Federated learning for predicting compound mechanism of action based on image-data from cell painting

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Mechanism of Action

An essential concept in drug discovery:

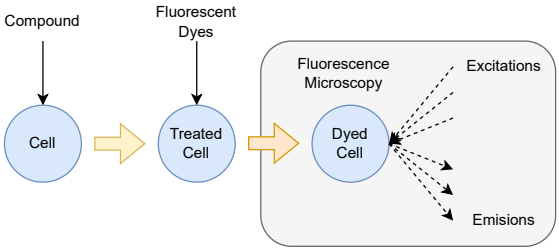
- Drugs are designed to produce therapeutic effects.
- At cellular level, drugs (compounds) interact with their target cells.
- Biochemical interactions can be categorised into distinct classes.

These classes are called *Mechanism of Action* (MoA).

A general question: Given a compound, how do we know its MoA?

Fluorescence cell painting

Fluorescence cell painting, a major approach for MoA identification:



- Fluorescence image X: $H \times W \times$ #excitations.
- MoA Y: Categorical variable.
- Model: An end-to-end neural network for classification $f_\theta : X \to Y$.

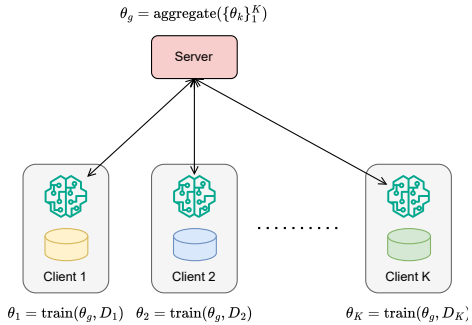
Federated learning

Performant neural network models rely on sufficient data, but

- Data collecting is costly.
- Data sharing is not possible across pharm entities.

We need collaborative machine learning without sharing the data.

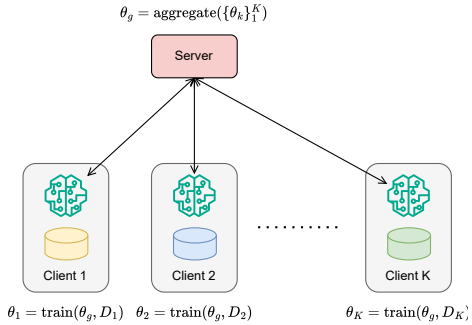
Federated learning (FL), a *collaborative machine learning* paradigm, *without data sharing*.



Problem solved?

Federated learning is *not* an on-the-shelf method:

- Local training: Choices of hyperparameters, optimisers, etc.
- Server aggregation: Model averaging or medianing, momentum for aggregation, etc.
- Local datasets: Size imbalance, statistical heterogeneity, etc.



Data heterogeneity problem in FL

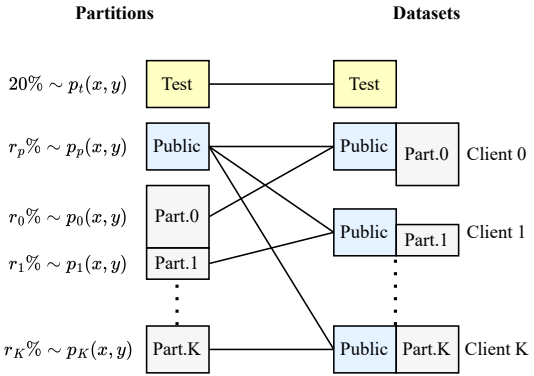
Data heterogeneity is the root of all evil for federated learning:

- Slow convergence.
- Suboptimal solutions.
- Fairness problem: across clients, and across classes.
- ...

In this work, we study the effectiveness of federated learning, and how data heterogeneity affects the performance, in the context of compound MoA prediction from fluorescence image-data.

Data & partitioning scheme

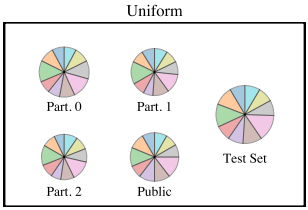
MoA	Encoding	Num. Images
retinoid receptor agonist	0	1026
protein synthesis inhibitor	1	1242
topoisomerase inhibitor	2	1728
Aurora kinase inhibitor	3	1080
ATPase inhibitor	4	1026
HSP inhibitor	5	1296
HDAC inhibitor	6	1782
JAK inhibitor	7	1188
PARP inhibitor	8	1134
tubulin polymerization inhibitor	9	1080



Simulation scenarios

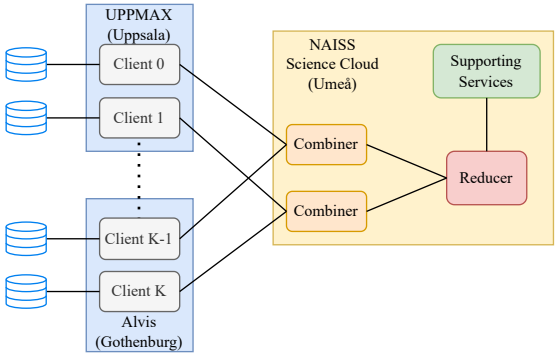
We simulate three scenarios:

- Uniform
- Unbalanced (in sizes)
- Non-IID (specialisation in certain MoAs)



Training system

- Base models: AlexNet, VGG13.
- Training schemes: Local traning, centralised tranining, federated training.
- Federated training: FEDn for geographically distributed training, and local simulation.

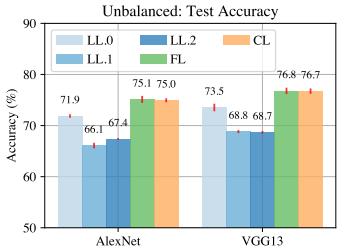


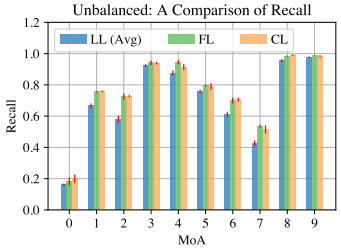
FL outperforms local learning and is comparable to centralised learning

In terms of average prediction accuracy for all MoA, and recall and precision for each individual MoA,

- FL models are significantly better compared with local models.
- FL models provide equivalent performances with their centralised counterparts.

This encourages pharm entities to join in FL rather than local training.

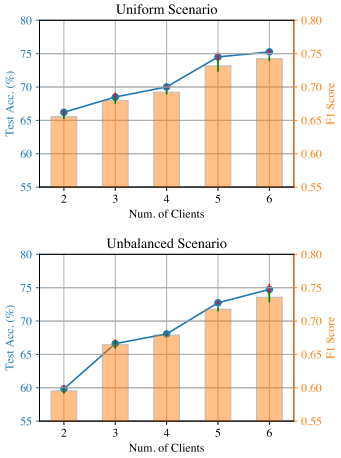




The more participants, the better prediction performance

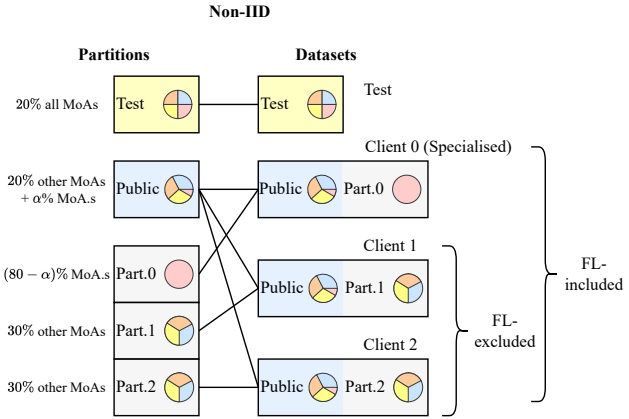
Under the condition that all local datasets are of the identical distributions, the more participants, the better prediction performance, despite the various sizes of local datasets.

This encourages existing participants to keep engaging in FL throughout the life cycle of a model.



Specialised participant brings benefits

We compare the performance of the federated models with the specialised client included and excluded.

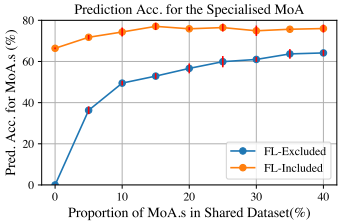


Specialised participant brings benefits

Including the specialising client in federated learning

- significantly improve the prediction accuracy for the specialised MoA.
- slightly improve the average prediction accuracy for all MoAs.

This encourages both specialised and general clients to join federated learning.



Conclusions

We conclude that

- Federated learning does bring benefits for MoA prediction from distributed data without sharing them.
- Our studies provide motivations for different (potential) participants.
- Theoretical studies for data heterogeneity are too pessimistic in the context of MoA prediction.

Thanks for your attention!

Questions?