Introduction to AI, ML & Data Analytics

https://github.com/Dr-AlaaKhamis/ISE518/tree/main/3_R&M

Lecture 5 – Monday September 8, 2025

Outline

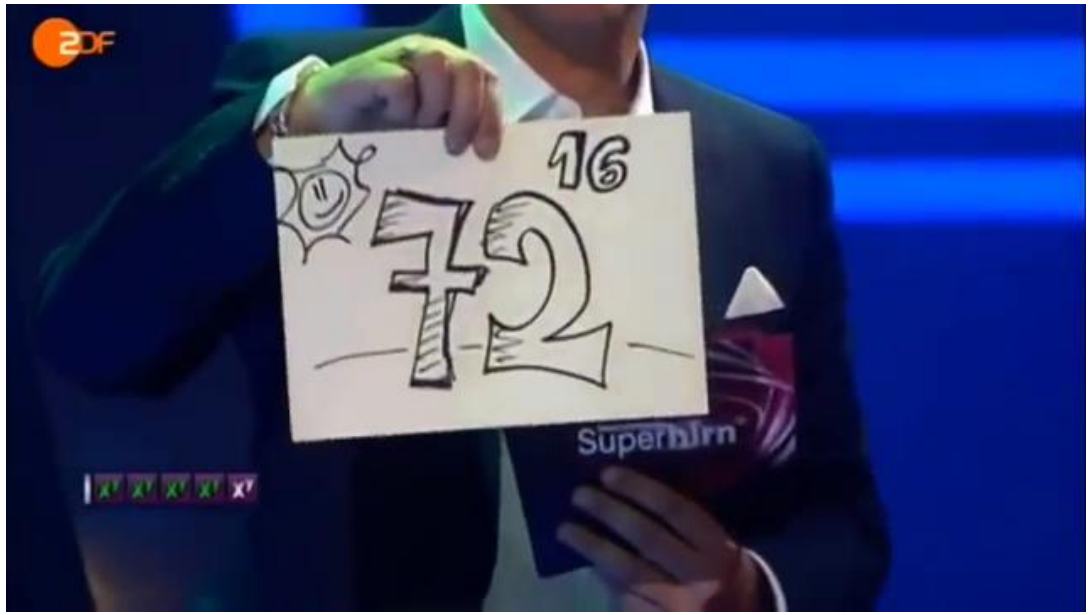
- Introduction to Artificial Intelligence
- Introduction to Machine Learning
- Responsible AI
- Data Analytics

Outline

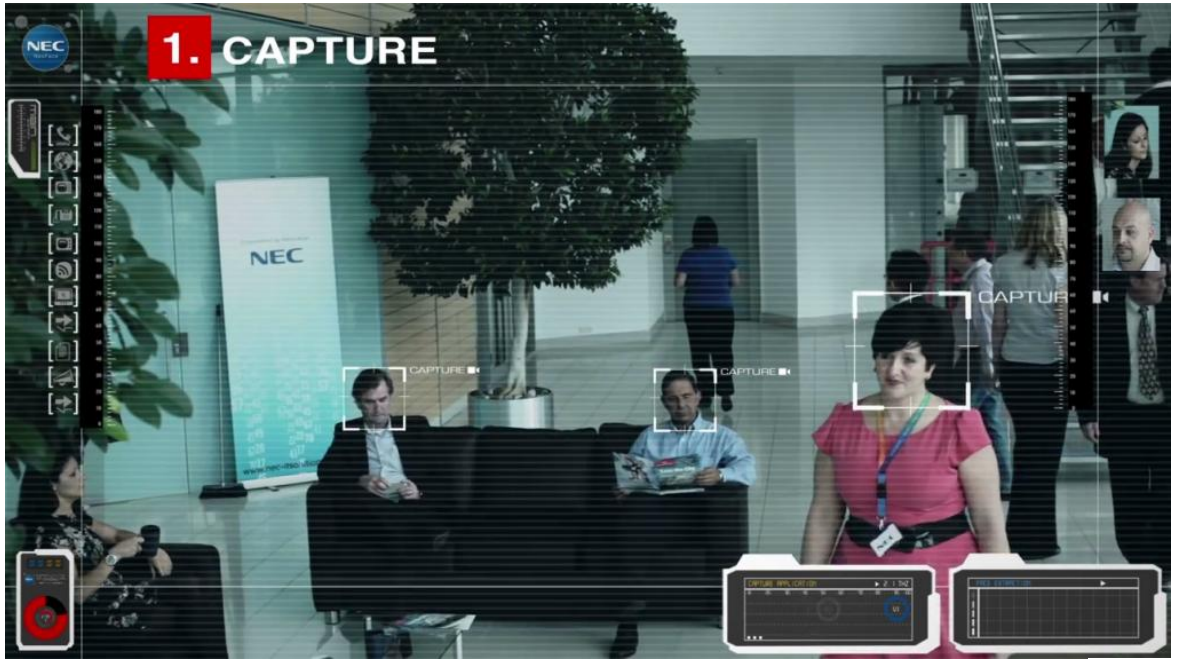
- **Introduction to Artificial Intelligence**
- Introduction to Machine Learning
- Responsible AI
- Data Analytics

Introduction to Artificial Intelligence

- Human vs. Machine Intelligence



Video



Video

Alaa Khamis, "Biological versus Non-Biological/Artificial Intelligence", Towards Data Science, March, 2019.

- Human vs. Machine Intelligence

	Human	Machine
Cost	Low initial cost and high running cost.	High initial cost (in case of robots) and low running cost (work 24/7).
Creativity	Creative	Uninspired
Permanency of Intelligence	Human intelligence is perishable. We could not preserve Einstein's intelligence after his death.	Machine intelligence is permanent. It is easy to preserve intelligent tools like Siri and Watson.
Ease of duplication and dissemination of knowledge	Slow language-based communication process, some expertise can never be duplicated.	Knowledge can be copied from a machine and easily moved to another one.
Better in	• fusing data from multiple sources and interpreting the outside world • distinguishing faces • identifying objects • recognizing language sounds • learning from few examples. A kid can differentiate between a man and a tree just by showing him/her one example. • develop new concepts/ imagination and creative reasoning.	• faster at performing arithmetic and logical operations • dealing with multi-dimensional data • discovering complex patterns such as that exist in financial, scientific, or product data. • operations that require fast, precise, highly repeatable actions • working in harsh environments (in case of robots).

Alaa Khamis, "Biological versus Non-Biological/Artificial Intelligence", Towards Data Science, March, 2019.

Any sufficiently advanced technology is indistinguishable from magic.

Arthur C. Clarke
(1917-2008)

Introduction to Artificial Intelligence

- **A day in the life of AI-empowered daily routines**

Home

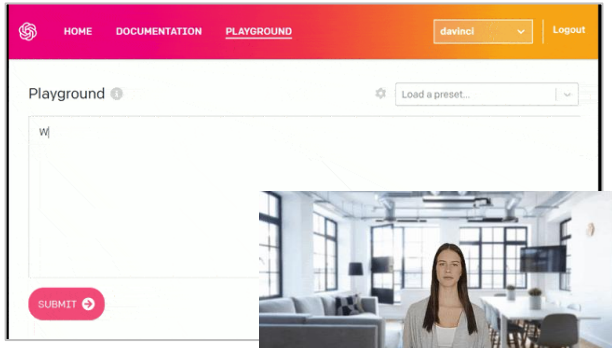
- Voice Assistant
- Smart Appliances
- Smart Thermostat
- Smart Meter

On Route

Education/Work

- Navigation Apps
- Location Intelligence Apps
- Shared Mobility
- Advanced Driver Assistance
- Self-driving Shuttles

- AI Coding Assistant (Copilot)
- Summarization (e.g., genie), Check Grammar (e.g., Grammarly), Translation (e.g., DeepL translate) and Excel AI formula generator (ExcelFormulaBot), NotebookLLM
- Human-like text generation (ChatGPT, Gemini, Grok, LeChat, Claude, DeepSeek,..)
- Image generation from text (Dall-e 2)
- Video generation (e.g., Synthesia, Google Transframer, CoDi)

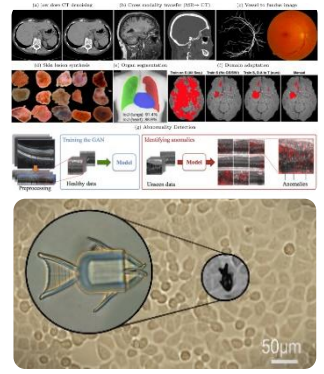


Shopping

- Voice search
- Search by images
- Semantic search
- Recommendation engines
- Online shopping behavior
- Last-mile delivery

Health

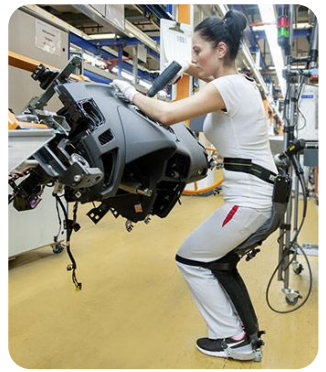
- Personalized Healthcare
- Diagnosis
- Treatment planning
- Rehabilitation
- Lab automation
- Drug discovery and delivery



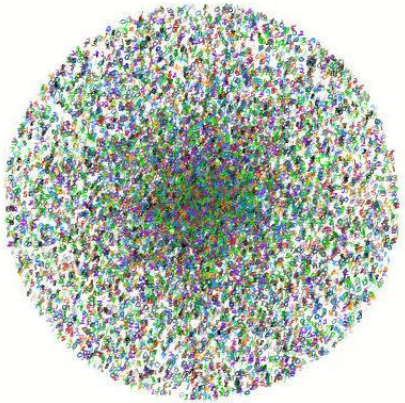
Introduction to Artificial Intelligence

- **What is Artificial Intelligence (AI)?**

Muscle Augmentation



Intelligence Augmentation (IA)

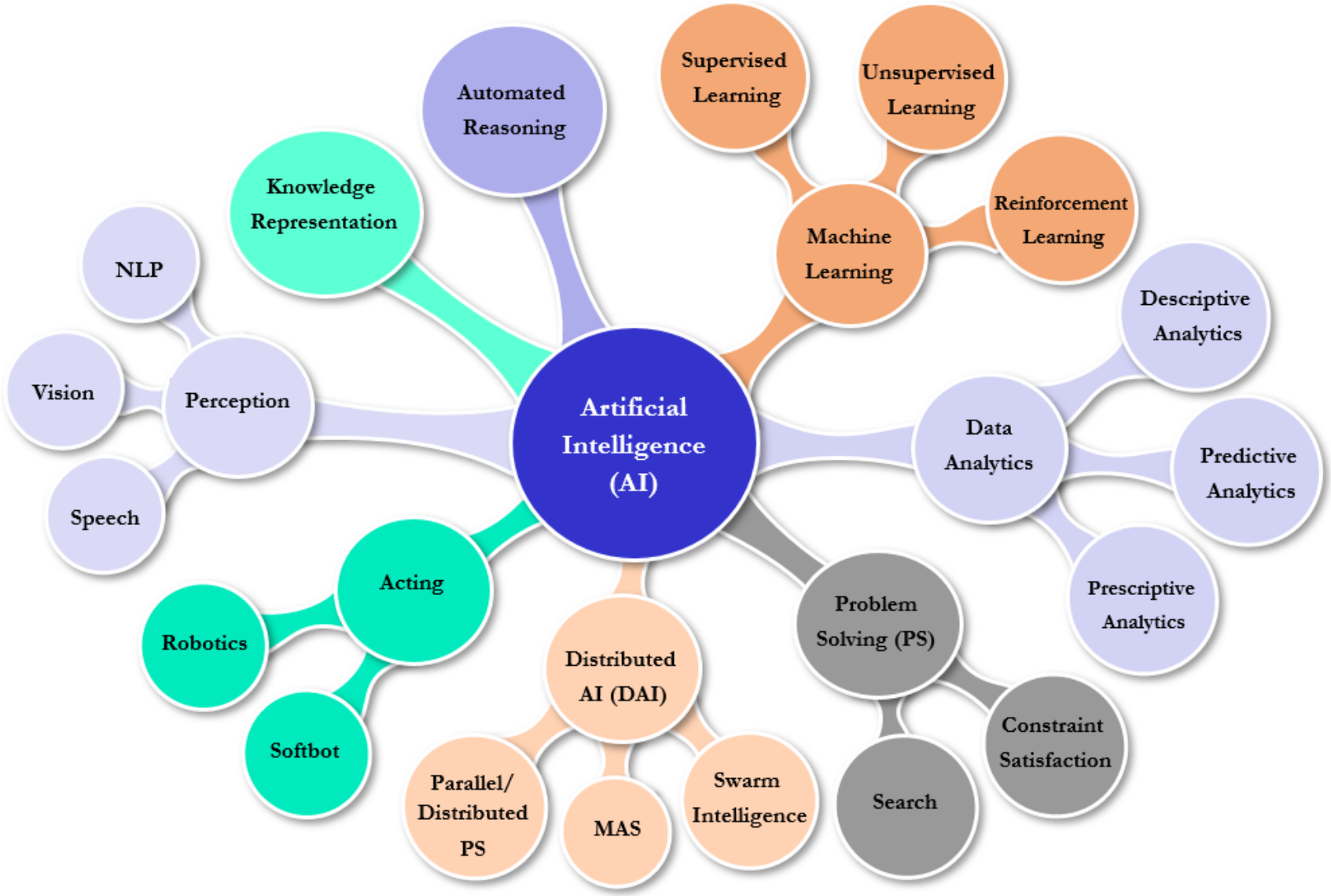


AI aims to create intelligent systems or machines that can exhibit intelligent behavior, often by **mimicking or drawing inspiration from biological intelligence**. These systems can be designed to function **autonomously or with some human guidance**, and ideally, they can adapt to environments with **diverse structures, observability levels, and dynamics**.

Alaa Khamis. *Optimization Algorithms: AI techniques for design, planning, and control problems*. Manning Publications, ISBN 978-1633438835, 2024.

Introduction to Artificial Intelligence

- **What is Artificial Intelligence (AI)?**

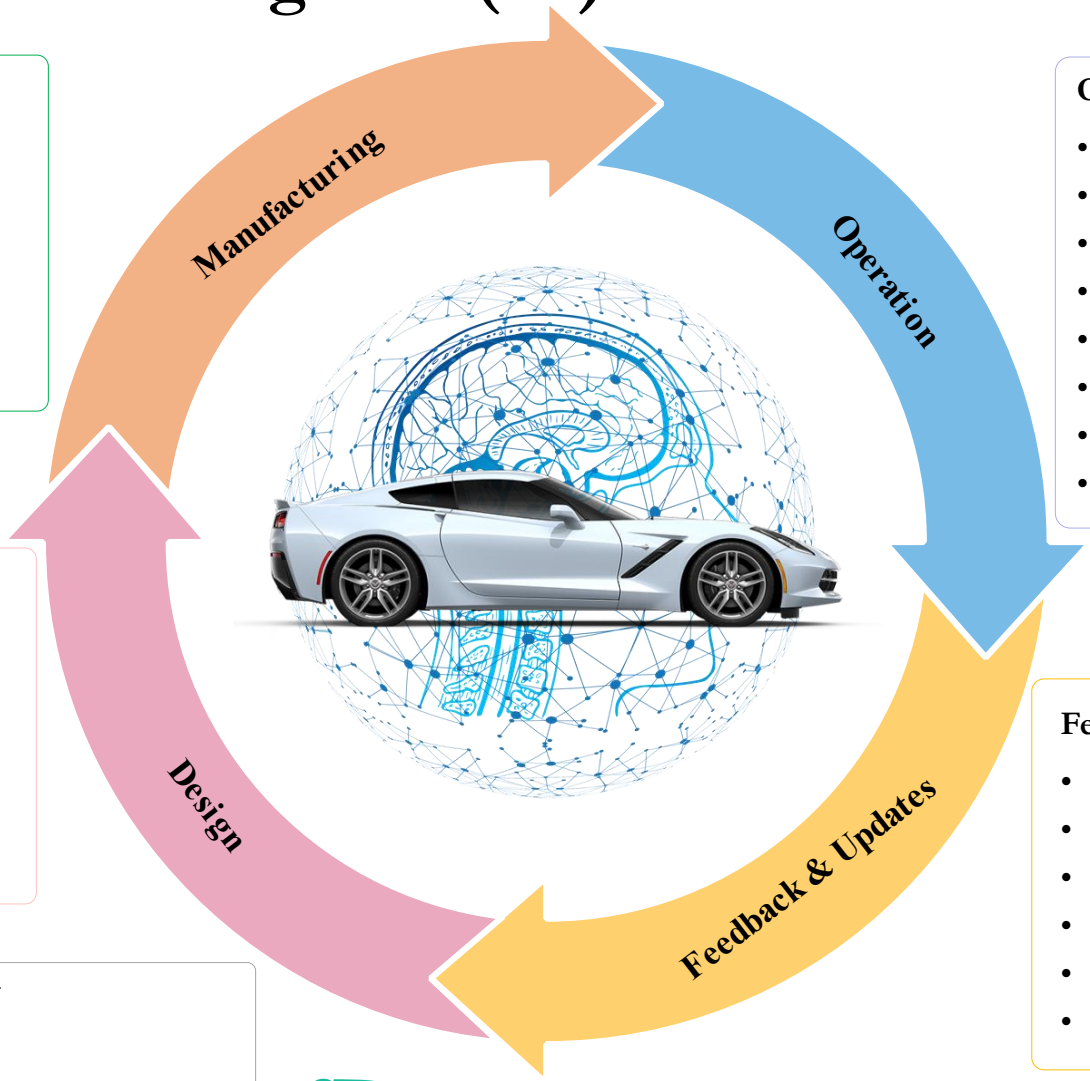


Alaa Khamis, "Biological versus Non-Biological/Artificial Intelligence", Towards Data Science, March, 2019.

- **What is Artificial Intelligence (AI)?: Automotive AI as an example**

Manufacturing

- Industry 4.0, Mass Customization
- Additive Manufacturing
- Robotic Process Automation (RPC)
- Quality Control, Calibration, Test Automation, Assembly Line Balancing, etc.



Operation

- Diagnostics & Prognostics
- Perception
- Localization
- Mapping
- Behavioral Control
- Planning
- ADAS and ADS
- Predictive Infotainment
- Digital Companion
- Dispatch and Routing
- Online Optimization
- Supply Chain Management
- Fleet Management
- Crowd Intelligence
- Data Monetization, Experience Monetization, etc.

Design

- Generative Design
- Engine Efficiency
- Crash Analysis
- New material discovery and characterization
- Battery Design, etc.

Feedback and Updates

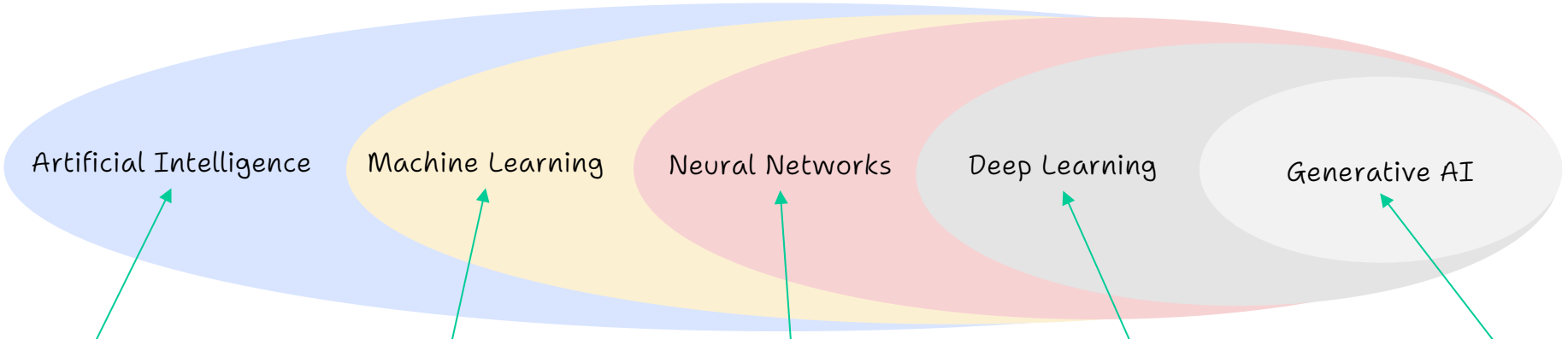
- Intelligent Agent Assistants
- Sentiment Analysis
- Customer Churn Prediction
- Automated Claims Processing
- Dynamic Pricing
- Incentive Optimization
- Personalized Loyalty
- Personalized Marketing
- Retail Support Bots
- Demand Planning
- Supply Chain Management
- Legal Analytics, etc.

Disposal and Recycling

- Predicting Battery Life
- Reduce Battery Ownership Cost
- Battery Recycling and AI-based Sorting
- Waste Management and Recycling, etc.

Introduction to Artificial Intelligence

- **What is Artificial Intelligence (AI)?**



Any techniques that enables computers to mimic and/or augment biological intelligence covering automation, reasoning, and decision-making

The ability to learn from experiences and observations without explicit programming

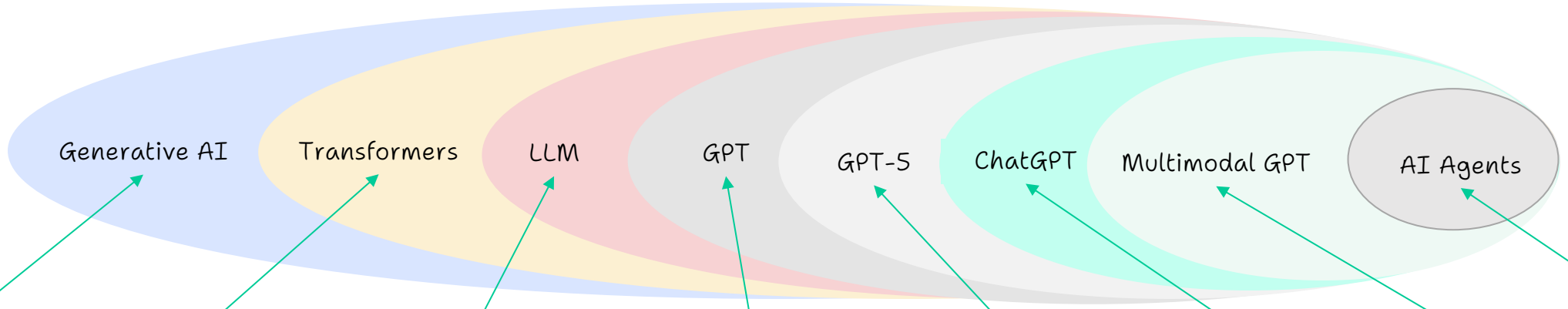
A highly simplified computational model of the biological brain designed for pattern recognition and feature extraction

DL enables learning representations of data with multiple levels of abstraction using deep neural networks. Examples: Convolutional neural network (CNN), Long short-term memory (LSTM), Autoencoders and Transformers

Generative AI focuses on models that can generate new content, like images, text, or audio. Examples, Generative Adversarial Networks (GANs) and Transformers.

Introduction to Artificial Intelligence

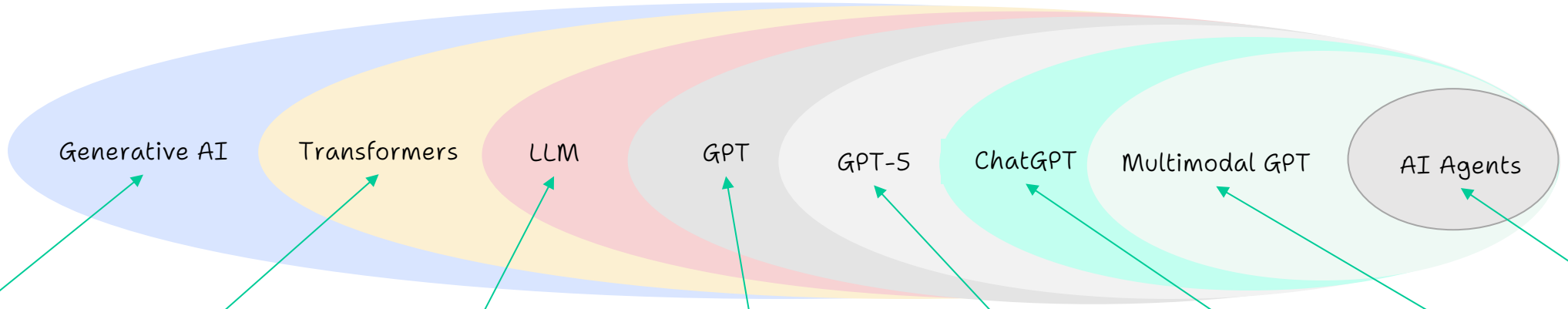
- **What is Artificial Intelligence (AI)?**



Generative AI	Transformers	LLM	GPT	GPT-5	ChatGPT	Multimodal GPT	AI Agents
Generative AI focuses on models that can generate new content, like images, text, or audio. Examples, Generative Adversarial Networks (GANs) and Transformers.	An example of a technology used in generative AI. It is a revolutionary deep learning architecture introduced by Google in 2017 that allows models to understand and generate language efficiently.	Large Language Models (LLMs) focus on processing and generating human-like text. Examples: Bidirectional Encoder Representations from Transformers (BERT) and Generative Pre-trained Transformer (GPT).	Generative Pre-trained Transformers (GPT is a specific subset of Generative AI that uses transformers for text generation.	An advanced LLMs, built on transformer architecture, trained on vast datasets to generate human-like responses.	A specific application of GPT-5, optimized for conversational AI and interactive use.	A version of the GPT model, like GPT-4o, that processes and generates both text and visual inputs, functioning as a Vision Large Model (VLM)	Intelligent connection between reasoning and action

Introduction to Artificial Intelligence

- **What is Artificial Intelligence (AI)?**



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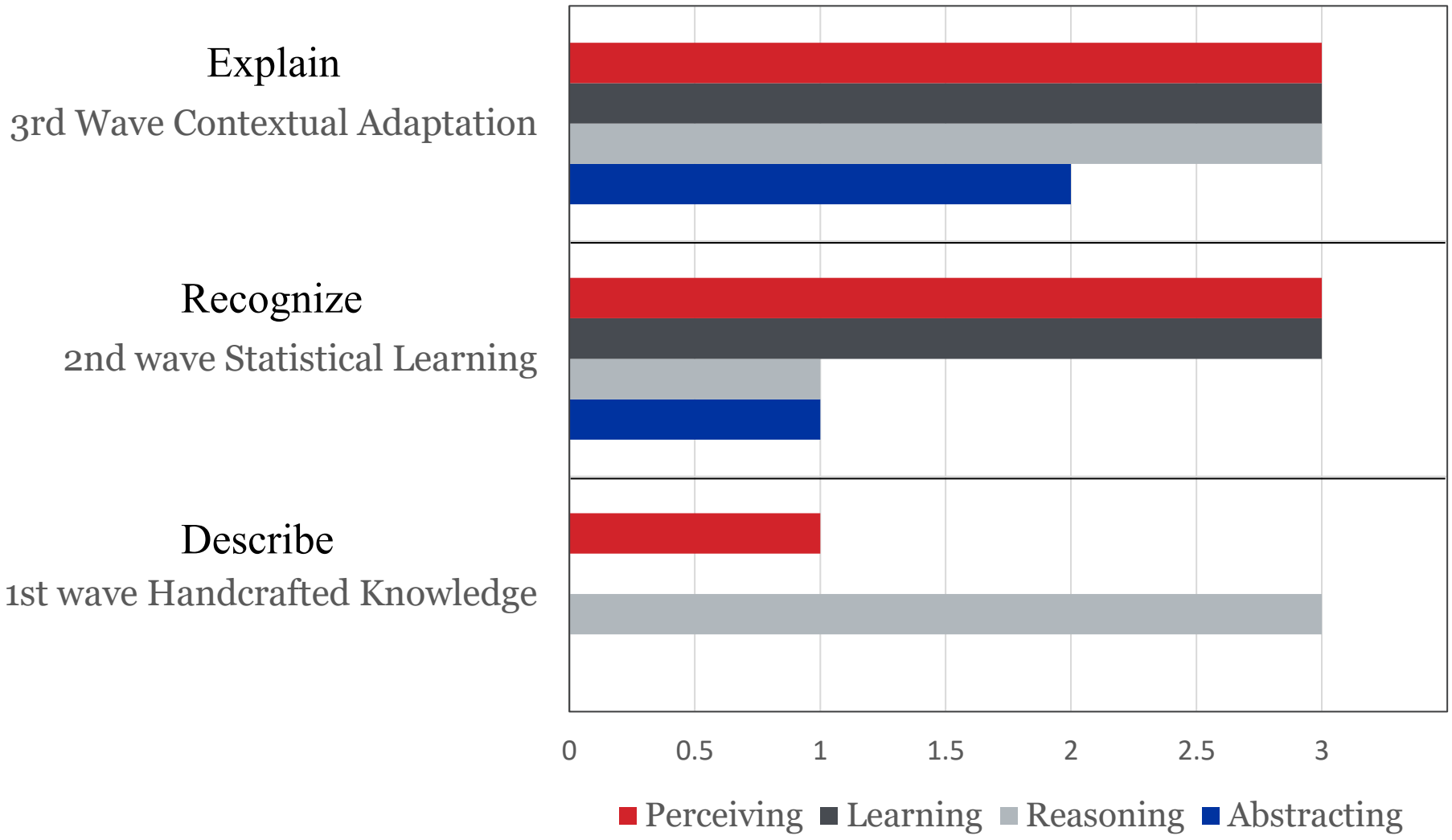
- **AI Waves: A DARPA Perspective**



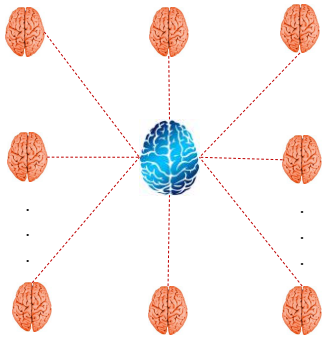
Introduction to Artificial Intelligence

- **AI Waves: Weak/Narrow AI versus Strong/AGI and ASI**

AI Wave	Domain	Brain Power
Artificial Narrow Intelligence (**AI**)	Domain-specific (image recognition, speech recognition, text mining, etc.)	**Looks similar** but not at the same level (supresses brainpower of **mouse**)
Artificial General Intelligence (**AGI**)	Cross-domain capability (***i*-level intelligence**)	Supresses brainpower of human
Artificial Superintelligence (**ASI**)	Cross-domain capability (***i*-level and *g*-level intelligence**)	Supresses brainpower equivalent to all human brains combined

Mouse brain

Human brain



Super brain

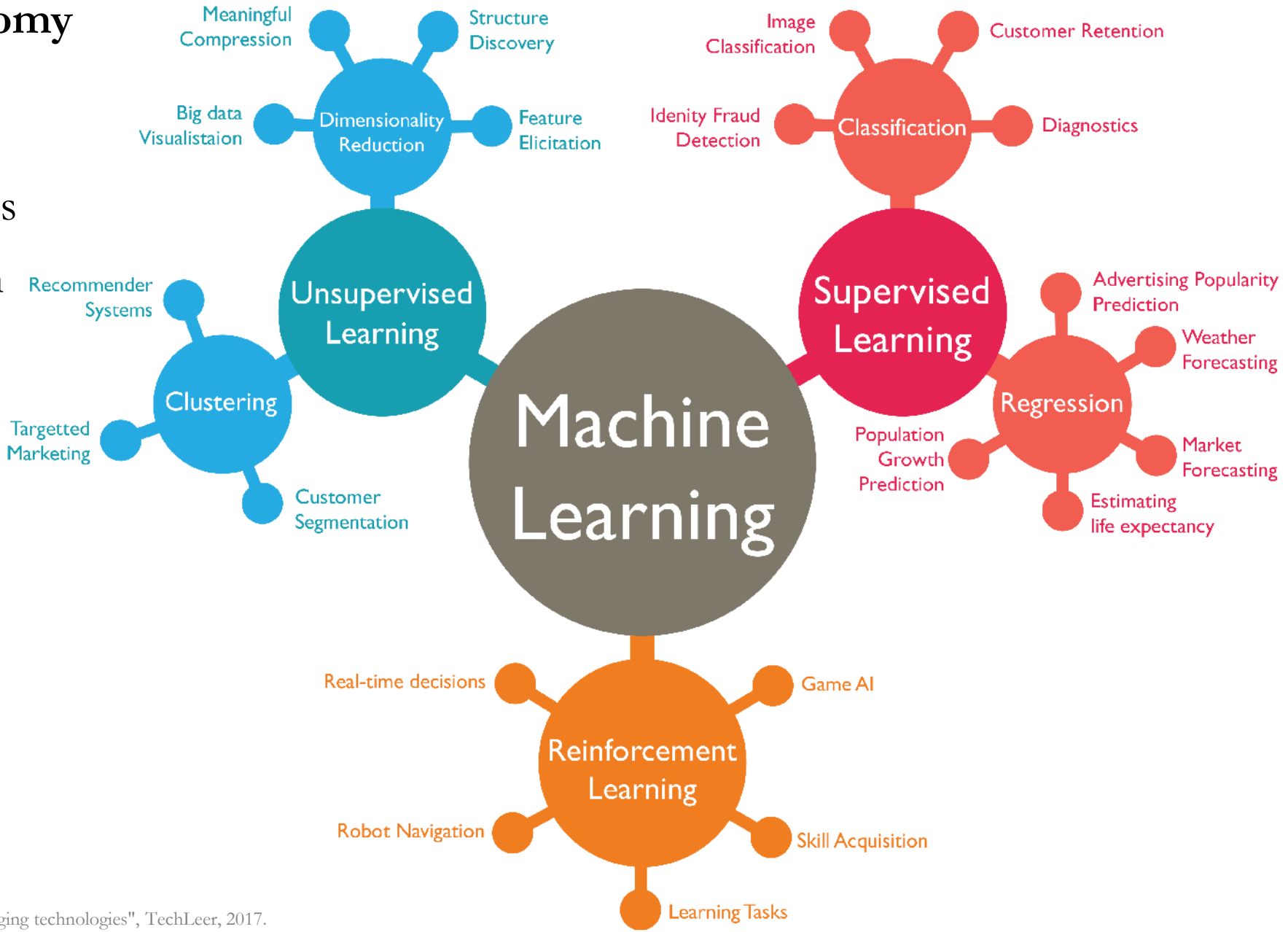
Outline

- Introduction to Artificial Intelligence
- **Introduction to Machine Learning**
- Responsible AI
- Data Analytics

Introduction to Machine Learning

- **Machine Learning Taxonomy**

  Machine learning (ML) is a subfield of AI that endows an artificial system or process with the ability to learn from experience and observation without being explicitly programmed.



Source: Vishakha Jha, "Machine Learning Algorithm - Backbone of emerging technologies", TechLeer, 2017.

Introduction to Machine Learning

- **Why is ML taking off?**

1 Big data availability

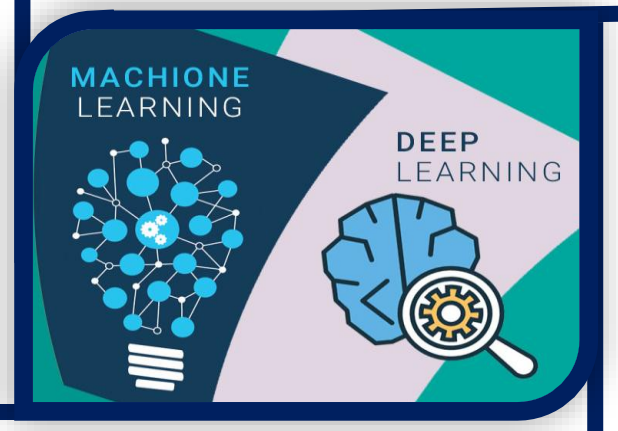
Facebook: 350 M images uploaded per day

Twitter community generates more than 12 terabytes of data per day

YouTube: 300 hours of video uploaded every minutes

Walmart: 2.5 Petabytes of customer data hourly

Autonomous Vehicles: 4-20 TB per day

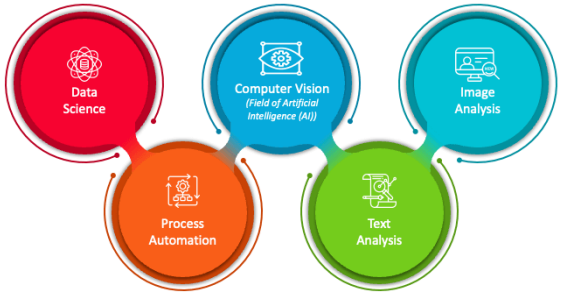


2 GPU/TPU/NPU acceleration

3 Huge investment on AI: the new space race

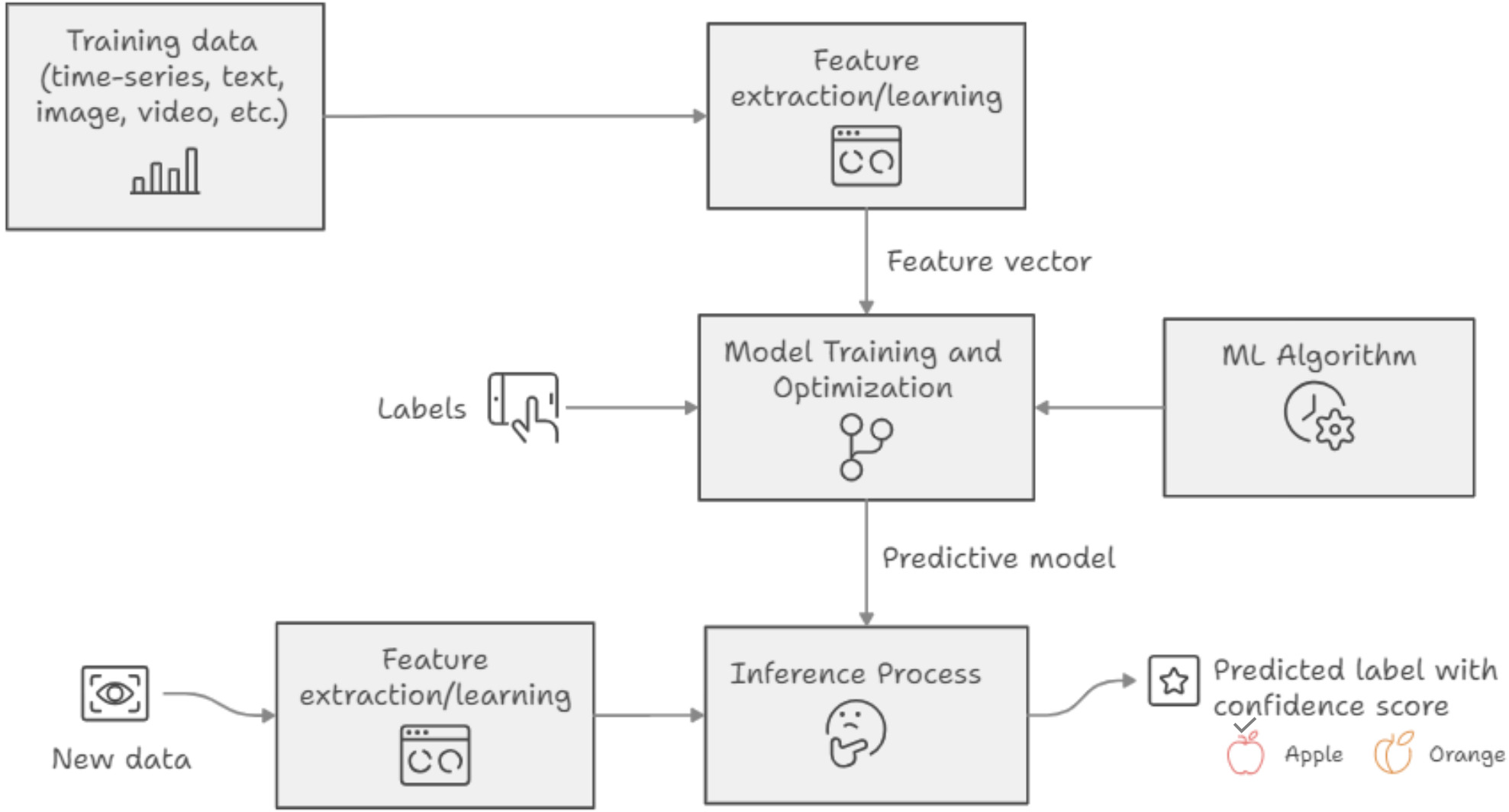
- China: expected to reach $38 billion in 2027 [ref]
- European Union: $31 billion investment by 2025 [ref]
- Canada: $2.4 billion in AI in 2024 budget [ref]
- UK: $1.2 billion in AI investment [ref]
- Softbank: invests $108 billion in AI companies [ref]

4 Democratization of AI/ML



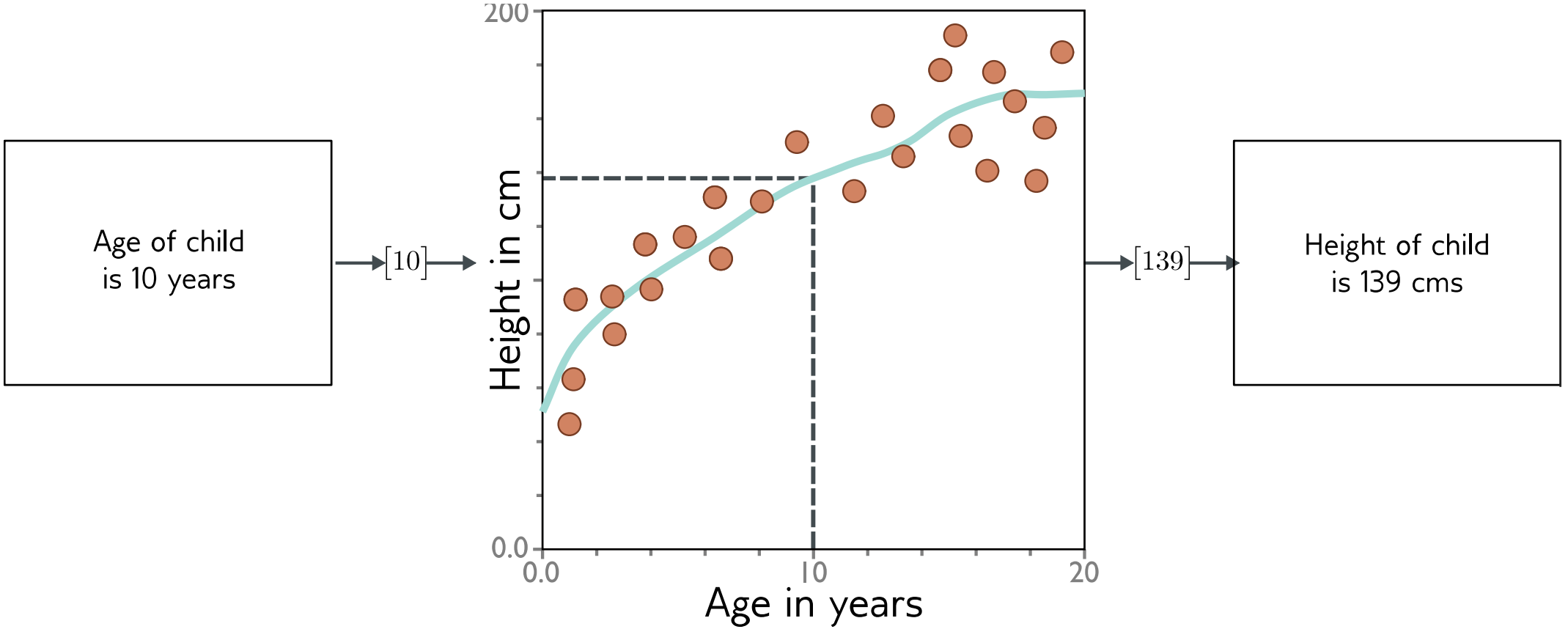
Introduction to Machine Learning

- **Supervised Machine Learning**



Introduction to Machine Learning

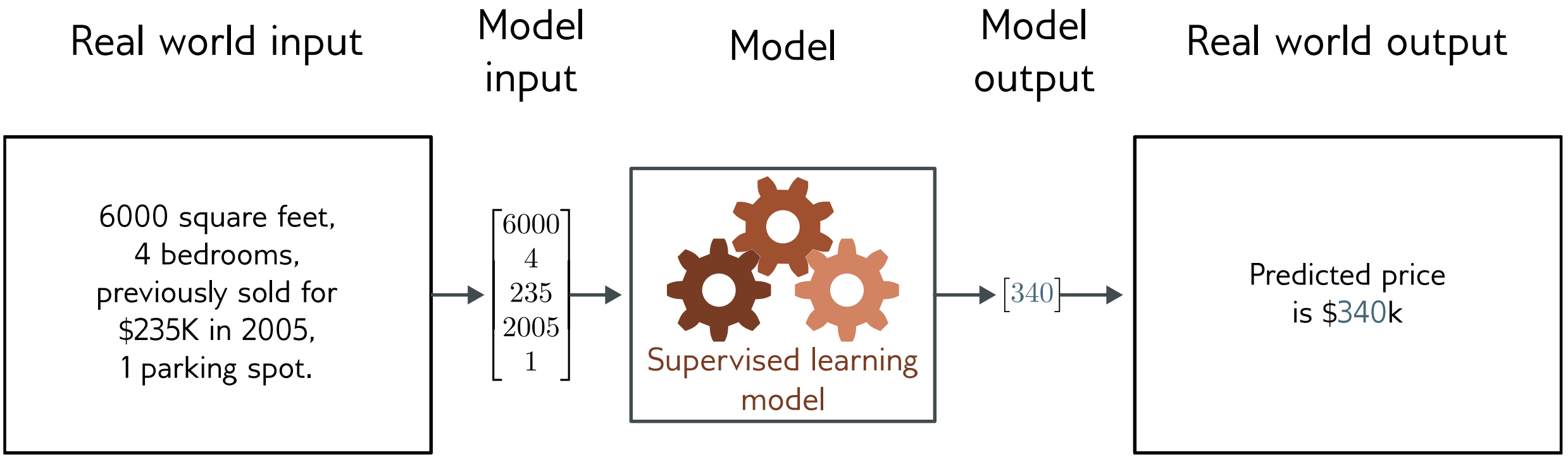
- **Supervised Machine Learning**



Source: Simon Prince. Understanding Deep Learning. MIT Press, 2023.

Introduction to Machine Learning

- **Supervised ML Applications: Regression**

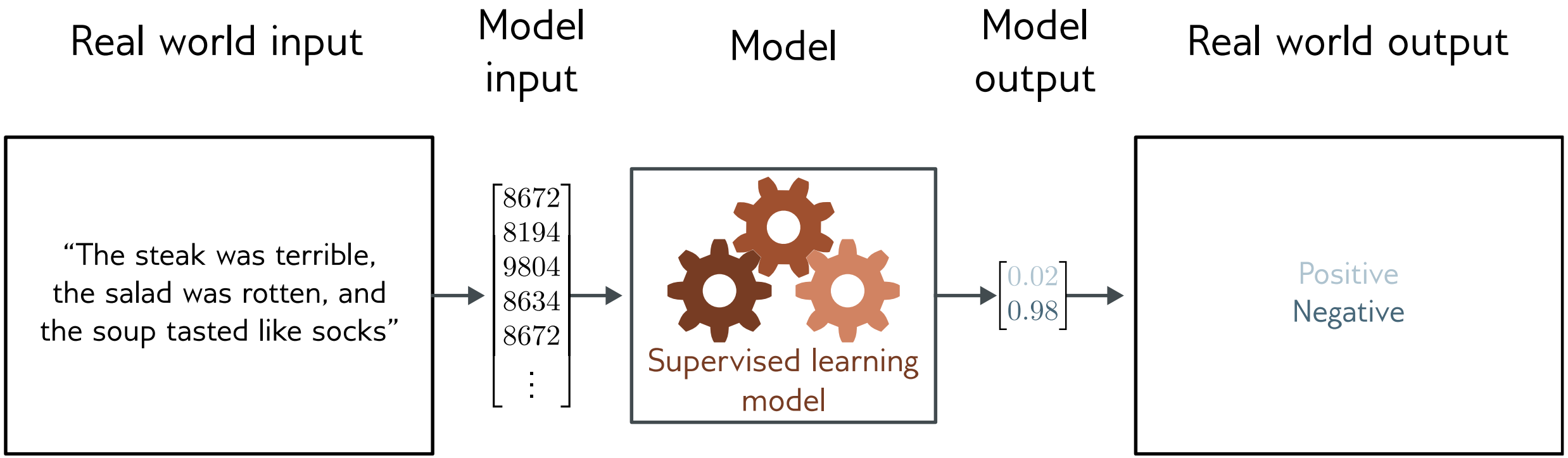


- Univariate regression problem (one output, real value)
- Fully connected network

Source: Simon Prince. Understanding Deep Learning. MIT Press, 2023.

Introduction to Machine Learning

- **Supervised ML Applications : Text Classification**

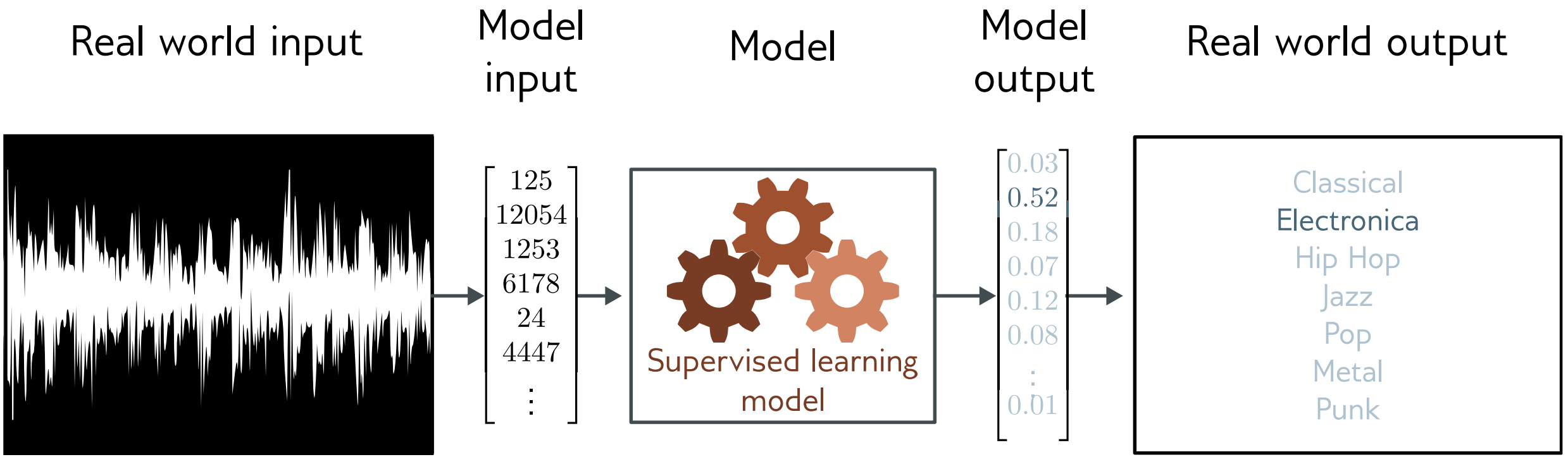


- Binary classification problem (two discrete classes)
- Transformer network

Source: Simon Prince. Understanding Deep Learning. MIT Press, 2023.

Introduction to Machine Learning

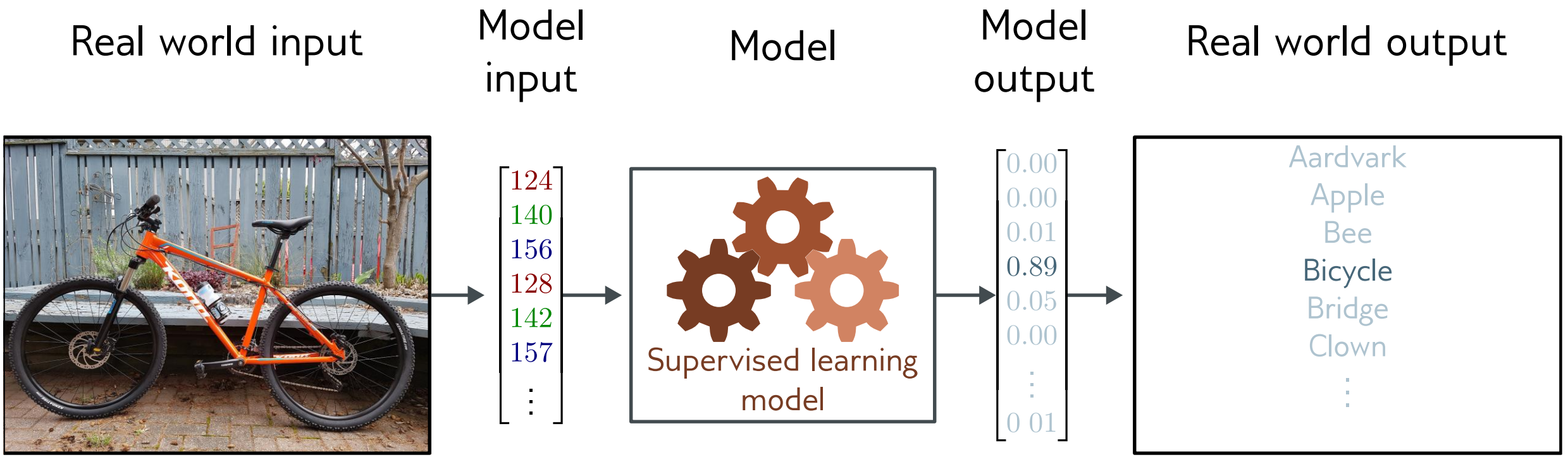
- **Supervised ML Applications : Music Genre Classification**



- Multiclass classification problem (discrete classes, >2 possible values)
- Convolutional network

Source: Simon Prince. Understanding Deep Learning. MIT Press, 2023.

- **Supervised ML Applications : Image Classification**



- Multiclass classification problem (discrete classes, >2 possible classes)
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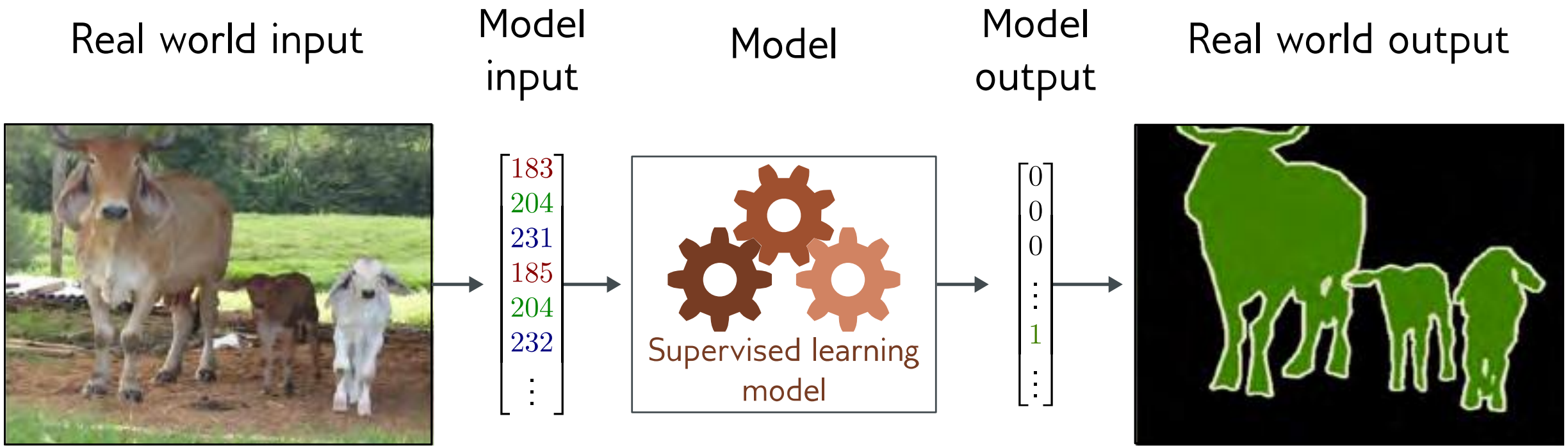
Source: Simon Prince. Understanding Deep Learning. MIT Press, 2023.

Introduction to Machine Learning

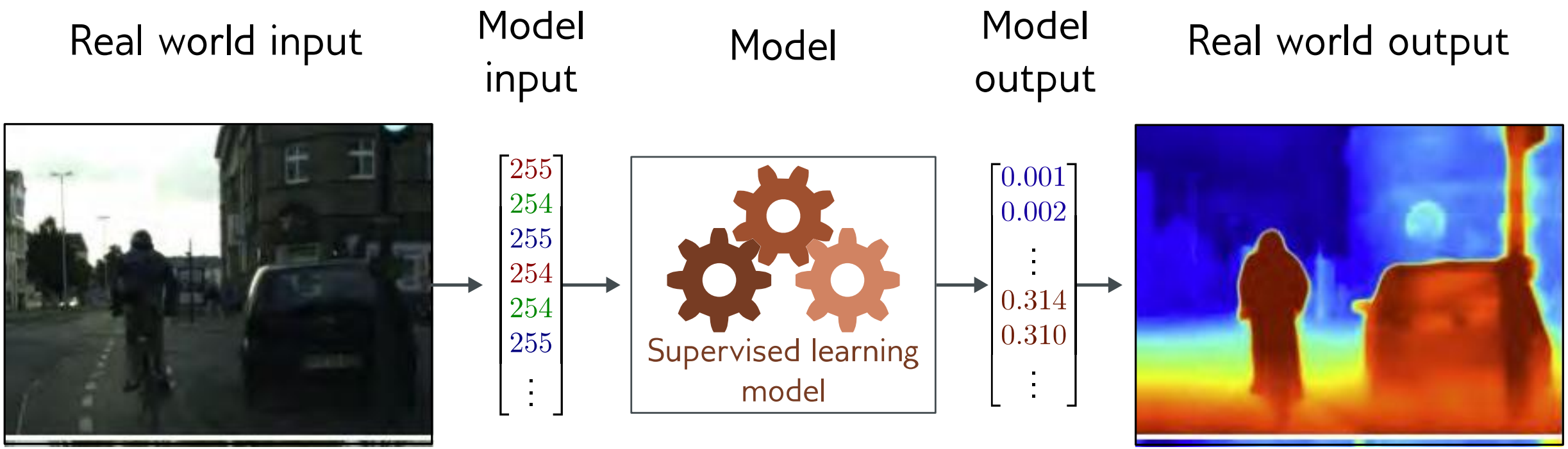
- **Supervised ML Applications : Image Segmentation**



- Multivariate binary classification problem (many outputs, two discrete classes)
- Convolutional encoder-decoder network

Source: Simon Prince. Understanding Deep Learning. MIT Press, 2023.

- **Supervised ML Applications : Depth Estimation**

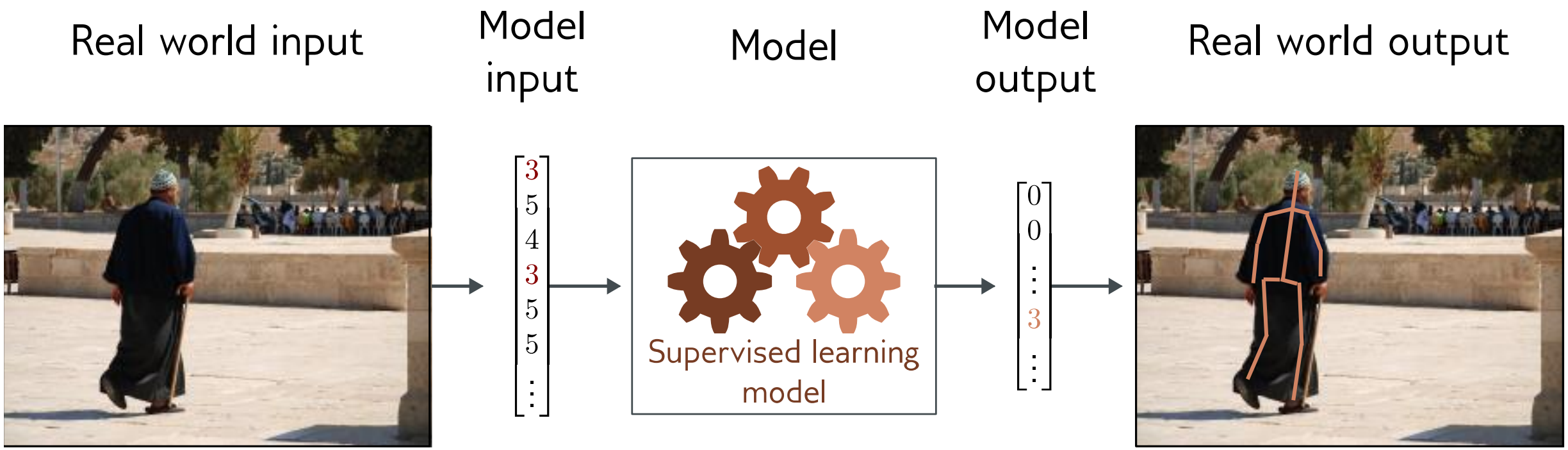


- Multivariate regression problem (many outputs, continuous)
- Convolutional encoder-decoder network

Source: Simon Prince. Understanding Deep Learning. MIT Press, 2023.

Introduction to Machine Learning

- **Supervised ML Applications : Pose Estimation**



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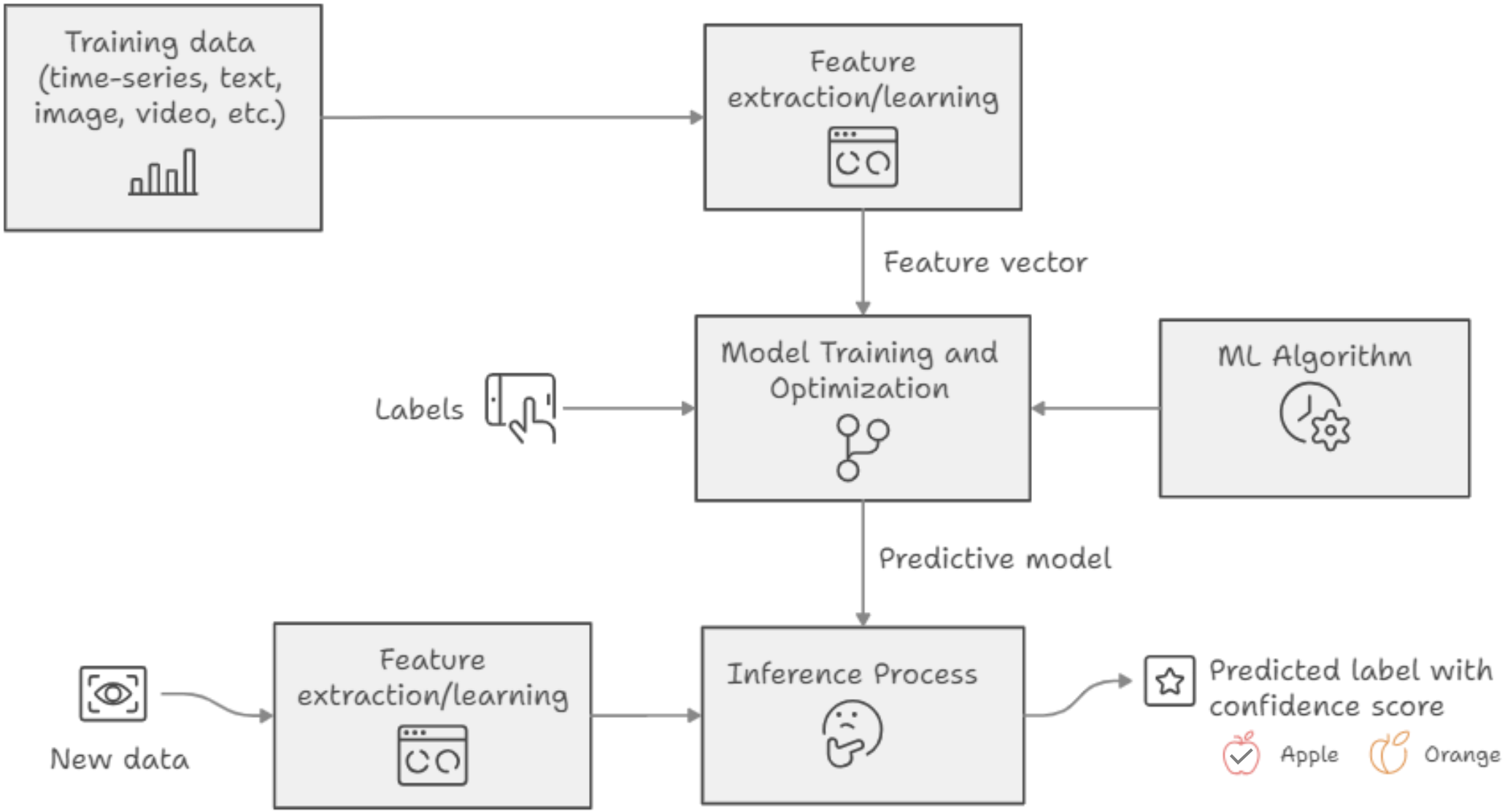
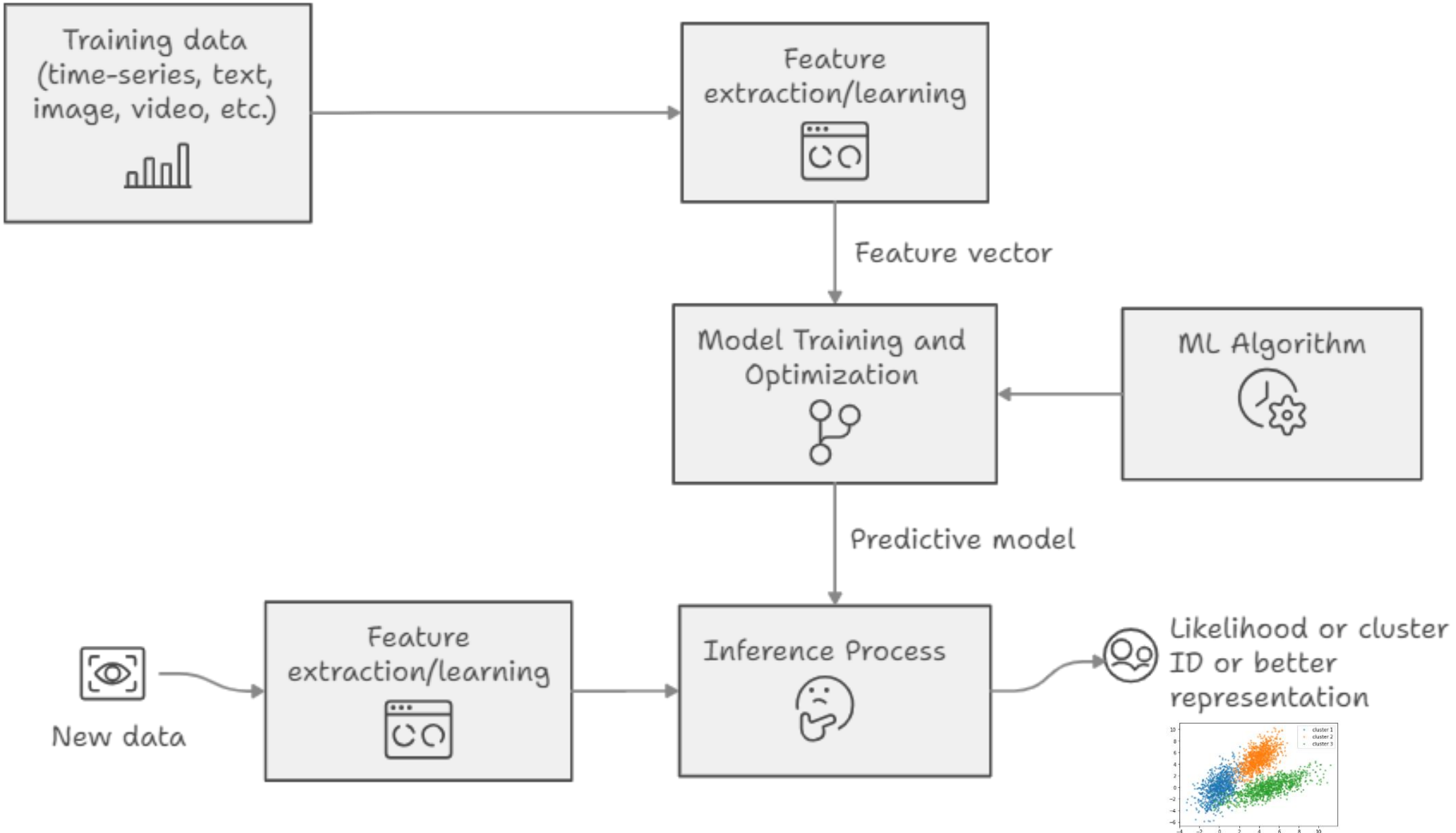
Introduction to Machine Learning

- **Supervised Learning**

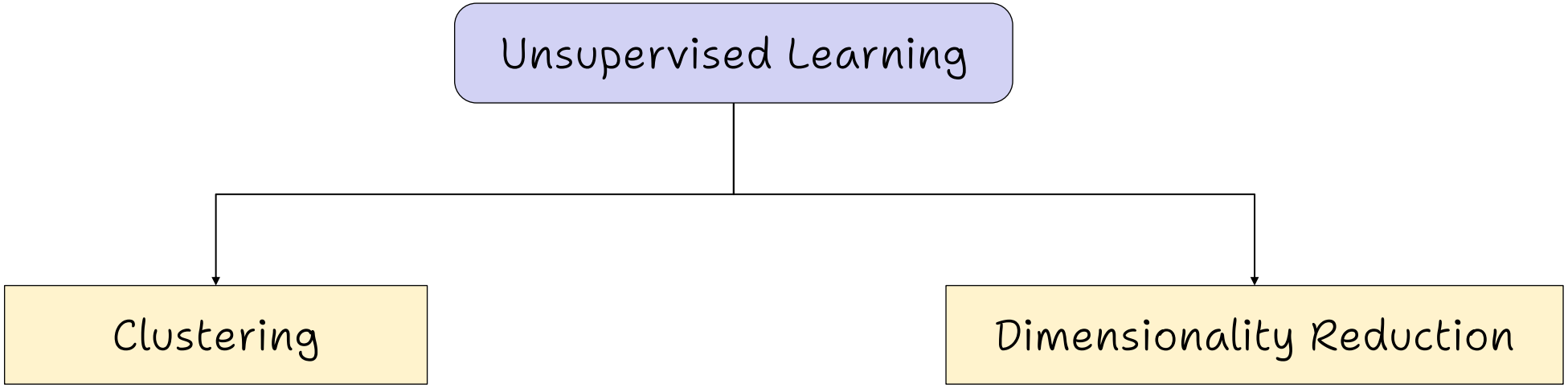


Introduction to Machine Learning

- **Unsupervised Learning**



- **Unsupervised Learning**



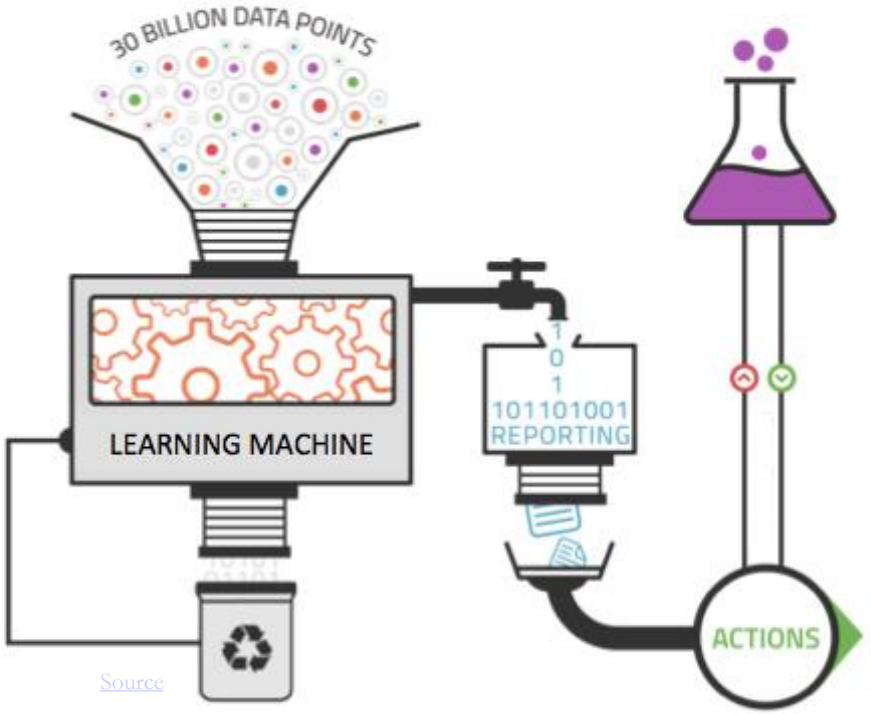
- K-means, X-means
- Self-Organizing Map (SOM)
- DBSCAN
- CLARA
- CHAMELEON
- Clustering Using Representatives (CURE)
- Robust Clustering using links (ROCK)

- Principal Component Analysis (PCA)
- Linear Discriminant Analysis (LDA)
- Latent Semantic Analysis (LSA)
- Truncated Singular Value Decomposition (SVD)
- Factor Analysis
- t-distributed Stochastic Neighbor Embedding (t-SNE)
- Uniform Manifold Approximation and Projection (UMAP)

- **Statistical ML Requirements**

  Three main requirements to apply data-driven ML:

  - Pattern exists;
  - Pattern cannot pin out mathematically using attainable and mathematically tractable models and
  - Data is available



Introduction to Machine Learning

- **Machine Learning versus Curve Fitting**

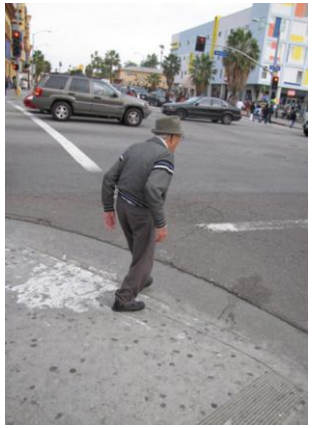
The learning algorithm seeks a mapping function $f: \mathrm{X} \times \mathrm{y} \longrightarrow \mathbb{R}$

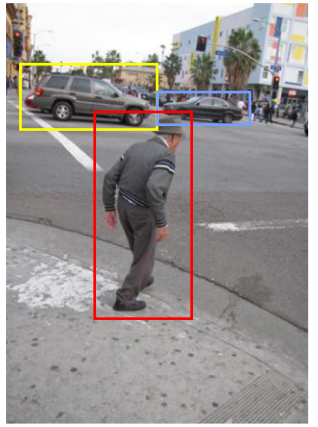
where X represents feature vector and y represents the output

The learned state returns y that gives a minimum cost/loss function $\mathrm{L}(\mathrm{y}, f(\mathrm{X}))$ over the joint distribution of all (y, X) of f:

$$f^* = \arg\min_f E_{\mathrm{y},\mathrm{X}} \mathrm{L}(\mathrm{y}, f(\mathrm{X})) = \arg\min_f E_{\mathrm{X}}[E_y(\mathrm{L}(\mathrm{y}, f(\mathrm{X})))|\mathrm{X}]$$

Model	Input	Output
Image classification	Image	Category
Speech recognition	Acoustic utterances	Spoken word as text
Machine translation	English sentence	Spanish sentence
Gaming	Current board state	Next move
Prognostic	Vehicle data	Vehicle condition
…	…	…





Introduction to Machine Learning

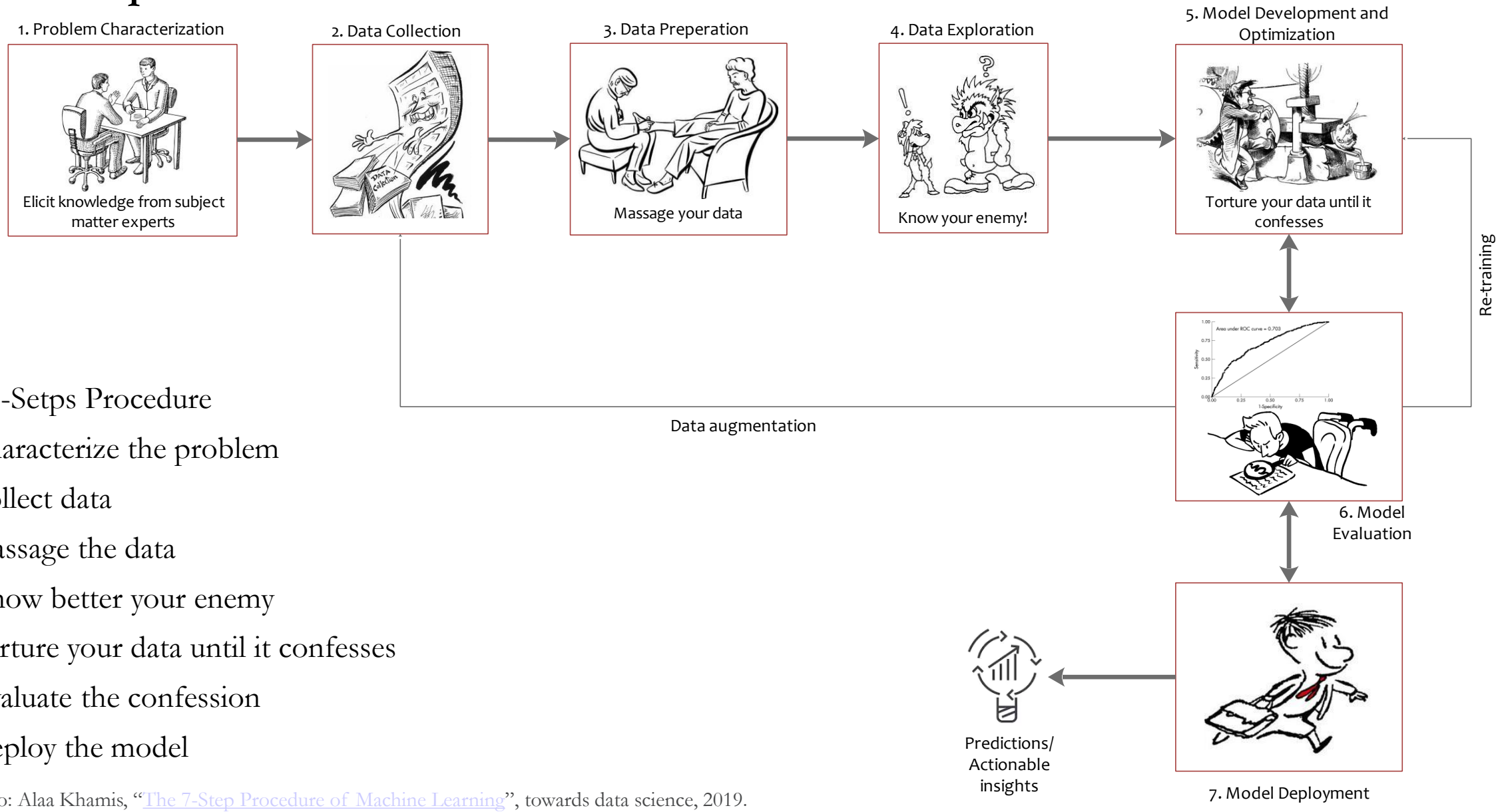
- **Machine Learning versus Curve Fitting**

Component	Curve Fitting	Machine Learning
Model (Hypothesis class)	$f(x) \in \mathrm{F}$	• Linear (Perceptron, SVM, Logistic regression, etc.) • Directed graphical model • Undirected graphical model • Matrices • Deep structure (Feedforward deep networks, RBM, RNN, CNN, CapsNets, GANs, GNNs)
Scoring Criterion	Population: $S(f) = E_{x,y}L(y, f(x))$ Sample: $\frac{1}{2}\sum_{i=1}^{n} L(y_i, f(x_i))$	Loss function, log loss, etc.
Search Strategy	$\hat{f} = \arg min_{f \in \mathrm{F}} S(f)$	Gradient decent, Stochastic gradient descent (SGD)

Name	Type	Description	Advantages	Disadvantages
Linear Regression		-The best fit line through all data points	-Easy to understand -you can clearly see what the biggest drivers odf the model are.	-sometimes to simple to capture cpmöex relationships between variables, -Tendency für the model to overfit.
Logistic Regression		-The adoption for linear regression to problembs of classification	-Easy to understand	-sometimes to simple to capture cpmöex relationships between variables, -Tendency für the model to overfit.
Decision Tree		-A graph that uses branching method to match all possible outcomes of a decision	-Easy to understand and implement.	-Not often use of ist own for prediction because it's also often too simple and not powerful enough for complex data.
Random Forest		- Takes the average of many decision trees. Each tree is weaker than the full decision tree, but combining them we get better overall performance.	-A sort of „wisdom of the crowd", Tend to result in very high quality results. -Fast to train	-Can be slow to output predictions relative to other algorithms. -Not easy to understand predictions.
Gradient Boosting		-Uses even weaker decision trees that increasingly focused on „hard examples"	-High-performing	-A small change in the future set or training set can create radical changes in the model. -Not easy to understand predictions.
Neural Networks		-Mimics the behaviour of the brain. NNs are interconnected Neurons that pass messages to each other. Deep Learning uses severak layers of NNs to put one after the other.	-Can handle extremely complex tasks. No other alsgorithm comes close in image recognition.	-very very slow to train. Because they have so many layers. Require a lot of power. -Almost impossible to understand predictions.

Introduction to Machine Learning

- **The 7-Step Procedure**



The 7-Setps Procedure

1. Characterize the problem
2. Collect data
3. Massage the data
4. Know better your enemy
5. Torture your data until it confesses
6. Evaluate the confession
7. Deploy the model

More info: Alaa Khamis, "The 7-Step Procedure of Machine Learning", towards data science, 2019.

Introduction to Machine Learning

- **Machine learning Challenges**

1. Problem Characterization (ill-structured problems, unknown unknowns or edge cases)
2. Data Collection (noise, control factors and adversarial cases)
3. Data Preprocessing (data imperfection, cleaning, fusion, feature extraction, etc.)
4. Modeling (No free lunch theorem)
5. Optimization (Many parameters to be tuned)
6. Evaluation (Metrics tradeoff)
7. Validation (Robustness test and mass validation)
8. Deployment (Operational AI, data mismatch)
9. Learning over time (model updates, domain adaptation, OTA, Edge, Fog, Cloud)
10. Model interpretability

Outline

- Introduction to Artificial Intelligence
- Introduction to Machine Learning
- **Responsible AI**
- Data Analytics

Responsible AI

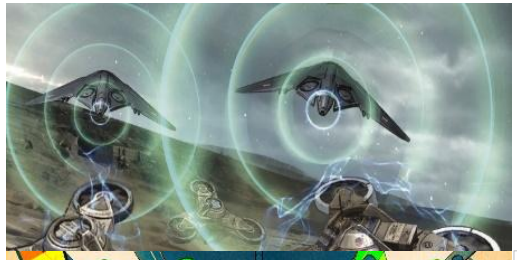
- **AI: Benefits or Risks?**

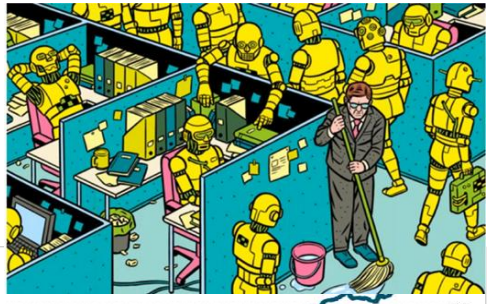
Andrew Ng

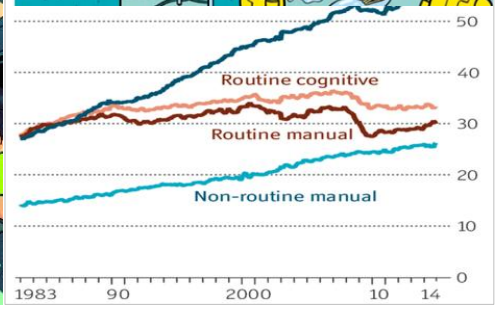
Sebastian Thrun

Ray Kurzweil

Benefits to the humanity







Significant existential risk

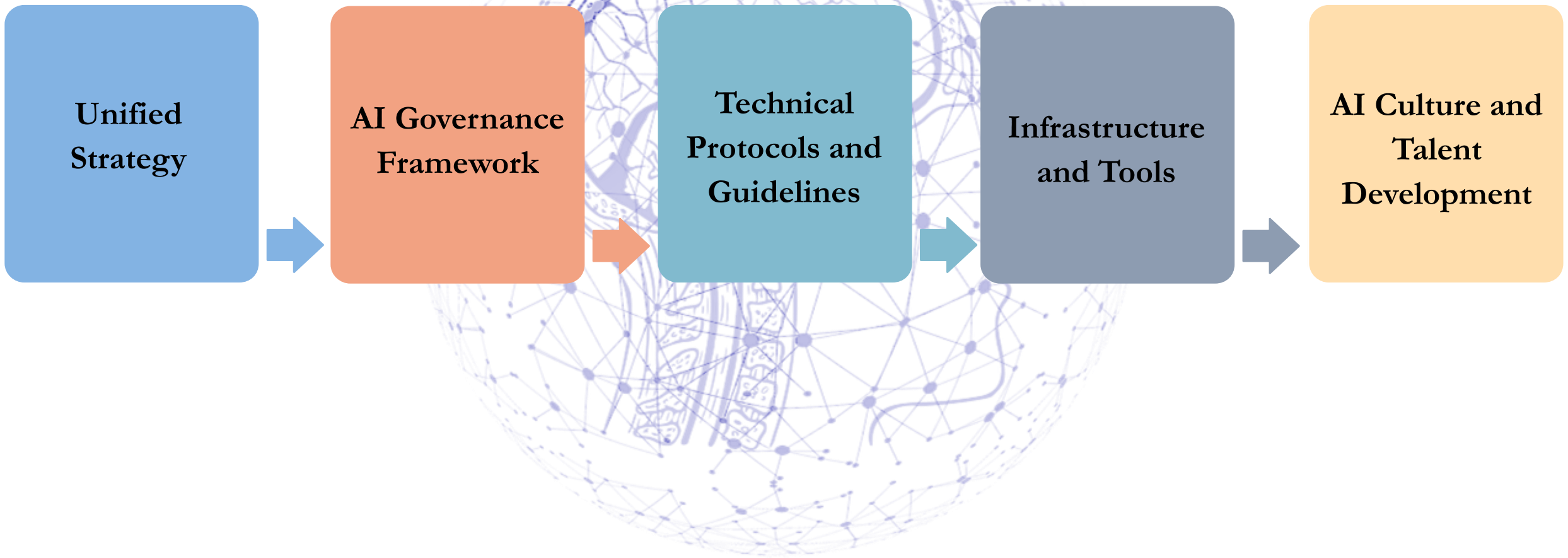
Stephen Hawking

Bill Gates

Elon Musk

Responsible AI

- Keys for successful adoption of Responsible AI



Responsible AI

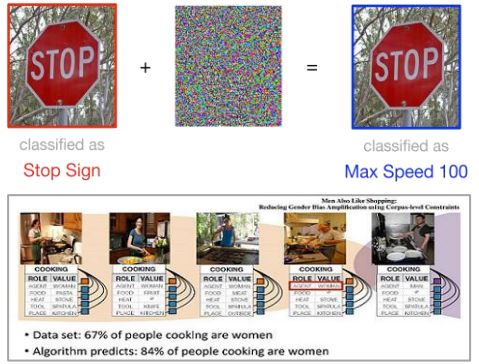
Responsible AI ⇒ Ethics + Safety + Security + Privacy + Compliance + Bias + Performance + Transparency

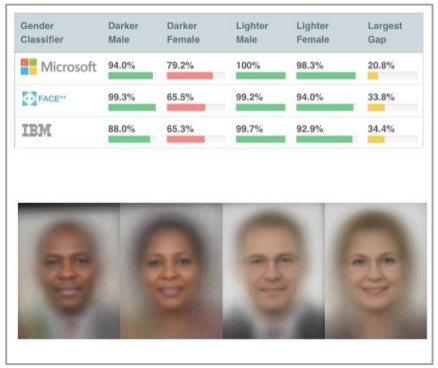
TECHNOLOGY

The Future of Artificial Intelligence Depends on Trust

If it is to drive business success, AI cannot hide in a black box. For more insight, see "3 Steps to Building Trust in AI."

by Anand Rao and Euan Cameron





Responsible AI

[Video]

Outline

- Introduction to Artificial Intelligence
- Introduction to Machine Learning
- Responsible AI
- **Data Analytics**

Data Analytics

Data Analytics is the process of **examining raw data to discover patterns, trends, and insights** that can support decision-making.

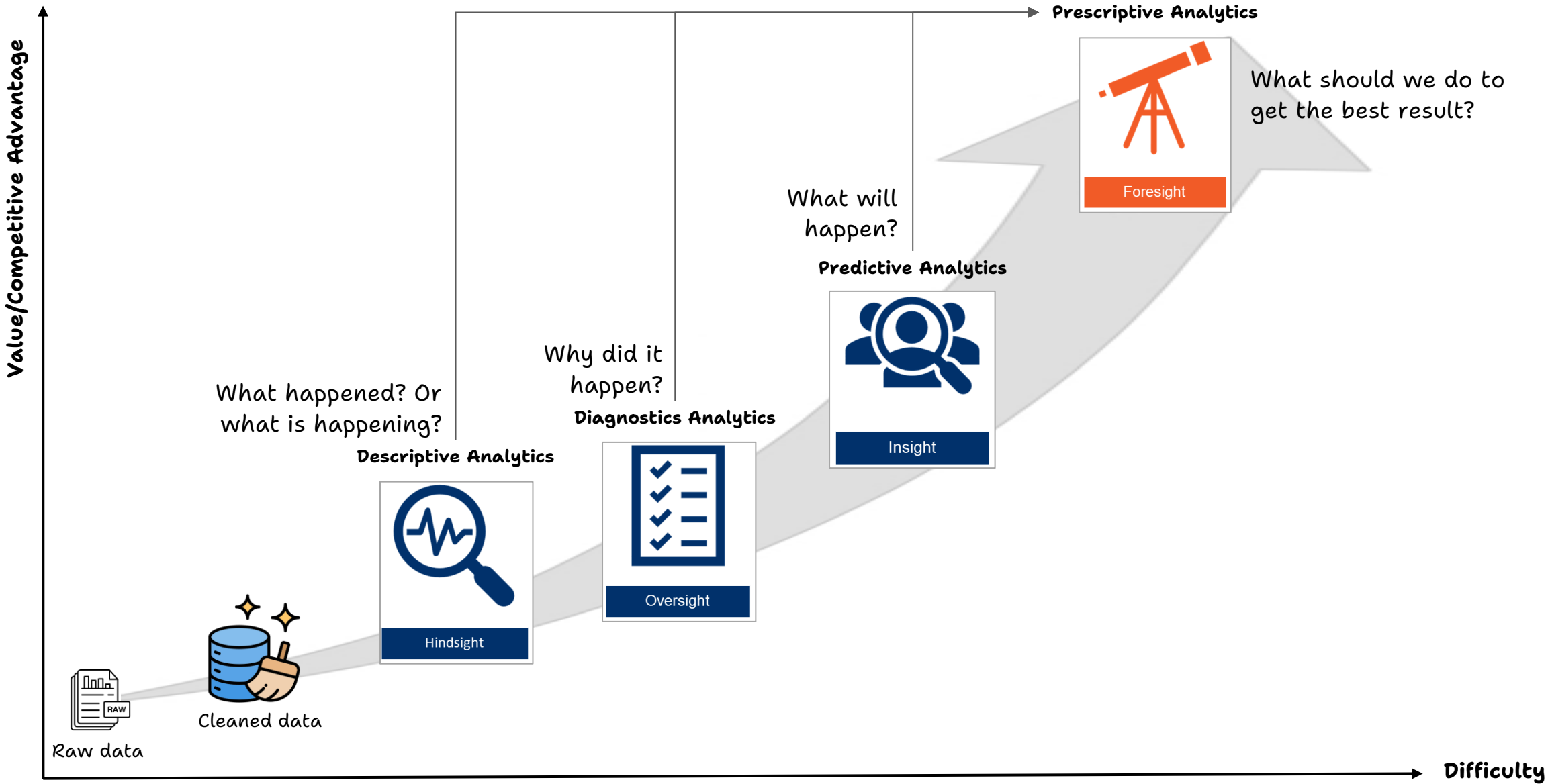
Data Analytics in maintenance and reliability is the process of **collecting, cleaning, and analyzing equipment and operational data** to uncover patterns, predict failures, and support better maintenance decisions.

It helps organizations:

- Understand past events (why failures happened).
- Monitor current conditions (detect anomalies).
- Predict future outcomes (estimate remaining useful life
- Optimize actions (decide the best time for maintenanc

Data Analytics

- The 4 Lines of Sight



Data Analytics

- Equipment data (sensor readings: temperature, vibration, pressure, age)
- Failure indicators and observed time-to-failure

Raw data

Cleaned data

Descriptive Analytics

Hindsight

What happened? Or what is happening?

- Summary statistics and failure rates
- Visualizations of distributions (e.g., time-to-failure histogram)
- Baseline understanding of asset performance

Diagnostics Analytics

Cleaned dataset (sensors, failure labels, time-to-failure)

Oversight

Why did it happen?

- Correlation analysis between variables and failures
- Feature importance rankings
- Visual insights (e.g., temperature vs. RUL plots)
- Identification of key drivers of degradation

Predictive Analytics

Historical labeled data (sensor values, asset age, failure outcomes, time-to-failure)

Insight

What will happen?

- Classification model: predicts short-horizon failure risk
- Regression model: estimates remaining useful life (RUL)
- Performance metrics (e.g., accuracy, AUC, RMSE)
- Forward-looking predictions for assets in operation

Prescriptive Analytics

Business cost parameters (planned vs. unplanned maintenance costs, risk thresholds)

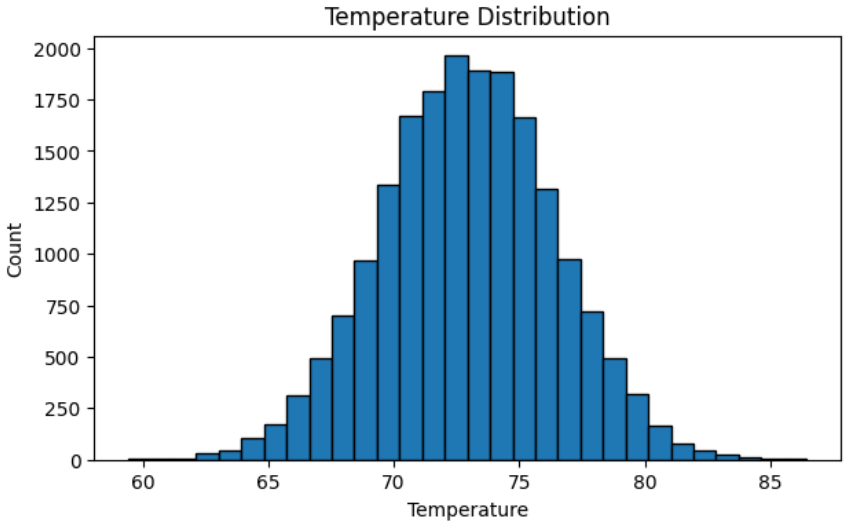
Foresight

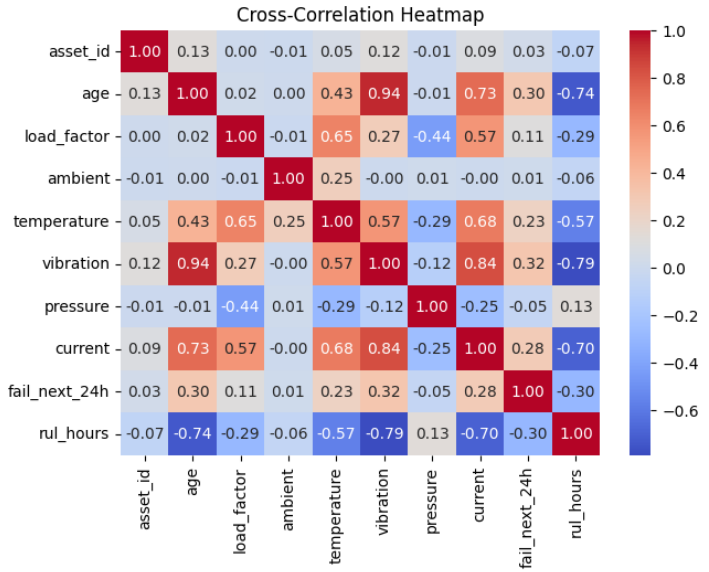
What should we do to get the best result?

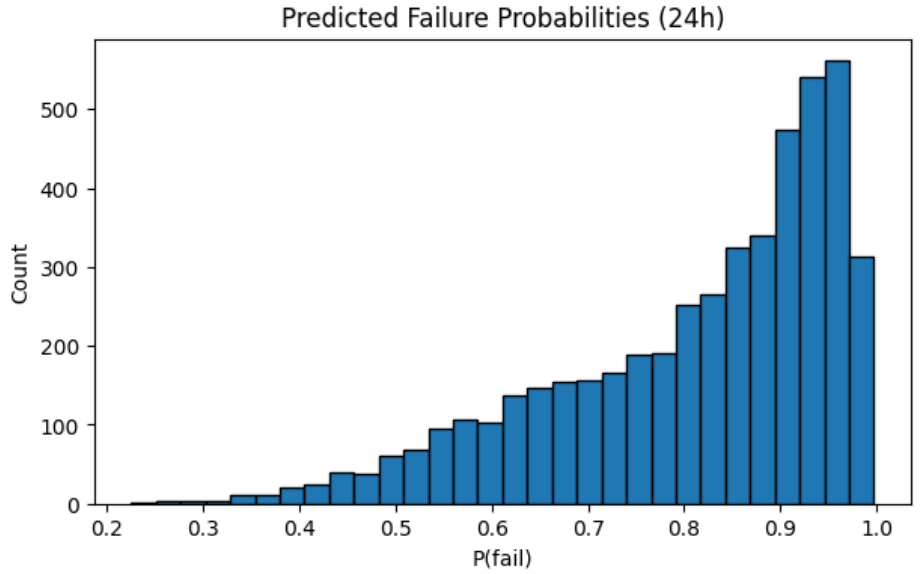
- Maintenance decision rules (maintain now vs. continue operating)
- Prioritized maintenance list based on risk or expected cost
- Actionable recommendations to minimize downtime and cost

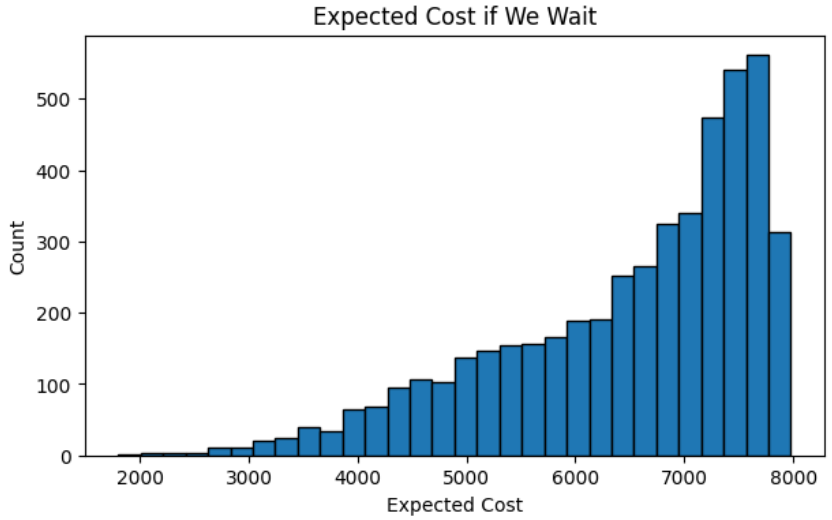
Data Analytics

- Hands-on Example









https://github.com/Dr-AlaaKhamis/ISE518/tree/main/4_Intro_DA