

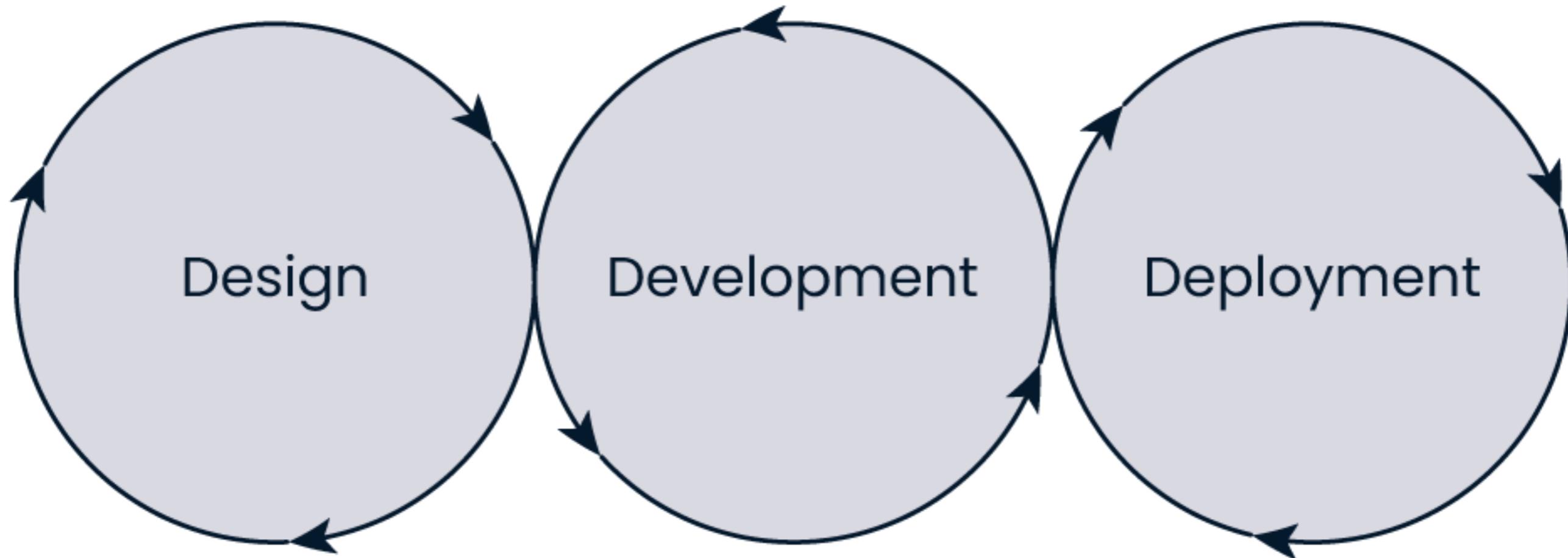
# Monitoring machine learning models

MLOPS CONCEPTS



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ML Engineer

# Monitoring & retraining

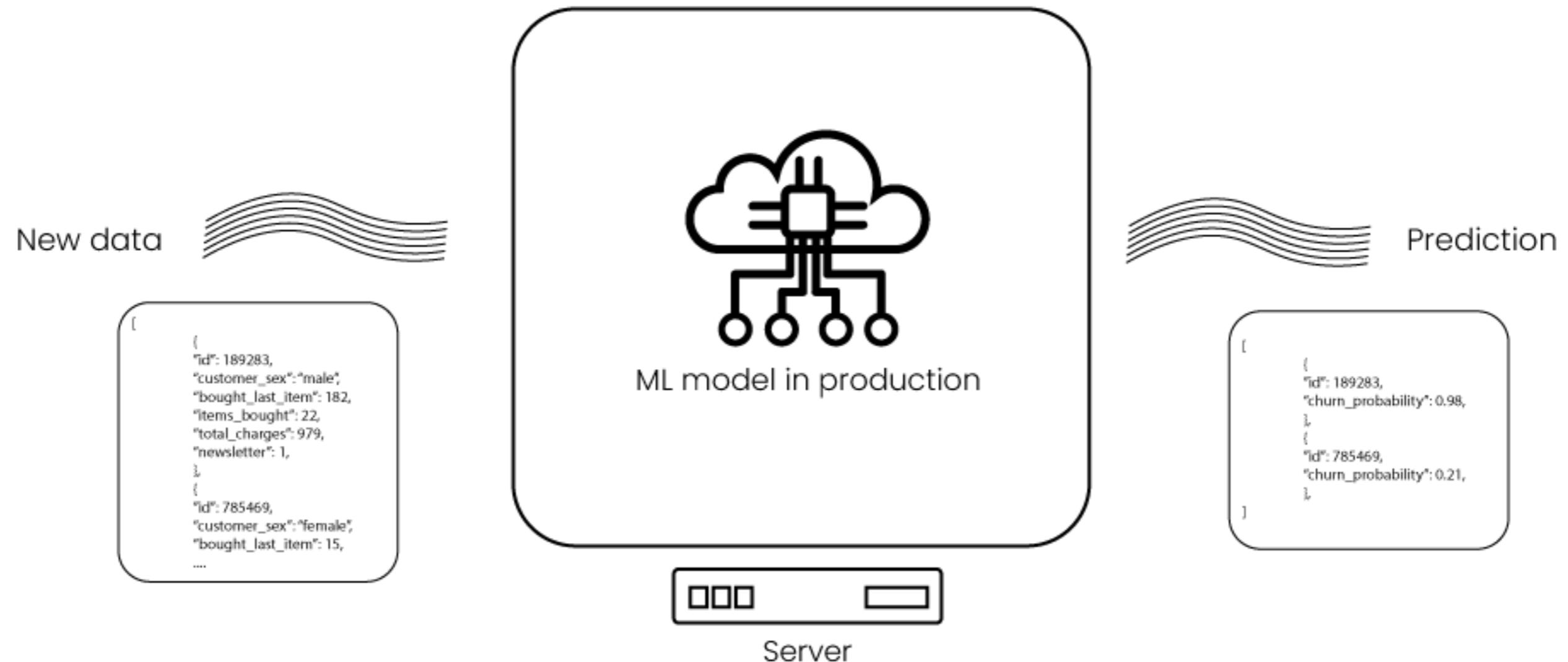


- Added value
- Business requirements
- Key metrics
- Data processing

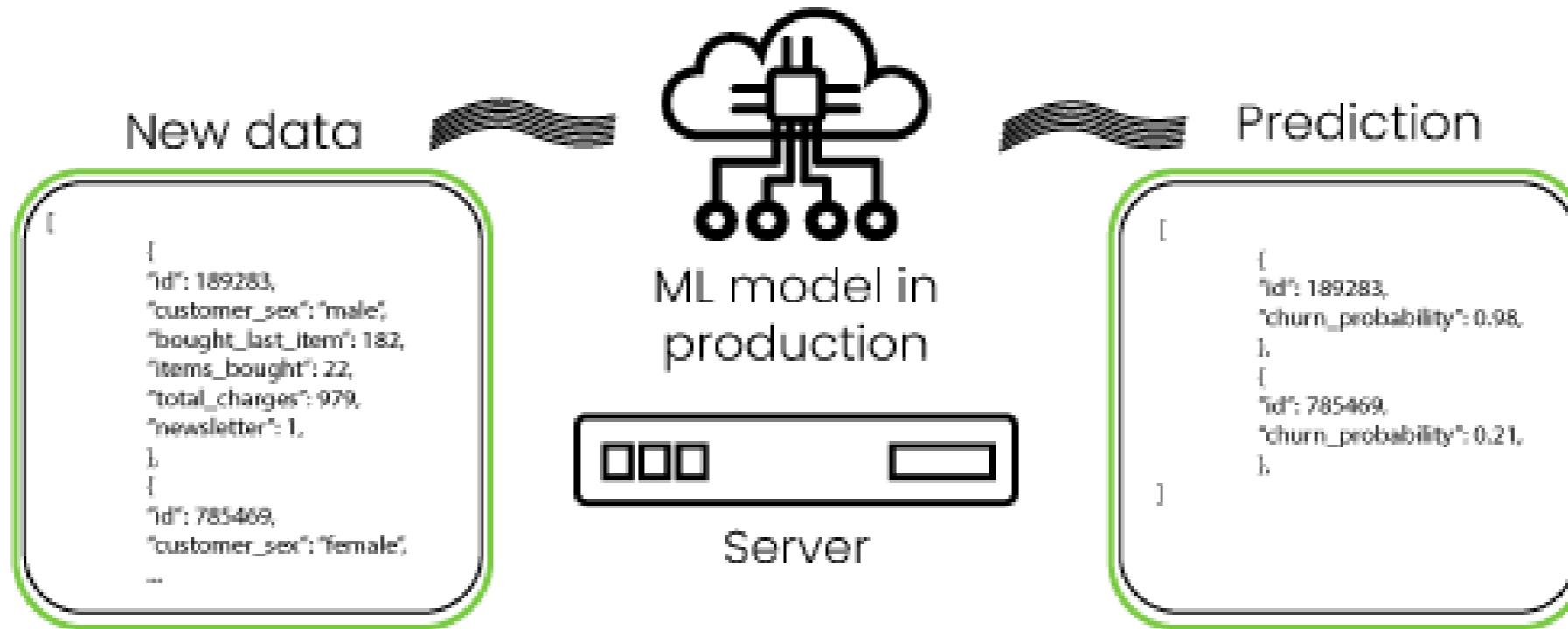
- Feature engineering
- Experiment tracking
- Model training & evaluation

- Runtime environments
- Microservices architecture
- CI/CD pipeline
- Monitoring & retraining

# Monitoring



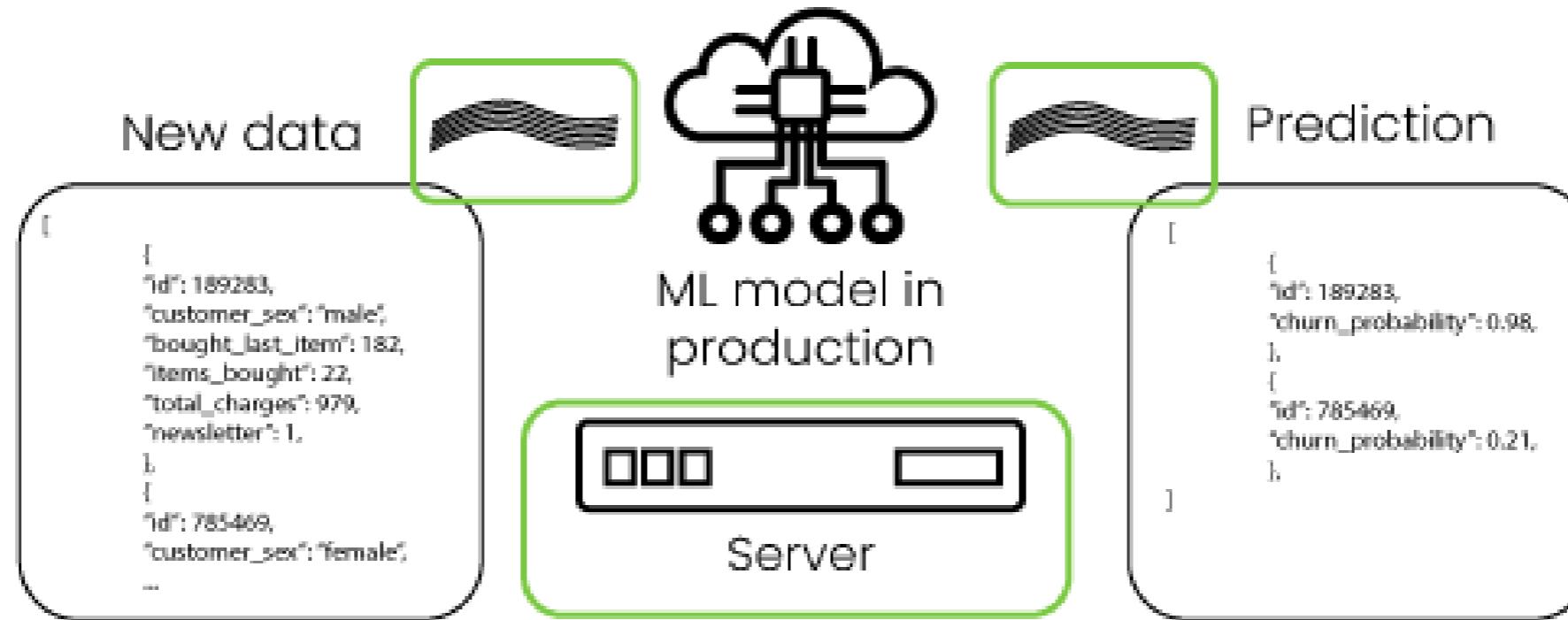
# Types of monitoring



**Statistical monitoring:** focuses on the input and output data, including predictions

*Examples:* customer X has a 72% probability of churning, customer Y has a 31% probability of not churning

# Types of monitoring



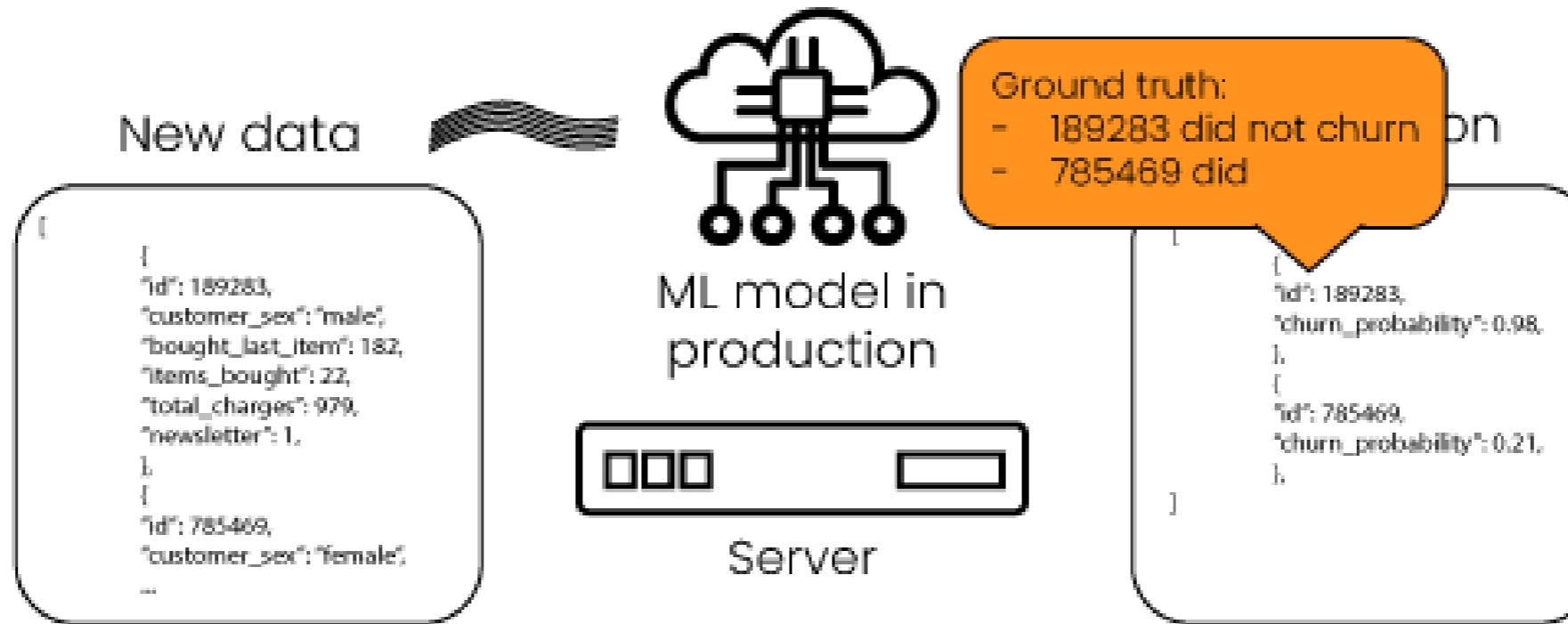
**Computational monitoring:** focuses on technical metrics

*Examples:* server CPU usage, number of incoming requests, number of predictions, downtime of server

# Statistical and computational monitoring

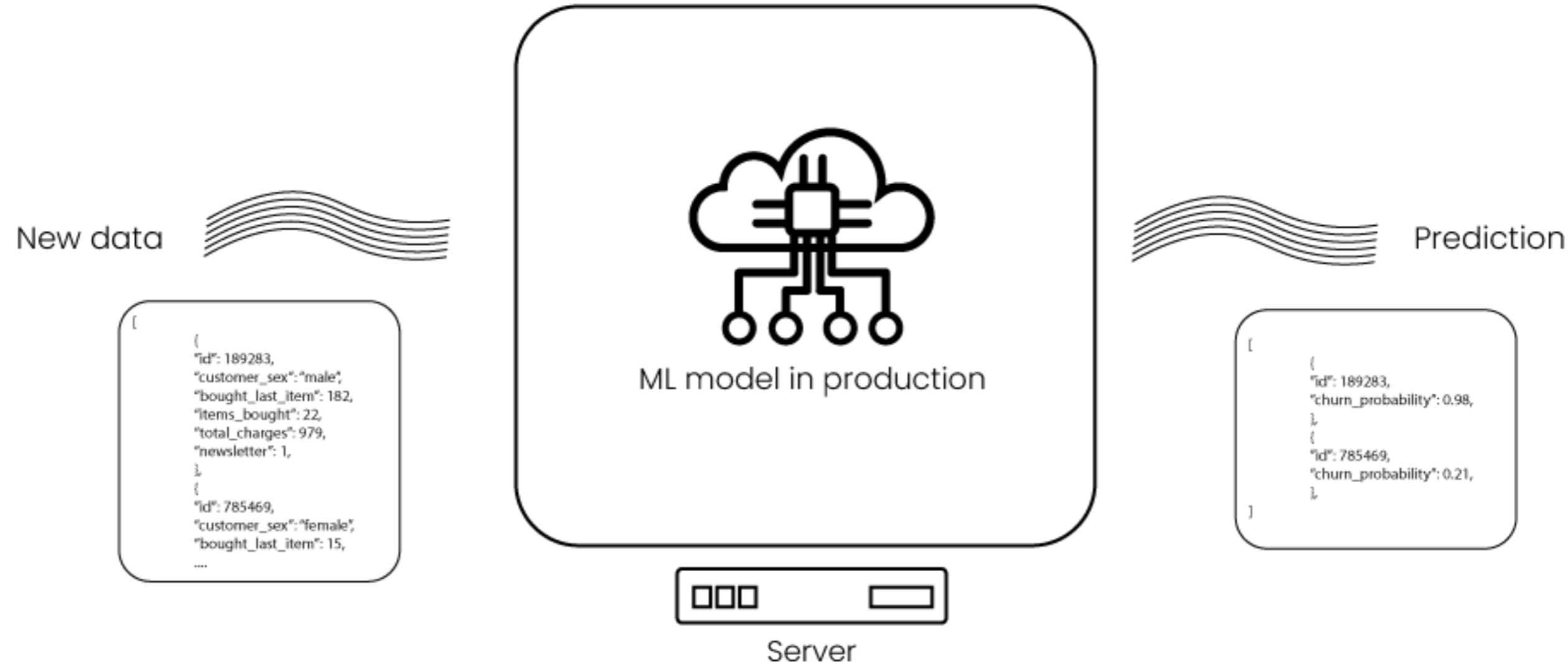


# Feedback loop



**Feedback loop:** the process through which the ground truth is used to improve the machine learning model

# Monitoring in production



# Let's practice!

MLOPS CONCEPTS

# Retraining a machine learning model

MLOPS CONCEPTS



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ML Engineer

# Retraining after changes

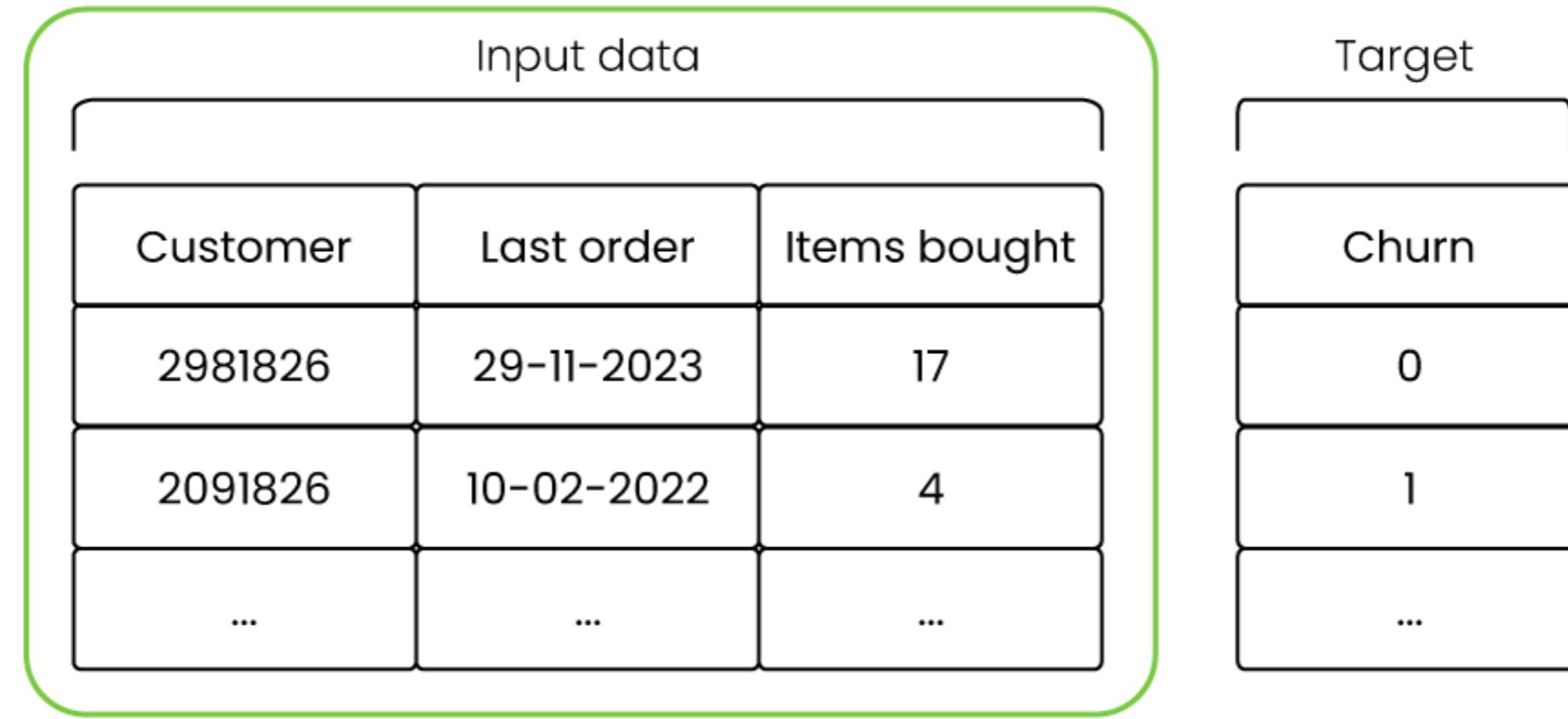


**Retraining:** use new data to develop a fresh version of the machine learning model

# Drift in data

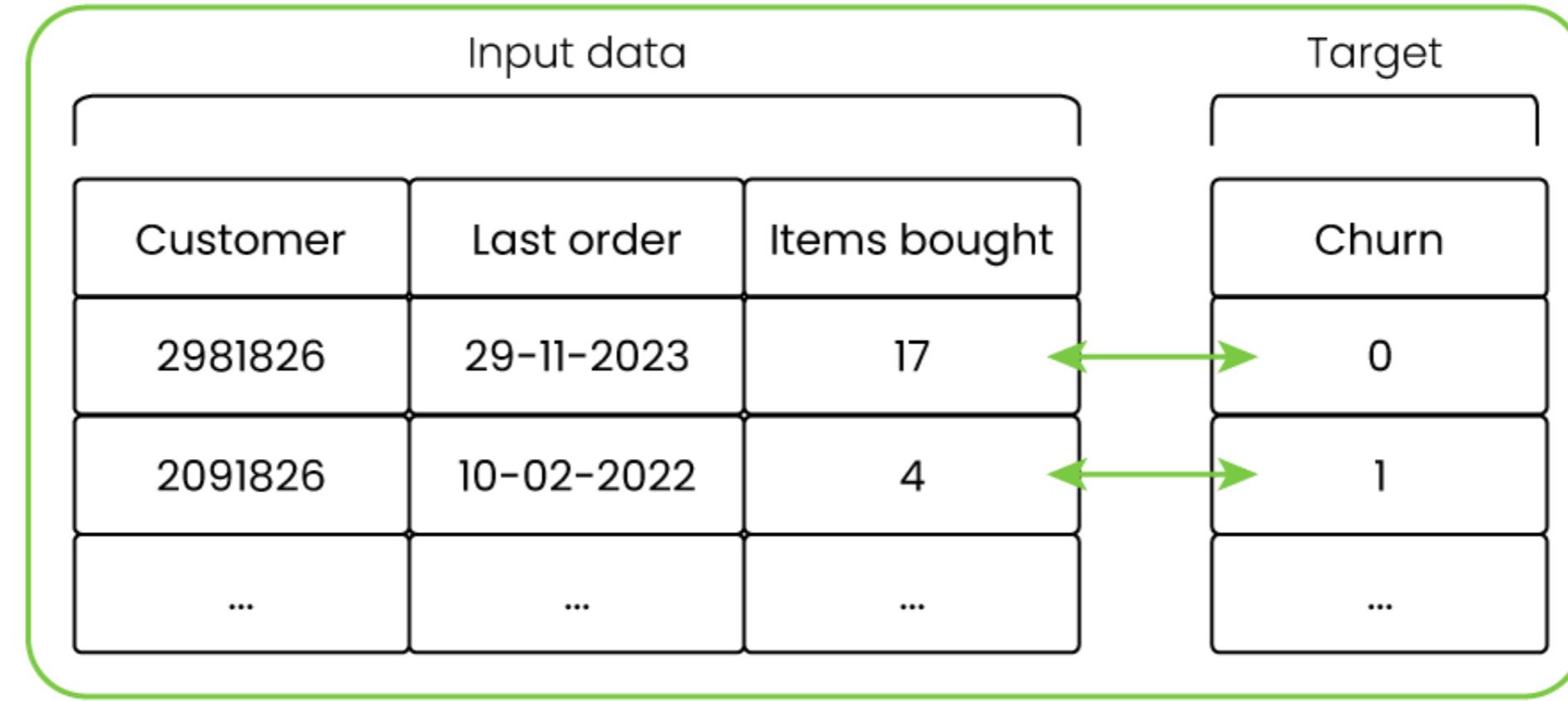
Input data			Target
Customer	Last order	Items bought	Churn
2981826	29-11-2023	17	0
2091826	10-02-2022	4	1
...	...	...	...

# Data drift



**Data drift:** changes in the input data

# Concept drift



**Concept drift:** changes in the relationship between input and output data

# How often to retrain?

- **Business environment:** how volatile is the data?
- **Cost:** how much does it cost to retrain?
- **Business requirements:** what is the required model performance?

# Retraining methods

Old data

Customer	Last order	Items bought
2981826	29-11-2023	17
2091826	10-02-2022	4
...	...	...

Churn
0
1
...



New data

Customer	Last order	Items bought
3029712	12-01-2024	17
4900298	18-04-2024	81
...	...	...

Churn
1
0
...



# Retraining methods

Old data

Customer	Last order	Items bought
2981826	29-11-2023	17
2091826	10-02-2022	4
...	...	...

New data

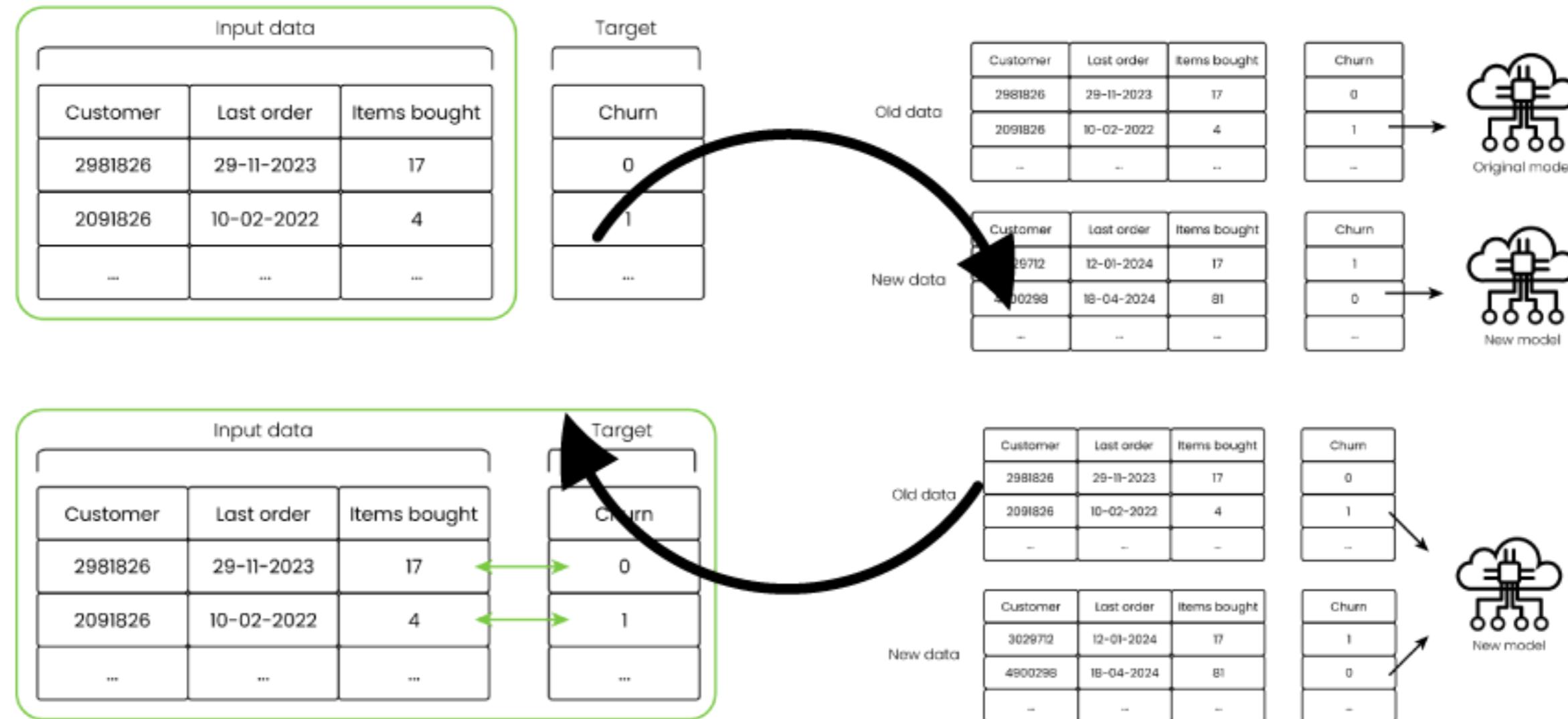
Customer	Last order	Items bought
3029712	12-01-2024	17
4900298	18-04-2024	81
...	...	...

Churn
0
1
...

Churn
1
0
...



# Automatic retraining



# Let's practice!

MLOPS CONCEPTS

# Levels of MLOps maturity

MLOPS CONCEPTS

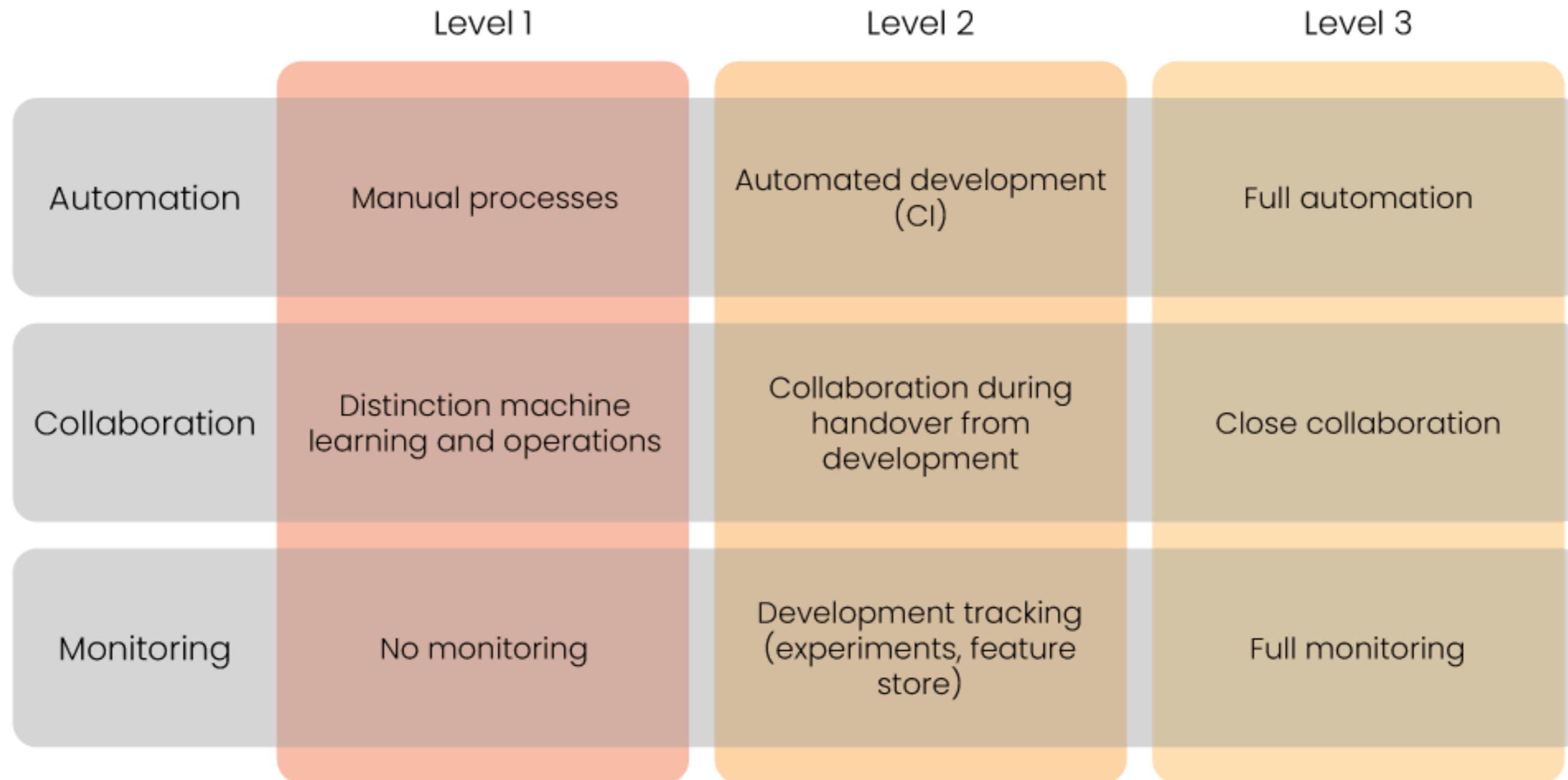


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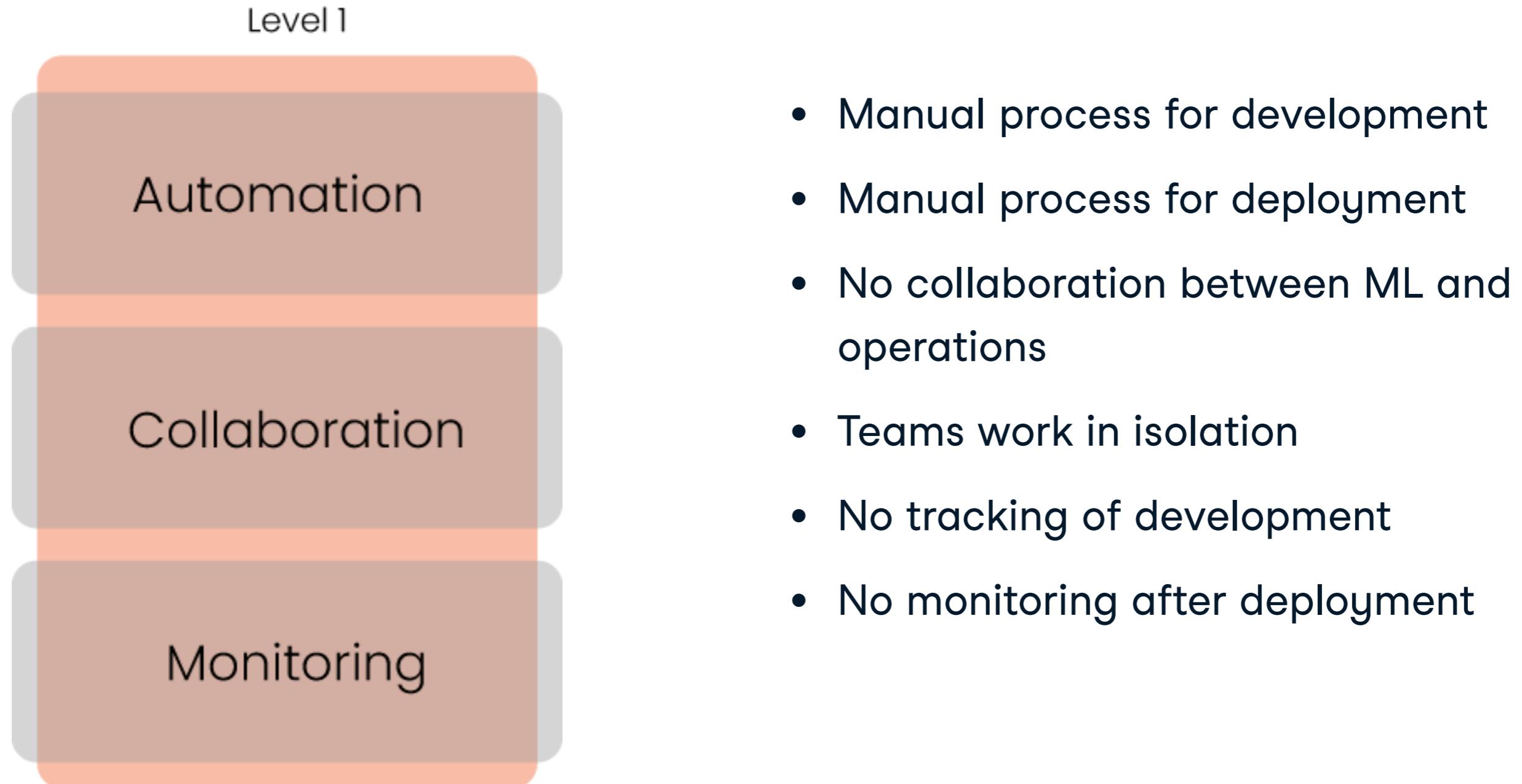
# MLOps maturity

- Level of **automation, collaboration, and monitoring** within MLOps processes
- Higher level is not necessarily better
- Focus on development and deployment phase

# Levels of MLOps maturity

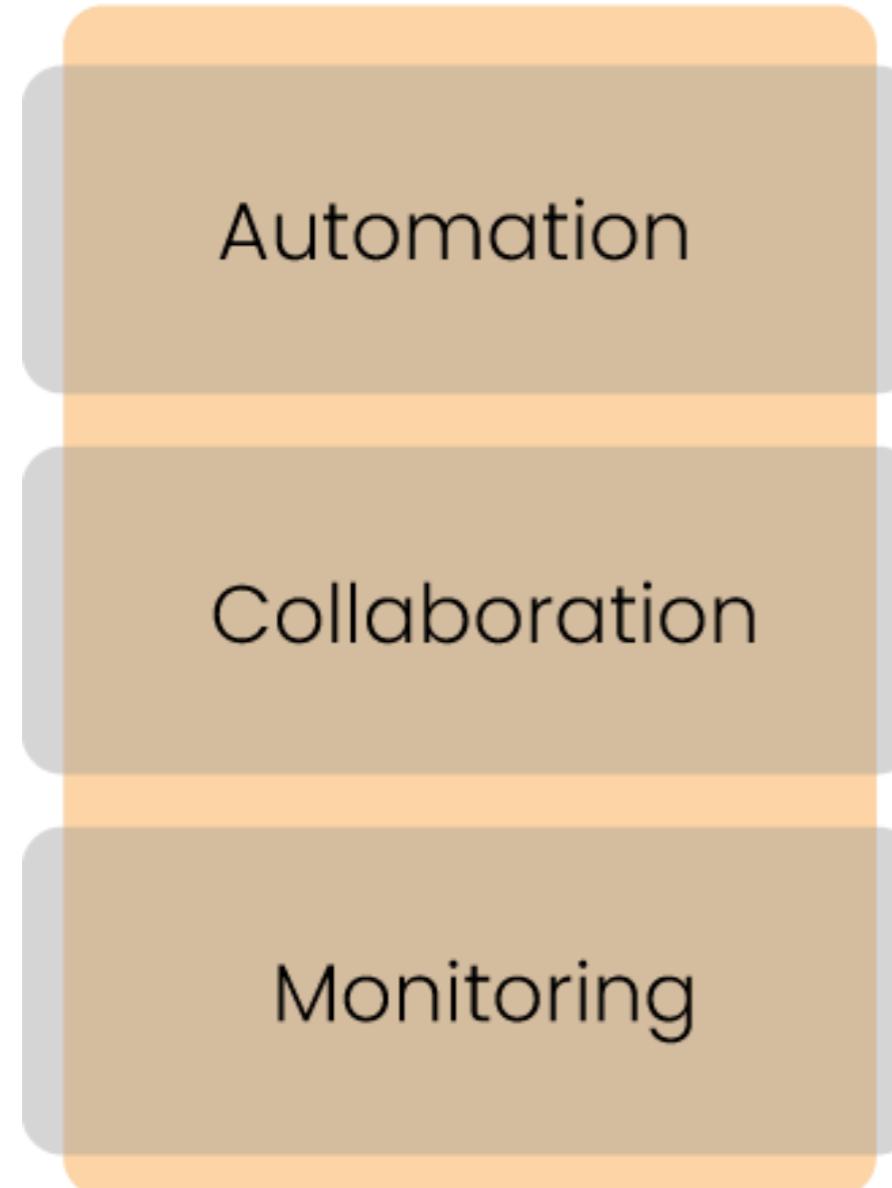


# Level 1: Manual processes



# Level 2: Automated development

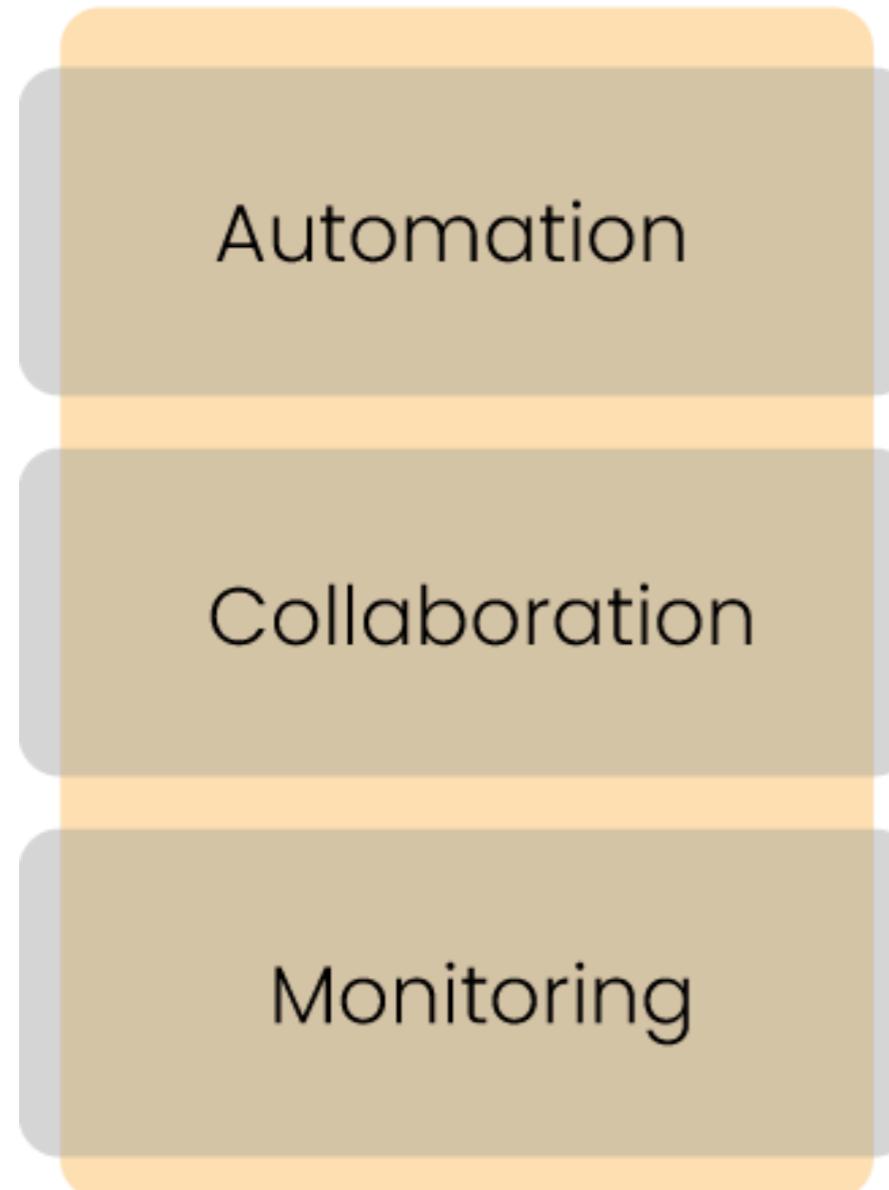
Level 2



- Automated development pipeline (Continuous integration)
- Manual process for deployment
- After development teams will collaborate to deploy model
- Tracking of ML experiments and features
- Little monitoring after deployment

# Level 3: Automated development and deployment

Level 3



- Automated development pipeline (CI)
- Automated deployment pipeline (CD)
- Close collaboration between teams
- Monitoring of development and deployment
- Potentially automatically triggering retraining

# Let's practice!

MLOPS CONCEPTS

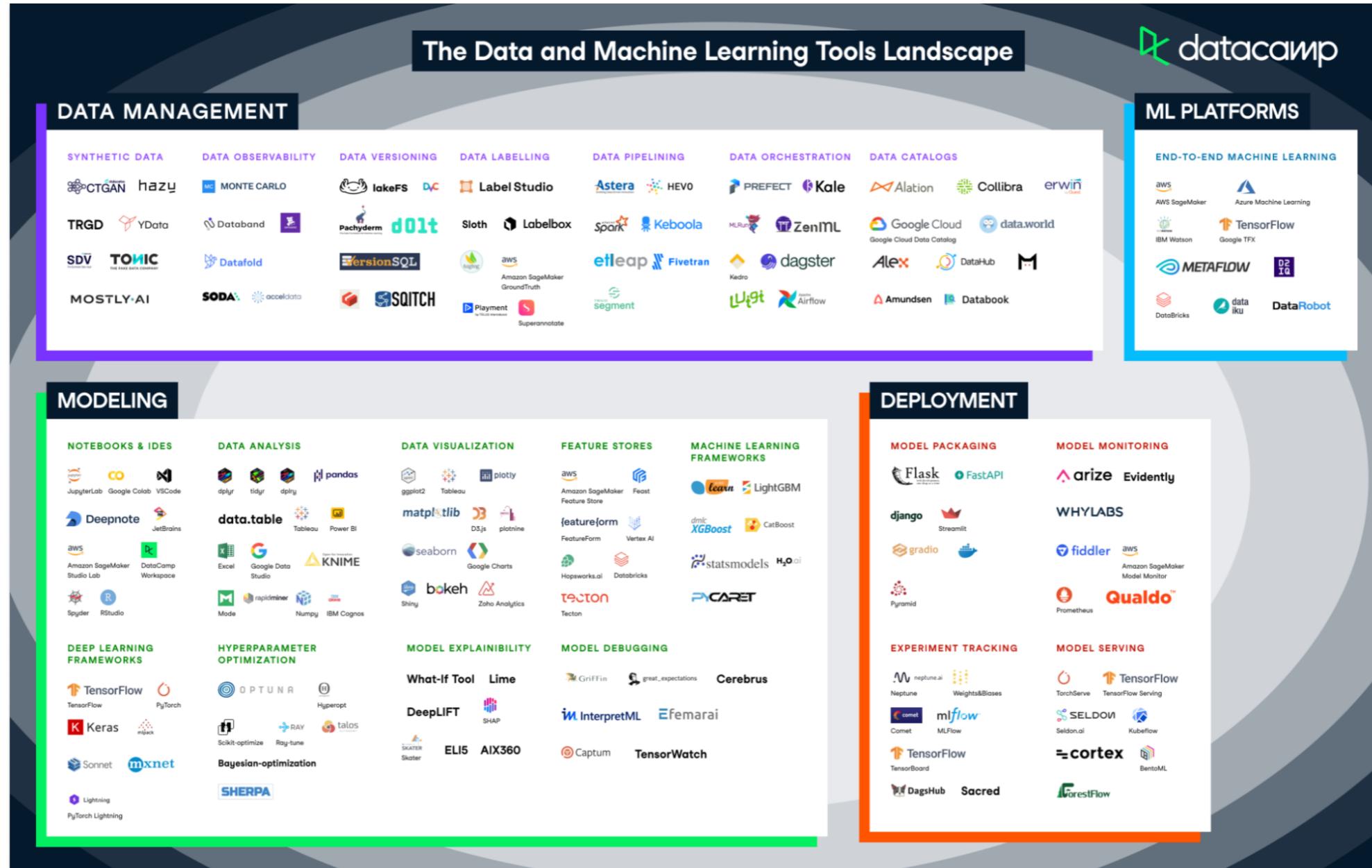
# MLOps tools

## MLOPS CONCEPTS



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# MLOps tools



<sup>1</sup> <https://www.datacamp.com/blog/infographic-data-and-machine-learning-tools-landscape>

# Feature store

- Both open-source
- **Feast**: self-managed
- **Hopsworks**: part of larger platform



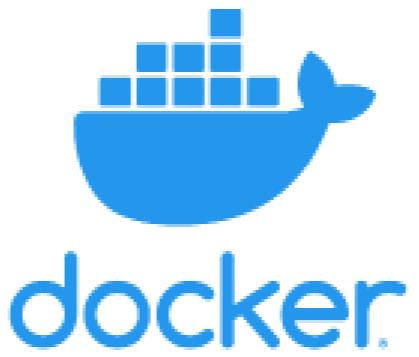
# Experiment tracking

- **MLFlow and ClearML:** full machine learning lifecycle tools
- **Weights and Biases:** tracking and visualizing experiments



# Containerization

- **Docker:** containerizing applications
- **Kubernetes:** running containerized applications
- **Cloud providers:** provides Kubernetes-like services



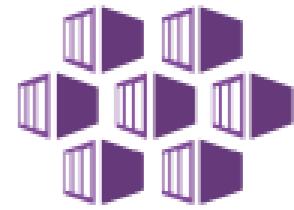
docker



kubernetes



Amazon EKS



Azure Kubernetes Service (AKS)



Google Kubernetes Engine

# CI/CD pipeline

- **Jenkins:** open-source continuous integration tool
- **GitLab:** code sharing and version control through repositories



**Jenkins**



**GitLab**

# Monitoring

- **Fiddler:** machine learning model monitoring
- **Great expectations:** data monitoring



great\_expectations

# MLOps platforms

Tools for full machine learning lifecycle

- AWS Sagemaker
- Azure Machine Learning
- Google Cloud AI platform



Amazon  
SageMaker



Azure Machine Learning



Google Cloud Platform

# Let's practice!

MLOPS CONCEPTS

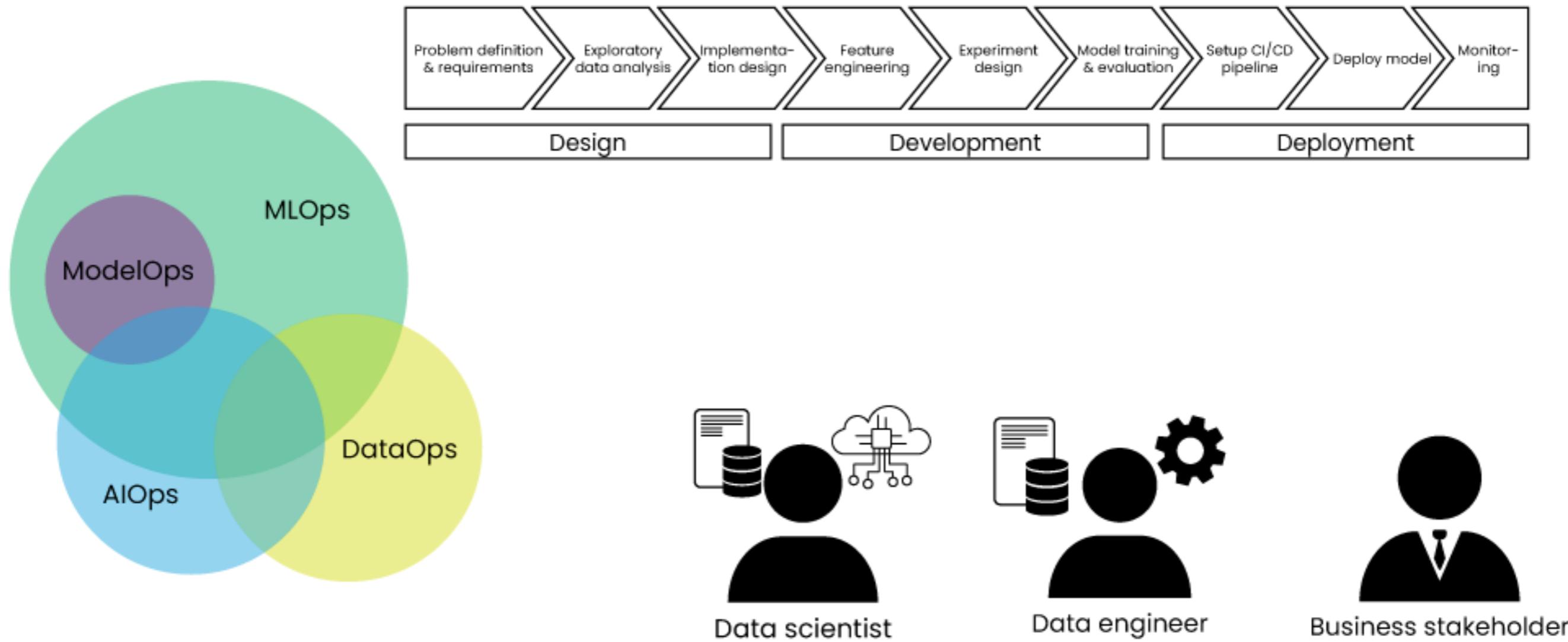
# Recap: MLOps concepts

MLOPS CONCEPTS

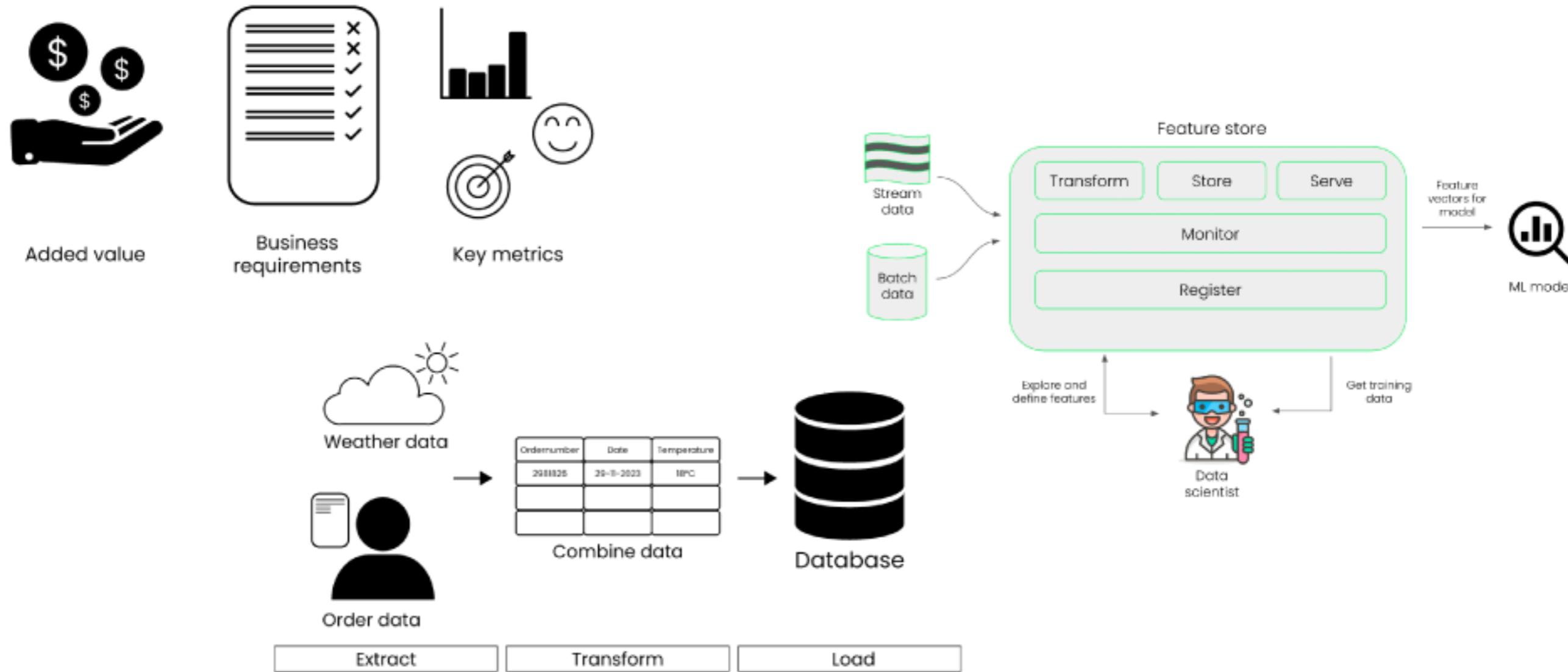


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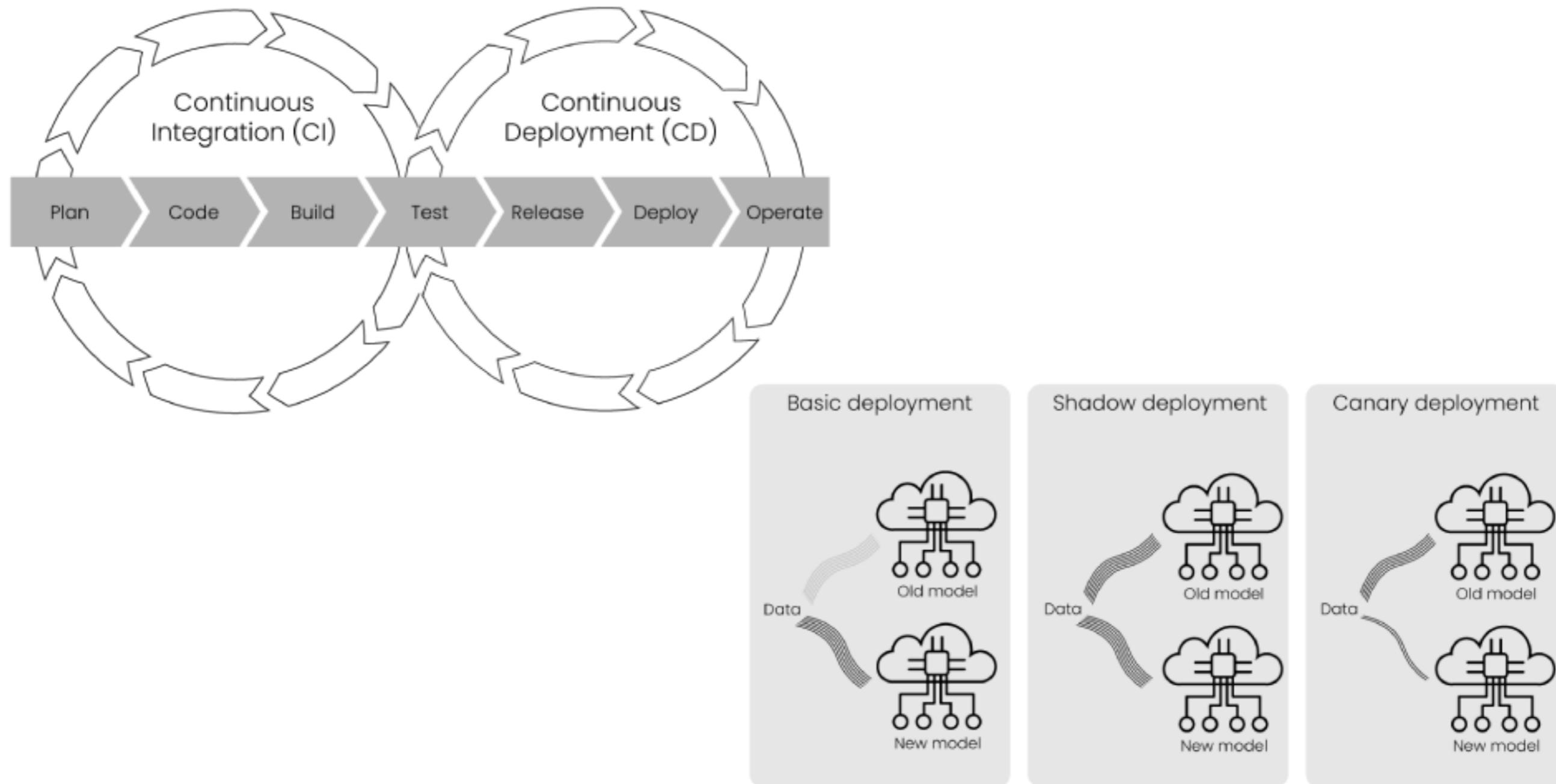
# What is MLOps?



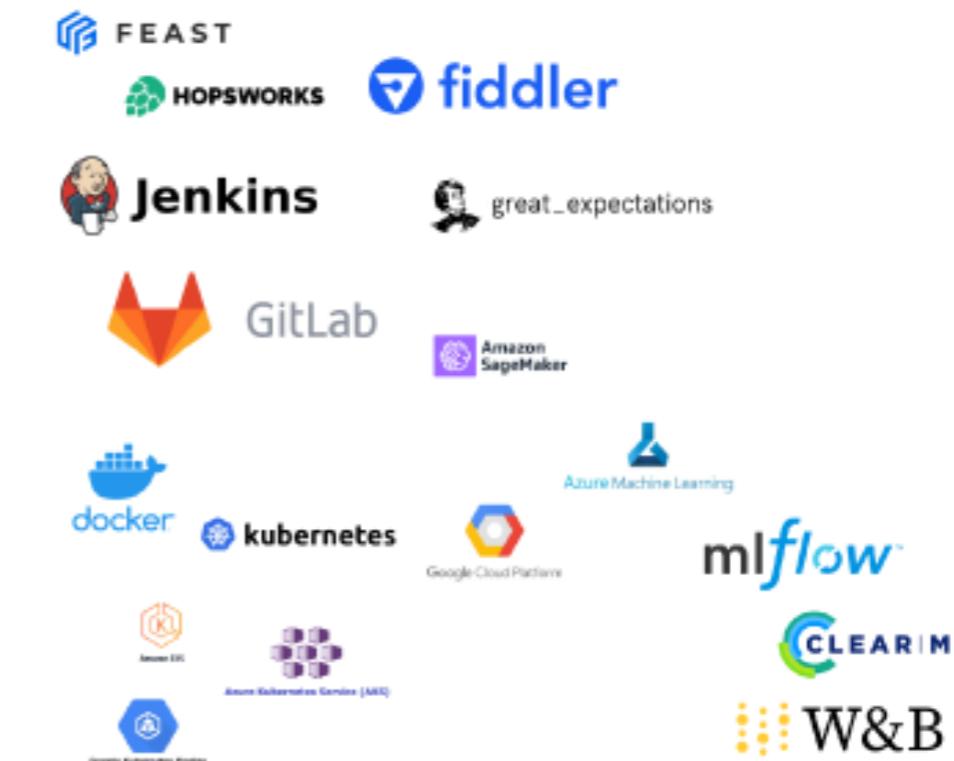
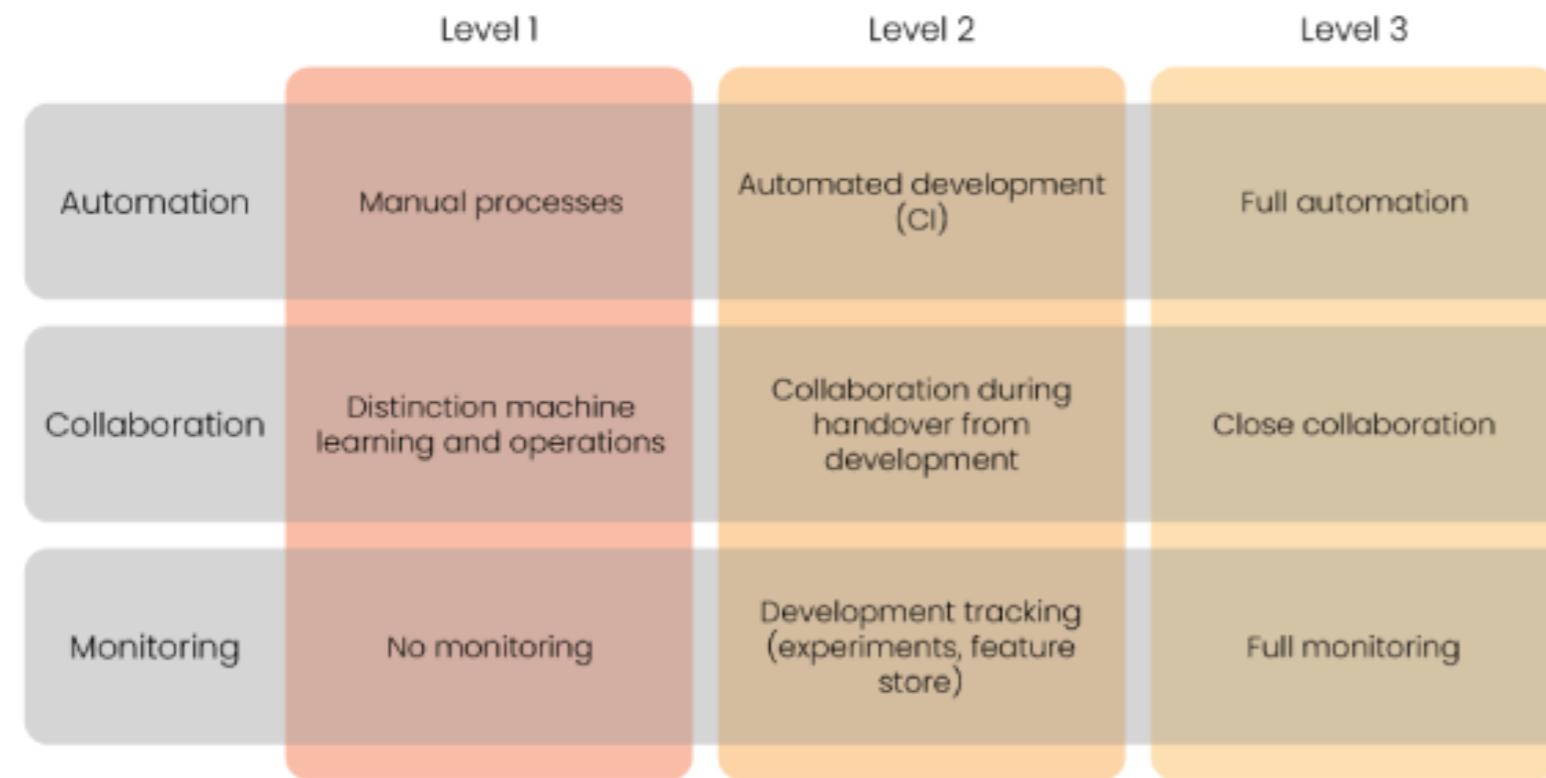
# Design and development



# Deployment



# Maintaining machine learning



# Congratulations!

MLOPS CONCEPTS