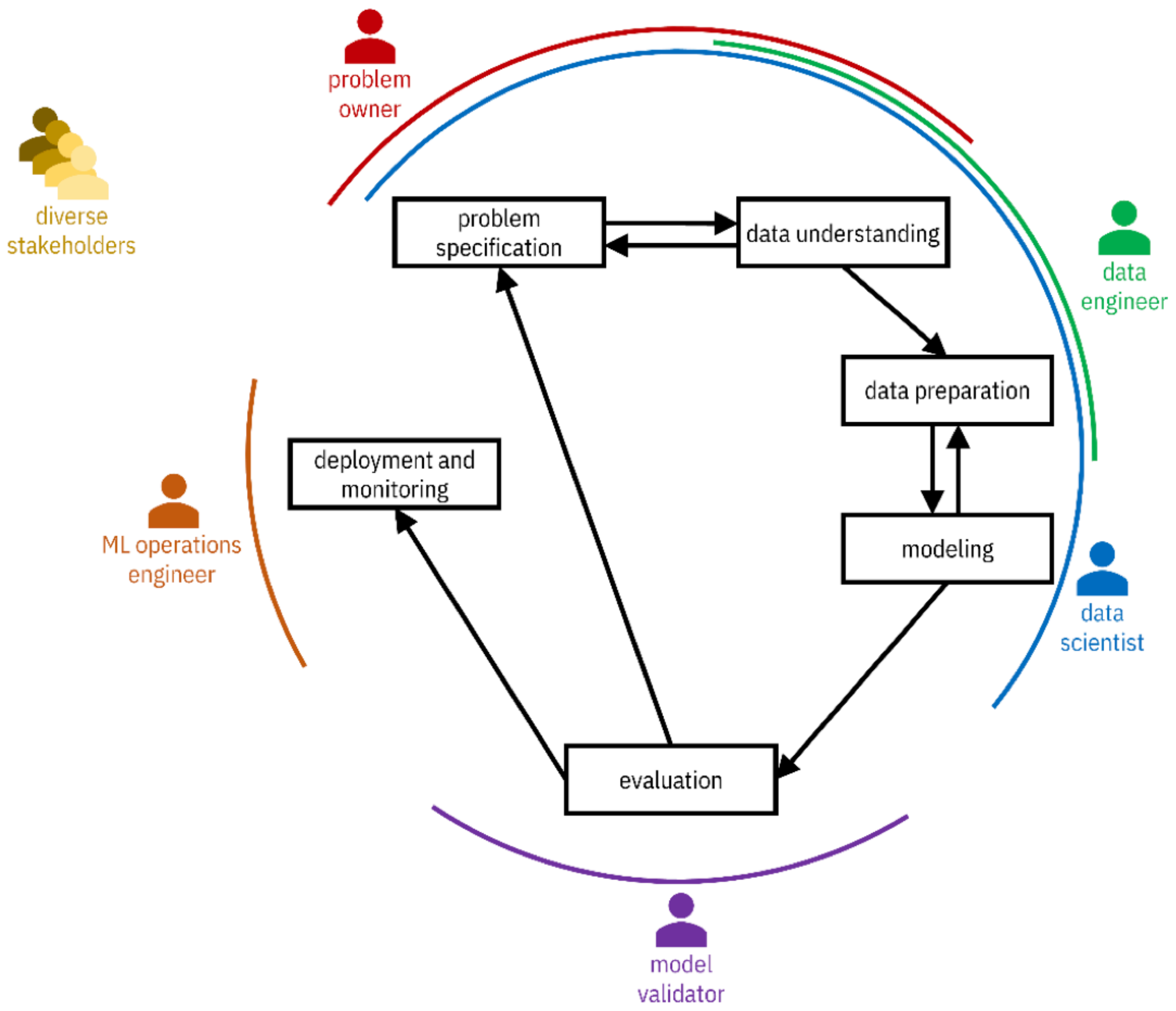
Machine Learning for Design

Lecture 2

Introduction to Machine Learning. *Part 2*

The Machine Learning Life-Cycle

Cross-Industry Standard Process for Data Mining (CRISP-DM) methodology

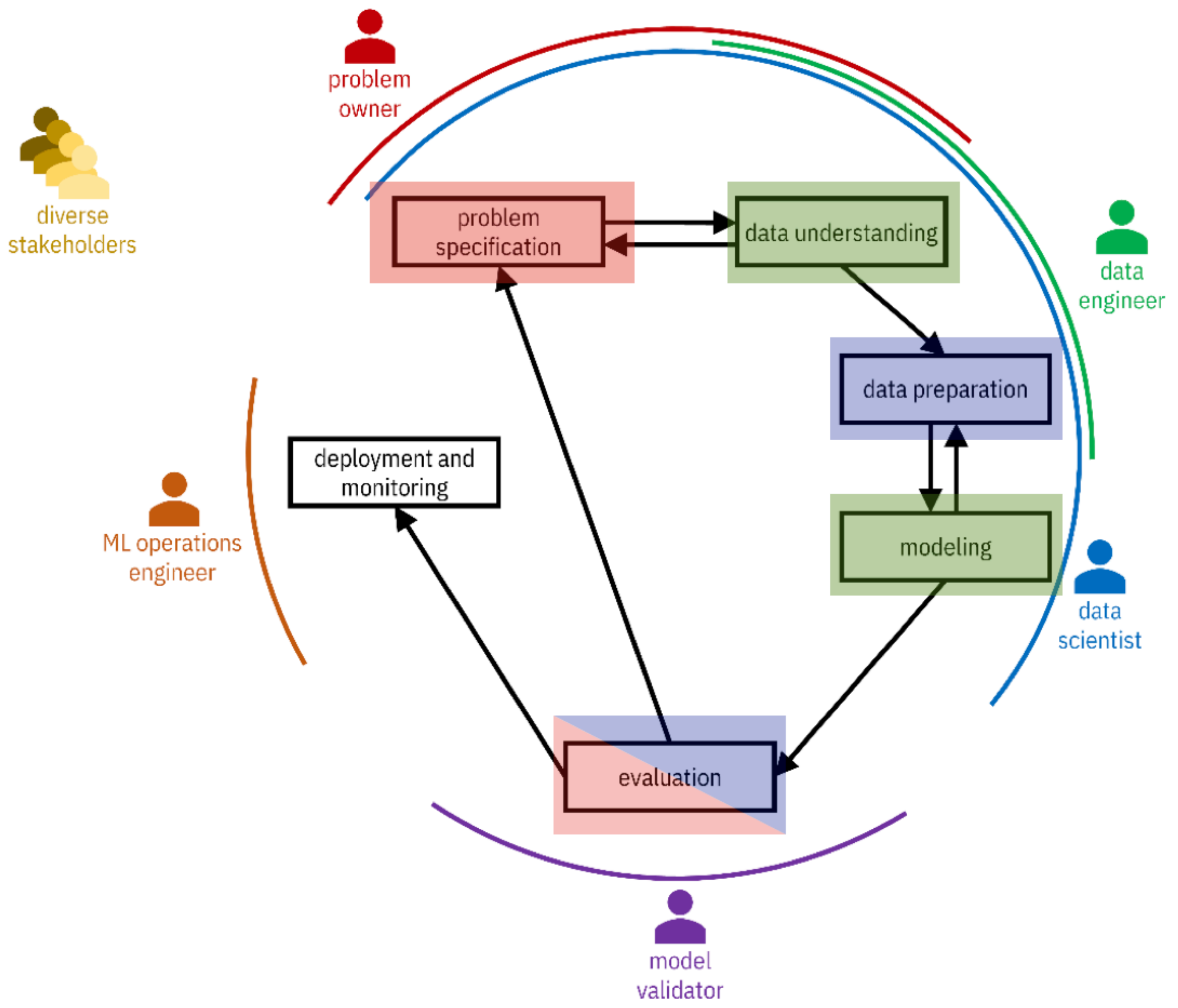


CRISP-DM In our course

Today and in all modules

In Module 4

In Module 3



Problem Specification

- What is the problem owner hoping to accomplish and why?
- Why am I (being asked to) solve it?
- Am I the right person to solve this problem?
- What are the (psychological, societal, and environmental) repercussions of building this technology?
- Should this thing be built at all?
- What are the metrics of success?

Data Understanding

Know your data!

- Data needs to be collected → Datasets
- What data is available?
- What data should be available but isn't?
- What population/system/process is your data representing?
- And what properties of such population/system/process are included (or excluded)?
- What biases (social, population, temporal) are present in your datasets?

Data Preparation

- **Data integration**
  - Extracting, transforming, and loading (ETL) data from disparate relevant databases and other data sources
  - This step is most challenging when dealing with big data sources
- **Data cleaning**
  - Filling missing values
  - Transforming value types (e.g. binning)
  - Dropping features that should not be considered
- **Feature engineering**
  - Transform the data to derive new features

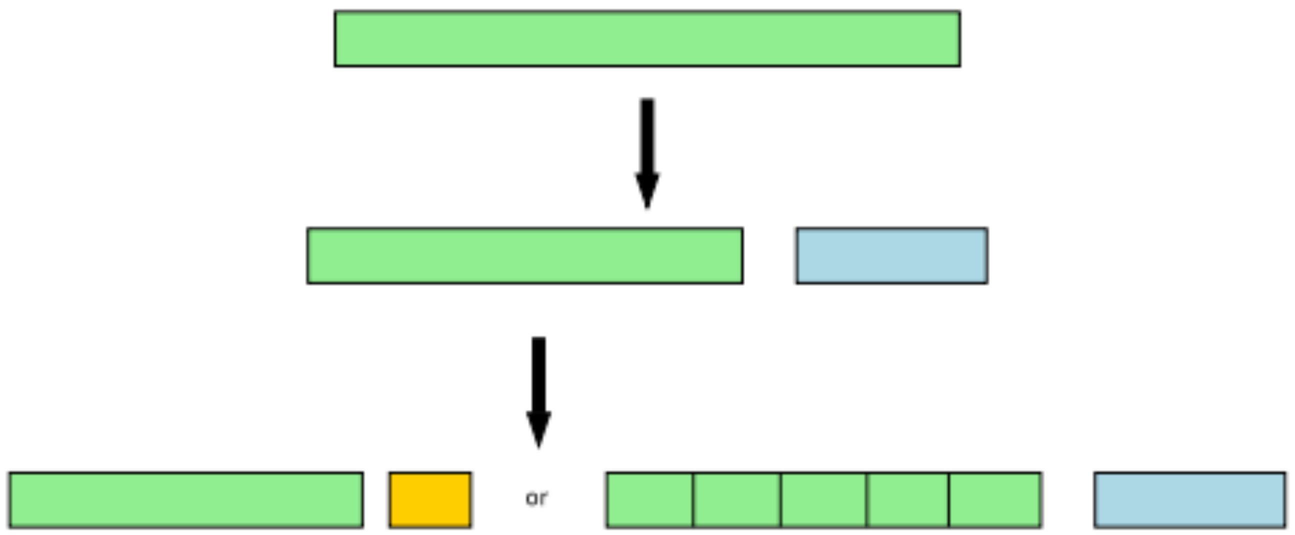
Modeling

- **Select** a training algorithm
- Use it to **find patterns** in the training dataset
- **Generalize** them to fit a statistical model
- **Enhance** the model to satisfy additional objectives and constraints captured in the problem specification
  - e.g., increase reliability, mitigate biases, generate explanations
- **No free-lunch theorem**
  - There is no one best machine learning algorithm for all problems and datasets


Training Data
Model Training
ML Model
Model Enhancement
Final ML Model

Evaluation

- Testing and validation of the model
  - Also against the problem specification requirements
- Performed on data not used for training
  - Hold out dataset



Model auditing/risk management

POLICY AND LEGISLATION | Publication 21 April 2021

Proposal for a Regulation laying down harmonised rules on artificial intelligence

The Commission has proposed the first ever legal framework on AI, which addresses the risks of AI and positions Europe to play a leading role globally.

The Proposal for a Regulation on artificial intelligence was announced by the Commission in April 2021. It aims to address risks of specific uses of AI, categorising them into 4 different levels: unacceptable risk, high risk, limited risk, and minimal risk.

In doing so, the AI Regulation will make sure that Europeans can trust the AI they are using. The Regulation is also key to building an ecosytem of excellence in AI and strengthening the EU's ability to compete globally. It goes hand in hand with the Coordinated Plan on AI.

View the proposal for a Regulation in all EU languages on EUR-Lex

See also

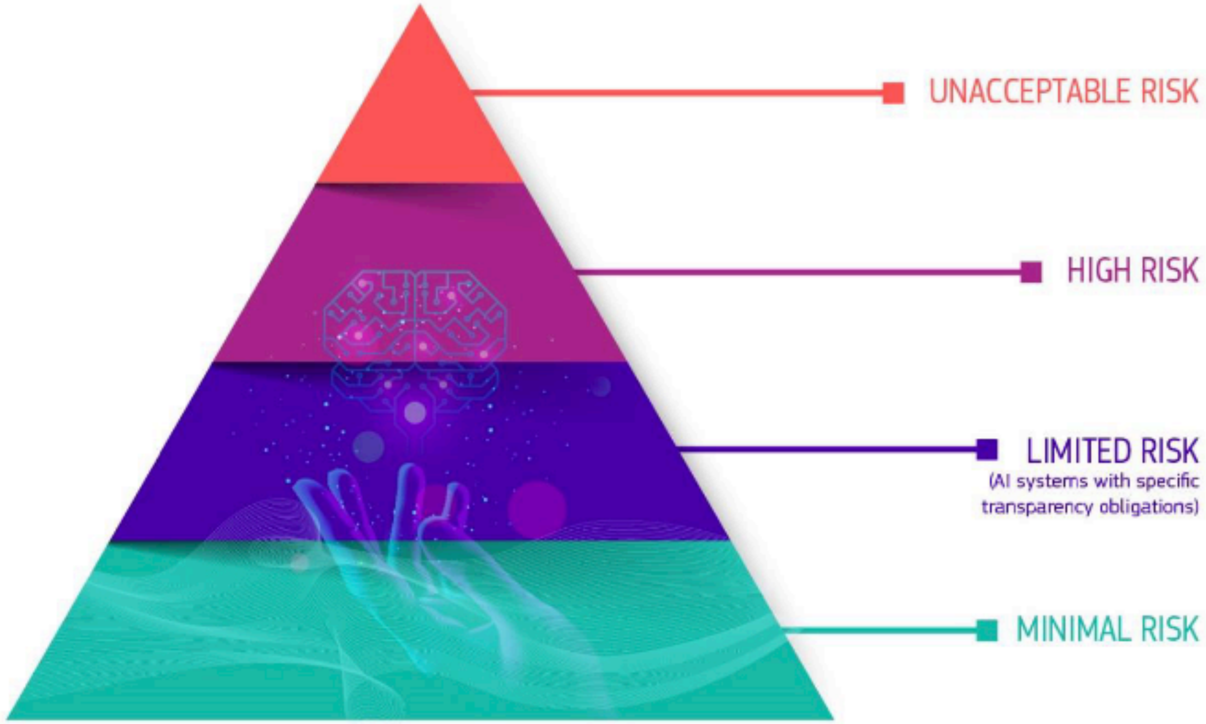
Communication on Fostering a European approach to Artificial Intelligence

Related topics

eHealth, Wellbeing and Ageing

Advanced Digital Technologies

Artificial intelligence



The Pyramid of Criticality for AI Systems

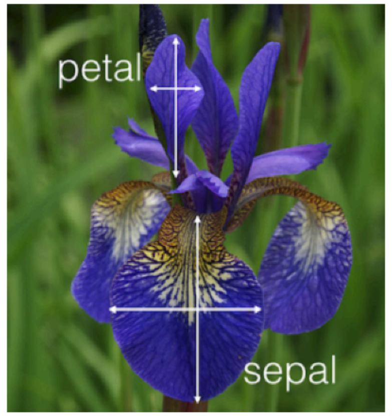
Deployment and monitoring

- What data infrastructure will bring new data to the model?
- Will predictions be made in batch or one-by-one?
- How much latency is allowed?
- How will the user interact with the system?
  - Is there a problem here?
- Tools to monitor the model's performance
  - And ensure it is operating as expected

Data

The raw material

Data



Feature Feature Feature Feature Label

sepal_lenght	sepal_width	petal_lenght	petal_width	Class
5.0	3.3	1.4	0.2	Iris-setosa
7.0	3.2	4.7	1.4	Iris-versicolor
5.7	2.8	4.1	1.3	Iris-versicolor
6.3	3.3	6.0	2.5	Iris-virginica

Record / Sample / Data Item

Label Value

Feature Value

Dataset Size

Dataset Dimensionality

Types of Features / Label Values

- **Categorical**
  - Named Data
  - Can take numerical values, but no mathematical meaning
- **Numerical**
  - -Measurements
  - Take numerical values (discrete or continuous)

Categorical Nominal

- No order
- No direction
- e.g. marital status, gender, ethnicity

Categorical Ordinal

- Order
- Direction
- e.g., letter grades (*A*,*B*,*C*,*D*), ratings (*dislike*, *neutral*, *like*)

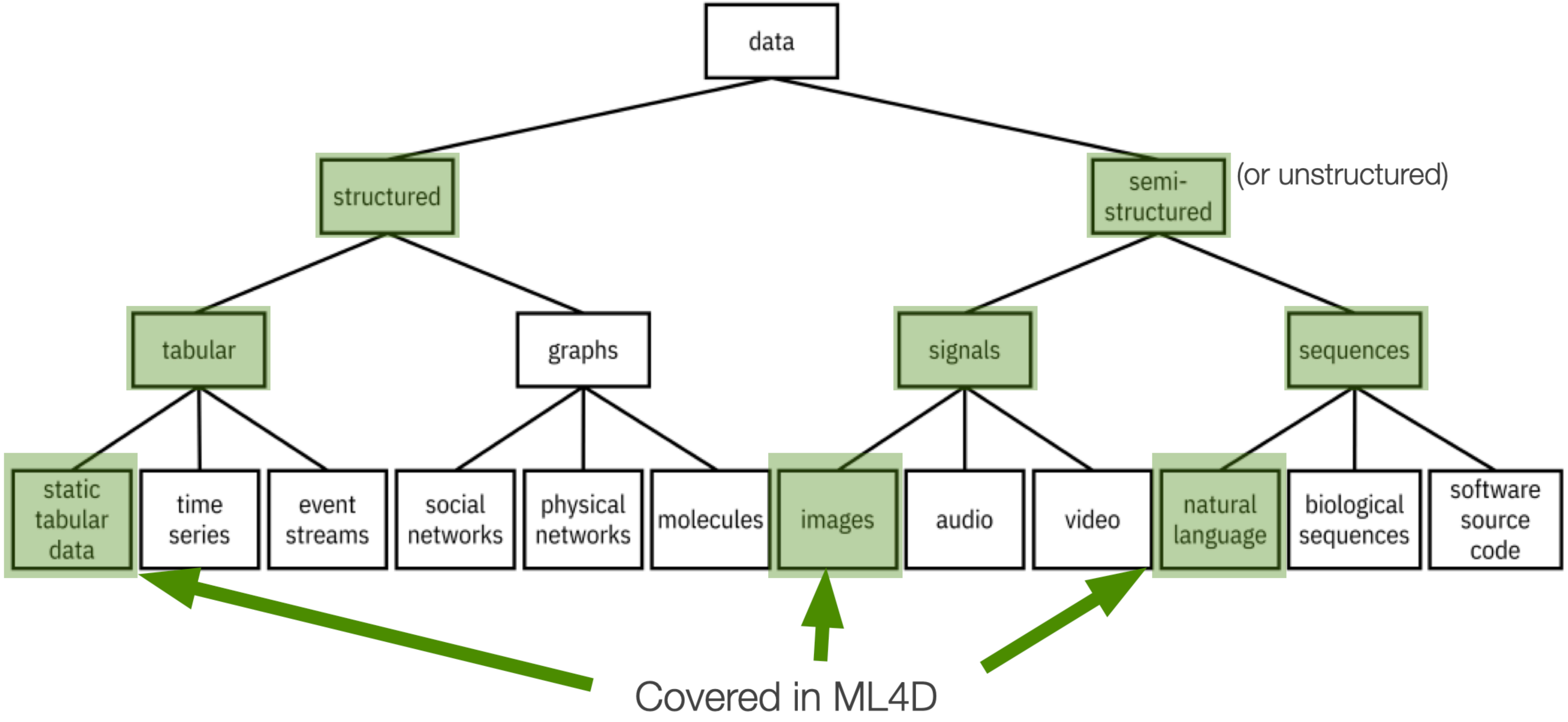
Numerical Interval

- Difference between measurements
- No true zero or fixed beginning
- e.g., temperature (C or F), IQ, time, dates

Numerical Ratio

- Difference between measurements
- True zero exists
- e.g., temperature (K), age, height

Data Modalities



Key Dimensions

Modality	Quantity	Quality	Freshness	Cost
Structured	Number of records	Errors	Rate of collection	Acquisition
Semi-structured	Number of features	Missing data		Licensing
		Bias		Cleaning and integrations

Static Tabular Data

Feature Feature Feature Feature Label

sepal_lenght	sepal_width	petal_lenght	petal_width	Class
5.0	3.3	1.4	0.2	Iris-setosa
7.0	3.2	4.7	1.4	Iris-versicolor
5.7	2.8	4.1	1.3	Iris-versicolor
6.3	3.3	6.0	2.5	Iris-virginica

Record / Sample / Data Item

Label Value

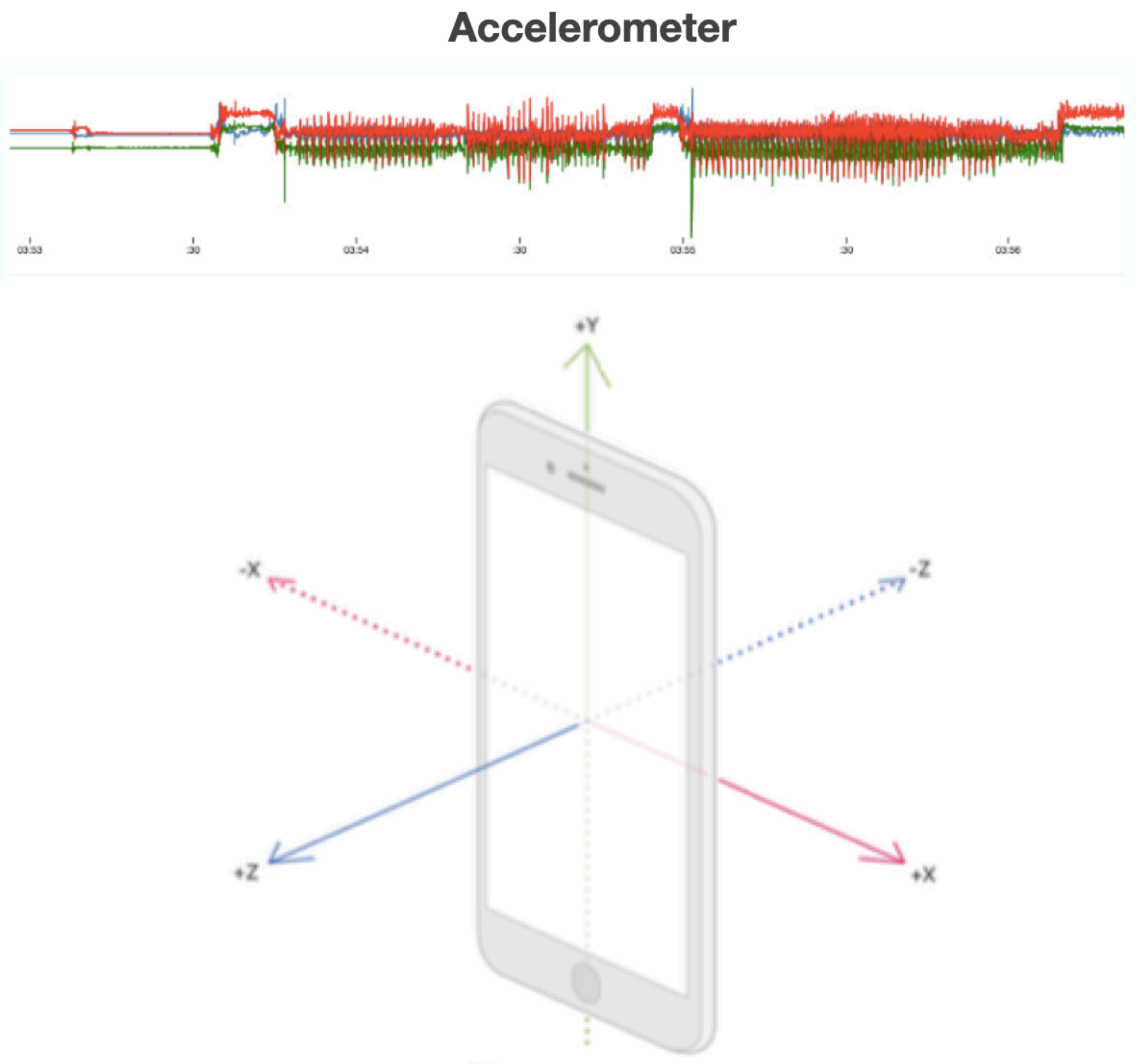
Feature Value

Dataset Size

Dataset Dimensionality

Time Series

- tabular data with **time** feature
- For instance
  - Sensor data, Stock market data
- Label is usually associated with a set of records
  - e.g. a continuous movement of the phone indicating an action



Time Feature

Timestamp	X	y	Z	Class
15060015925	2.04	3.72	8.12	
15060015943	1.96	4.73.68	7.56	Device Rotation
15060015980	1.63	3.56	6.53	
1506001610	1.06	3.76	5.81	

Images

- Visual content acquired through cameras, scanners, etc.
- Each pixel in an image is a feature
  - But spatially and geometrically organised
  - e.g., edges, corners
- Feature values are numerical values across channels
  - e.g., *R,G,B*
- Dimensionality → *n x m*

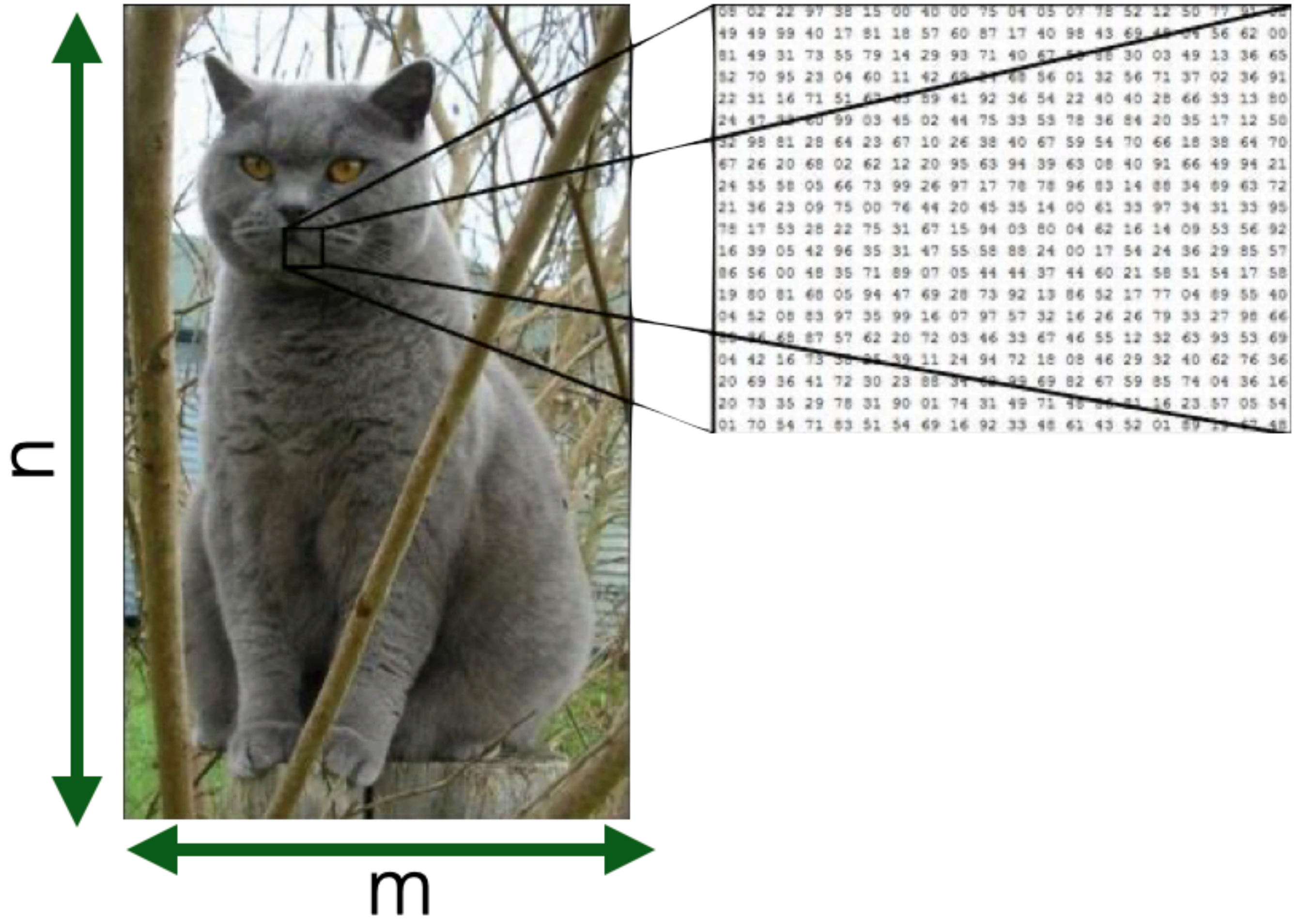


Image →

P(1,1)	P(2,1)	P(3,1)	...	P(n,m)	Class
255, 0, 0	255, 1, 1	255, 0, 0		R,G,B	Cat
255, 213, 0	255, 213, 1	255, 213, 4		R,G,B	Dog
					Cat
					Duck

More in Module 1

Textual documents

- Sequence of alphanumerical characters
  - Short: e.g. tweets
  - Long: e.g Web documents, interview transcripts
- Features are (set of) words
  - Words are also syntactically and semantically organised
- Feature values are (set of) words occurences
- Dimensionality → at least dictionary size

Document

I	Wear	Mask	...	W(n)	Class
1	1	1		0	Spam
0	0	1		0	Not Spam
					Spam

More in Module 2

Data Sources

Purposefully Collected Data	Administrative Data	Social Data	Crowdsourcing
Survey	Call records	Web pages	Distributed sensing
Census	Financial transactions	Social Media	Implicit crowd work (e.g. captcha)
Economic Indicators	Travel Data	Apps	Micro-work platforms (e.g Amazon Mechanical Turk)
Ad-hoc sensing	GPS Data	Search Engines	

Data Sources

Purposefully Collected Data	Administrative Data	Social Data	Crowdsourcing
Modality: mostly structured	*Modality*: mostly structured	*Modality*: mostly semi-structured	*Modality*: all
Quantity: low	*Quantity*: high	*Quantity*: low	*Quantity*: mid-low
Quality: high	*Quality*: high	*Quality*: low	*Quality*: mid
Freshness: low	*Freshness*: high	*Freshness*: high	*Freshness*: mid
Cost: high	*Cost*: high	*Cost*: low	*Cost*: mid-low

Categories of Machine Learning

How do machines learn?

On Models

> A physical, mathematical, logical, or conceptual representation of a system, entity, phenomenon, or process

- A **simple(r)** representation of reality helping us understand how something works or will work.
  - **Not truthful**, just a **useful** one
- The goal of models is to make a particular part or feature of the world more accessible to understand, define, quantify, visualise, or simulate

Examples of models

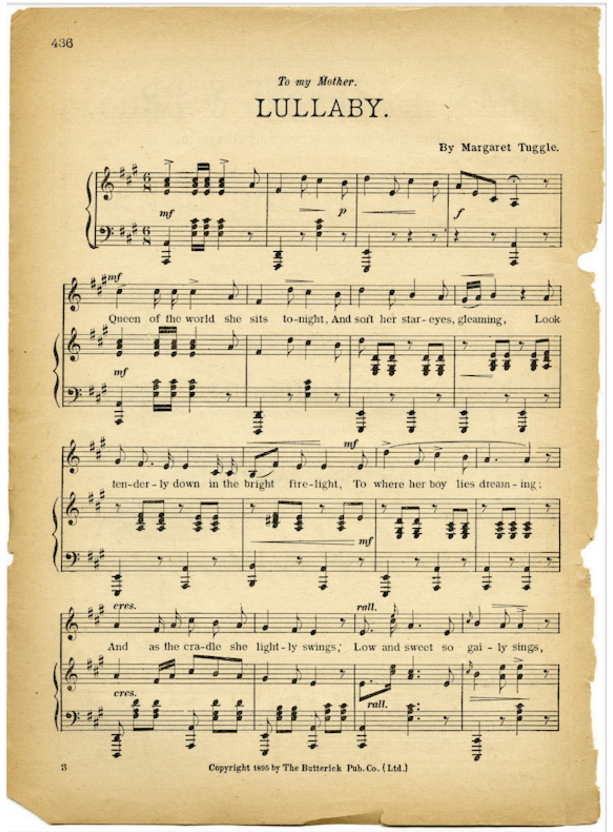
Architecture plans

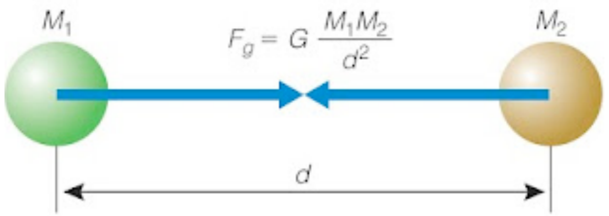
Maps

Music Sheet

Mathematical laws of physics!

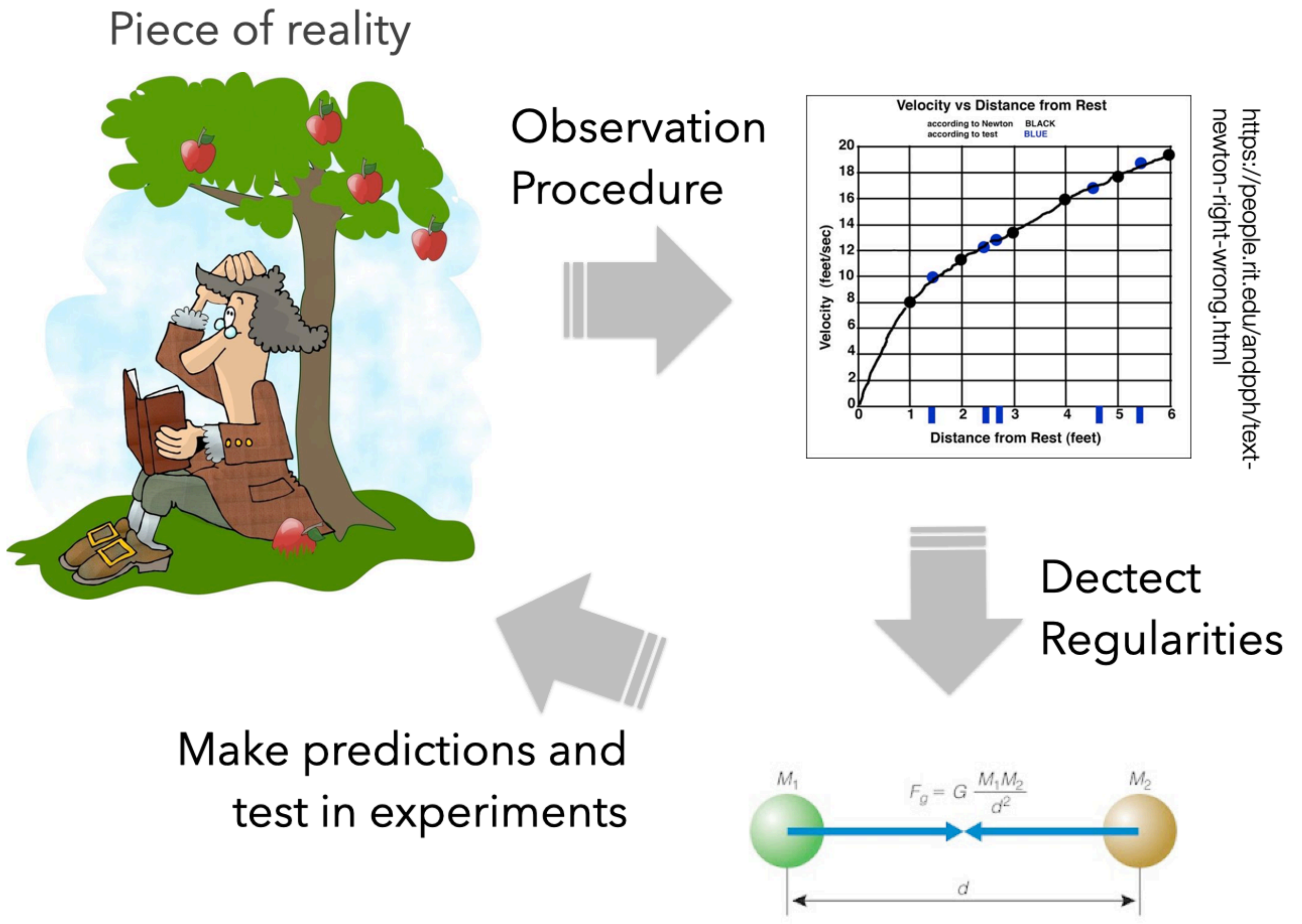
Machine Learning (statistical) Models





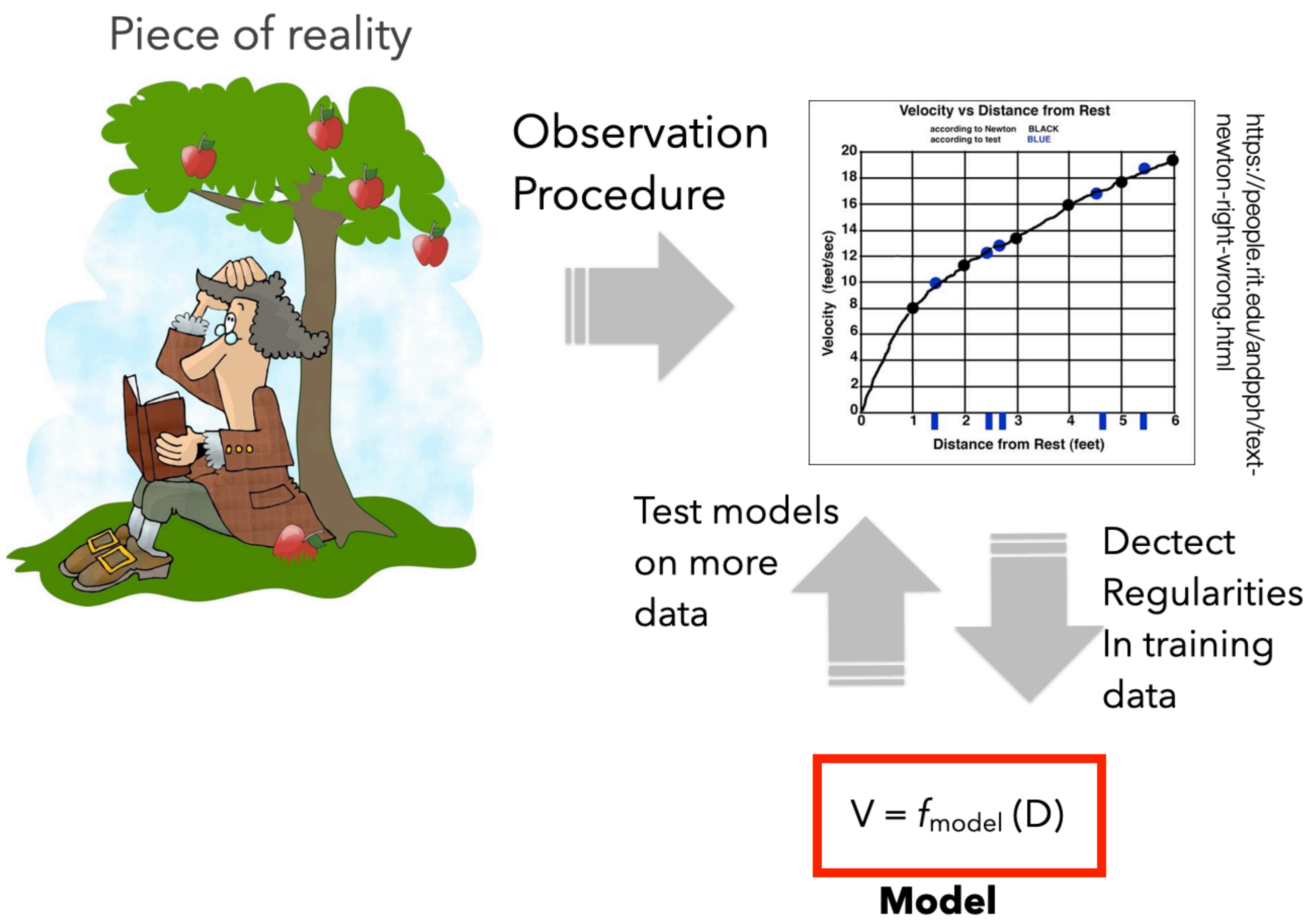
Scientific Models

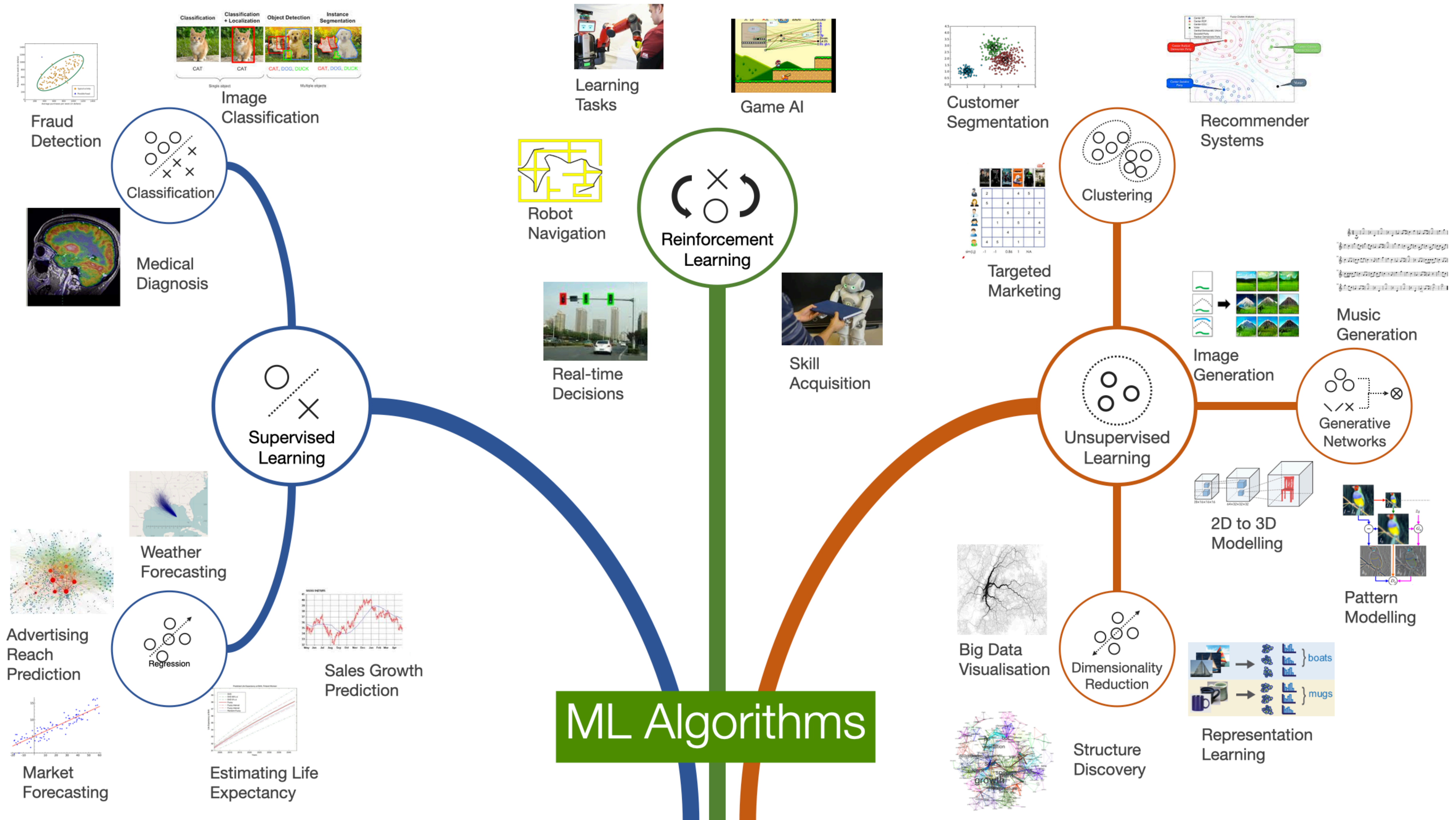
- GOAL: explain reality
- Created to make predictions about the outcomes of future experiments
  - e.g., apples on the moon
- Tested against the **outcome**
- If data from new experiments don't agree, the model has to be modified/extended / refined
  - Falsifiability
- Scientific models should be *small* and *simple*.
- They should generalize phenomena observed in new ways.



ML Models

- GOAL: describe the data
- Designed to capture the *variability* in observational data by exploiting regularities/symmetries/redundancies
- A good ML model doesn't need to explain reality, it **just describe data**
- They don’t need to be simple or transparent, or intelligible. Just **accurate**
  - *Black box*
- ML models may be large and complex.
- They should generalize to new data obtained in the same way as the training data
  - Same application context and data acquisition process



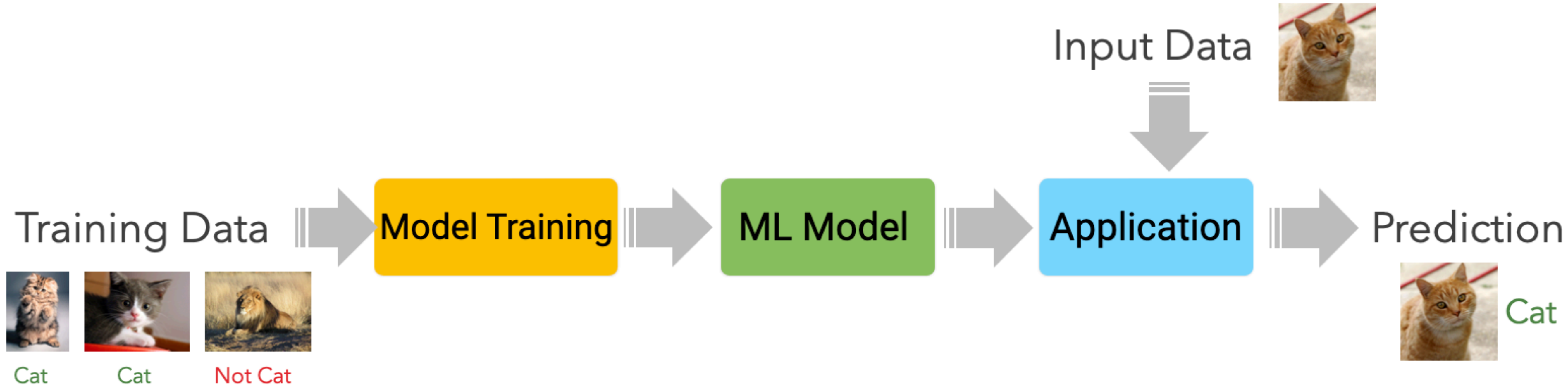


Credits: B. Timmermans, Z. Szlavik

Supervised Learning

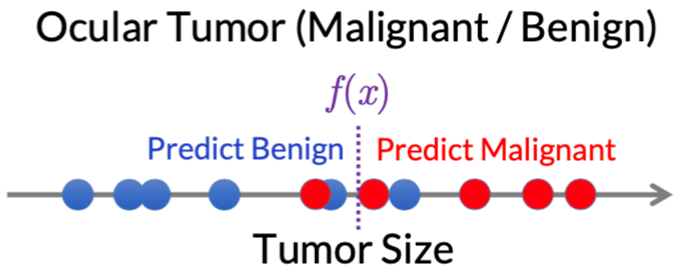
- Input: **labeled** data
  - Data + expected prediction
- During training, labels are used to associate patterns with outputs
- Learns how to make input-output **predictions**

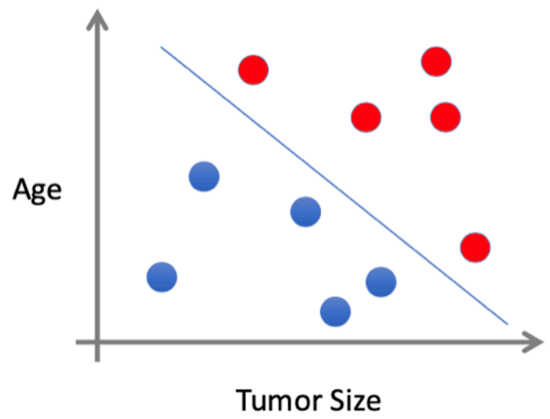
- *Classification*
- *Regression*
- *Ranking*
- *Recommendation*

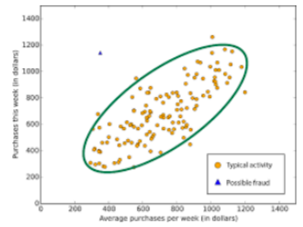

Training Data
Cat
Cat
Not Cat
Model Training
ML Model
Input Data
Application
Prediction
Cat

Classification

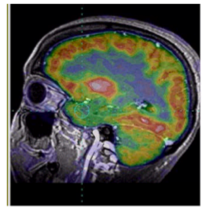
- Learn to output a **category label**
- Binary
  - e.g. *Spam / not Spam*, *Cat / not cat*
- Multi-class
  - e.g. *cat, dog, bird*







Fraud Detection



Medical Diagnosis

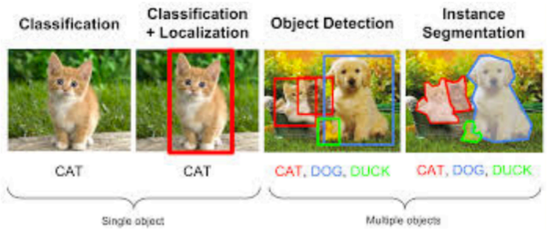
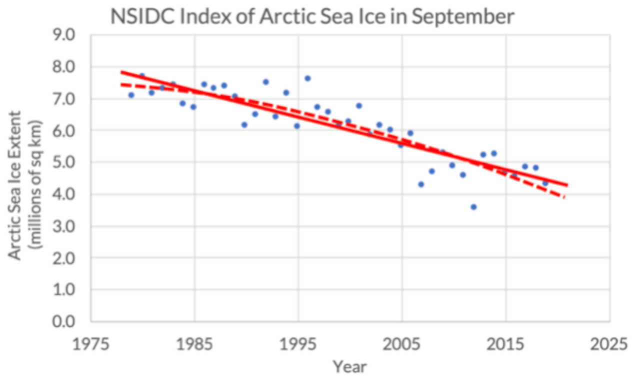
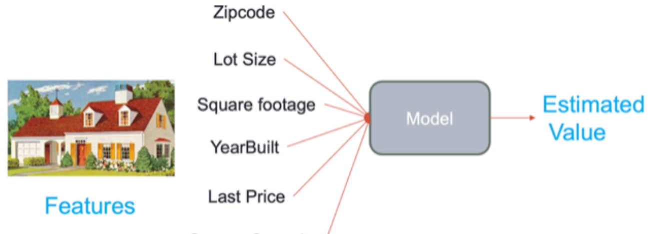


Image Classification

Regression

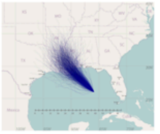
- Learn to output one or more **numbers**
  - e.g., value of a share, number of stars in a review



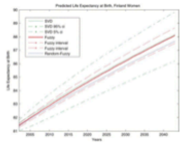


Estimating Home Prices

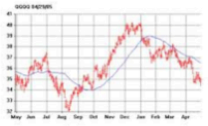
Advertising Reach Prediction



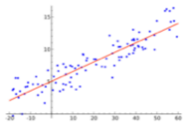
Weather Forecasting



Estimating Life Expectancy



Sales Growth Prediction

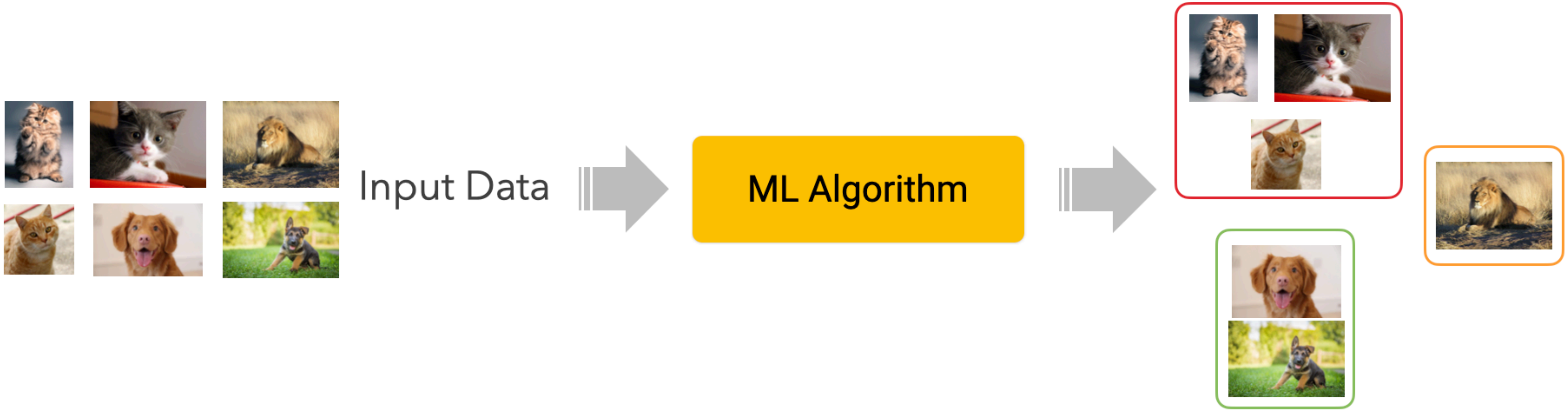


Market Forecasting

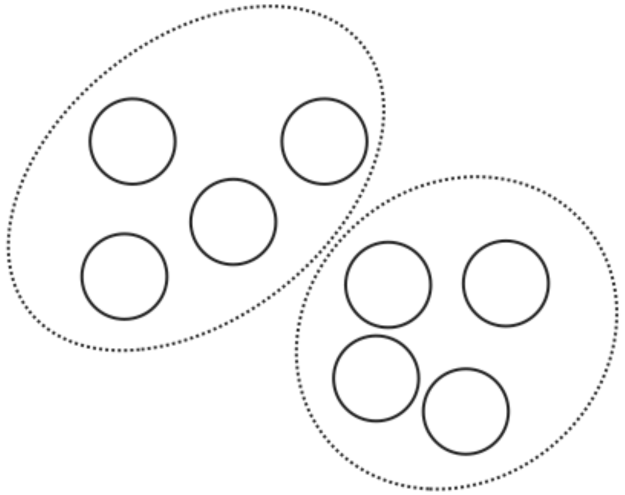
Unsupervised Learning

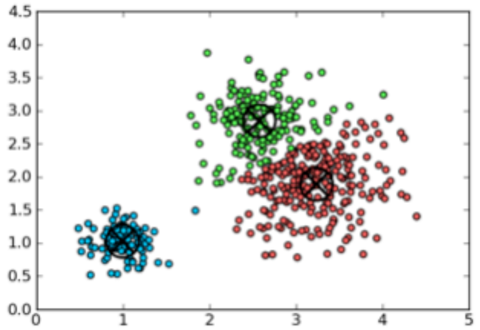
- Input: **unlabeled** data
- The machine learns structures (patterns) from the data without human guidance

- *Clustering*
- *Dimensionality Reduction* (e.g. Large Language Models)
- *Anomaly detection*

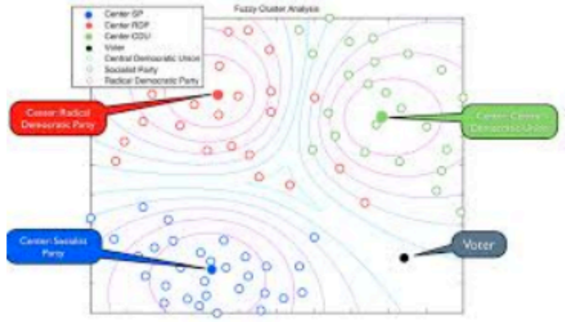

Input Data
ML Algorithm

Clustering





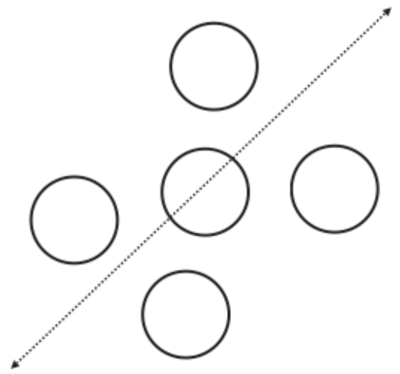
Customer Segmentation

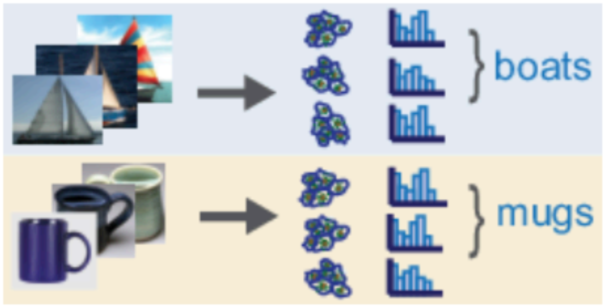


Targeted Marketing

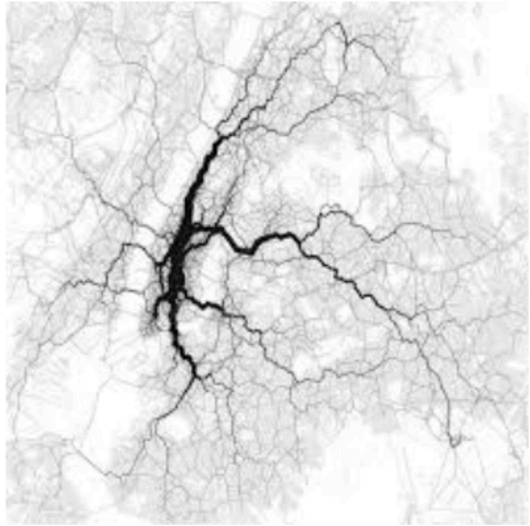
Recommender Systems

Dimensionality Reduction

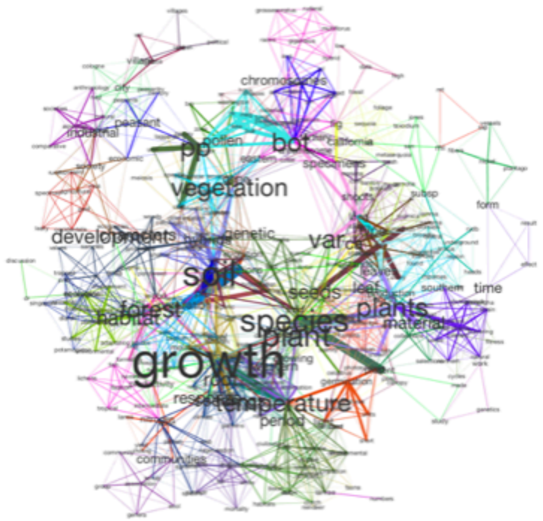




Foundational Models
For Transfer Learning



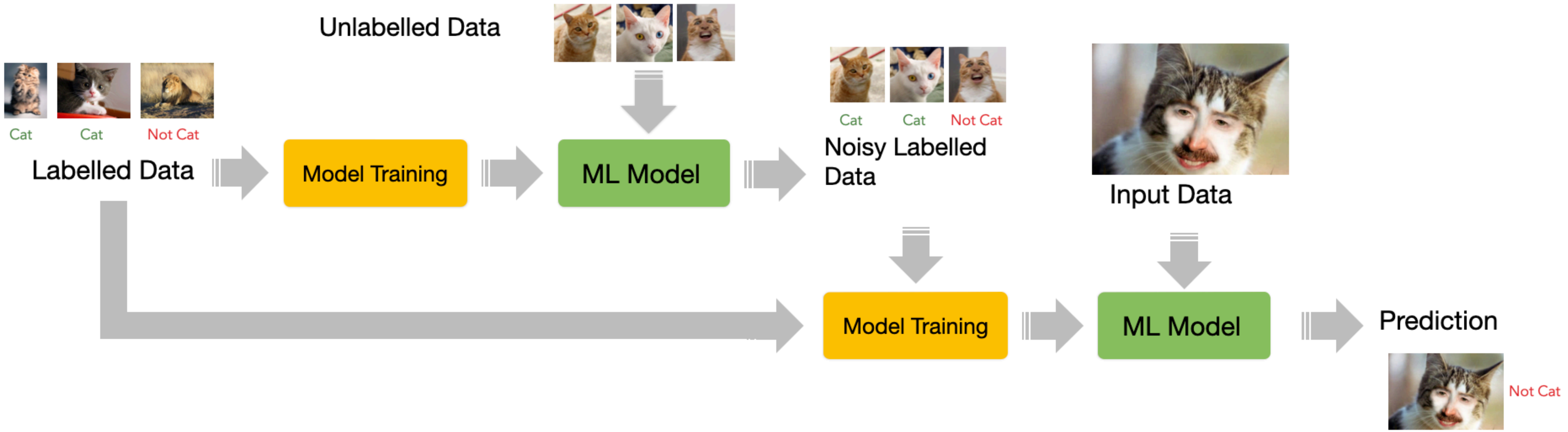
Big Data Visualisation



Structure Discovery

Semi-Supervised Learning

- Combination of **supervised** and **unsupervised** learning
- Few **labeled** data in the input are used to create **noisy labeled data**
- With more labeled data, the machine learns how to make input-output **predictions**

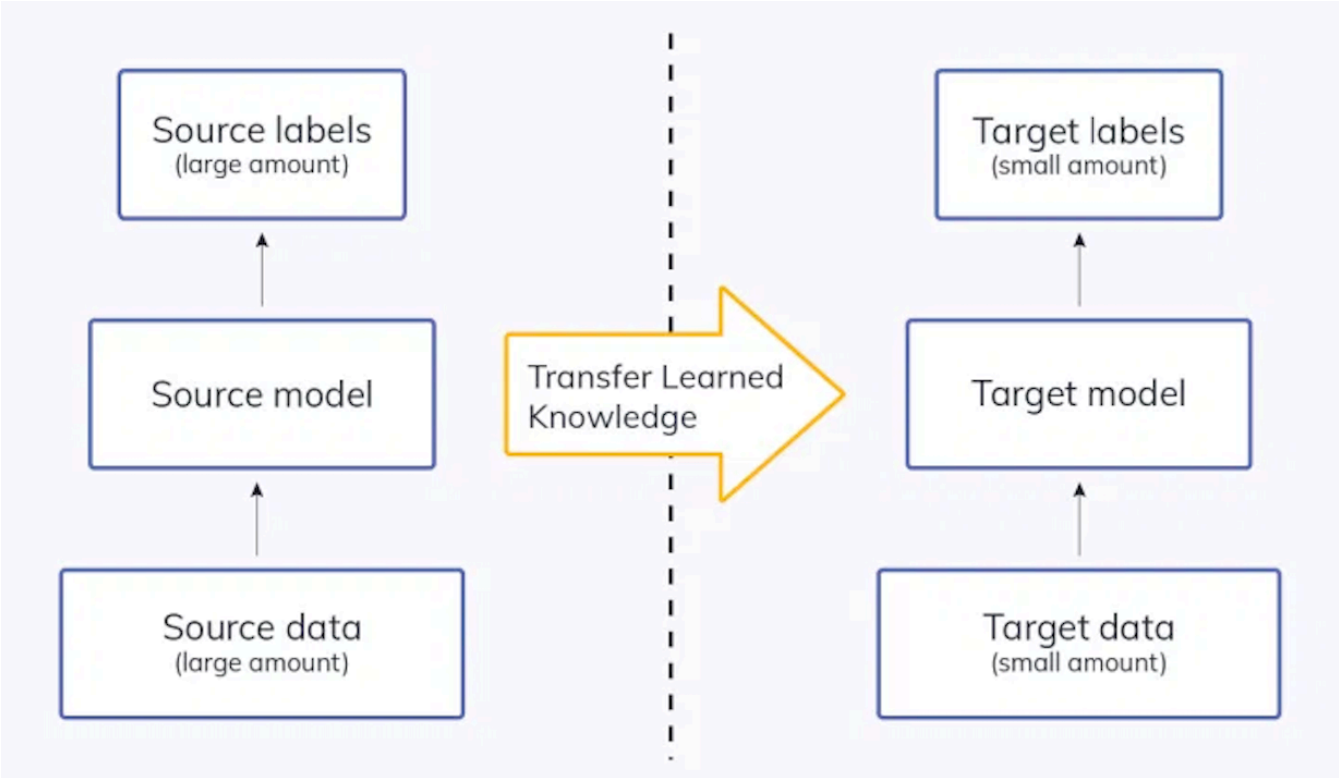

Unlabelled Data
Cat
Cat
Not Cat
Labelled Data
Model Training
ML Model
Cat
Cat
Not Cat
Noisy Labelled Data
Input Data
Model Training
ML Model
Prediction
Not Cat

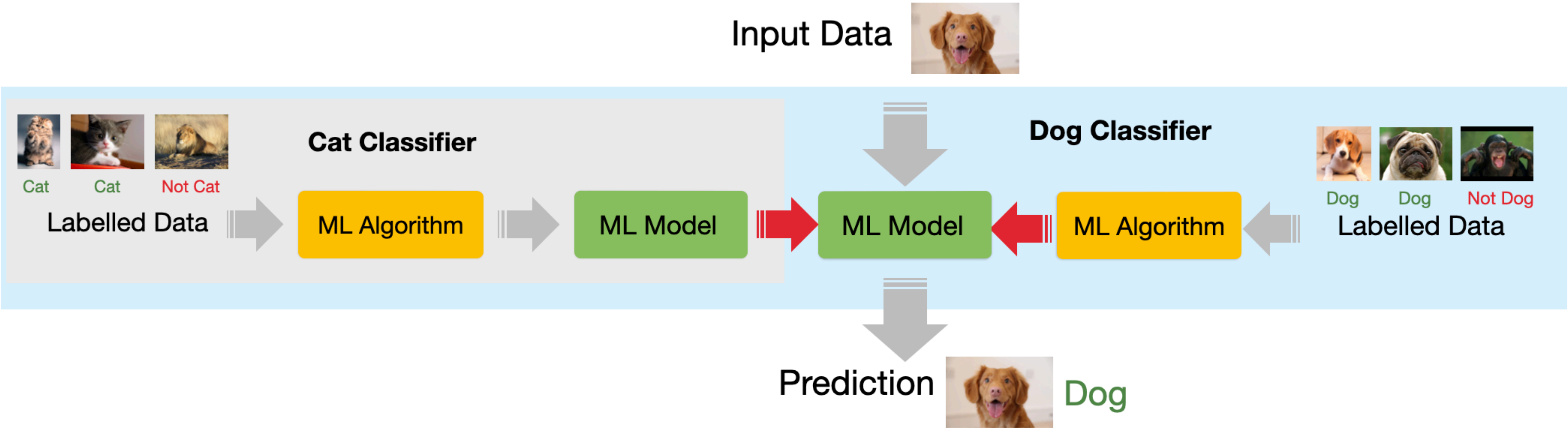
Transfer Learning

Often called *fine-tuning*

Reuse a model trained for one task is **re-purposed** (tuned) on a different but related task

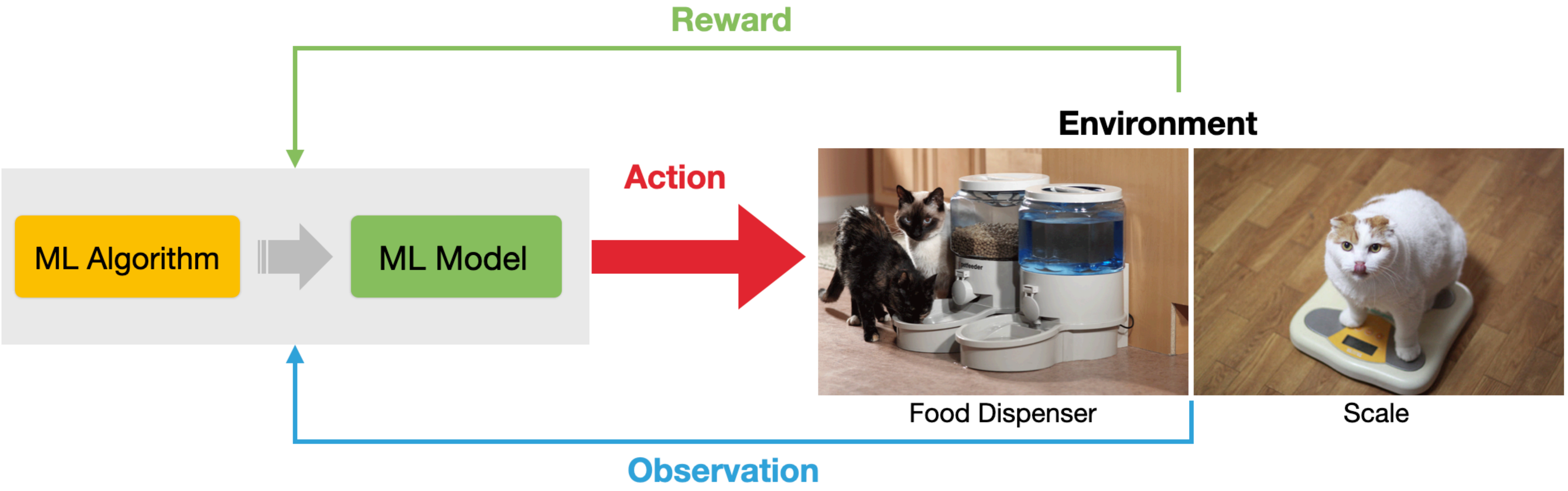
Useful in tasks lacking abundant data




Input Data
Cat
Cat
Not Cat
Labelled Data
Cat Classifier
ML Algorithm
ML Model
ML Model
Dog Classifier
ML Algorithm
Dog
Dog
Not Dog
Labelled Data
Prediction
Dog

Reinforcement Learning

- Data about the **environment** and **reward function** as input
- The machine can perform **actions** influencing the environment
- The machine learns behaviours that result in **greater reward**


Reward
Environment
Action
ML Algorithm
ML Model
Food Dispenser
Scale
Observation

Don’t forget domain expertise

- ML makes some tasks automatic, but we still need our brains
- More in Module 3 and Module 4

- Defining the prediction task
- Define the evaluation metrics
- Designing features
- Designing inclusions and exclusion criteria for the data
- Annotating (hand-labelling) training (and testing) data
- Select the right model
- Error analysis

Machine Learning for Design

Lecture 2

Introduction to Machine Learning. *Part 2*