

# Production: Introduction to ML Systems

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# Introduction

# Agenda

- 1.1 Overview of ML Systems
  - When to Use ML
  - ML in Production
  - ML vs Traditional Software
- 1.2 Introduction to ML System Design
  - Business and ML Objectives
  - Requirements of Data-Driven Products
  - Iterative Process
  - Framing ML Problems

# Agenda

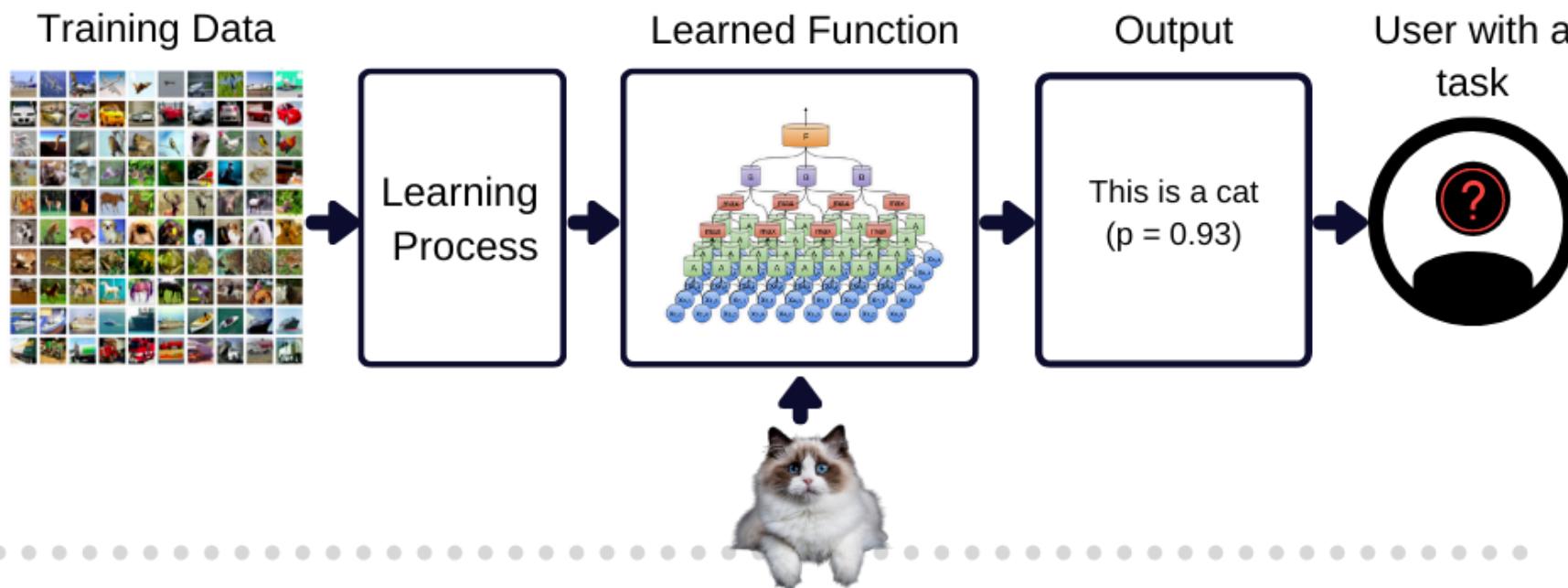
- **1.3 Project Setup**
  - Introduction.
  - Repo File Structure.
  - Git, authorization, and production pipelines.
  - VS Code and Git.
  - Python virtual environments.
  - Branching Strategies.
  - Commit Messages.

# About

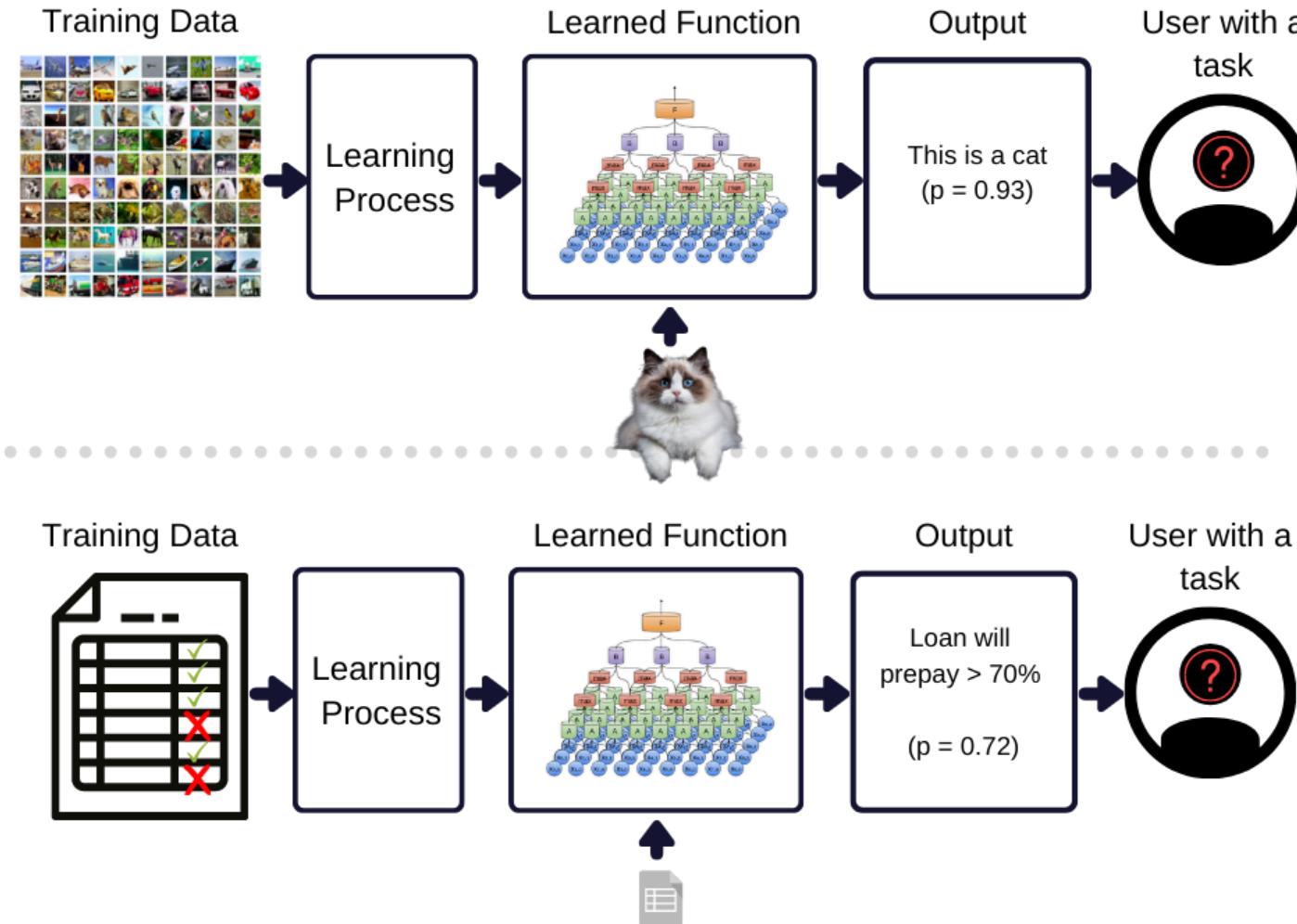
- These notes are based on Chapters 1 and 2 of *Designing Machine Learning Systems*, by Chip Huyen.

# Machine Learning

# ML: An Illustration



# ML: An Illustration



# What is Machine Learning (ML)?

"A computer program is said to learn from experience  $E$  with respect to some class of tasks  $T$  and performance measure  $P$ , if its performance at tasks in  $T$ , as measured by  $P$ , improves with experience  $E$ ." (Mitchel, 1997)

"Machine learning is an approach to (1) learn (2) complex patterns from (3) existing data and use these patterns to make (4) predictions on (5) unseen data."  
(Huyen, 2022)

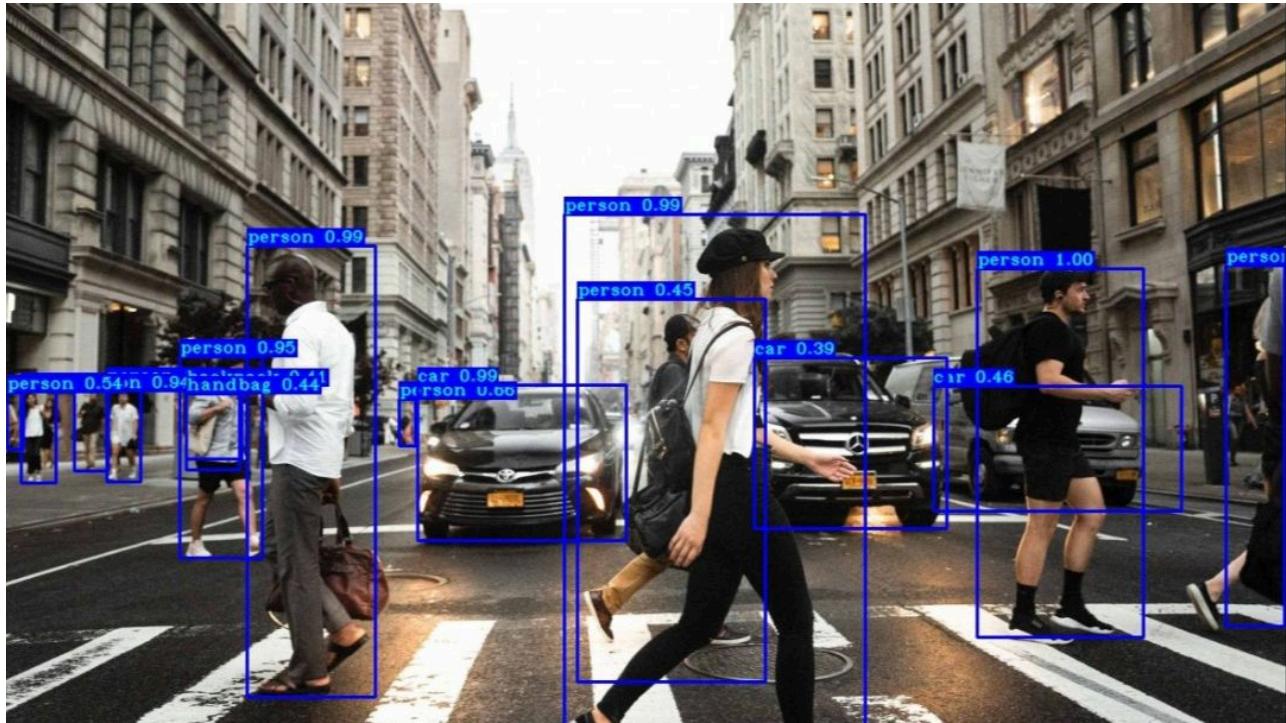
# What is Machine Learning (ML)?

ML is a collection of methods that allow a computer to:

- **Learn autonomously** to perform a task based on a set of examples and without being explicitly programmed to perform the task.
- **Gain from experience** such that the method performs better in the measure that it observes additional examples.
- **Generalize results** beyond the data used for training the method.

# Why Use Machine Learning?

- ML is used when a task is too complex or impractical to program explicitly.
- When applied successfully, ML will enable
  - Greater scale: automation.
  - Better performance.
  - Doing things that were not possible before.
- [\(Image Source\)](#)



# When to Use ML?

- A business problem is not the same as an ML problem.
  - Generally, a business will be concerned with profit maximization (directly or indirectly): increasing sales, cutting costs, enhancing customer satisfaction, reducing churn, increasing time on the website, etc.
    - The objective of an ML method is to enhance the performance of the task, given more data.
    - Optimising ML performance metrics does not automatically translate to optimizing business performance.
- Some of the most popular business applications of ML are in areas where business and ML performance overlap: fraud detection, recommender systems, etc.

# ML System Design

# Characteristics of ML Use Cases (1/4)

## Learning is involved

- The system can learn autonomously.
- Given a series of inputs, the system learns how to produce outputs.
- Not every ML model can learn any hypothesis; more complex models will tend to be more flexible.

## Complex patterns

- There are patterns to learn, and they are complex.
- ML solutions are only helpful if there are patterns.
- An ML model can learn simple patterns, but the cost of applying ML may be unreasonable.

## Characteristics of ML Use Cases (2/4)

### Existing data

- Data is available, or it is possible to collect data.
- Out-of-domain predictions may fail because of a lack of training data.
- Online (real-time) learning systems could be deployed and trained using production data.

### Predictions

- ML algorithms will generate predictions. Therefore, the problem to solve should be predictive.
- A prediction could be about a future event (forecast) or an event that is difficult to observe (e.g., fraud detection or clustering).

# Characteristics of ML Use Cases (3/4)

## Unseen data

- Unseen data shares patterns with the training data.
- The learning method generalizes reasonably well on testing data.

## It is repetitive

- ML algorithms perform better with experience: repetitive tasks afford such experience.

## The cost of incorrect predictions is low

- Achieving perfect performance may not be possible.
- Human-level performance or better could be achieved.

## Characteristics of ML Use Cases (4/4)

### It is at scale

- Upfront costs are involved: infrastructure, staff, DevOps.
- Setting up an ML system that caters to many ML models concurrently.

### Patterns are constantly changing

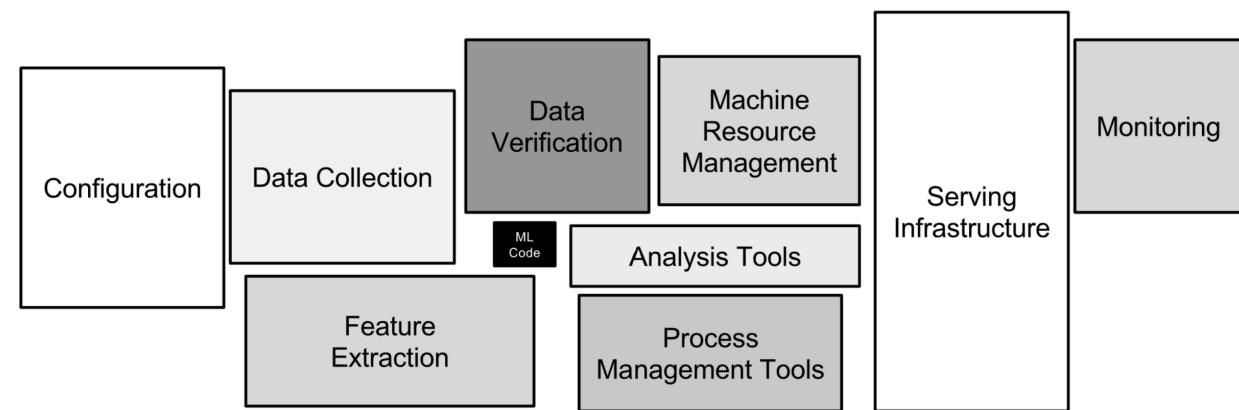
- Hard-coded solutions can become stale and outdated.
- The ML system's environment changes: economics, social behaviour, trends, etc.
- Feedback: the ML system informs a company's actions, affecting, in turn, the company's interactions with the external environment.

# ML Systems Design

- ML methods are not ML systems: the learning method needs to be applied to data, assessed, tuned, deployed, governed, and so on.
- ML system design is a system approach to MLOps, i.e., we will consider the system holistically, including
  - Business requirements.
  - Data stack.
  - Infrastructure.
  - Deployment.
  - Monitoring.

# ML Systems Design

- MLOps: a set of tools and best practices for bringing ML into production.
- Image: (Sculley, 2015)



# How is ML in Production Different?

# ML in Research vs Production

Dimension	Research	Production
Requirements	State-of-the-art model performance on benchmark datasets	Different stakeholders have different requirements
Computational priority	Fast training, high throughput	Fast inference, low latency
Data	Static	Constantly shifting
Fairness	Often not a focus	Must be considered
Interpretability	Often not a focus	Must be considered

## Business and ML Objectives (1/5)

Different stakeholders require different things

- ML engineers: increase performance or efficiency of recommender system.
- Sales: recommend more profitable options.
- Product: reduce latency.
- Platform: stability.
- Manager: control costs.

## Business and ML Objectives (2/5)

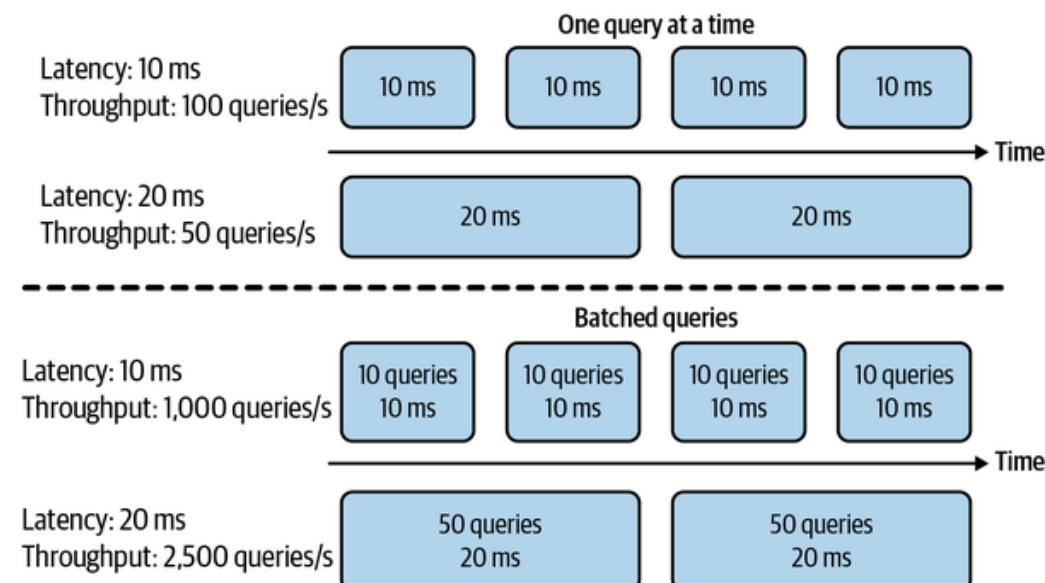
### Computational priorities during model development

- Training is the bottleneck.
- Throughput, the number of cases processed, should be maximized.

# Business and ML Objectives (3/5)

## Computational priorities in production

- Fast inference is desirable.
- Latency, the time between when a query is received and when it is addressed, should be minimized.
- Latency is usually measured using percentiles of time elapsed (e.g., 99th percentile should be below X ms.)



## Business and ML Objectives (4/5)

### Data

- Data quality.
- Historical vs constantly generated data.

### Fairness

- Fair and ethical decision-making is a key requirement.
- ML algorithms make predictions based on encodings of past observations: they can perpetuate the biases in the data and more.

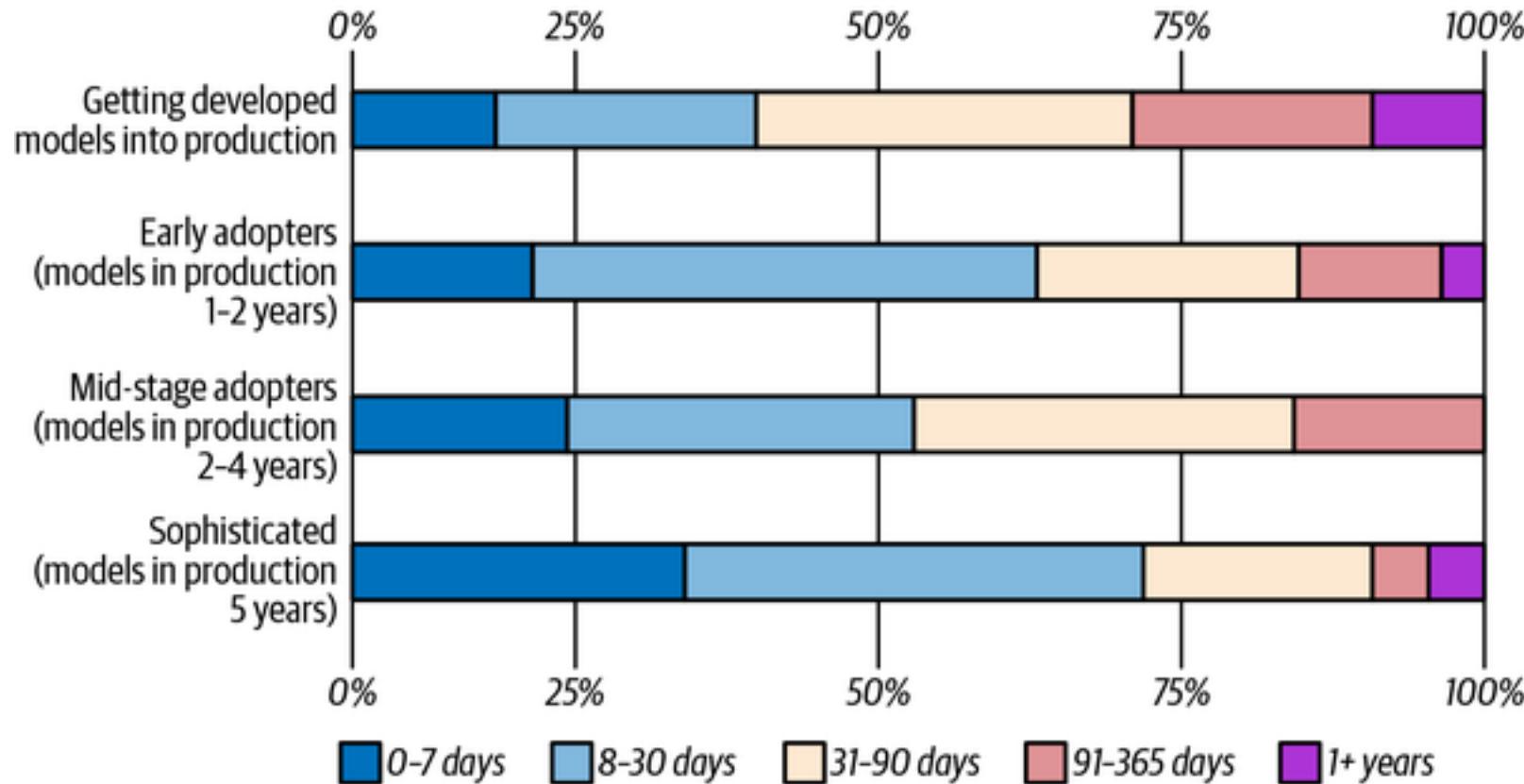
## Business and ML Objectives (5/5)

### Explainability

- Trust.
- Legal requirements.
- Informativeness: Besides predictions, we require feature importance and other information about our results.
- Transferrability: Can learning from a scenario be applied to other scenarios?

# Requirements of ML Systems

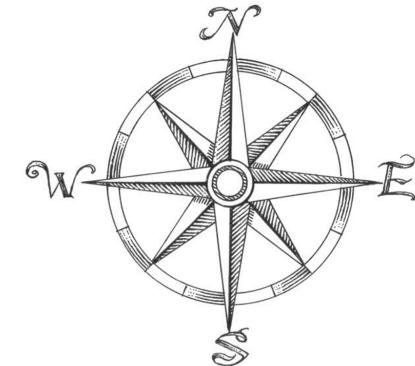
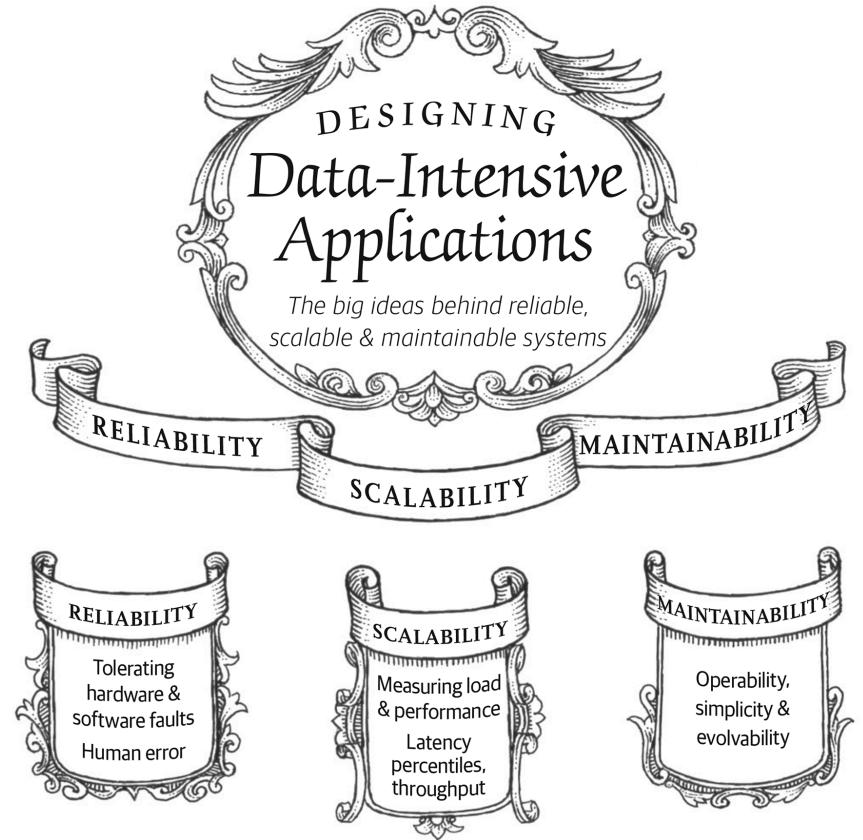
# Lead Time to Production



(Huyen, 2022)

# Designing Data-Intensive Applications

- Many applications today are data-intensive instead of compute-intensive.
  - The limit factor is data and not computation.
  - Concerns: the amount of data, the complexity of data, and the speed at which it changes.
- ML Systems tend to be embedded in data-intensive applications.
- (Kleppmann, 2017)



# Fundamental Requirements of ML Systems (1/2)

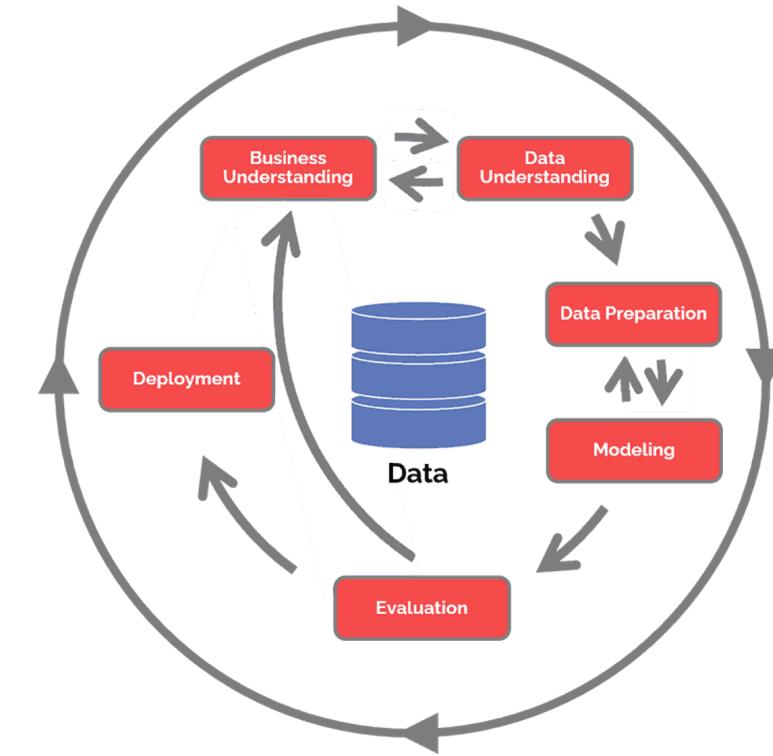
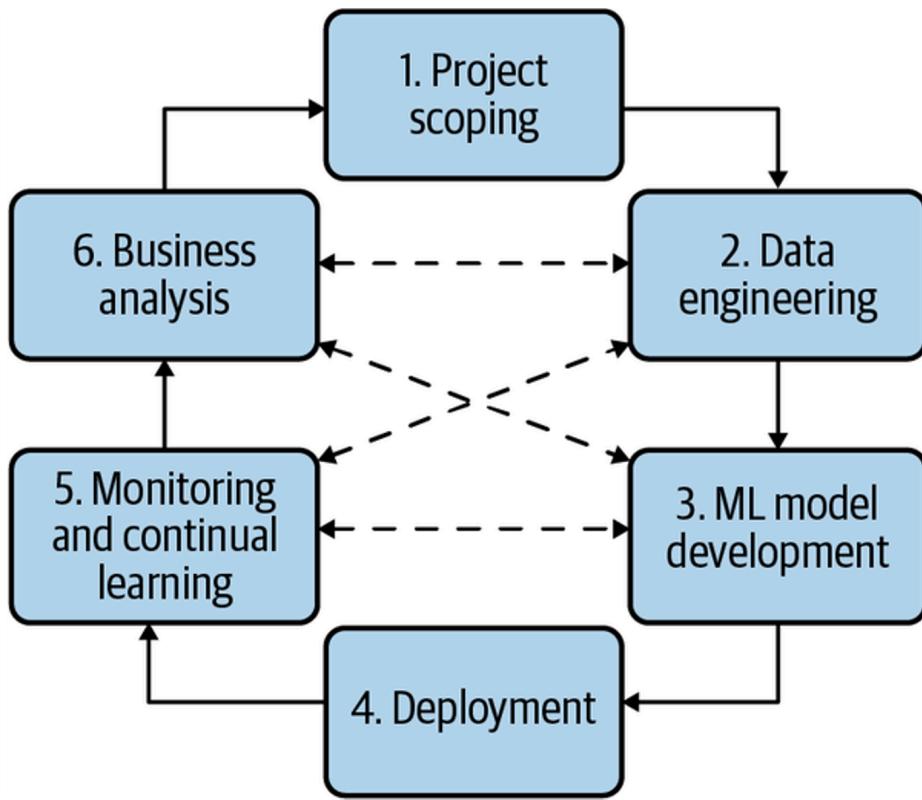
- **Reliability:** The system should continue to perform the correct function at the desired level of performance, even in the face of adversity.
  - May require reporting uncertainty of results.
    - Remove "silent failures": The system should alert the users to unexpected conditions.
    - If all else fails, shut down gracefully (e.g., close connections, log errors, alert downstream processes, etc.)
- **Scalability:** To ensure the possibility of growth.
  - Increase complexity.
  - Traffic volume or throughput.
  - Model count.

## Fundamental Requirements of ML Systems (2/2)

- **Maintainability:** To allow different contributors to work productively on the same system.
  - Maintain existing capacities.
  - Expand to new use cases.
- **Adaptability:** To shifting data distributions and business requirements.
  - The system should allow for the discovery of aspects for performance improvements.
  - Allow updates without service interruptions.

# ML System Design: An Iterative Process

# Developing ML Systems



Have things changed that much? (Huyen, 2022) and [CRISP-DM \(c. 1999\)](#)

# Framing ML Problems

- The output of an ML model dictates the type of ML problem.
- In general, there are two types of ML tasks
  - Classification.
  - Regression.
- A regression model can be framed as a classification model and vice versa.
  - Regression to classification: apply quantization.
  - Classification to regression: predict the likelihood of class.

# Framing ML Problems (1/2)

## Binary Classification

- Two classes.
- Simplest classification problems

## Multiclass Classification

- More than two (mutually exclusive) classes.
- High cardinality (number of classes) problems will be more complex than low cardinality problems.
- High cardinality can be addressed with a hierarchical classification approach: first, classify into large groups, then classify into specific labels.

## Framing ML Problems (2/2)

### Multilabel Classification

- An observation can have more than one label.
- One approach is to treat the problem as multiclass by creating unique labels out of combinations of individual labels.
- Another approach is one-vs-rest, where each label is treated with a different binary classification model.

## Objective Functions (1/2)

- ML requires an objective function to guide the learning process through optimization.
- In the context of ML:
  - Regression tasks generally employ error or accuracy metrics: Root Mean Square Error (RMSE) or Mean Absolute Error (MAE).
  - Classification tasks are generally performed using log loss or cross-entropy.

## Objective Functions (2/2)

- Log loss or cross-entropy loss is a performance metric that quantifies the difference between predicted and actual probabilities.
- In a two-class setting, it is given by

$$H(y, p) = -\frac{1}{N} \sum_{i=1}^n (y_i \ln(\hat{p}_i) + (1 - y_i) \ln(1 - \hat{p}_i))$$

- Formulation is related to maximum likelihood: minimizing negative log-likelihood is the "same" as minimizing log loss.

# Objective Functions

- Assume the actual value is 1.
- If the model is confident and correctly predicted 0.9, then

$$\text{Loss} = -(1 * \ln(0.9)) = 0.1054$$

- If the model is unsure and predicts 0.5, then

$$\text{Loss} = -(1 * \ln(0.5)) = 0.6932$$

- If the model is confident but incorrectly predicted 0.1, then

$$\text{Loss} = -(1 * \ln(0.1)) = 2.3026$$

# Our Reference Architecture

# The Flock Reference Architecture

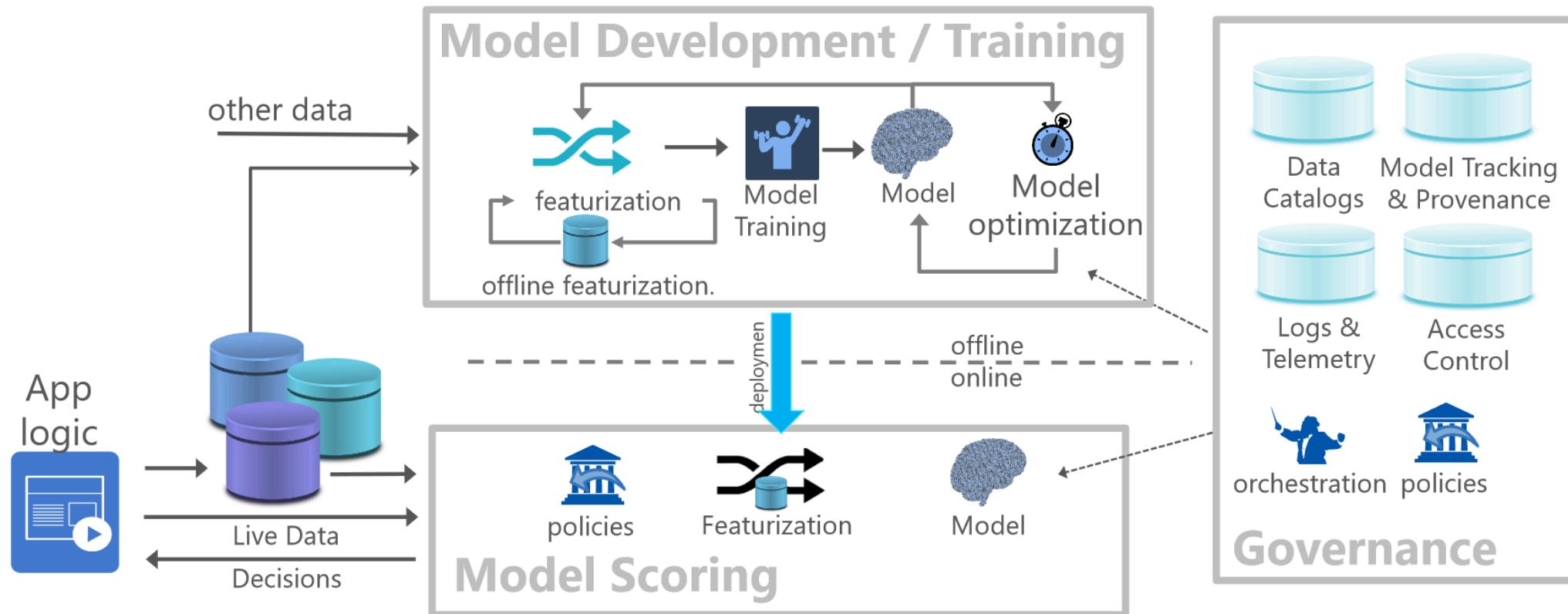


Figure 1: Flock reference architecture for a canonical data science lifecycle.

# References

## References (1/2)

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