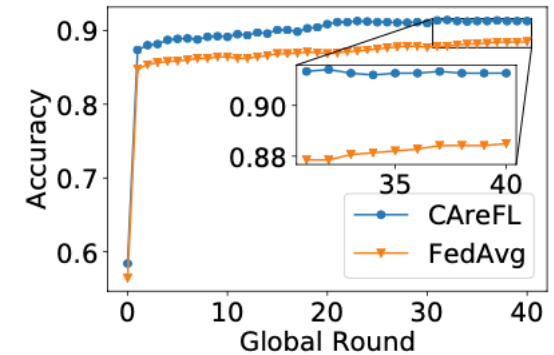
Deployment and Payoff



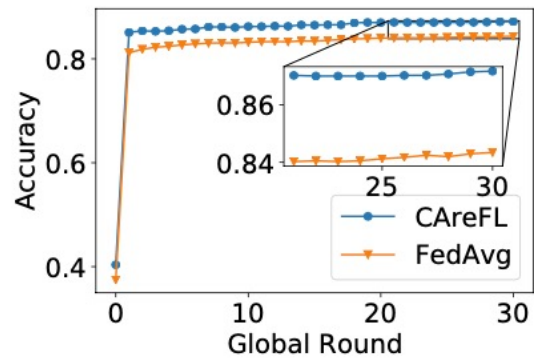
(a) Leukemia LR



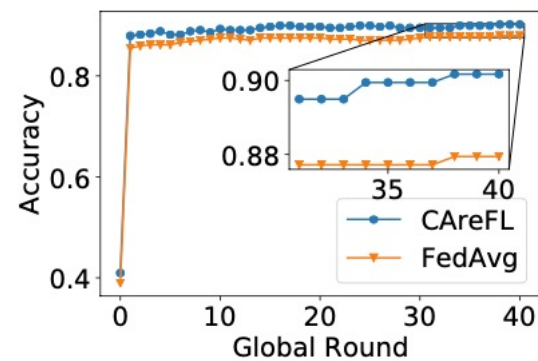
(c) Biopsy LR



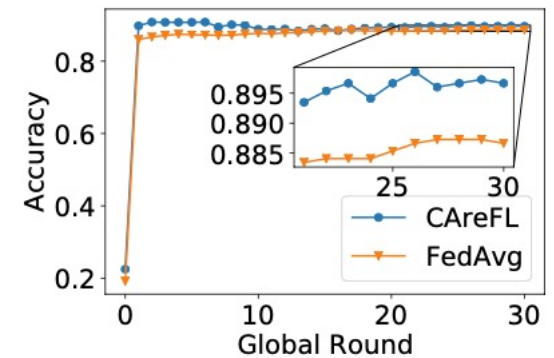
(e) Pneumonia LR



(b) Leukemia SBT



(d) Biopsy SBT



(f) Pneumonia SBT



User Interface

DASHBOARD

- Federations
- Participants
- Topics

Federations

All federations' contribution records

Search by fed name or description | Start date To End date | Filter

Reset

DATE: SEP 17, 2021

Leukemia offline v5.0

This use case is for modeling recurrence risk after hematopoietic stemcell transplantation for acute...

89.6%

8

DATE: SEP 15, 2021

Leukemia online LR v5.0

This use case is for modeling recurrence risk after hematopoietic stem cell transplantation for acute...

91.0%

8

DATE: AUG 13, 2021

Biopsy online v7.0

This use case is a study on

88.9%

Leukemia offline v5.0

Date: September 17, 2021 | Participants: 8 | Topic: Leukemia

This use case is for modeling recurrence risk after hematopoietic stem cell transplantation for acute leukemia. A total of 62,000 leukemia patients were included in the study, and 2830 samples were included after screening for acute leukemia and hematopoietic stem cell transplantation (709 positive cases and 1054 negative cases were taken as the end point for recurrence within one year after surgery). In terms of feature selection, 239 features were selected to participate in the study combined with the medical knowledge of leukemia. Nonsequential data were processed by federated normalization and One HOT coding, while sequential data were processed by time-boxed feature engineering. Serious Non-IID exists in both sample data distribution and positive and negative case distribution.

Participant Contribution

Participant	Contribution
1	0.75
2	0.3
3	0.85
4	0.95
5	0.4
6	0.15
7	0.25
8	0.55



Award



Innovative Applications of Artificial Intelligence

CERTIFICATE
Innovative Application Award

For the Paper Entitled

“Contribution-Aware Federated Learning for
Smart Healthcare”

By

Zelei Liu, Yuanyuan Chen, Yansong Zhao, Han Yu, Yang Liu, Renyi Bao, Jinpeng
Jiang, Zaiqing Nie, Qian Xu, and Qiang Yang

A handwritten signature in blue ink, appearing to read 'Meinolf Sellmann', is written over a horizontal line.

Meinolf Sellmann – Program Co-Chair





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