Privacy-Preserving AI: Privacy-preserving machine learning techniques. Federated learning and differential privacy

Artificial Intelligence System Engineering

Data driven AI

- AI Systems and applications that heavily rely on data
  - Make predictions
  - Learn
  - Perform tasks
- Data is the foundation
- Models use datasets to learn patterns, relationships, and correlations
- Models enhance their performance as additional relevant data becomes accessible

Data driven AI

- Adaptability
- Data is the core input
- The process is itterative

Data driven AI

- Data driven organizations (Klas Haller)

Privacy-Preserving Machine Learning (1)

- Machine Learning as a Service (MLaaS)
- Facebook–Cambridge Analytica scandal (2018)
- Facebook ML-based facial recognition technology lawsuit (2020)

- Google developed Randomized Aggregatable Privacy-Preserving Ordinal Response (RAPPOR)

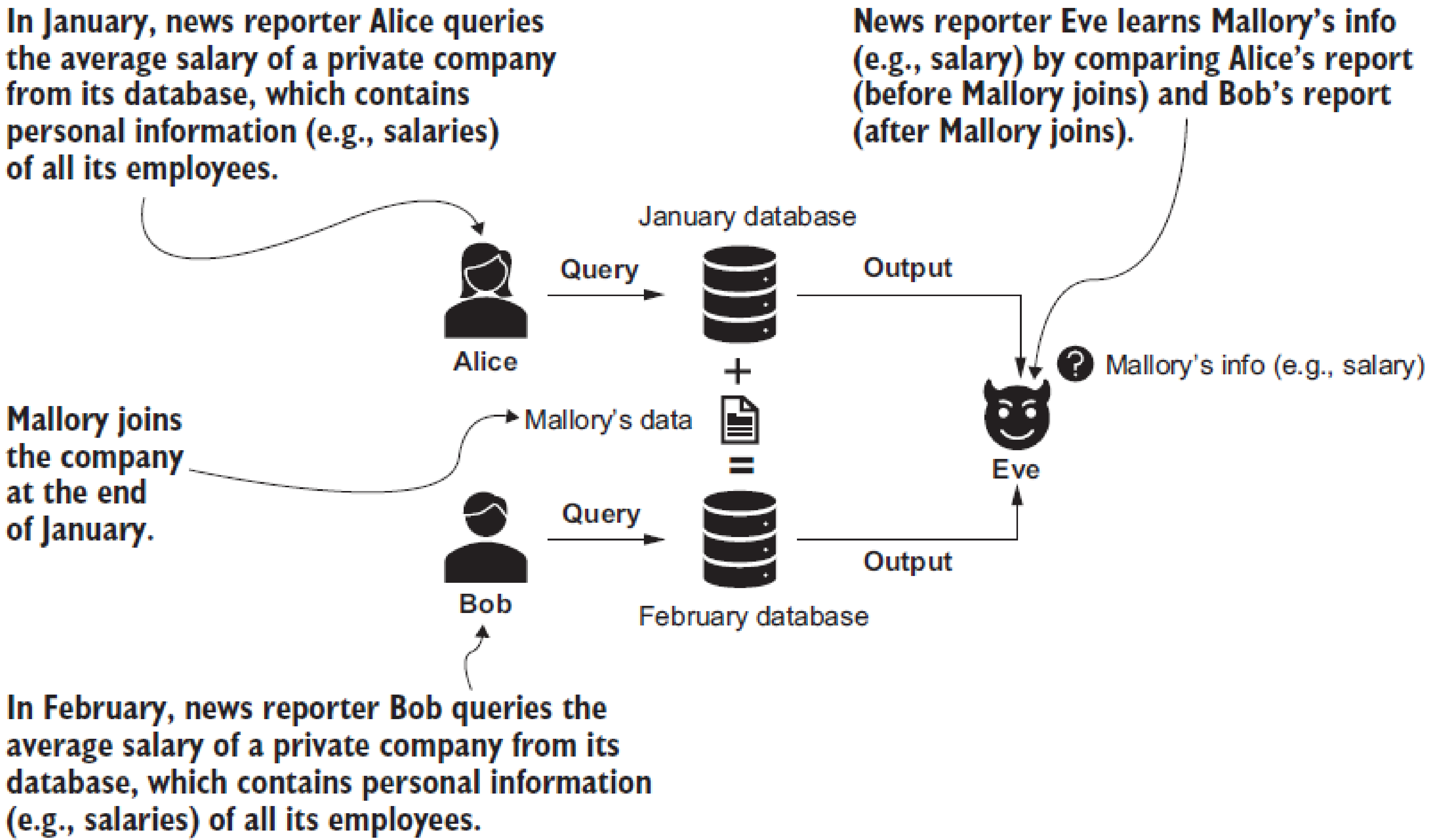
Privacy-Preserving Machine Learning (2)

- Privacy-preserving ML (PPML) algorithms
- Threats and attacks:
    - De-anonymization (re-identification)
    - Reconstruction attacks
    - Parameter inference attacks
    - Model inversion attacks
    - Membership inference attacks

Privacy-Preserving Machine Learning (3)

- Securing privacy:
  - Differential privacy (DP)
  - Local differential privacy
  - Privacy-preserving synthetic data generation
  - Privacy-preserving data mining techniques
    - Privacy-preserving data mining (PPDM)
    - Data collection stage: randomization techniques
    - Data publishing and processing: remove certain attributes, data sanitization (generalization, suppresion, anotamization, perturbation)
    - Output: Association rule hiding, Downgrading classifier effectiveness,Query auditing and restriction
    - Compressive privacy

Differential privacy



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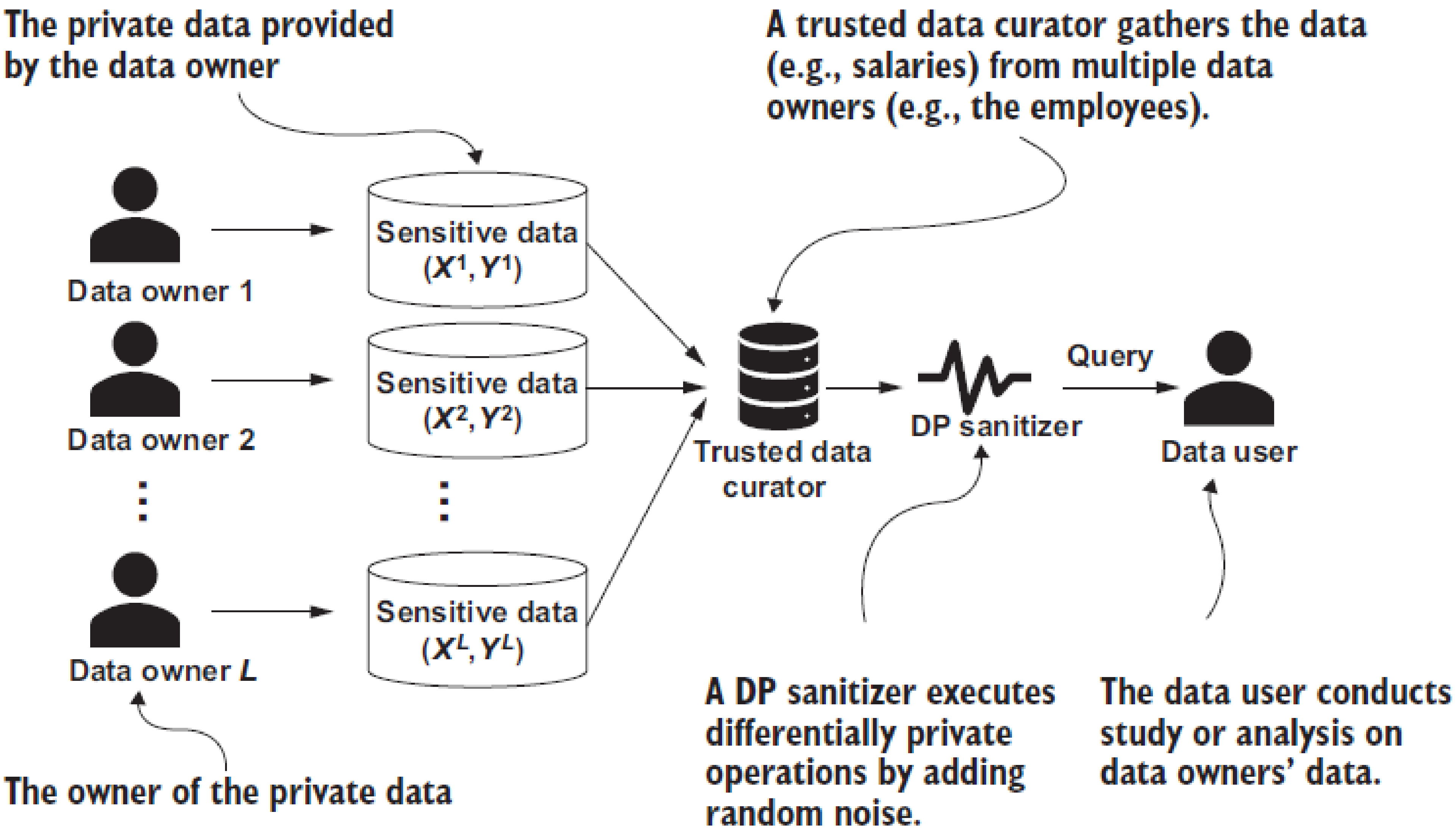

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Mechanisms of differential privacy

- Binary mechanism (randomized response)
- Laplace mechanism
- Exponential mechanism
- Etc…

- https://diffprivlib.readthedocs.io/en/latest/modules/mechanisms.html
- https://rbcborealis.com/research-blogs/tutorial-12-differential-privacy-i-introduction/

Applying differential privacy in machine learning

- Input perturbation
- Algorithm perturbation
- Output perturbation
- Objective perturbation
  - (https://kronosapiens.github.io/blog/2017/03/28/objective-functions-in-machine-learning.html)

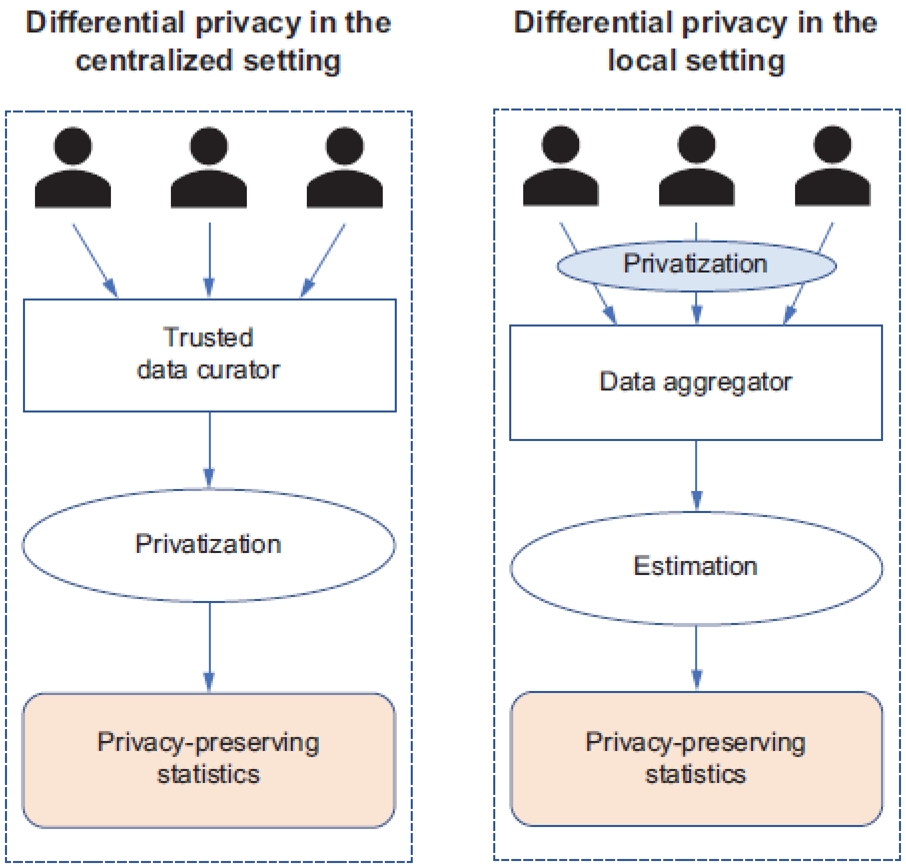
Differentially private supervised learning algorithms

- Differentially private naive Bayes classification (https://arxiv.org/abs/1905.01039)
- Differentially private logistic regression (https://systems.cs.columbia.edu/private-systems-class/papers/Chaudhuri2009Privacy.pdf)
- Differentially private linear regression (https://arxiv.org/abs/2007.05157)

Differentially private unsupervised learning algorithms

- Differentially private k-means clustering
  - https://dl.acm.org/doi/10.1145/2857705.2857708
  - https://arxiv.org/abs/2406.11649
  - https://ieeexplore.ieee.org/abstract/document/9064731

Local differential privacy



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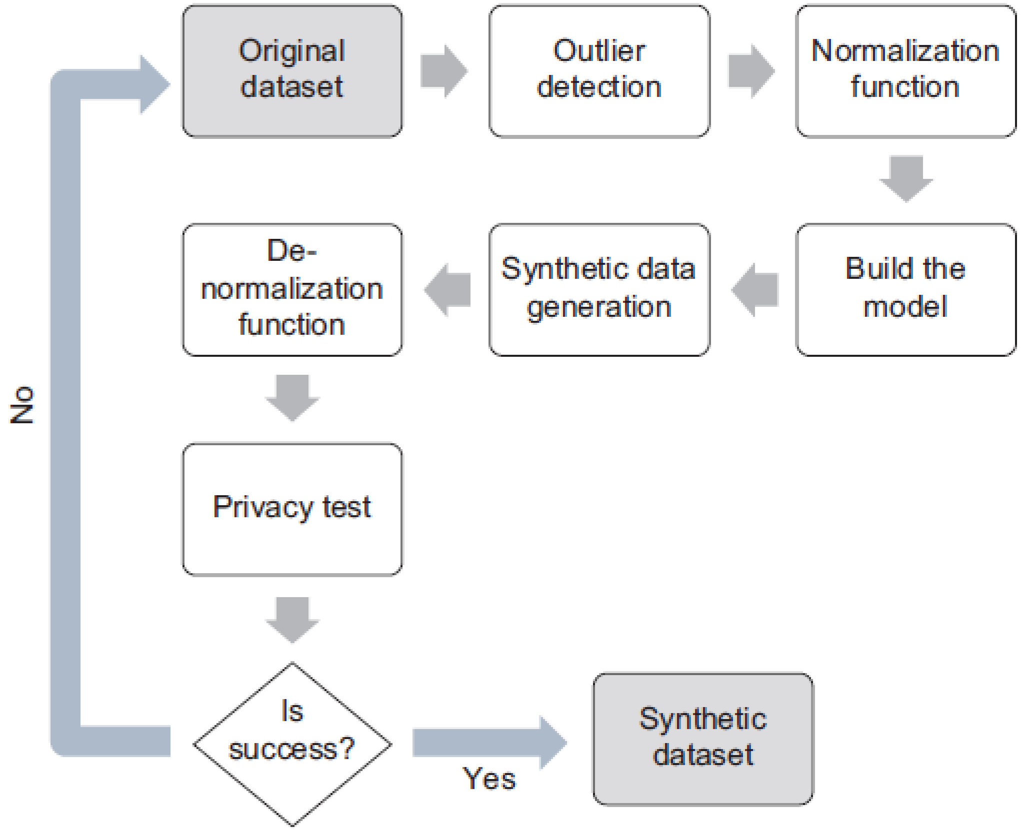
The mechanisms of local differential privacy

- Direct encoding
- Histogram encoding
- Unary encoding
- Examples with code:
  - https://programming-dp.com/ch13.html
- Survey (paper): https://onlinelibrary.wiley.com/doi/10.1155/2020/8829523

Advanced LDP mechanisms

- The Laplace mechanism for LDP
- Duchi’s mechanism for LDP
- The Piecewise mechanism for LDP

Privacy-preserving synthetic data generation



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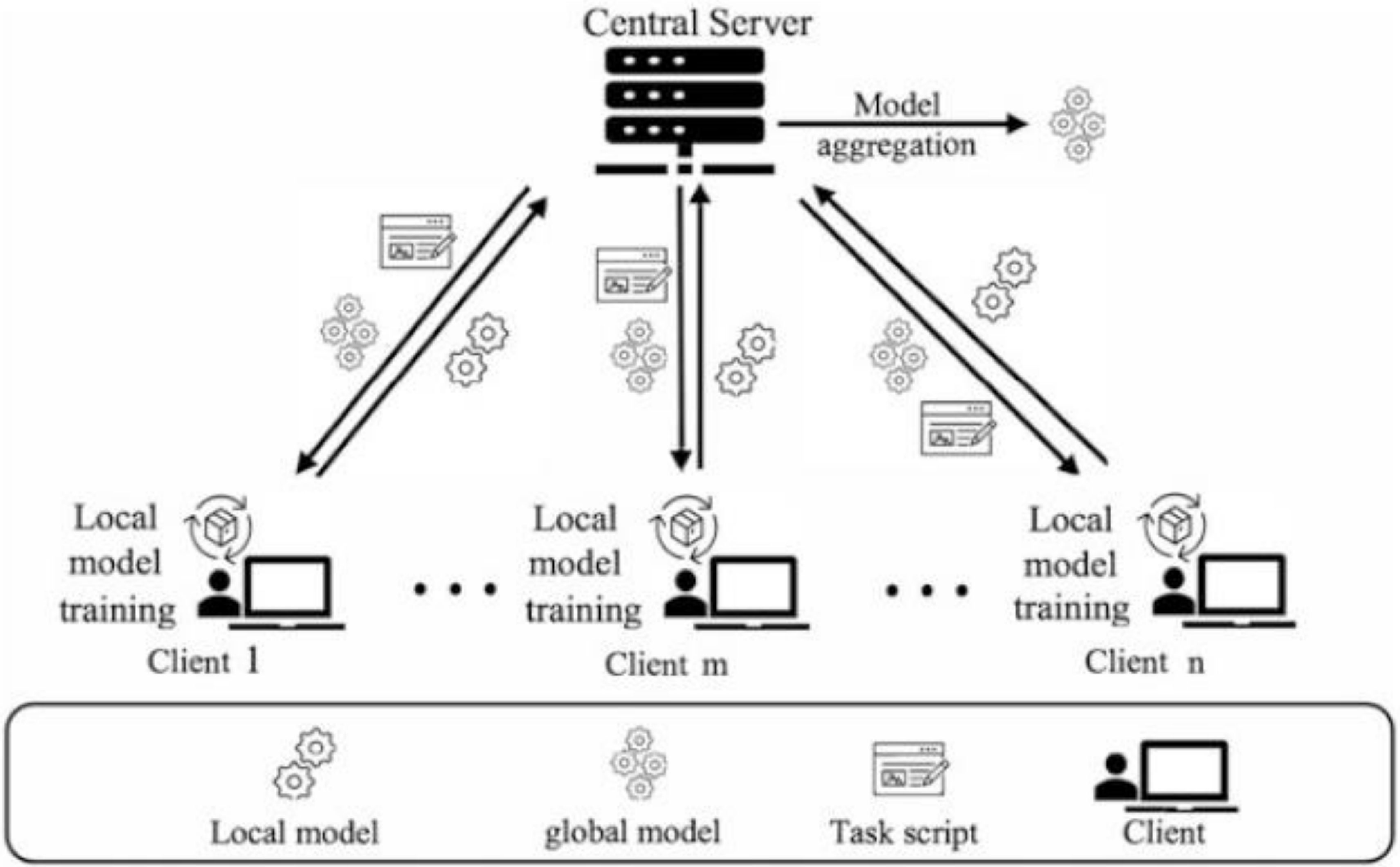
Federated learning

- A decentralized approach to machine learning where models are trained across multiple devices or servers (referred to as "clients") while keeping the data localized on those devices

Federated learning



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Federated learning: Vulnerabilities

- Clients
- Server
- Aggregator
- Communication

Attacks in Federated Learning

- Inference attacks
- Poisoning attacks
- GAN-Based attacks

Defense techniques

- Differential Privacy (DP)
- Secure Multi-party Computation (SMPC)
- Secure Data Aggregation
- Anonymous Communication and Shuffle Model

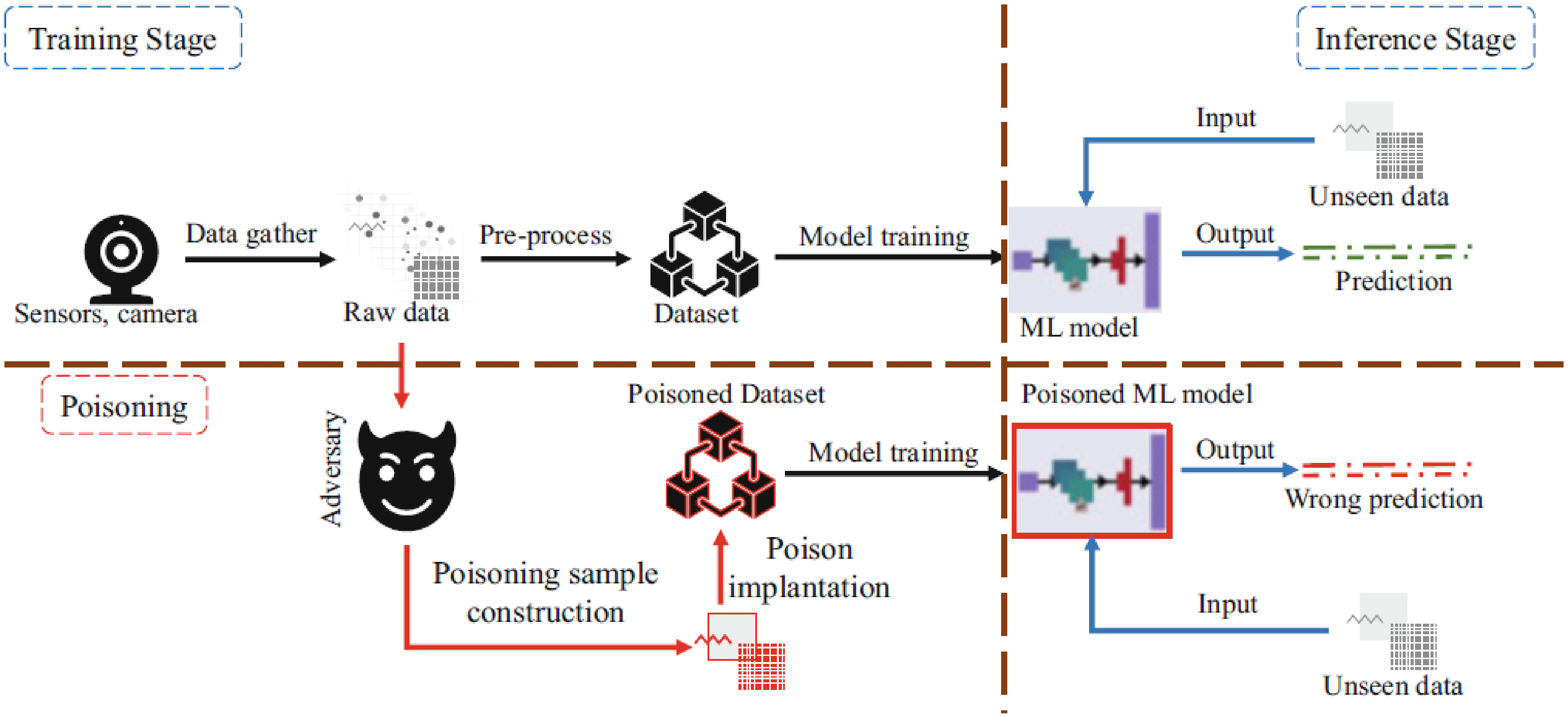
Inference Attacks in FL

- Model Inversion Attacks:
  - Attackson aggregated gradient
  - Attackson global model
- Property Inference Attacks
- Membership Inference Attacks:
  - Data knowledge
  - Training knowledge
  - Model knowledge
  - Output knowledge
- Model Inference Attacks

Counter-Inference Attacks

- Machine Learning Optimization-Based Defense
- Perturbation-Based Defense
- Knowledge Distillation
- AdversarialMachine Learning
- Encryption-Based Methods

Poisoning attacks



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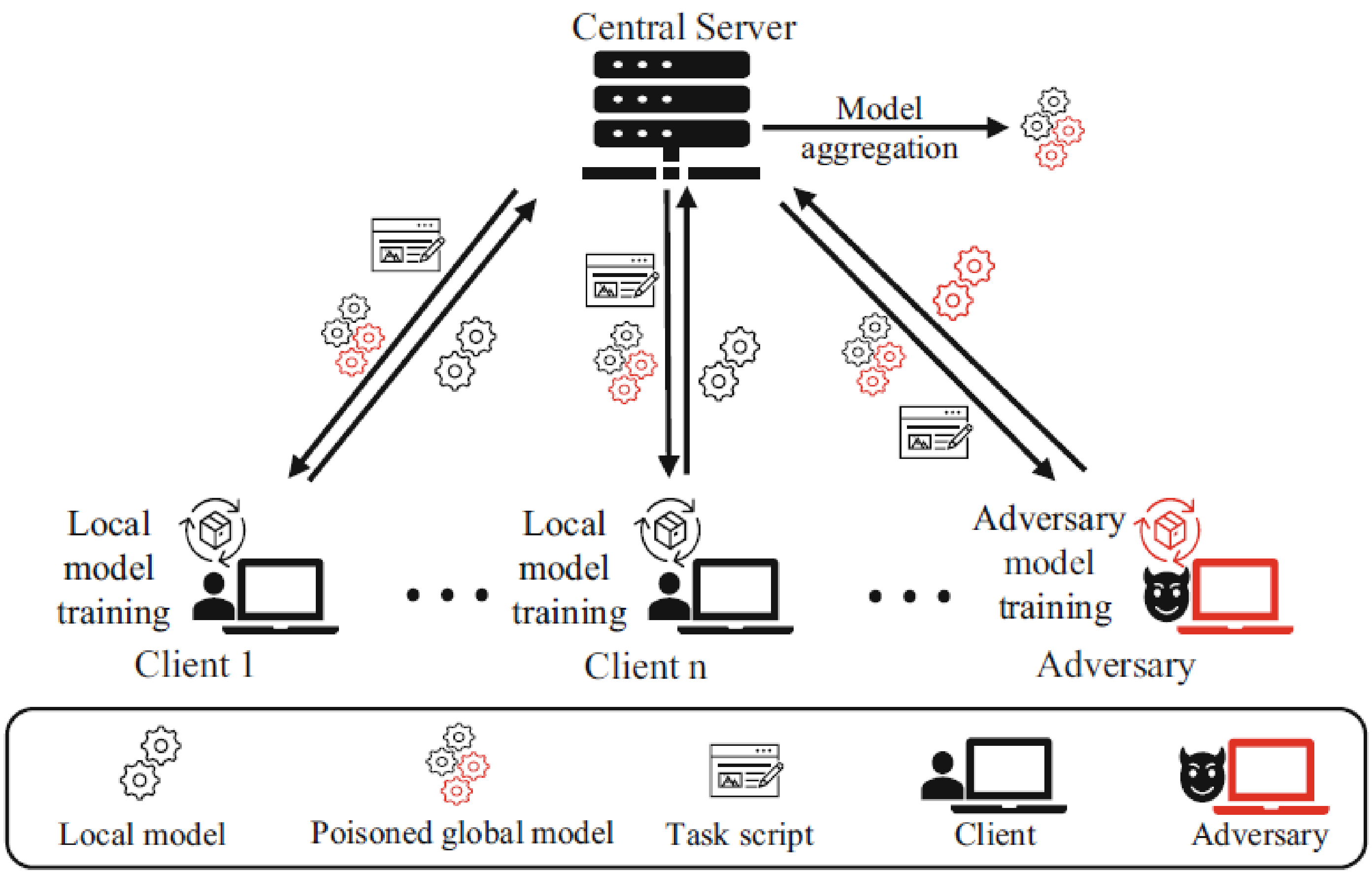
Poisoning attacks in FL



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Poisoning attacks in FL

- Targeted Poisoning Attacks
- Untargeted Poisoning Attacks
- Backdoor Poisoning Attacks
- https://www.researchgate.net/publication/347178320_Threats_to_Federated_Learning

Counter Poisoning Attacks

- Counterattacks from Data Perspective
  - Byzantine-resilient algorithm for distributed SGD
  - Trimmed mean
  - Bulyan
- Counterattacks from Behavior Perspective
- Other (research papers)

Differential Privacy in FL

- Centralized Differential Privacy
- Local Differential Privacy
- Distributed Differential Privacy
- Variant Differential Privacy
- The Combinationof Differential Privacy and OtherMethods