Open Set Recognition
Federated Learning

DMQA Open Seminar (2025. 10. 17)

Data Mining & Quality Analytics Lab.

김다빈

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  - Data Mining & Quality Analytics Lab. (김성범 교수님)
  - M.S Student (2025.09 ~ Present)
- **Research Interest**
  - Federated Learning
  - Open Set Recognition
  - Semi-supervised Learning
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Open Set Recognition **Federated Learning**

데이터 프라이버시 문제를 해결하기 위해서 여러 클라이언트가 로컬 데이터를 중앙 서버로 직접 전송하지 않고, 각자의 데이터로 모델을 학습한 후 모델 파라미터만을 공유하여 전역 모델을 공동으로 학습하는 방식

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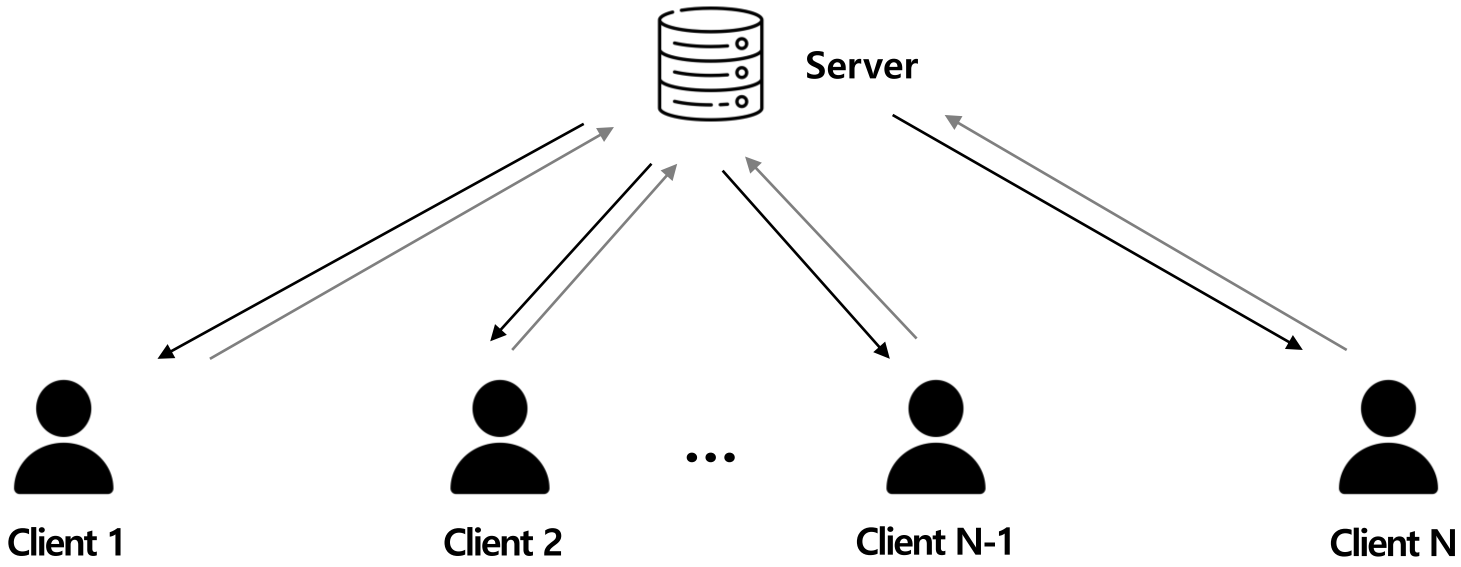

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Open-Set Semi-Supervised Learning + Federated Learning

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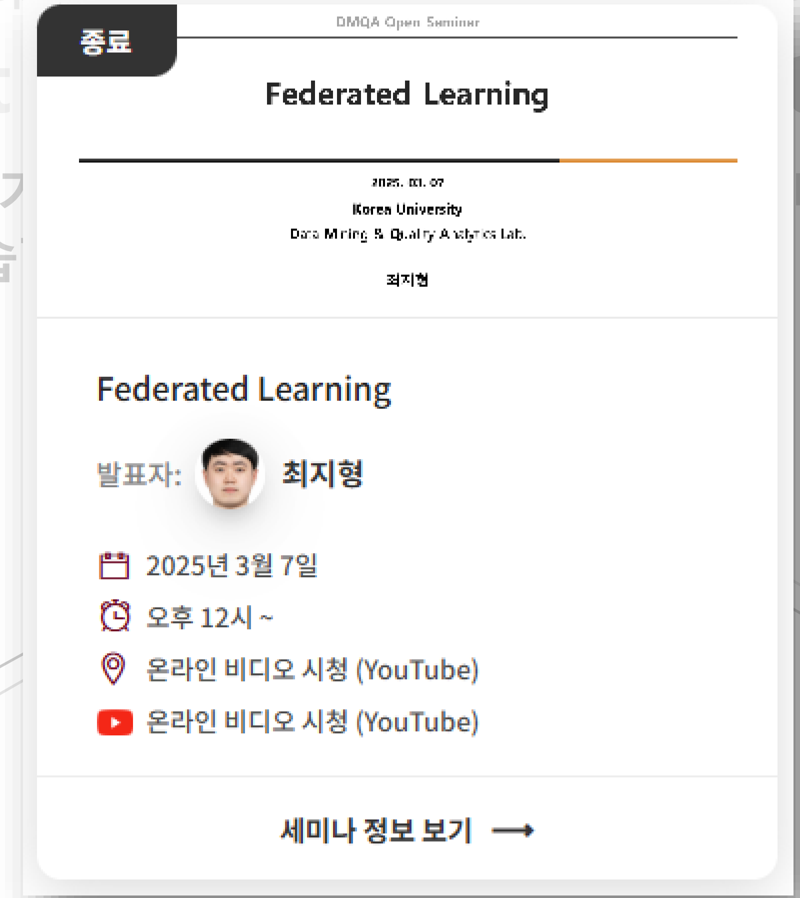

Client 1 Client 2 Client N-1 Client N

Open-Set Semi-Supervised Learning + Federated Learning

Open Set Recognition Federated Learning

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Open-Set Semi-Supervised Learning + Federated Learning

Open Set Recognition Federated Learning

여러 클라이언트가 가진 데이터가 서로 다른 클래스 분포를 가지고 있을 때,
알려진 클래스(known)와 알려지지 않은 클래스(unknown)를 동시에 고려하는 연합 학습 방식

: Known classes

: Unknown class

Open-Set Semi-Supervised Learning + Federated Learning

Open Set Recognition Federated Learning

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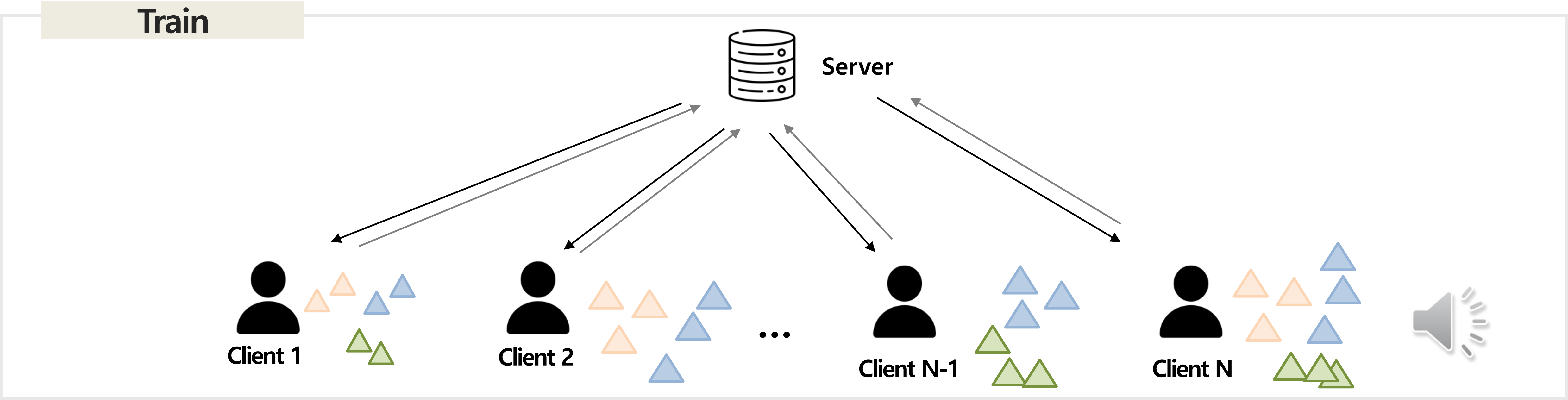

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Open-Set Semi-Supervised Learning + Federated Learning

Open Set Recognition Federated Learning

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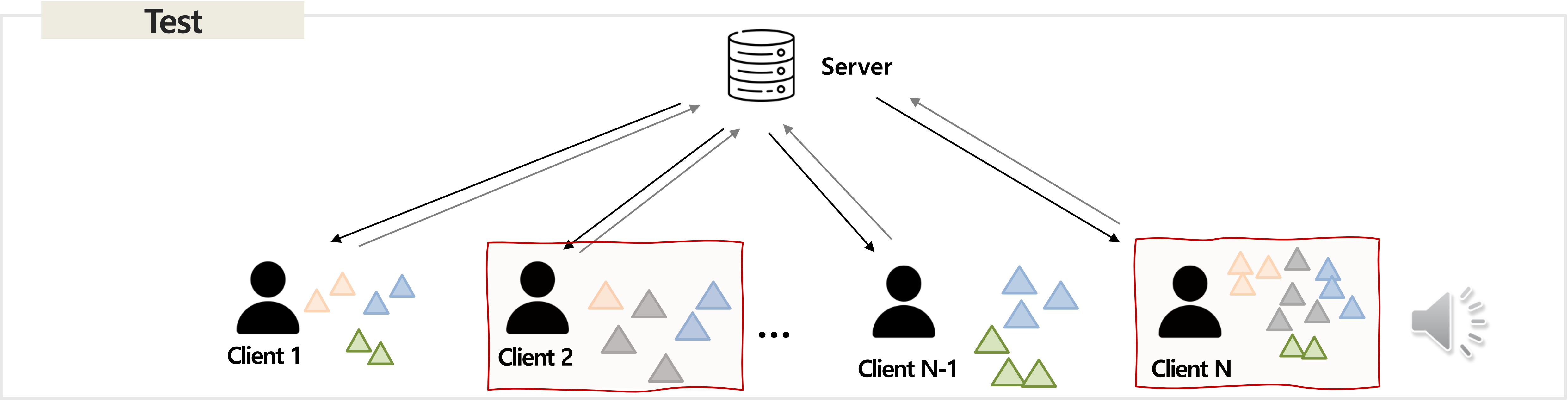
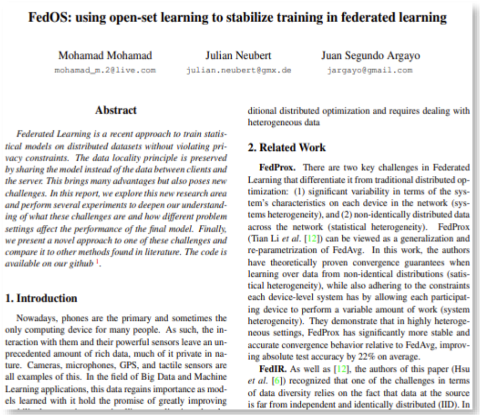


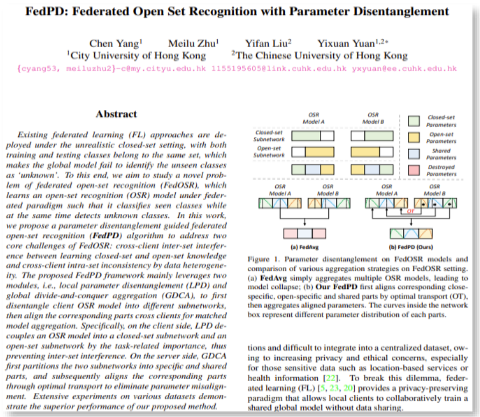
Related Works

Open Set Recognition Federated Learning

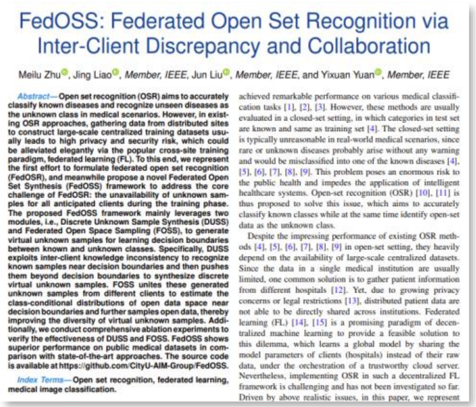
FedOS
[arXiv 2022]



FedPD
[ICCV 2022]



FedOSS
[IEEE 2024]



1. FedOS

FedOS: using open-set learning to stabilize training in federated learning

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FedOS

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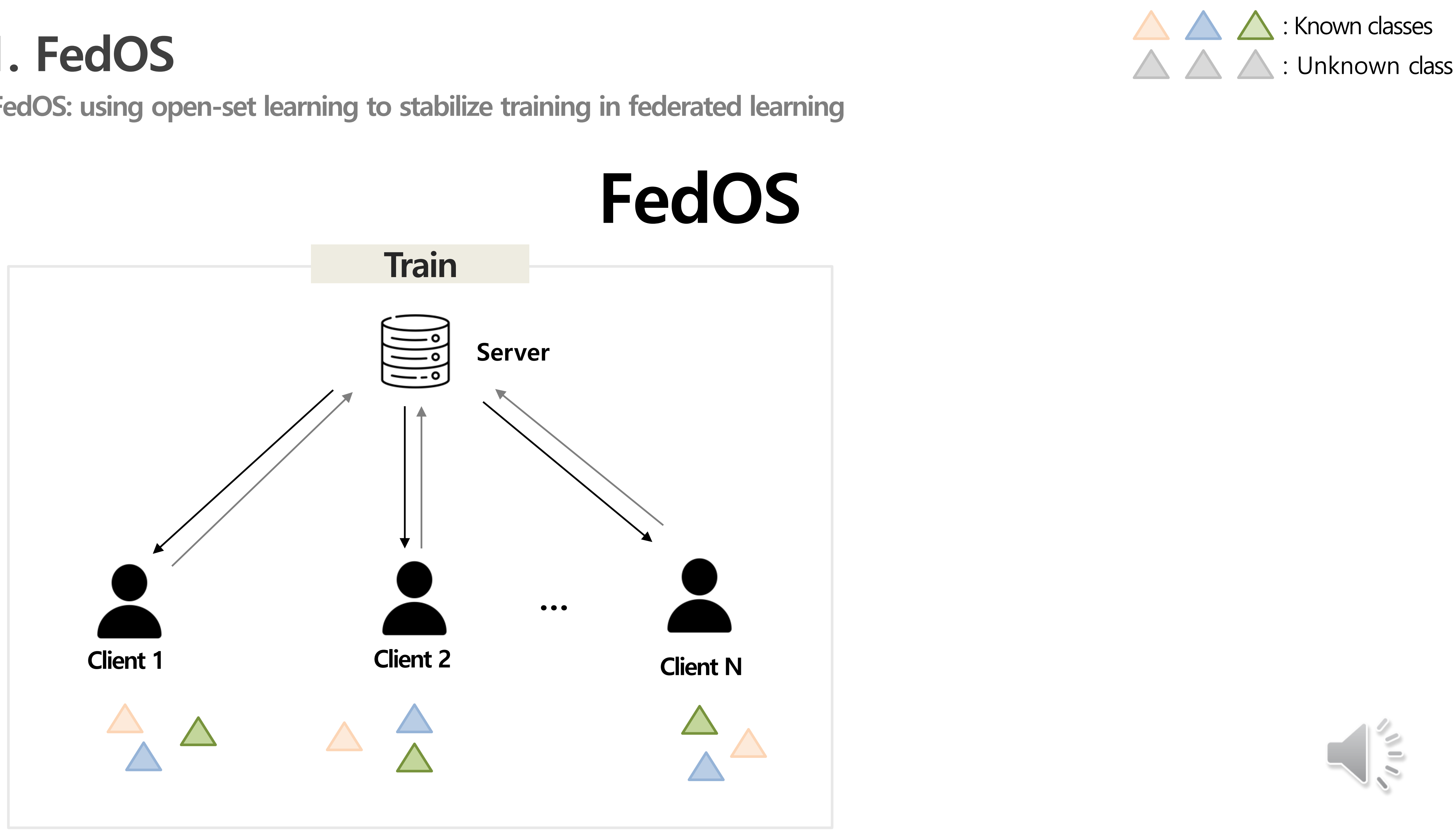

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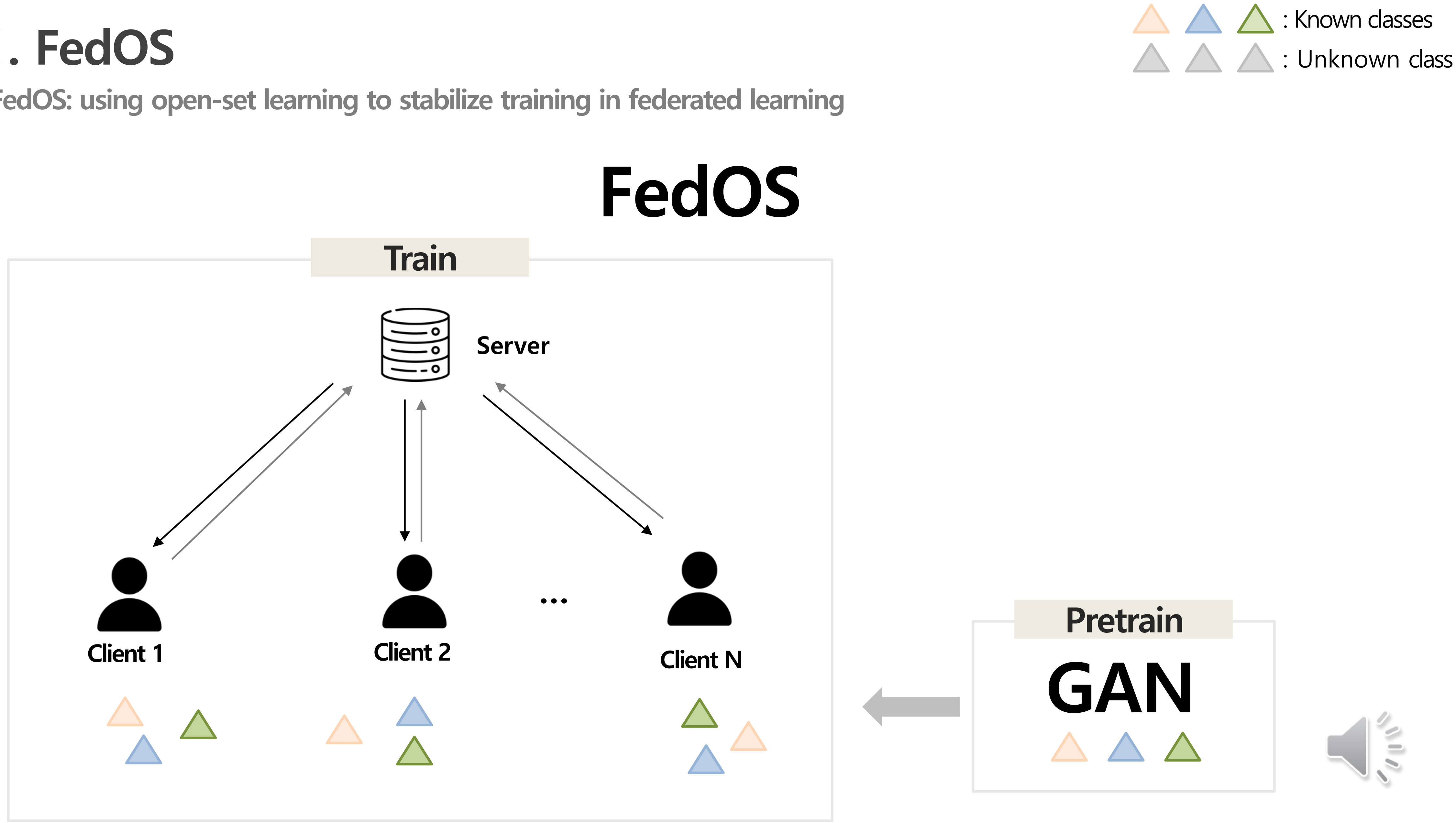

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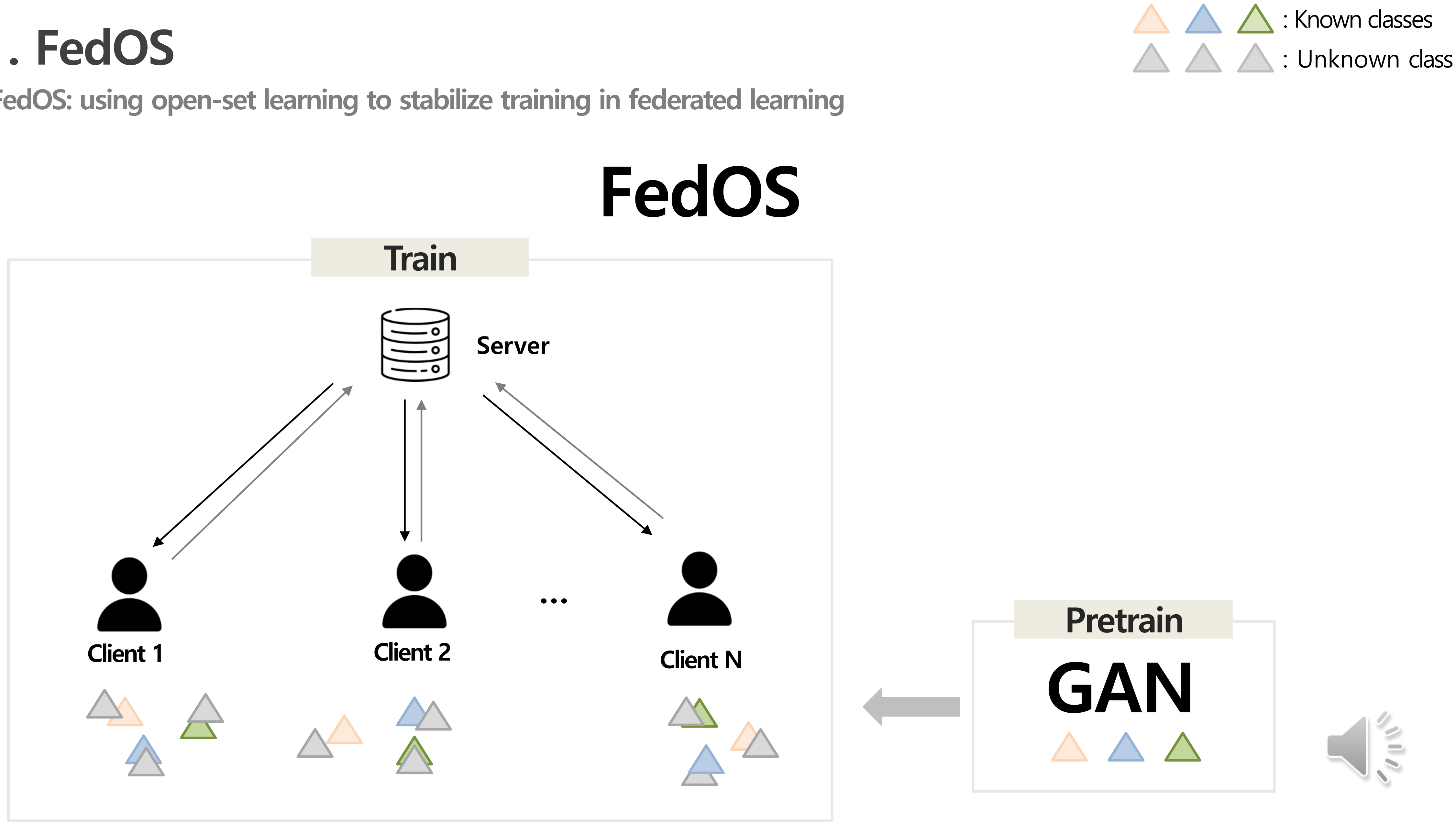

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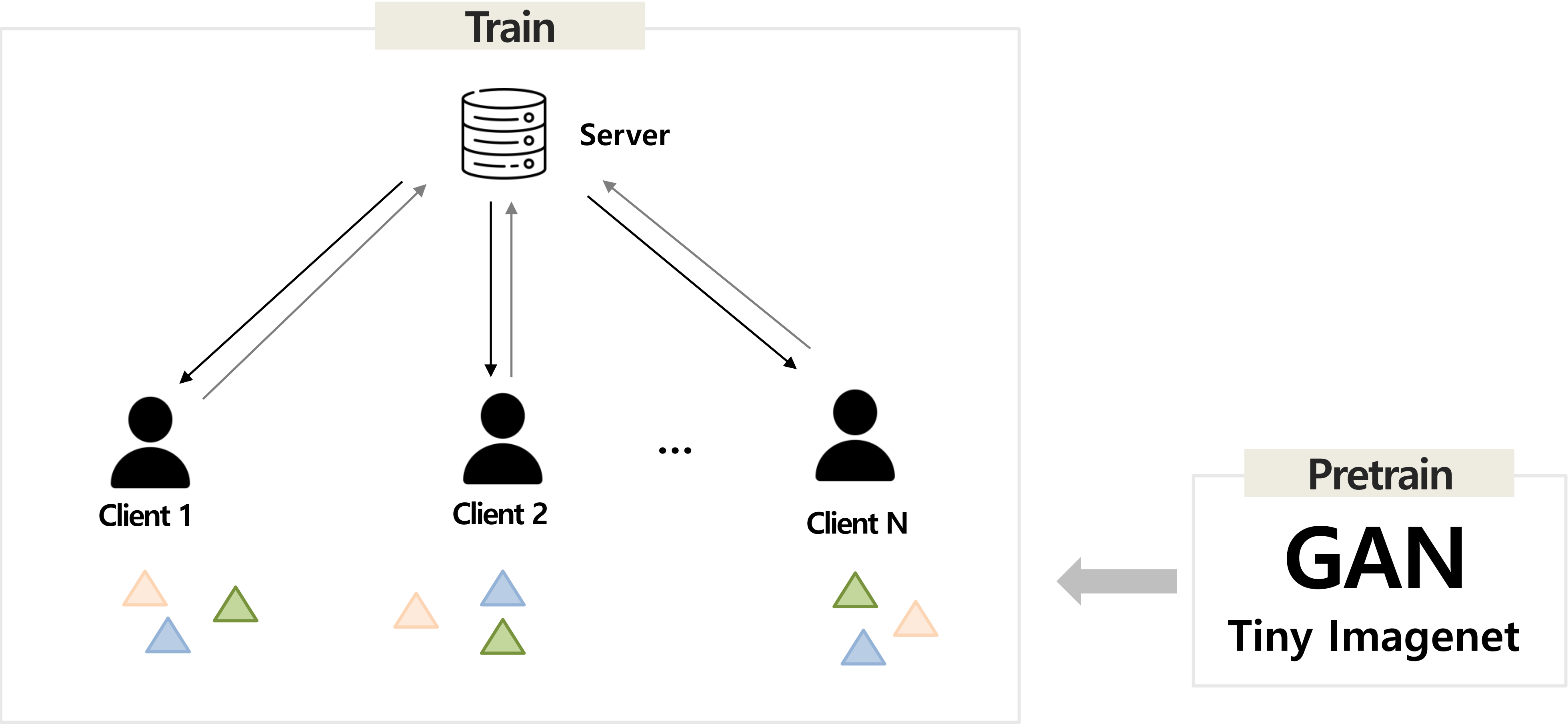

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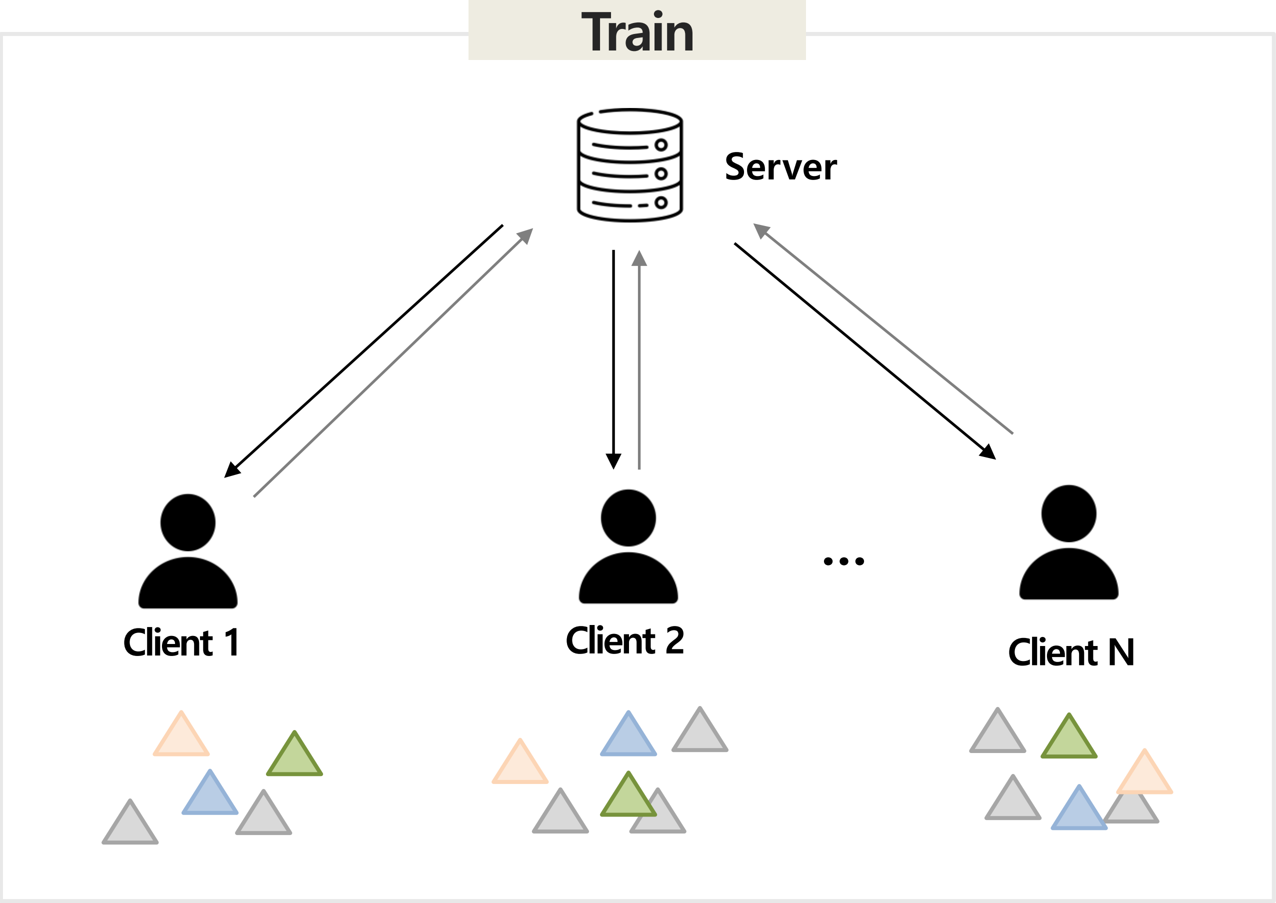

Experiments & Results

- 데이터셋: CIFAR-10
- 정량 평가: Accuracy
- Known class의 개수: 6 / Unknown class의 개수: 4

Relative accuracy @N rounds

	Alpha=1				Alpha=0.01			
Methods	**@125**	**@250**	**@375**	**@500**	**@125**	**@250**	**@375**	**@500**
FedAvg	65.94	82.17	83.03	88.34	40.41	41.92	51.19	60.75
FedIR	77.66	82.98	89.03	89.36	**51.75**	**59.56**	64	69.03
FedProx	63.85	82.07	86.51	91.4	28.81	37.64	48.58	48.58
FedOS	**77.92**	**84.09**	**94.98**	**95.85**	46.6	56.13	**64.7**	**69.11**

FedPD

FedPD

closed-set과 open-set에 관여하는 파라미터는 분리되어있다

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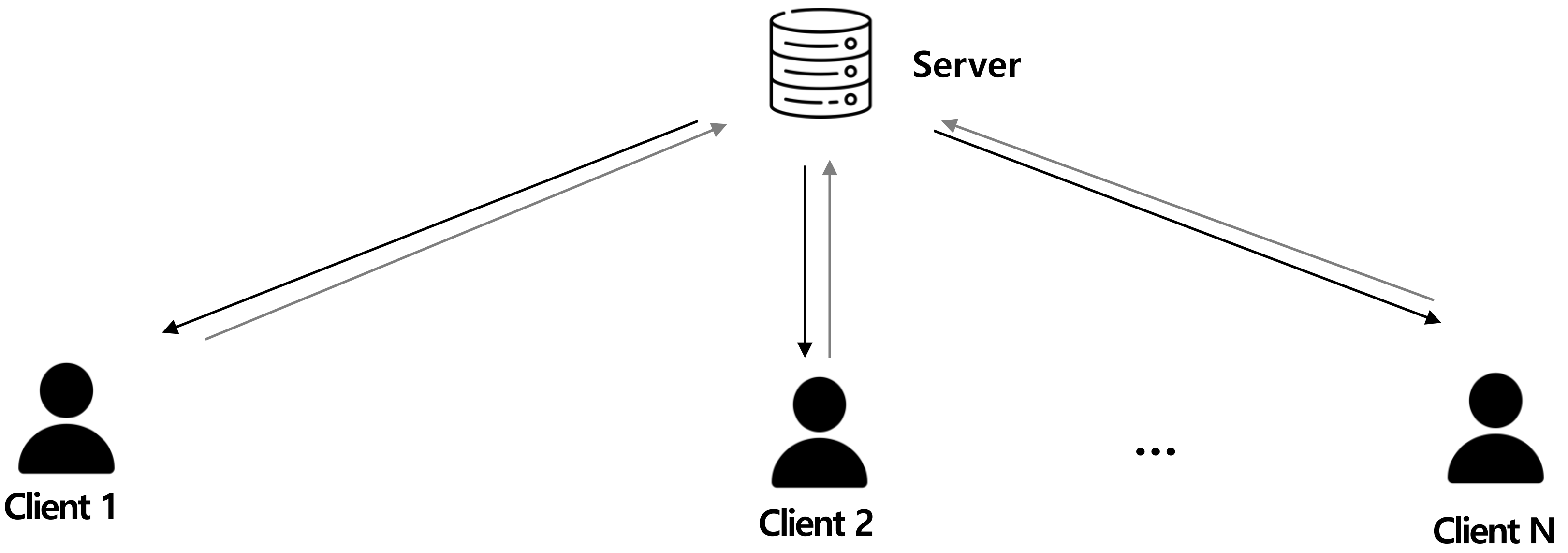

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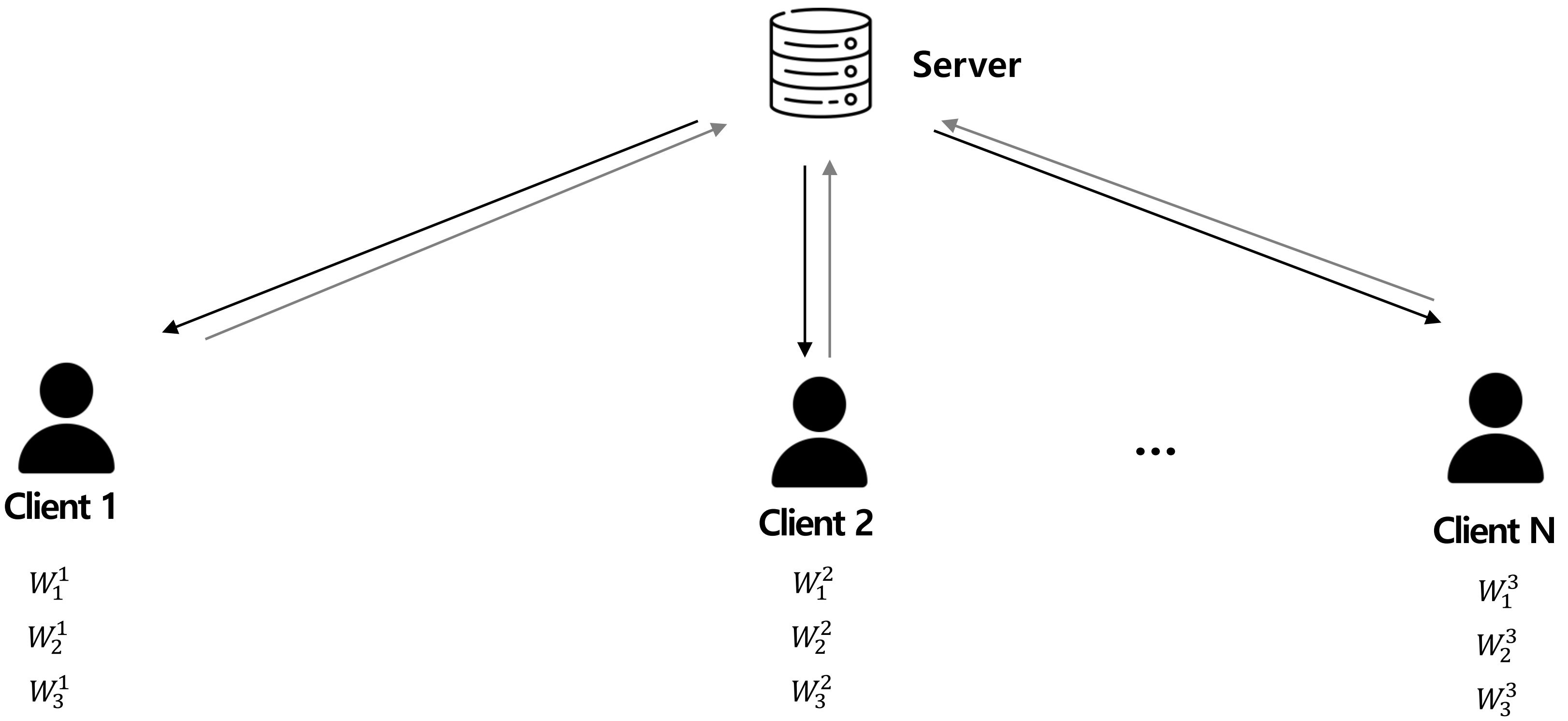
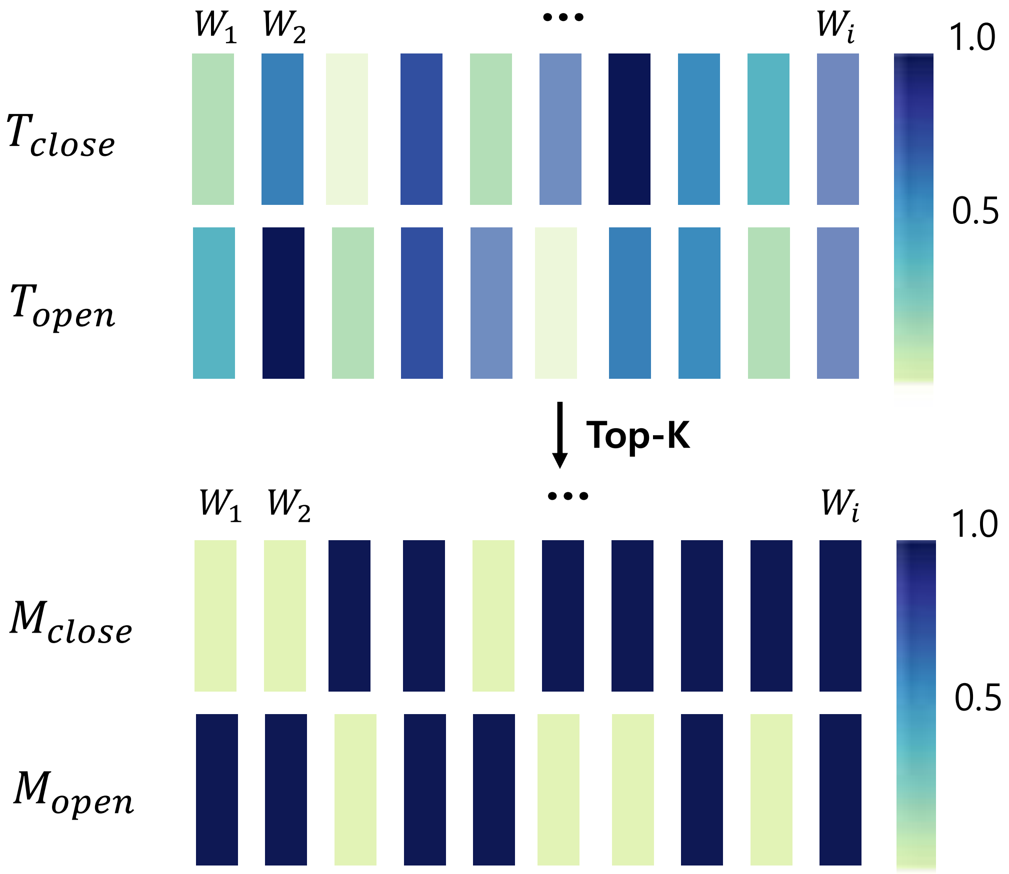


2. FedPD

Federated Open Set Recognition with Parameter Disentanglement

FedPD closed-set과 open-set에 관여하는 파라미터를 분리하자



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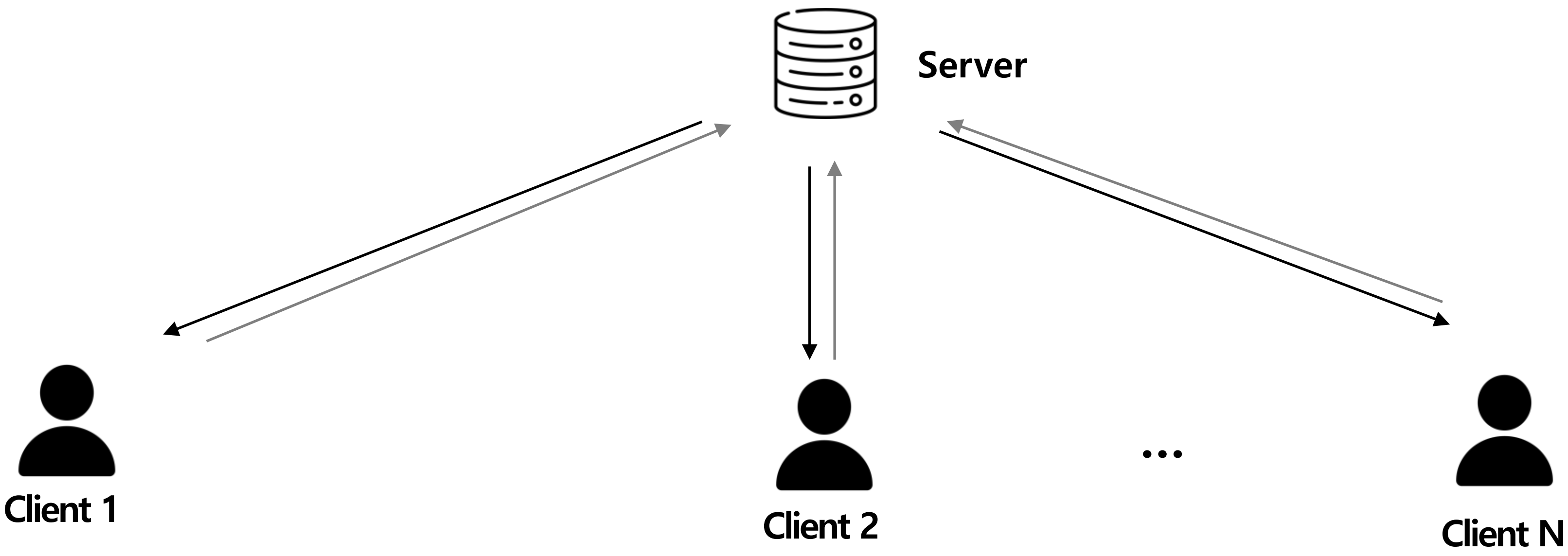


Client 1:

$W_1^1: closed-set$

$W_2^1: open-set$

$W_3^1: closed-set$

Client 2:

$W_1^2: closed-set$

$W_2^2: closed-set$

$W_3^2: open-set$

Client N:

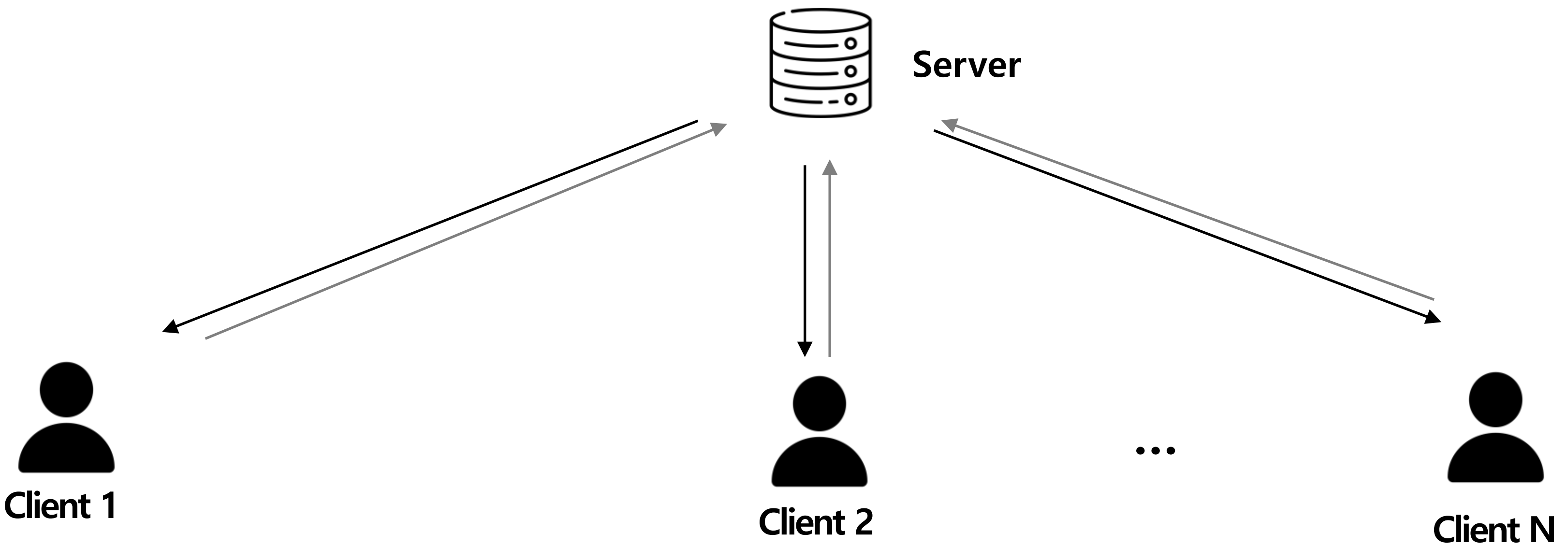
$W_1^3: open-set$

$W_2^3: closed-set$

$W_3^3: closed-set$

FedPD

클라이언트 간 의미가 같은 파라미터를 정렬해 올바르게 집계하자



Client 1	Client 2	Client N
$W_1^1: closed-set$	$W_1^2: closed-set$	$W_1^3: open-set$
$W_2^1: open-set$	$W_2^2: closed-set$	$W_2^3: closed-set$
$W_3^1: closed-set$	$W_3^2: open-set$	$W_3^3: closed-set$

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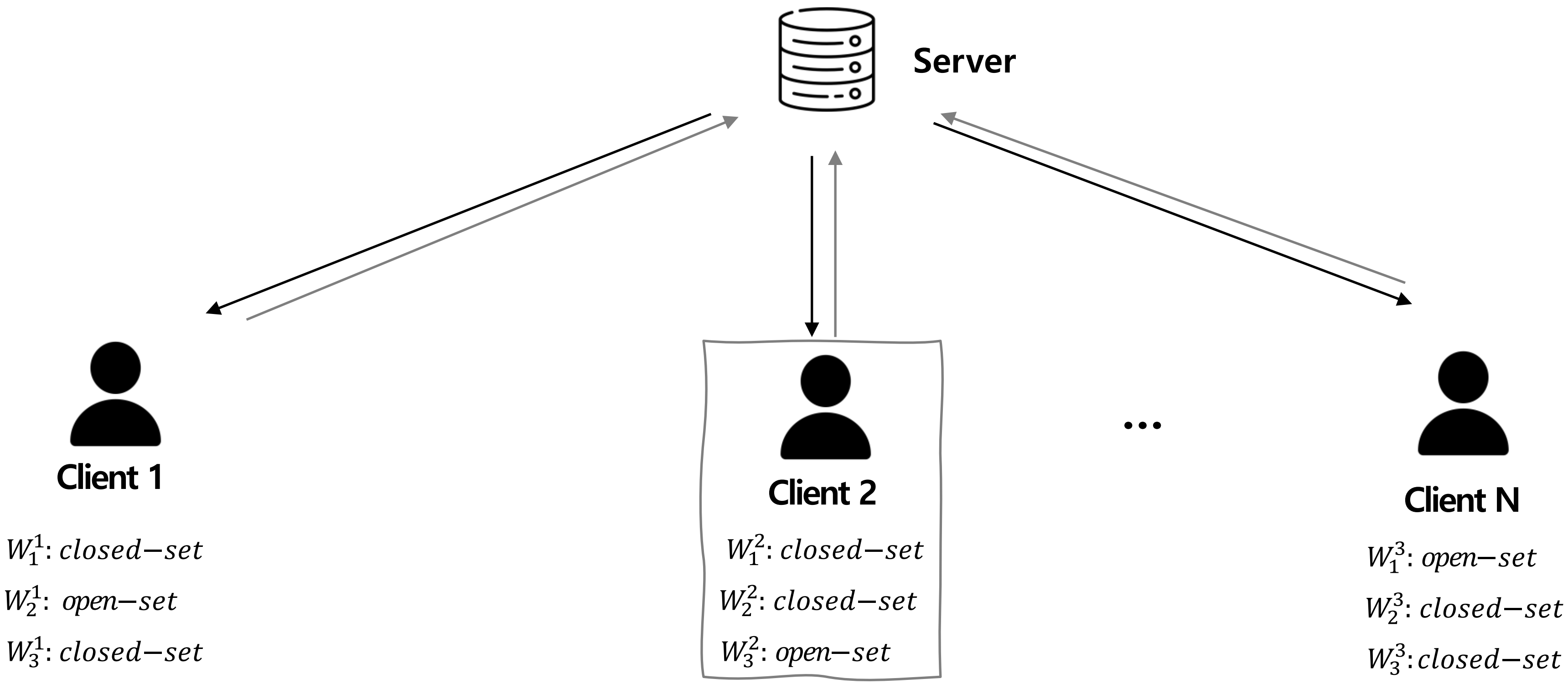

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$$\tilde{S}^k_{close} = OT(S^k \odot P^k_{close}, S^2 \odot P^2_{close})$$
$$\tilde{S}^k_{open} = OT(S^k \odot P^k_{open}, S^2 \odot P^2_{open})$$
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의미적으로 가장 가까운 대응 관계

✓ 2번 client의 closed-set 파라미터를 기준으로
k번째 클라이언트의 closed-set 파라미터 중 가장 의미적으로 가까운 것은 무엇인가

FedPD

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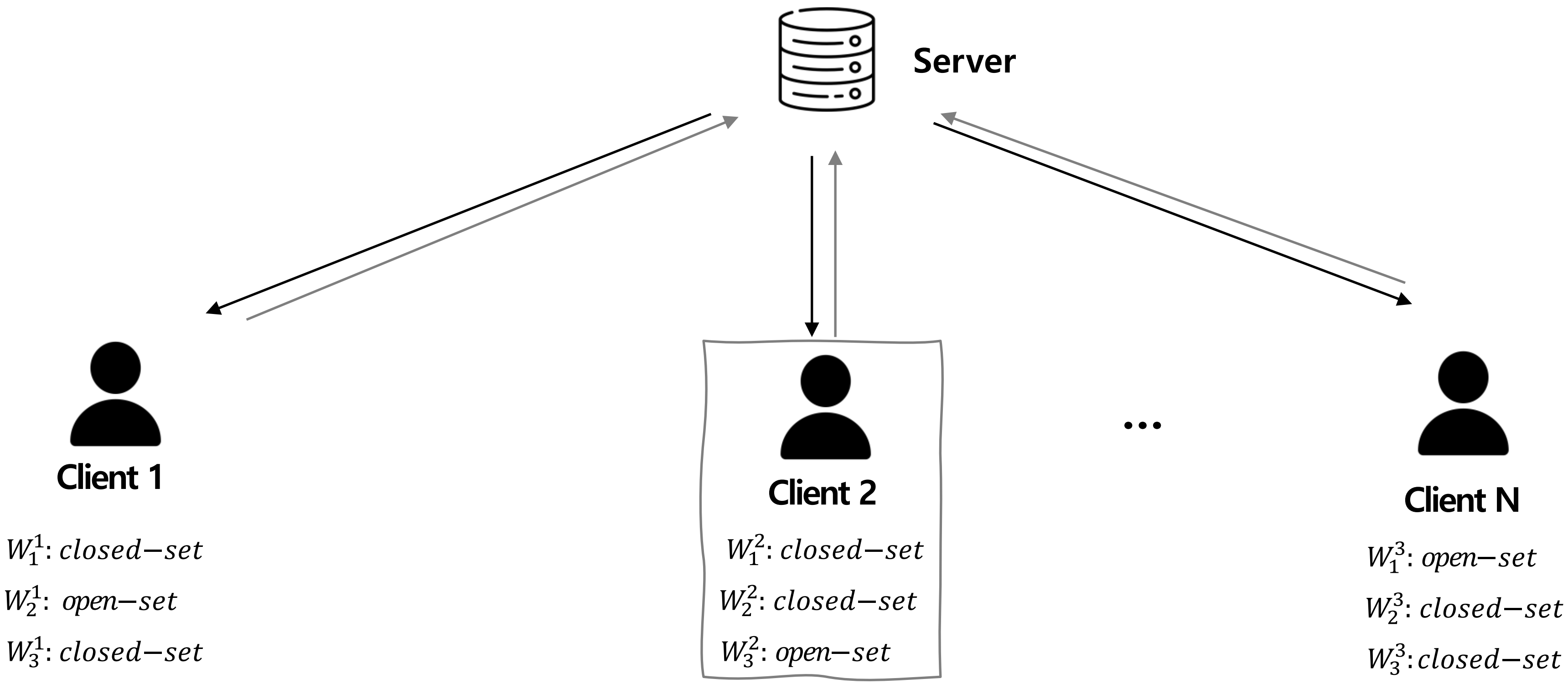

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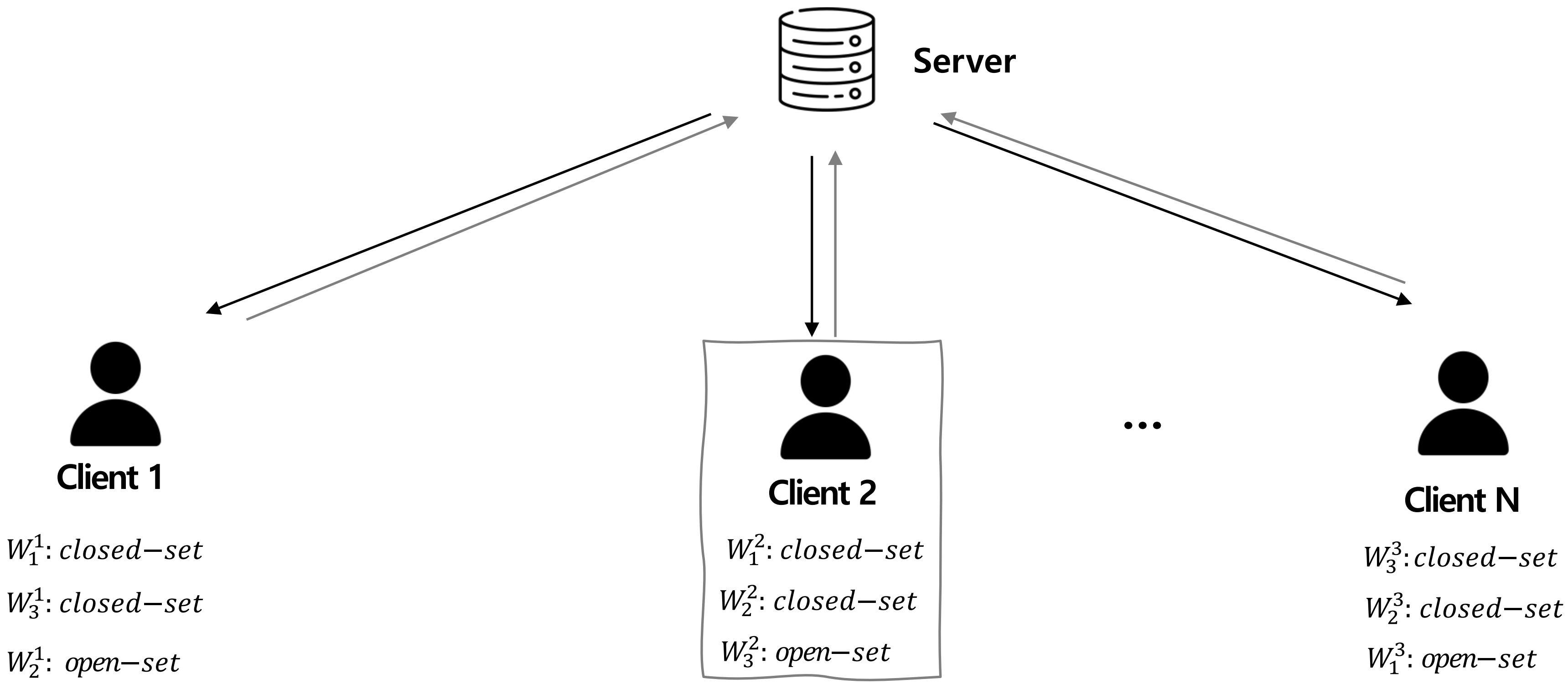


Experiments & Results

- 데이터셋: Handwritten digital recognition FL Dataset (HDR-FL)
  - ✓ MNIST, SVHN, USPS, SynthDigits and MNIST-M
- 정량 평가:
  - ✓ Closed-set classification: Accuracy
  - ✓ Open-set detection: AUROC
- Known class의 개수: 6 / Unknown class의 개수: 4

Methods	Closed-set ACC						Open-set AUC					
	MNIST	SVHN	USPS	Synth	MNIST-M	Avg	MNIST	SVHN	USPS	Synth	MNIST-M	Avg
SoftMax	96.69	76.06	97.97	83.99	83.69	87.68	77.38	65.41	88.80	70.53	66.24	73.67
OpenMax[2]$_{(CVPR'16)}$	95.54	63.13	97.97	81.15	76.57	82.87	77.78	57.37	89.21	69.78	60.88	71.00
RPL[4]$_{(ECCV'20)}$	98.33	77.22	98.13	84.76	86.32	88.95	77.87	66.70	89.53	73.17	73.23	76.10
PROSER[43]$_{(CVPR'21)}$	98.04	75.81	97.20	86.92	84.93	88.58	83.63	65.57	90.28	71.76	69.75	76.20
ARPL[3]$_{(TPAMI'21)}$	97.17	69.83	96.44	84.64	84.22	86.46	85.65	59.79	92.53	69.70	68.17	75.16
DIAS[26]$_{(ECCV'22)}$	97.50	70.66	97.62	86.11	86.81	87.74	82.90	67.33	90.69	77.48	71.92	78.06
SSB[35]$_{(ICLR'22)}$	96.41	60.12	97.46	82.82	74.86	82.33	88.53	57.68	90.45	73.40	70.01	76.01
FedPD$_{(Ours)}$	**98.73**	**78.06**	**98.56**	**89.32**	**90.14**	**90.96**	**90.98**	**69.46**	**93.31**	**79.43**	**73.64**	**81.36**

2. FedPD

Federated Open Set Recognition with Parameter Disentanglement

Experiments & Results

- 데이터셋: CIFAR-10
- 정량 평가:
  - ✓ Closed-set classification: Accuracy
  - ✓ Open-set detection: AUROC
- Unknown class의 개수: 4개, 6개, 8개로 실험

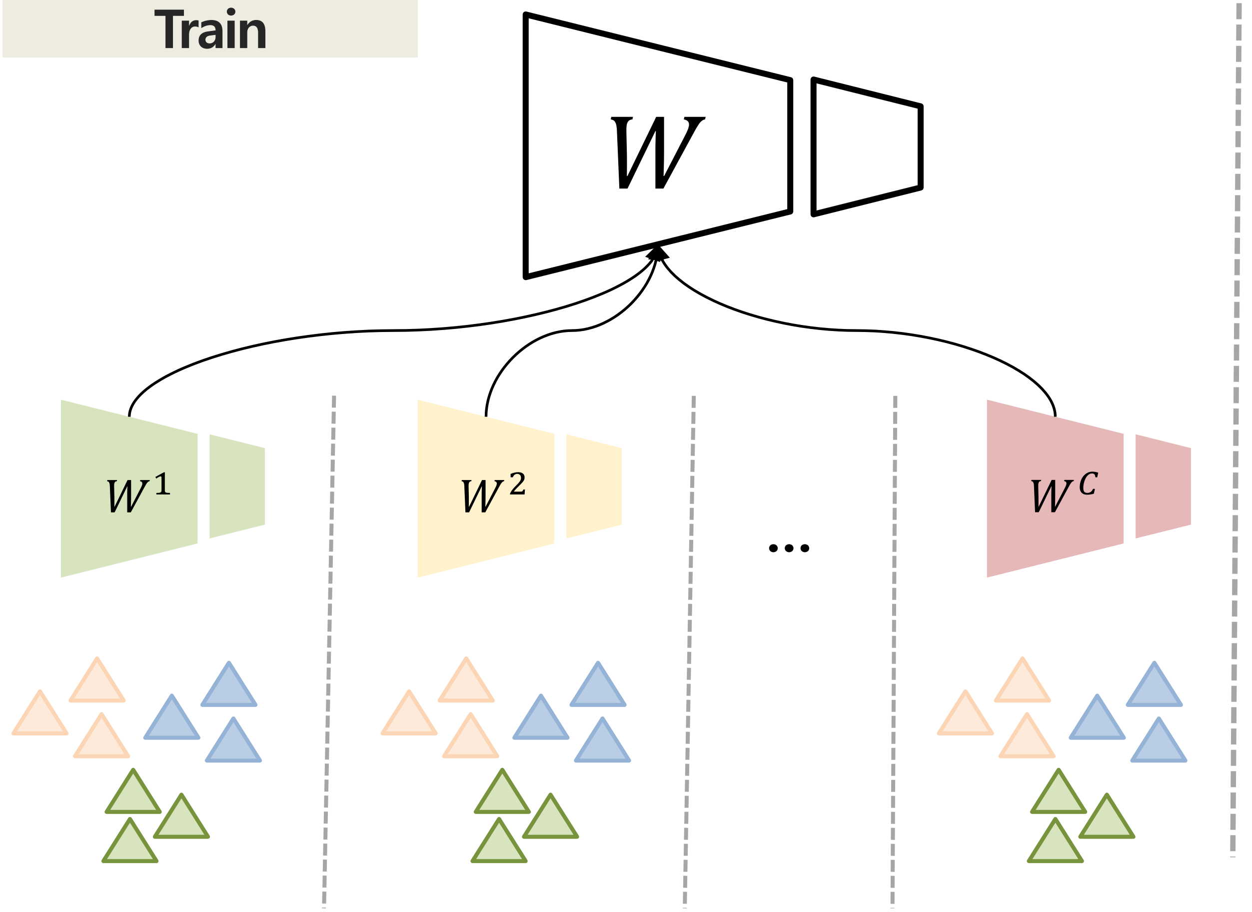
Method	Known=4		Known=6		Known=8	
	Closed-set ACC	Open-set AUC	Closed-set ACC	Open-set AUC	Closed-set ACC	Open-set AUC
SoftMax	83.23 ±0.28	65.70±0.14	83.14±0.38	72.00±0.44	72.17±0.41	61.11±0.45
OpenMax[2] $_{(CVPR'16)}$	83.24 ±0.08	65.96±0.14	84.56±0.24	81.69±0.59	72.72±0.40	61.52±0.38
RPL[4] $_{(ECCV'20)}$	81.23 ±0.11	65.10±0.05	78.78±0.43	68.72±0.43	72.98±0.33	61.36±0.32
PROSER[43] $_{(CVPR'21)}$	84.15 ±0.13	69.04±0.07	85.77±0.48	80.69±0.27	70.50±0.21	60.48±0.41
ARPL[3] $_{(TPAMI'21)}$	83.91 ±0.09	69.02±0.12	86.54±0.53	79.83±0.69	73.63±0.37	66.78±0.64
DIAS[26] $_{(ECCV'22)}$	84.85 ±0.04	70.32±0.09	87.74±0.16	81.66±0.25	74.53±0.37	67.75±0.34
SSB[35] $_{(ICLR'22)}$	84.27±0.06	68.85±0.11	86.04±0.70	82.41±0.33	75.54±0.18	67.97±0.23
FedPD $_{(Ours)}$	**86.28±0.07**	**71.50±0.07**	**89.43±0.22**	**85.07±0.50**	**75.87±0.16**	**69.12±0.45**

FedOSS

: Known classes
: Unknown class

FedOSS

Train



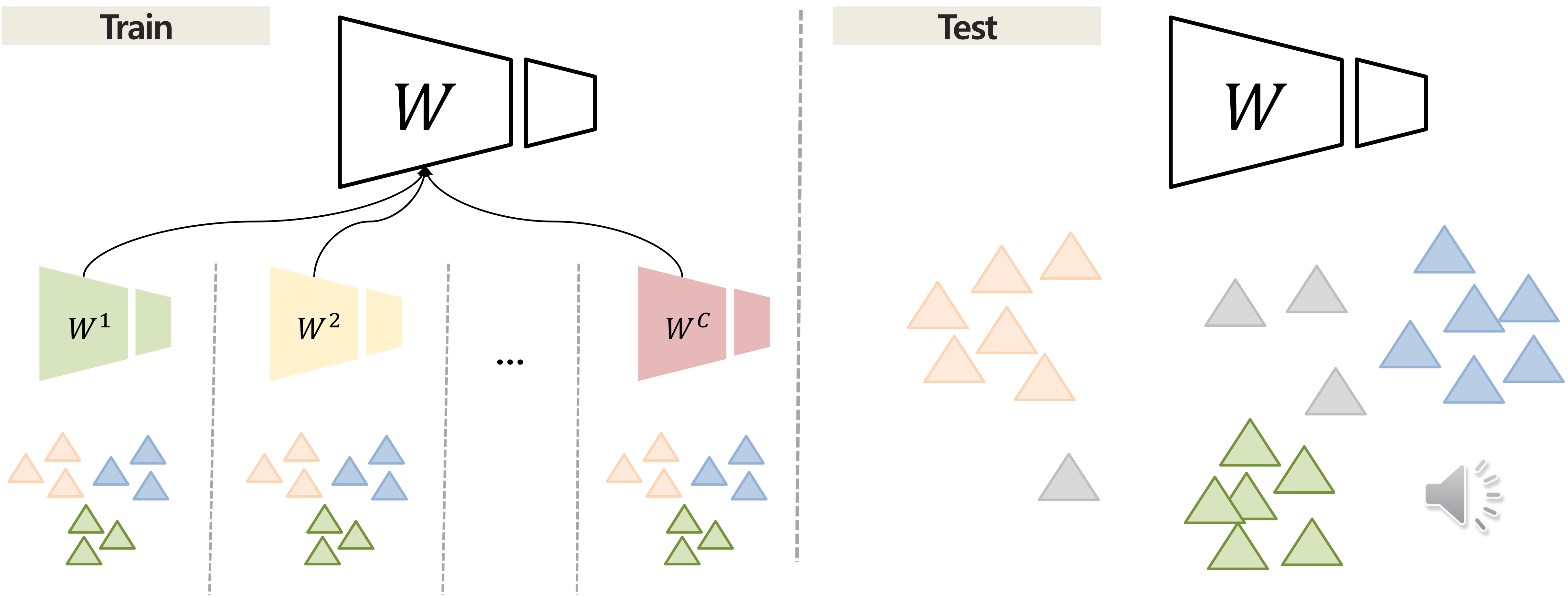
3. FedOSS

Federated Open Set Recognition via Inter-Client Discrepancy and Collaboration

: Known classes

: Unknown class

FedOSS



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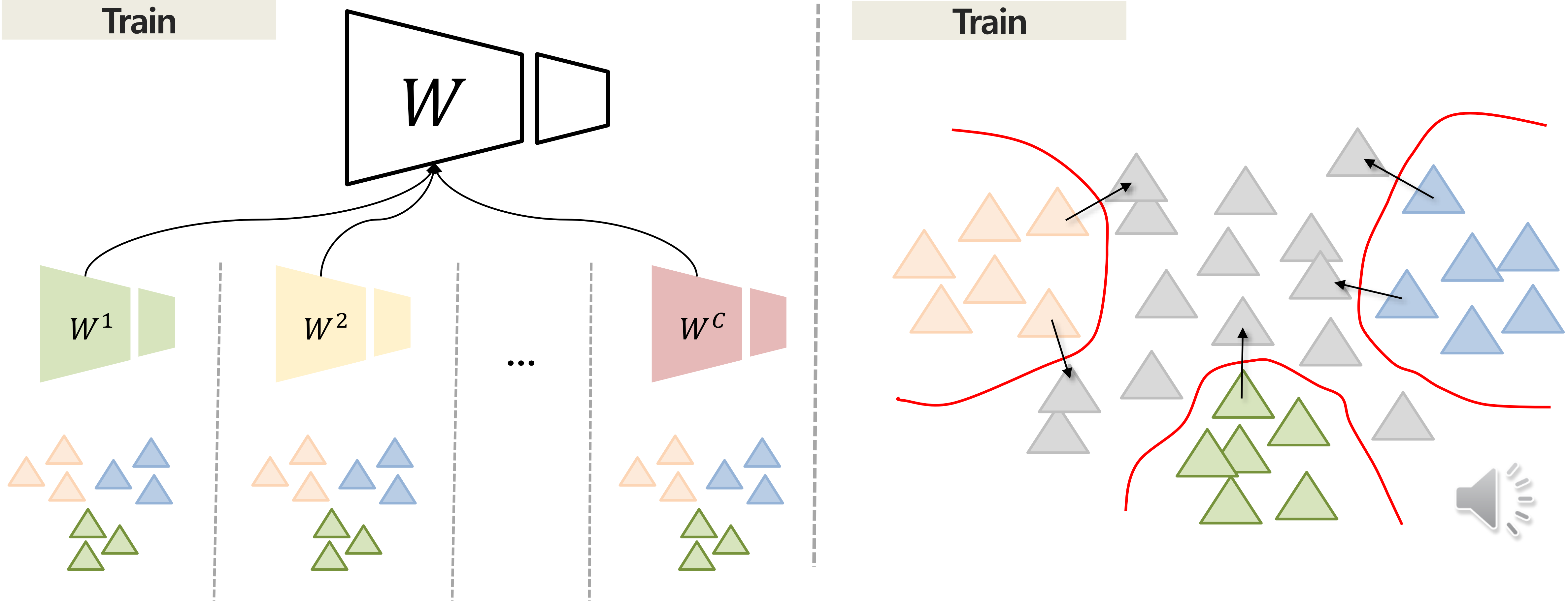

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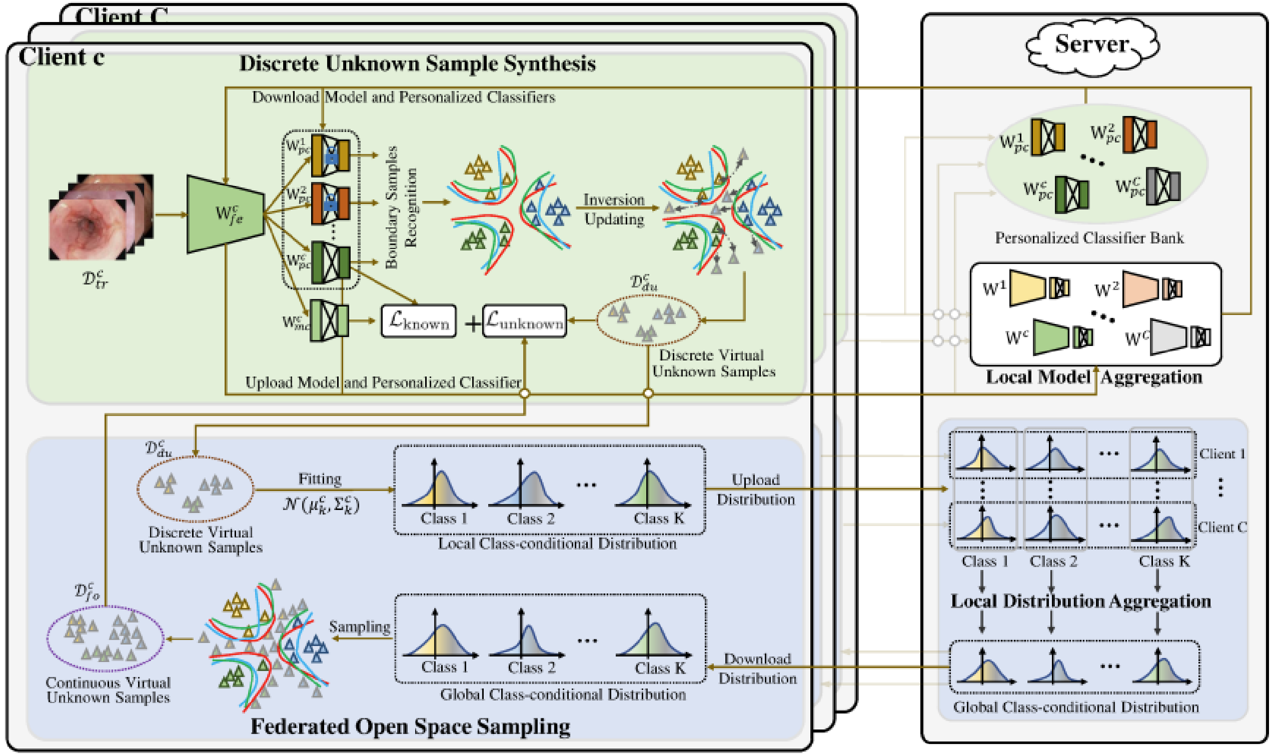
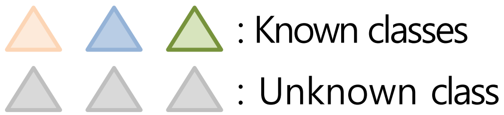


Fig. 2. The overview of the proposed FedOSS framework to federated open set recognition (Best view in color). FedOSS overcomes the challenge in unavailability of open data via discrete unknown sample synthesis (DUSS) and federated open space sampling (FOSS). DUSS utilizes the client discrepancy to recognize boundary samples, which are used to synthesize unknown samples via inversion updating. The generated unknown samples from all clients are inputted into FOSS to estimate the distribution of open space for sampling diverse unknown data.

3. FedOSS

Federated Open Set Recognition via Inter-Client Discrepancy and Collaboration



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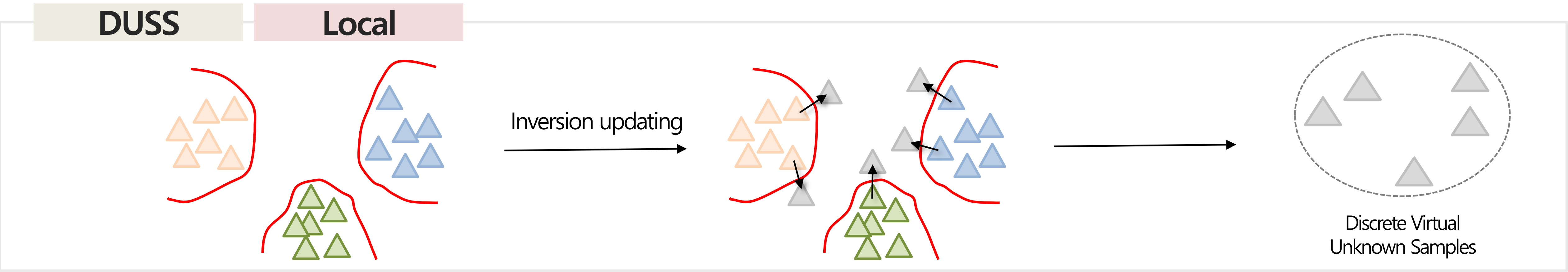

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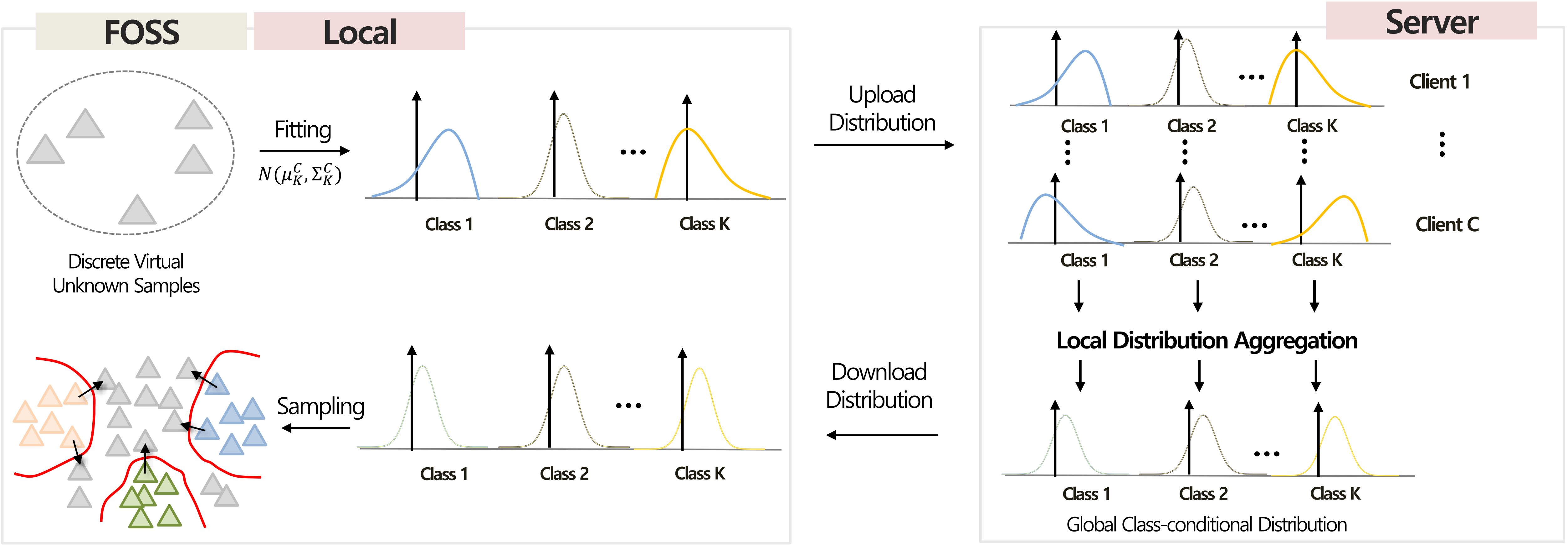

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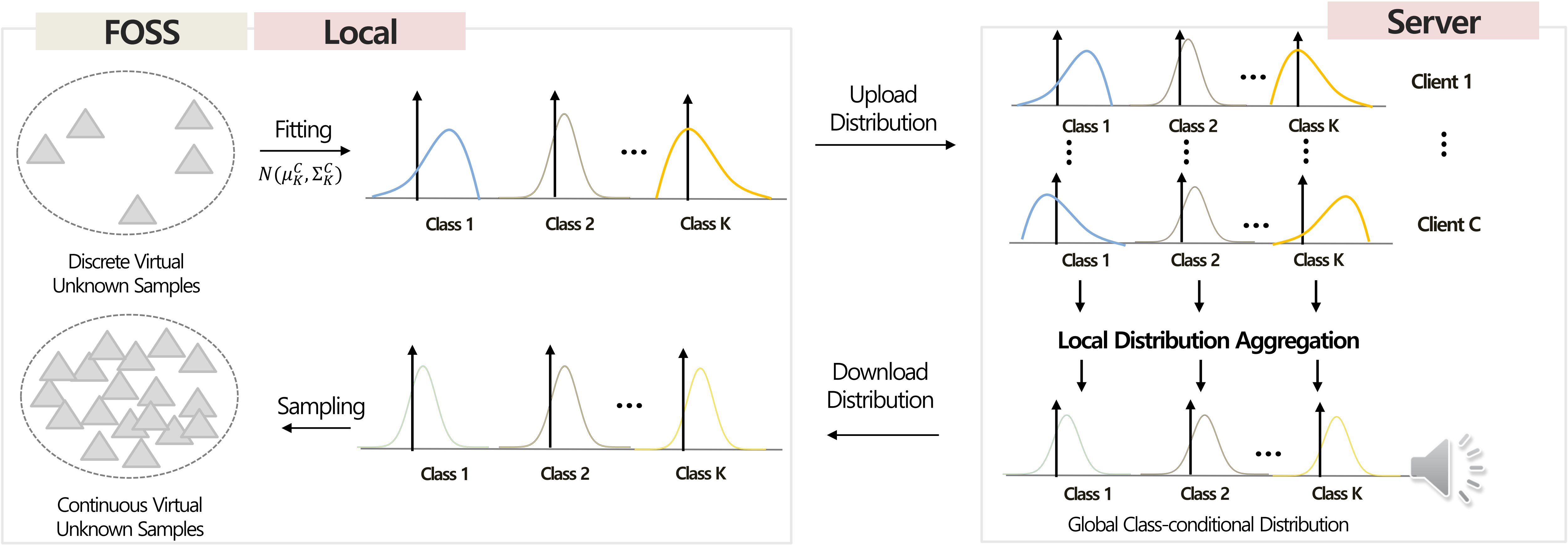
: Known classes
: Unknown class

FedOSS



Experiments & Results

- 데이터셋: Microscopic Peripheral Blood Cell Dataset(17,092 데이터, 8 classes)
- 정량 평가: ACC(%)/ Recall(%)/ Precision(%)/ F1-score(%)
- Unknown class의 개수: 3개, 5개로 실험

Methods	U = 3				U = 5			
	ACC (%)	Recall (%)	Precision (%)	F1-score (%)	ACC (%)	Recall (%)	Precision (%)	F1-score (%)
Softmax	70.42±3.52	81.03±1.19	72.09±2.76	59.56±4.07	44.20±2.11	74.48±0.51	62.48±5.17	48.78±1.99
OpenMax [4]	73.96±7.32	76.72±4.11	74.98±6.35	72.52±6.70	65.78±3.72	71.88±3.63	72.05±2.13	65.04±1.91
CPN [5]	74.72±5.58	82.18±4.18	75.12±4.43	74.81±5.41	70.89±2.01	83.17±1.70	73.77±2.25	73.07±1.10
CAC [6]	75.50±6.42	82.67±4.54	75.52±5.94	75.75±6.23	74.85±2.54	85.86±1.25	74.86±1.58	75.54±1.21
PROSER [7]	77.48±3.39	82.99±4.21	77.56±2.26	77.64±2.99	61.01±7.36	81.42±1.97	69.29±2.19	64.74±4.38
FedMix [60]	72.18±4.83	73.90±7.12	72.82±5.91	71.92±7.50	57.26±10.56	74.74±7.10	65.87±3.64	61.97±6.54
SSB [8]	78.71±7.92	83.38±4.73	79.46±6.56	79.05±7.19	73.46±10.86	84.41±4.97	73.92±6.25	74.28±9.04
OVRN [9]	77.35±8.02	**83.45±5.54**	78.87±5.36	77.65±7.50	77.95±4.16	**87.49±1.31**	76.20±2.08	78.00±2.90
Ours	**80.04±5.38**	82.46±5.31	**80.73±4.02**	**81.06±4.59**	**82.91±4.27**	84.54±3.80	**79.97±1.96**	**80.56±3.58**

Experiments & Results

- 데이터셋: Gastrointestinal Endoscopy Dataset(10,662 데이터, 15 classes)
- 정량 평가: ACC(%)/ Recall(%)/ Precision(%)/ F1-score(%)
- Unknown class의 개수: 3개, 9개로 실험

Methods	U = 3				U = 9			
	ACC (%)	Recall (%)	Precision (%)	F1-score (%)	ACC (%)	Recall (%)	Precision (%)	F1-score (%)
Softmax	77.41±8.19	84.75±0.37	81.64±4.39	76.60±3.75	60.62±3.67	84.43±0.96	66.81±2.50	65.86±1.46
OpenMax [4]	80.27±5.41	81.80±7.74	84.91±1.87	79.79±7.80	65.99±1.88	82.09±3.24	66.89±7.96	69.80±3.39
CPN [5]	80.35±5.19	84.36±4.86	80.30±7.90	80.25±7.06	61.03±9.31	82.21±3.47	64.81±8.68	67.57±7.55
CAC [6]	83.34±4.65	87.52±1.73	84.67±2.59	84.67±2.60	64.73±6.51	83.51±1.11	68.37±4.40	70.11±4.82
PROSER [7]	85.70±2.95	**89.05±0.67**	86.28±2.65	85.56±1.25	69.29±3.05	85.66±2.79	72.44±2.08	73.16±1.23
FedMix [60]	83.62±3.27	86.27±2.18	80.86±5.71	82.52±4.23	69.92±3.38	82.85±1.46	72.76±1.71	73.33±3.32
SSB [8]	80.89±4.74	84.92±3.13	83.83±2.53	81.89±3.48	66.45±5.59	83.55±3.29	71.70±2.93	72.06±4.73
OVRN [9]	78.49±9.29	84.47±2.63	83.09±2.95	81.58±4.86	71.45±7.78	**86.72±2.86**	74.84±3.84	76.06±5.35
Ours	**88.29±1.80**	88.29±3.07	**89.07±1.46**	**87.78±3.23**	**77.17±2.05**	86.23±2.01	**77.89±0.94**	**79.41±2.46**

Experiments & Results

- 데이터셋: 3D Organ Classification Dataset(1743 데이터, 11 classes)
- 정량 평가: ACC(%)/ Recall(%)/ Precision(%)/ F1-score(%)
- Unknown class의 개수: 4개, 7개로 실험

Methods	U = 4				U = 7			
	ACC (%)	Recall (%)	Precision (%)	F1-score (%)	ACC (%)	Recall (%)	Precision (%)	F1-score (%)
Softmax	67.72±1.29	82.20±2.81	71.45±1.47	72.27±1.73	44.89±3.24	75.57±1.96	56.82±0.62	52.79±2.29
OpenMax [4]	49.95±3.19	56.94±9.58	52.36±1.72	49.44±6.66	66.38±4.80	54.04±6.62	68.20±10.92	52.45±5.71
CPN [5]	59.12±3.12	74.25±1.84	65.84±3.83	65.20±1.70	40.40±7.13	63.81±6.59	51.54±13.07	48.43±6.95
CAC [6]	71.92±5.36	82.90±3.91	75.34±6.58	76.38±5.59	44.40±5.37	73.45±2.80	53.72±3.71	54.99±2.66
PROSER [7]	78.22±1.64	86.76±2.53	79.96±0.89	81.92±1.11	51.77±11.59	69.19±10.41	64.51±7.98	56.60±9.92
FedMix [60]	77.75±2.89	**87.06±3.09**	80.78±1.86	81.79±2.86	43.84±2.97	72.45±3.52	55.38±6.49	53.05±4.74
SSB [8]	67.81±3.98	81.51±2.04	75.21±5.45	74.19±4.19	46.23±7.03	70.88±5.60	58.16±5.33	52.66±6.69
OVRN [9]	64.18±1.30	78.59±2.64	73.77±4.56	71.17±2.10	57.69±3.52	**79.82±2.09**	61.59±4.30	62.55±4.25
Ours	**80.42±2.92**	81.77±1.81	**85.36±3.87**	**82.84±2.28**	**78.32±3.41**	75.44±4.02	**80.86±1.59**	**75.81±3.30**

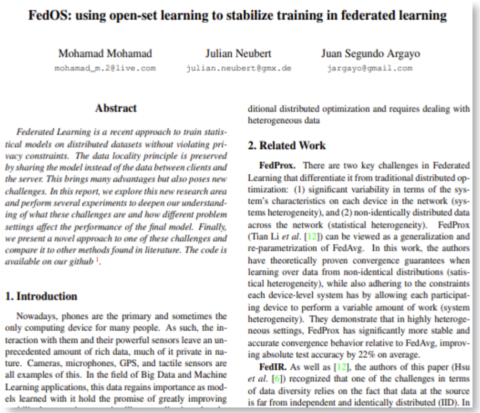
Conclusion

Open Set Recognition Federated Learning

✓FedOSR의 초기 아이디어
✓GAN을 활용해 unknown 샘플을 합성

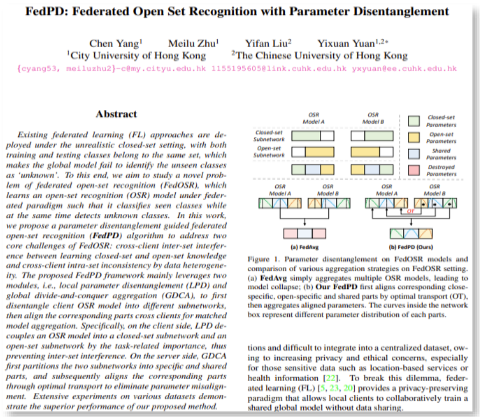
✓경계부 샘플을 밀어 unknown 합성
✓클라이언트들이 생성한 unknown을 연합 샘플링

FedOS
[arXiv 2022]


FedOS: using open-set learning to stabilize training in federated learning

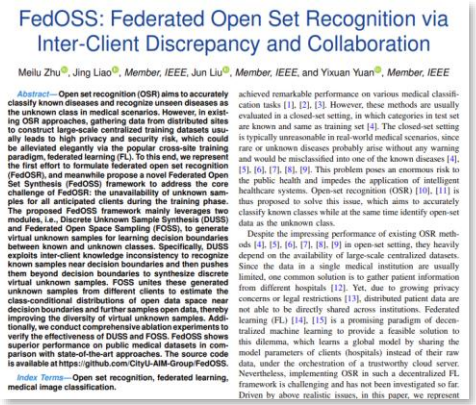
Mohamad Mohamad, Julian Neubert, Juan Segundo Argayo

FedPD
[ICCV 2022]


FedPD: Federated Open Set Recognition with Parameter Disentanglement

Chen Yang[1], Meilu Zhu[1], Yifan Liu[2], Yixuan Yuan[1,2*]
[1]City University of Hong Kong [2]The Chinese University of Hong Kong

FedOSS
[IEEE 2024]


FedOSS: Federated Open Set Recognition via Inter-Client Discrepancy and Collaboration

Meilu Zhu, Jing Liao, Member, IEEE, Jun Liu, Member, IEEE, and Yixuan Yuan, Member, IEEE

✓클라이언트 모델 파라미터를 Closed-set / Open-set 서브네트워크로 분해
✓서버에서 Optimal Transport 기반 정렬로 부분별 집계

Thank you