Machine Learning (ML)

Chapter 1:

Introduction to Machine Learning

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Course Outline

- ✓ Introduction to Machine Learning and its applications
- ✓ Statistical Learning
- ✓ Linear regression
- ✓ Multiple Linear Regression
- ✓ Multivariate Multiple Regression
- ✓ Classification and Clustering algorithms (Logistic Regression, KNN and Performance Evaluation)
- ✓ Gradient Decent (GD), Stochastic Gradient Decent (SGD), and Cross-validation, Regularization
- ✓ Unsupervised Learning
- ✓ Support Vector Machine (SVM)
- ✓ Support Vector Classification (SVC)
- ✓ Decision Trees and Random Forest algorithms
- ✓ Artificial Neural Network (ANN)
- ✓ Deep Learning (DL)
- ✓ Neural Network and Convolutional Neural Networks (CNNs)
- ✓ Transfer Learning and Model Acceleration
- ✓ Ensemble learning techniques
- ✓ Multi-task Learning (MLT)
- ✓ State-of-the-art algorithms

Assessment

- ✓**Assignments and homework:** 30%
- ✓**Project/Research**: 35%.
- ✓**Midterm :** 15%
- ✓**Final Exam**: 20%

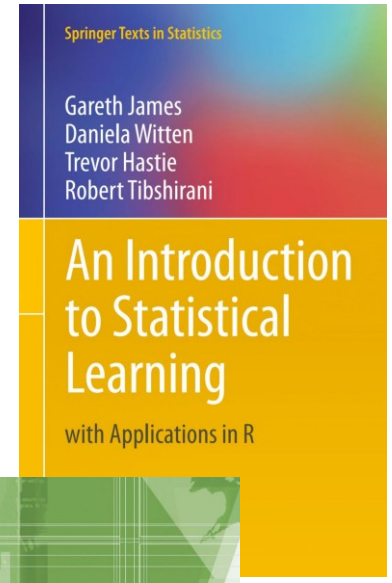
Slides and class materials: Moodle

Contact me: saeedvand@ntnu.edu.tw

Textbooks

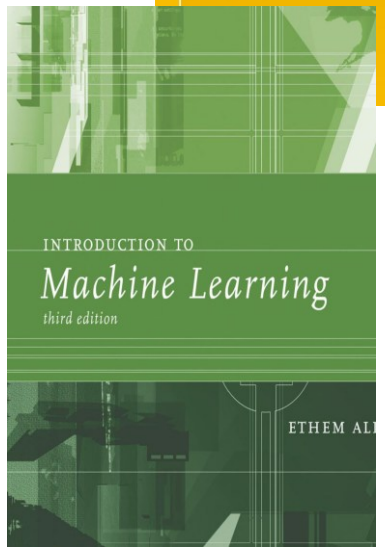
✓**An Introduction to Statistical Learning,** second edition

[Gareth James • Daniela Witten • Trevor Hastie • Robert Tibshirani]



✓**Introduction to Machine Learning,** third edition

[Ethem Alpaydin]



Practices

- We prefer **Python,** but ML is not limited to any specific programming language

- **Suggestion is to use IDEs like:**
  - ✓ Visual Studio Code (IDE)

  - ✓ PyCharm (IDE)

  - ✓ Notepad ++

  - ✓ Jupyter Notebooks

Note: For data science Anaconda is also useful.

kaggle

- Online data science projects and machine learning.
- Competitions, datasets, …

https://www.kaggle.com/

Outline

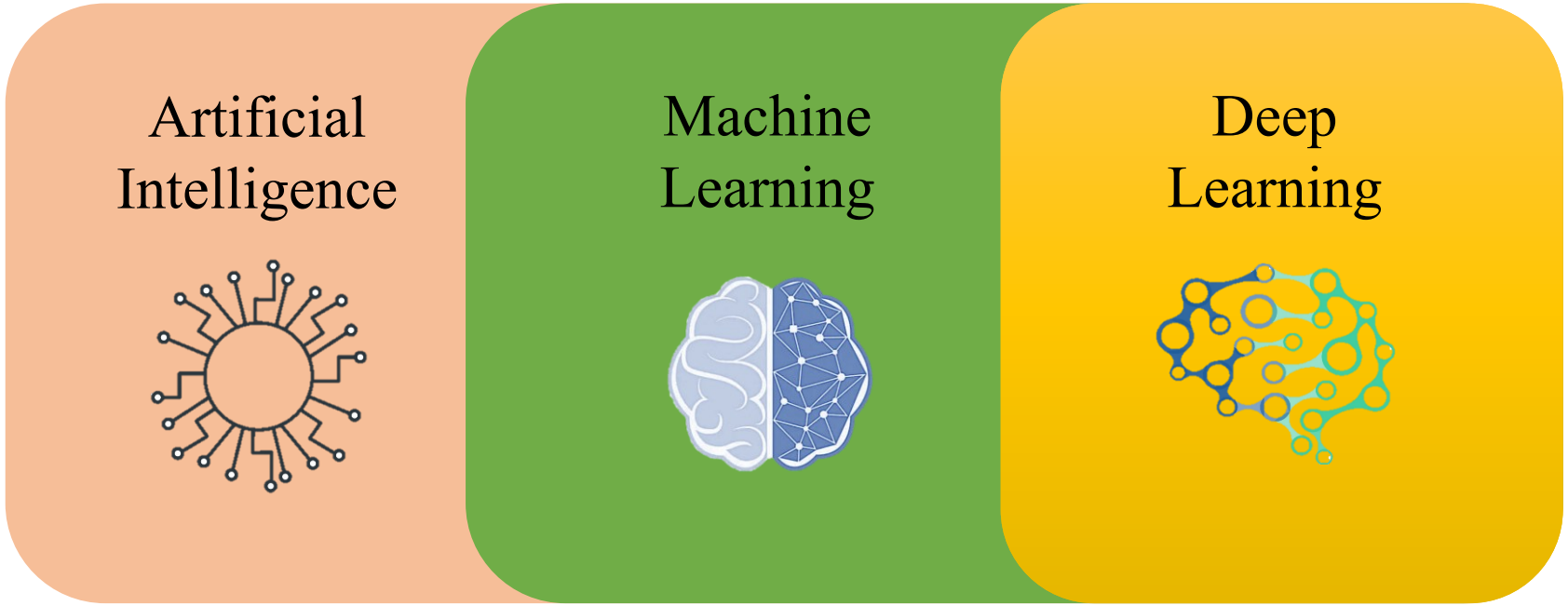
Chapter 1:

- ✓ Introduction to Machine Learning (ML)
- ✓ History of Machine learning
- ✓ Supervised learning, Unsupervised learning, Reinforcement learning definitions
- ✓ Semi-Supervised learning definition
- ✓ The latest general advances in Machine Learning

Aim of this chapter:

- ✓ Understanding the concept and overview of the Machine Learning (ML) and also discuss the important elements of ML along with key advances.

Machine learning history?



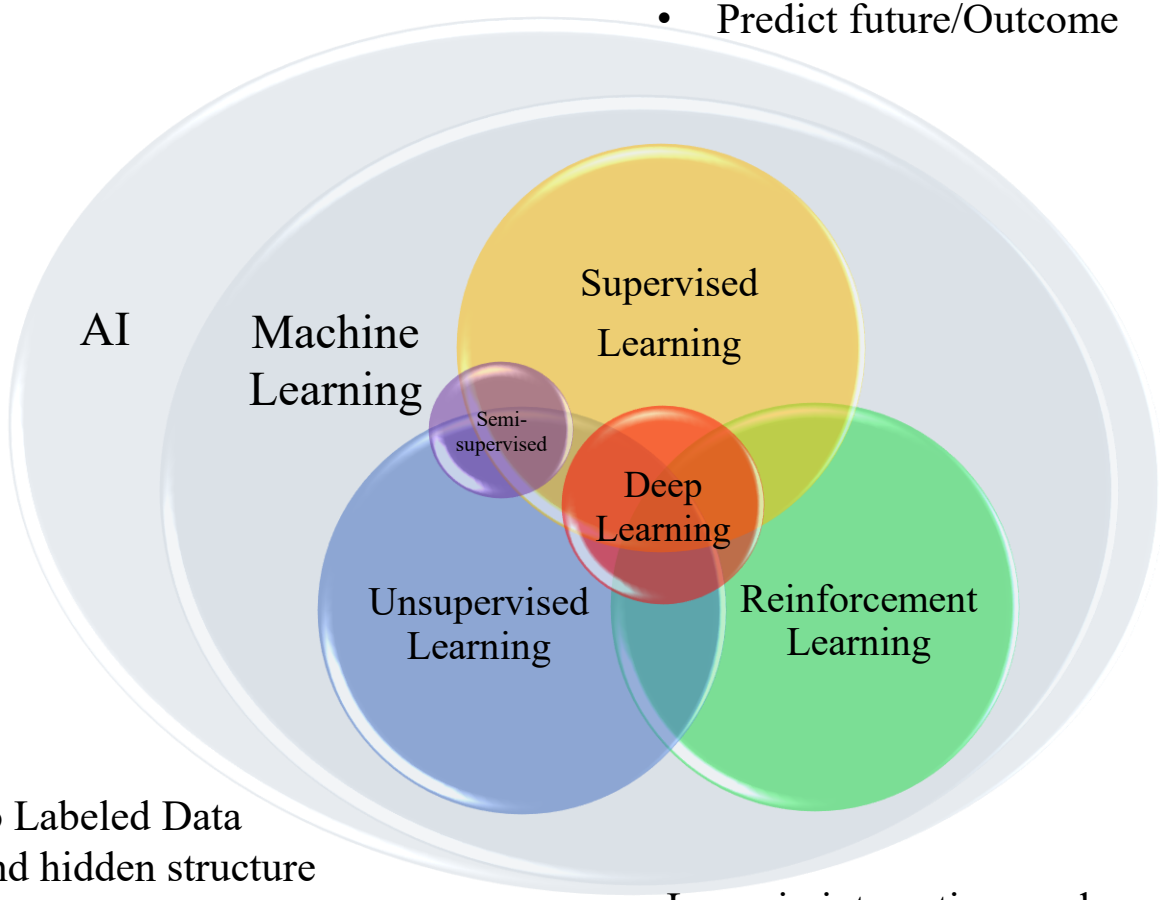
What is the Machine Learning

Machine Learning (ML)

ML is a type of AI that:

- Allows us to predict outcomes **without being explicitly programmed**.
- Building methods **that "learn" a model** based on the **sample data.**

- Labeled Data
- Predict future/Outcome



- No Labeled Data
- Find hidden structure
- e.g. K-means clustering

- Learn in interaction mode
- Reward
- Decision process

Different Machine Learning directions

Supervised learning:

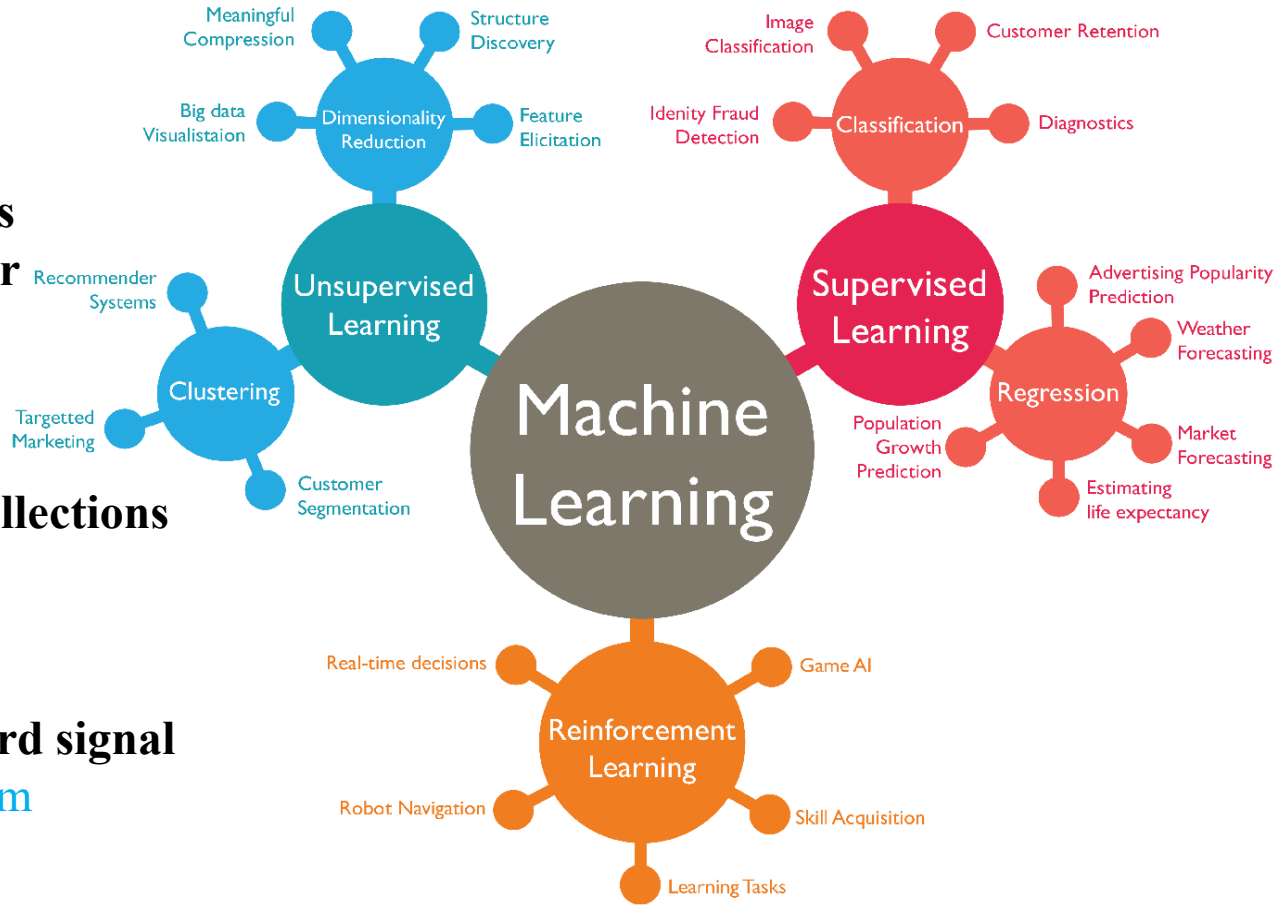
- ✓ Learning from a **training set of labeled examples** provided by a knowledgeable **external supervisor**

Unsupervised learning:

- ✓ Is typically about **finding structure hidden in collections of unlabeled data**.

Reinforcement learning

- ✓ Reinforcement learning is **trying to maximize a reward signal** instead of trying to find hidden structure (Learning from interaction)



Semi-Supervised Learning

The breakthrough moments in machine learning

Key moments in ML algorithms history?

1. **1950s:** The **Perceptron algorithm** was invented, marking the beginning of the field of **artificial neural networks (ANN)**.

2. **1980s:** The development of the **backpropagation algorithm** revolutionized the **training of neural networks**.

3. **1990s: Support Vector Machines (SVMs)** became a popular method for solving **classification** problems.

The breakthrough moments in machine learning

Key moments in ML algorithms history?

4. **2010s: Deep learning** emerged and greatly improved the performance of **image recognition**, **speech recognition**, and **natural language processing** (NLP) tasks.

5. **Recent years:** The **growth of reinforcement learning (RL)** has led to significant advancements in robotics, gaming, and autonomous systems.

Machine learning's stunning applications- Jeopardy

- ✓ **Jeopardy playing,** IBM Watson, 2011
- ✓ DeepQA as underlying technology behind IBM Watson.

Exploring how to integrate:

- Natural Language Processing
- Information Retrieval
- Machine Learning
- Knowledge Representation
- Reasoning

Machine learning's stunning applications- Self-driving cars

Self-driving cars

1. Object detection and recognition
2. Path planning
3. Decision-making
4. Predictive maintenance
5. User behavior analysis
6. Simulation and testing

Does all these are only based on Deep Learning algorithms nowadays?

Machine learning's stunning applications- Self-driving cars

Self-driving cars

- ✓ Many self-driving car systems use a **combination of traditional ML and DL techniques**.
  - E.g. feature extraction and object segmentation with CNNs.

- ✓ In **addition to DL**, the traditional machine learning techniques such as **decision trees**, **support vector machines (SVMs)**, and **random forests** are also used in self-driving cars.

- ✓ Several companies are using traditional ML techniques along with DL for developing self-driving car technology.
  1. Waymo (a subsidiary of Alphabet Inc.)
  2. Tesla
  3. Cruise (a subsidiary of General Motors)
  4. Uber ATG (Advanced Technologies Group)
  5. Baidu Apollo
  6. Zoox (a subsidiary of Amazon)
  7. Aurora Innovation
  8. Mobileye (a subsidiary of Intel)
  9. Aptiv
  10. Argo AI (a subsidiary of Ford and Volkswagen)

Machine learning's stunning applications

Natural language processing

ChatGPT (Chat Generative Pre-trained Transformer)

- ✓ A chatbot proposed by OpenAI, released at 2022 November.
- ✓ Aim is to generate human like responses.
- ✓ Uses both supervised and reinforcement learning (PPO) techniques.
- ✓ Uses transfer learning

1.BERT (developed by Google)
2.Gemini (developed by Google DeepMind)
3.RoBERTa (developed by Facebook)
4.T5 (developed by Google)
5.XLNet (developed by Carnegie Mellon University and Google)
6.Megatron (developed by NVIDIA)
7.GShard (developed by Google)

Supervised Learning

Input:

- ✓ Set of labeled input data (training set):

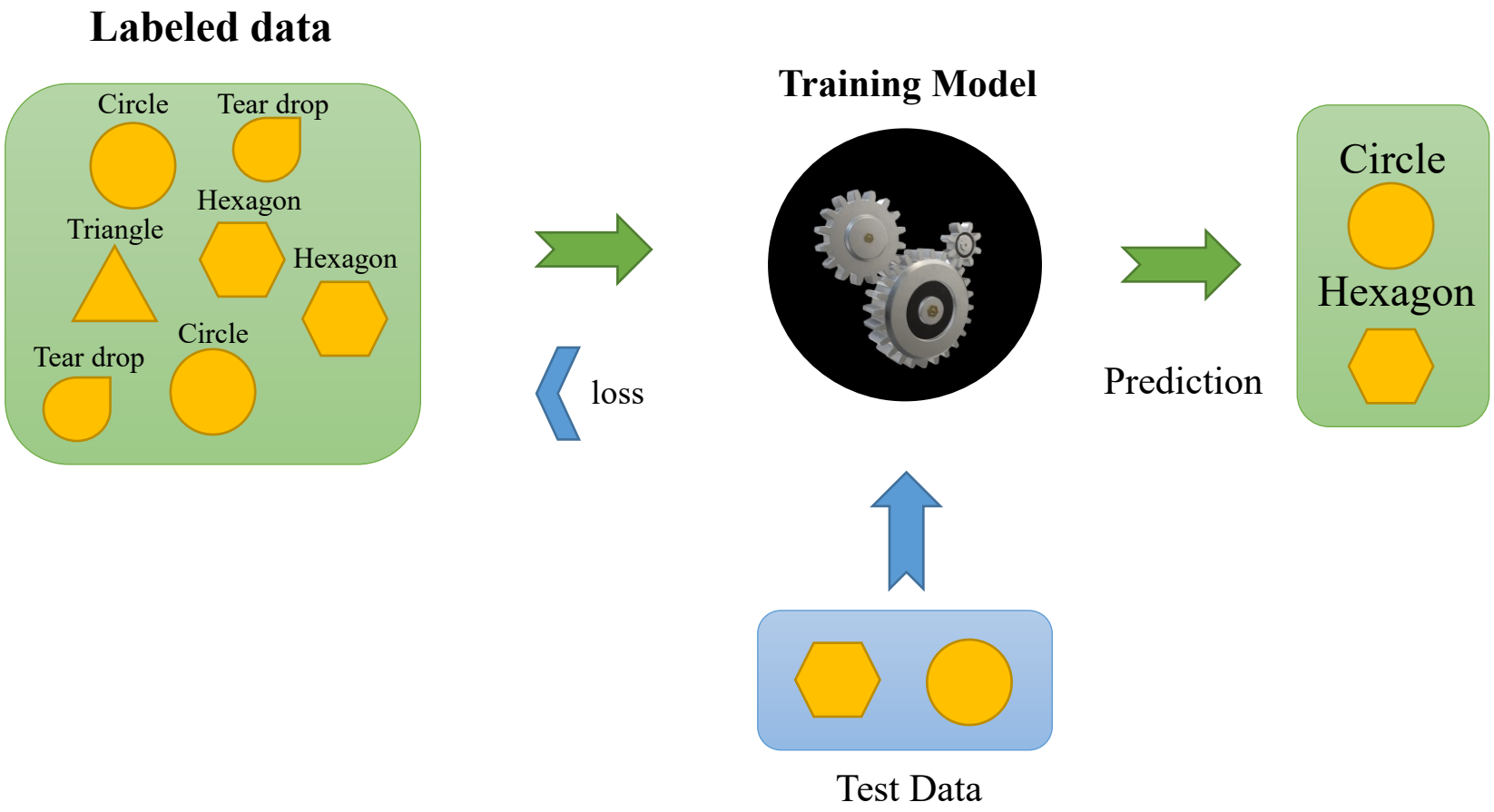
$$\{(x_1, y_1), (x_2, y_2), \dots, (x_m, y_m)\}$$

Objective:

- ✓ Finding a good approximation for predicting new data that has minimum error:

$$f: X \to Y$$

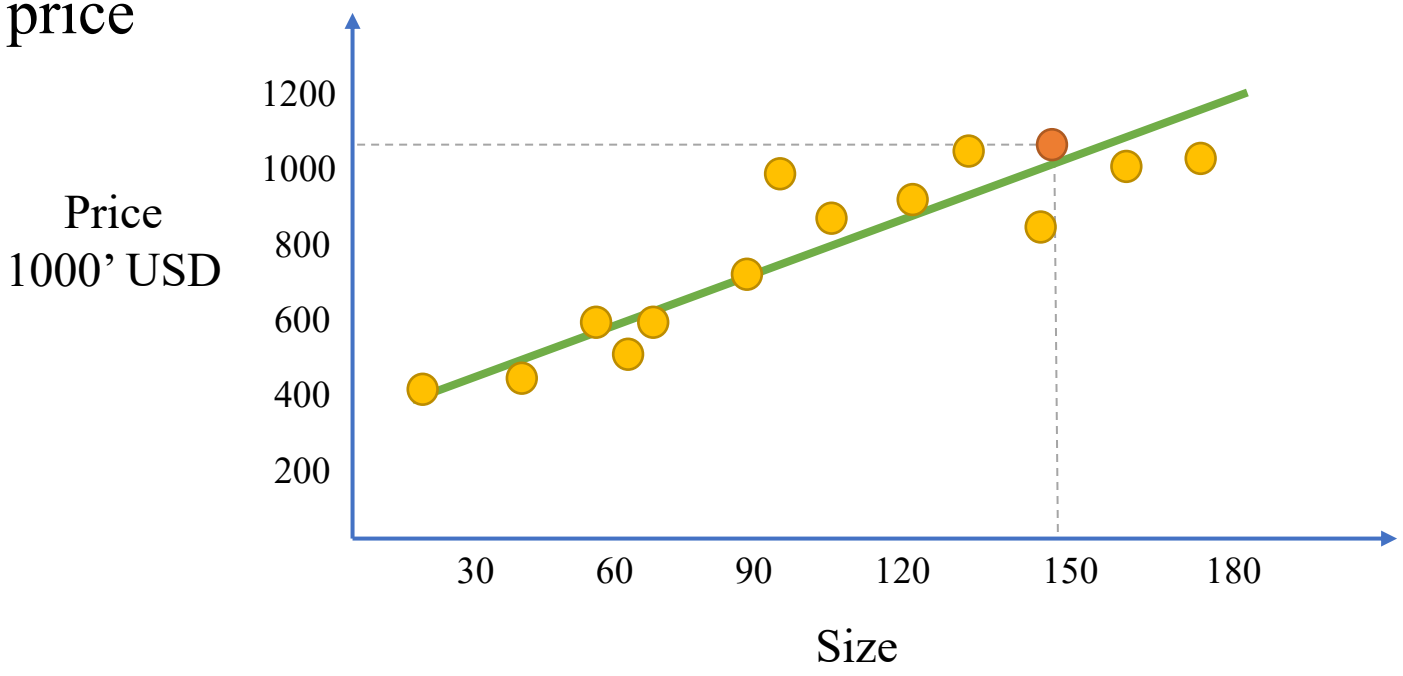
Supervised learning



Supervised learning - Example

Price Prediction

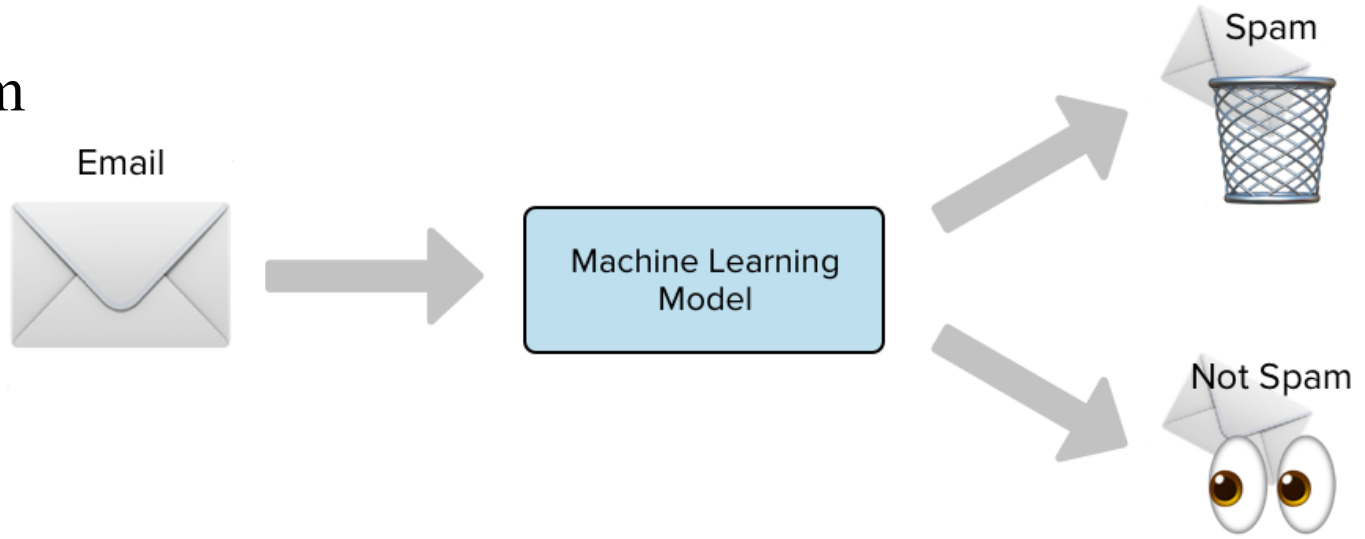
Input: Home size
Output: price



Supervised learning - Example

Spam detection

Input: Emails
Output: Spam or not spam



Important features

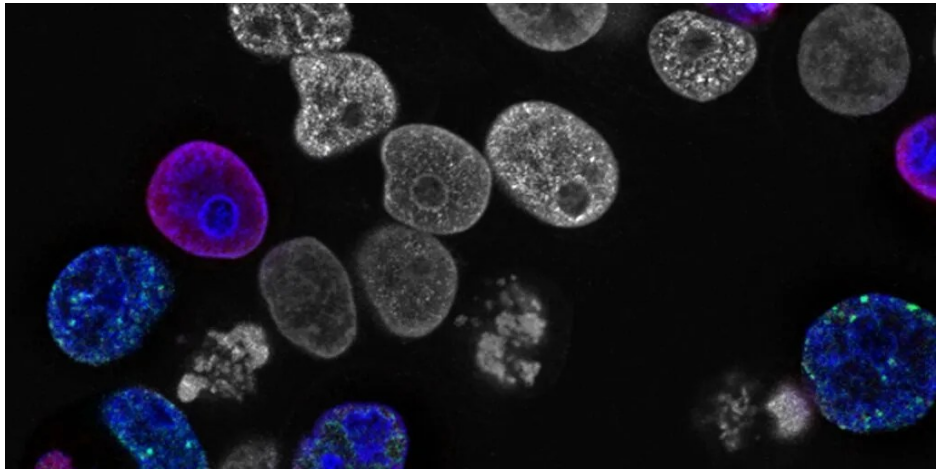
- Sender
- Time
- Contents
- Header
- Symbols used in email
- Links
- Attachments format
- ….

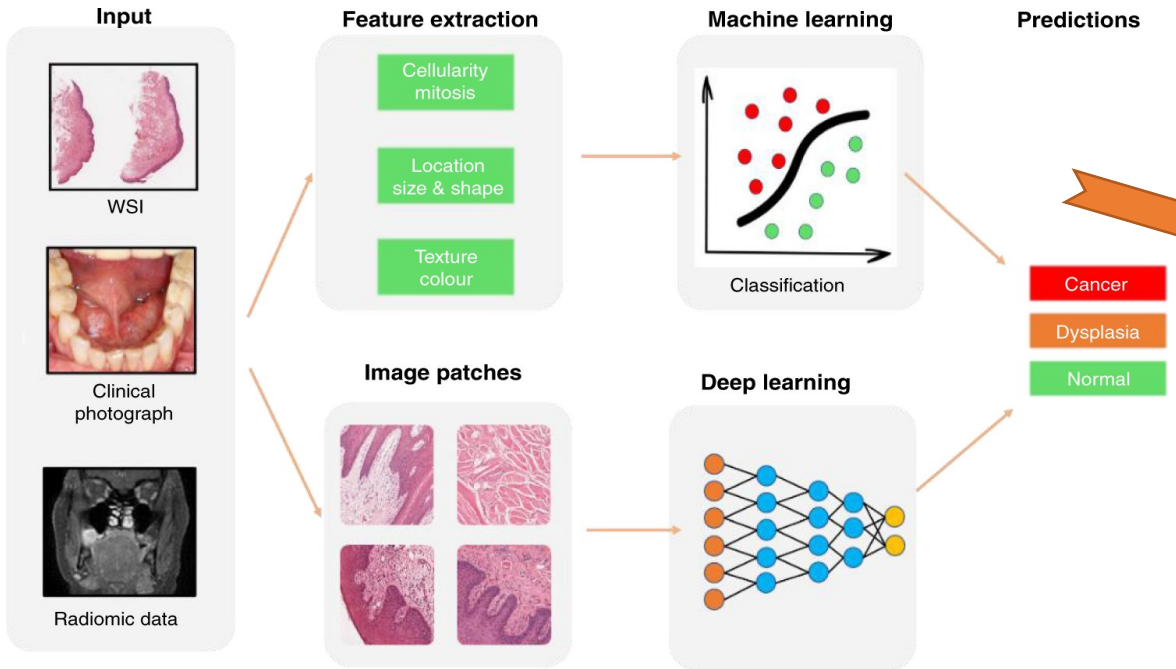
Supervised learning - Example

Cancer detection

Input: Scan images

Output: Cancer, dysplasia, normal





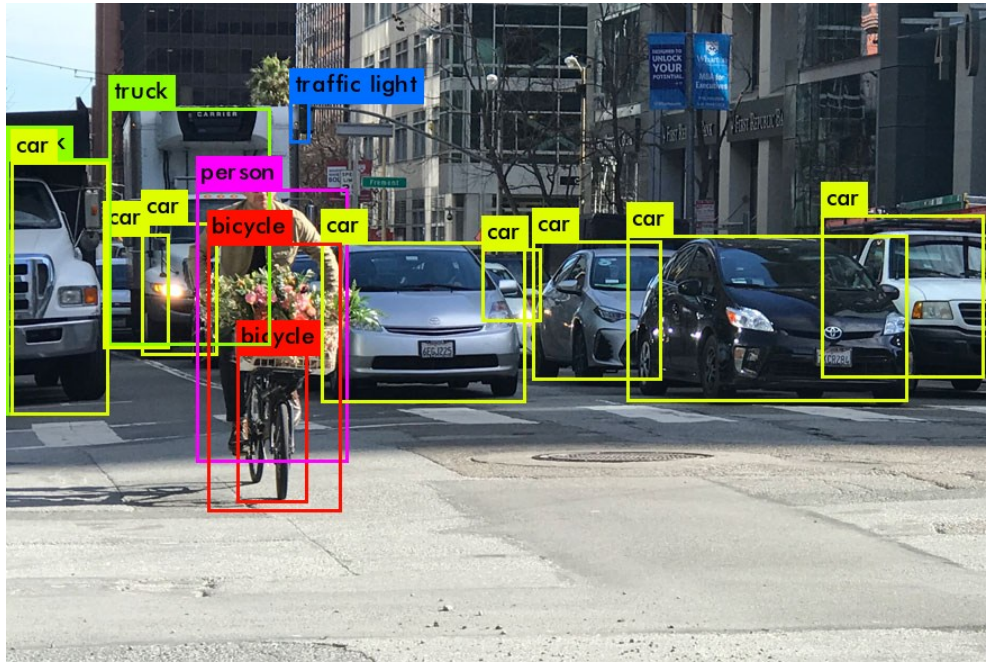
When the amount of training data is limited can be better option

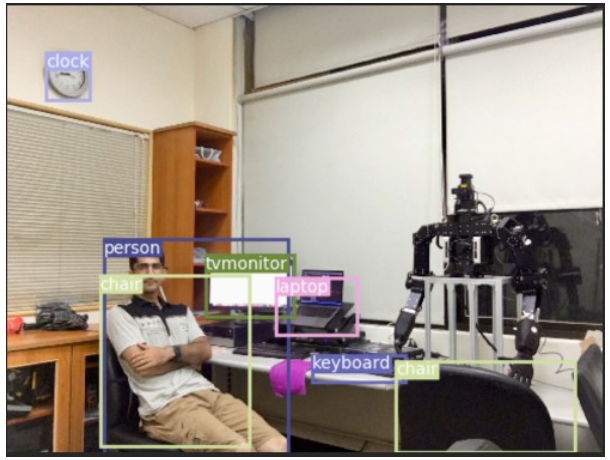
Supervised learning - Example

Object detection

Input: Images

Output: Object class and location





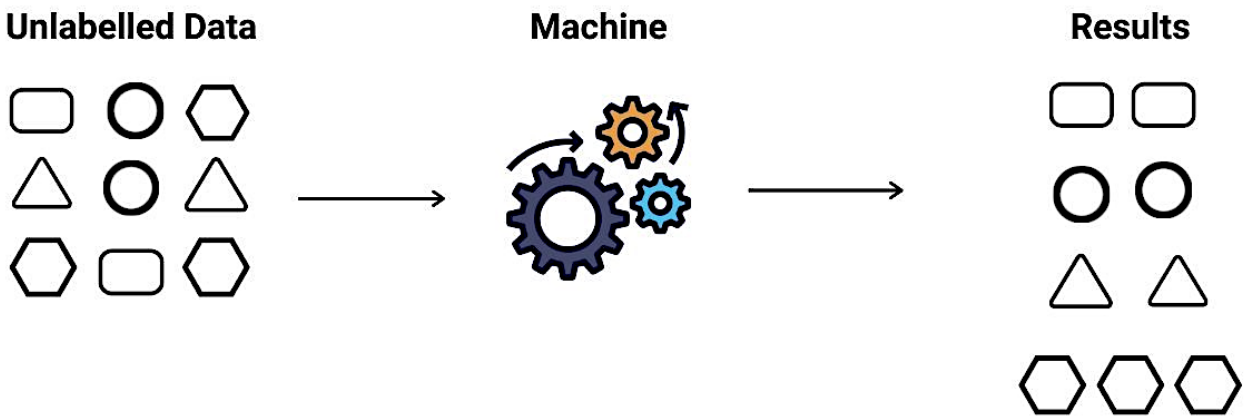
Supervised learning - Example

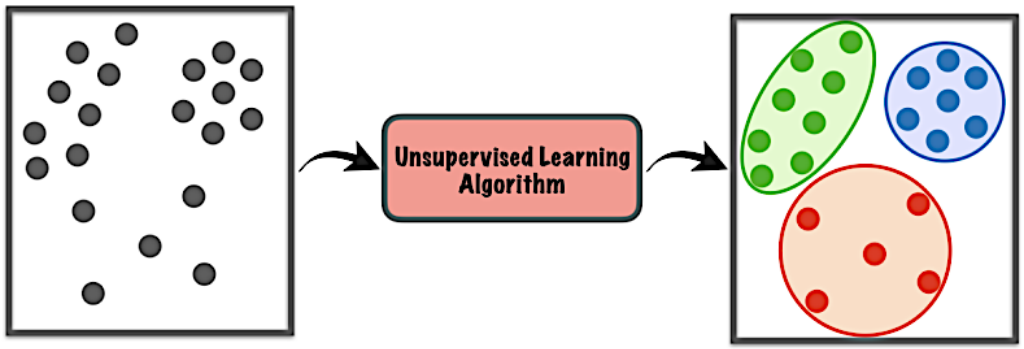
Face Recognition or Detection

Input: Images and/or point cloud
Output: verified, unverified,
Detected, not detected

Unsupervised learning

✓ Need to find **hidden patterns** in large unlabeled datasets.



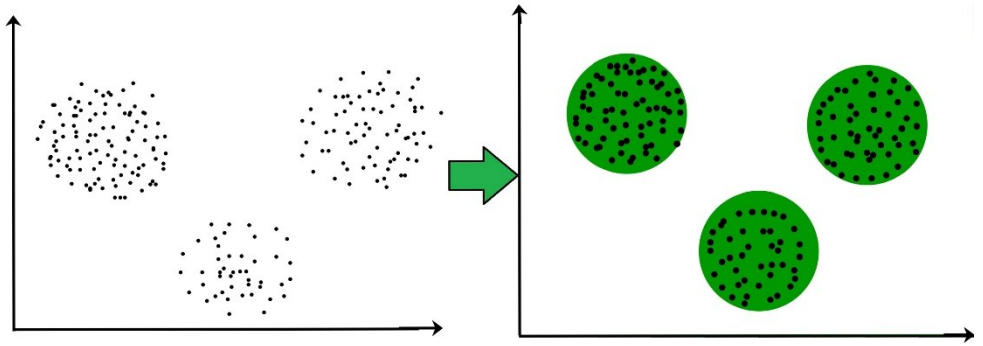


Unsupervised learning - Example

Marketing

Input: People's purchasing habits
Output: Groups of people

- ✓ Distinguishing different customer groups for developing business or marketing or strategies (similarity detection).



Unsupervised learning - Example

News Clustering

Input: News content
Output: Groups of news

Unsupervised learning - Example

Astronomy

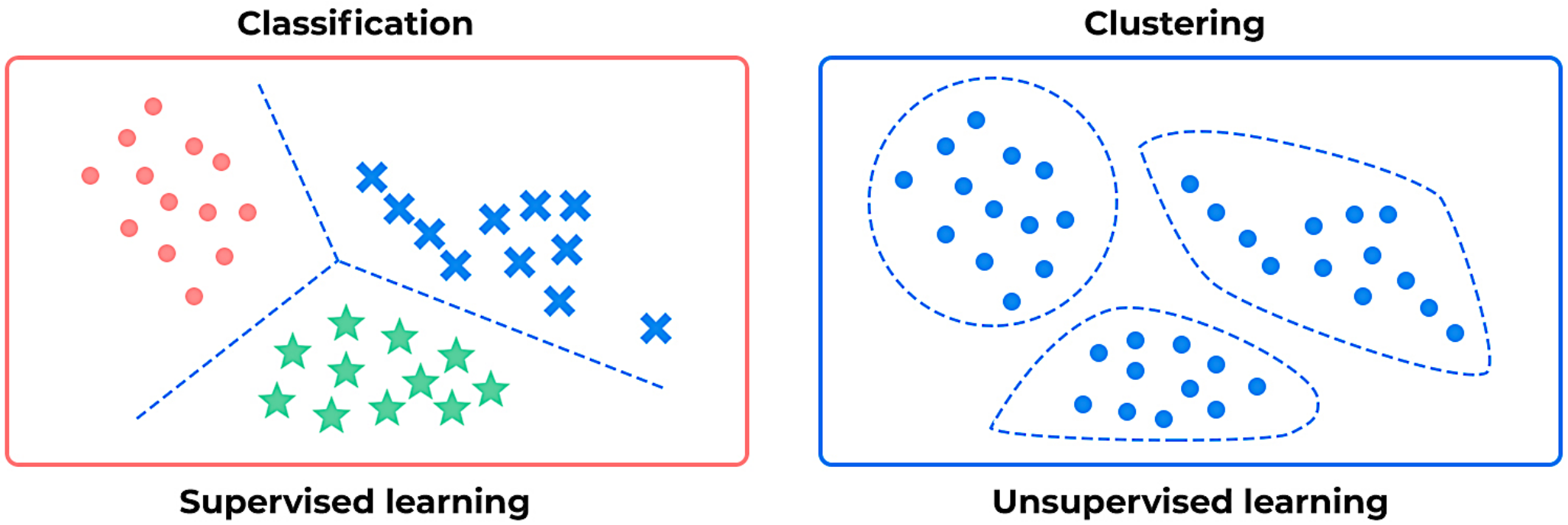
- ✓ Identifying new types of astronomical objects
- ✓ Characterizing galaxy populations
- ✓ Analyzing large datasets from telescopes

Unsupervised learning - Example

Social media analyzes

1. **Sentiment analysis**: Tracking public opinion on a topic or brand.
2. **Trend analysis:** Identifying what topics are currently popular.
3. **Customer segmentation:** Identifying target audiences for marketing campaigns.
4. **Influencer identification:** Finding influential social media users.
5. **Brand monitoring:** Tracking brand mentions and public sentiment.
6. **Crisis management:** Identifying and responding to negative publicity.
7. **Customer feedback analysis:** Identifying common themes in feedback.
8. **User behavior analysis:** Understanding user interaction and finding improvement opportunities.
9. **Personalized content recommendations:** Recommending content based on user interests.

Supervised vs Unsupervised learning

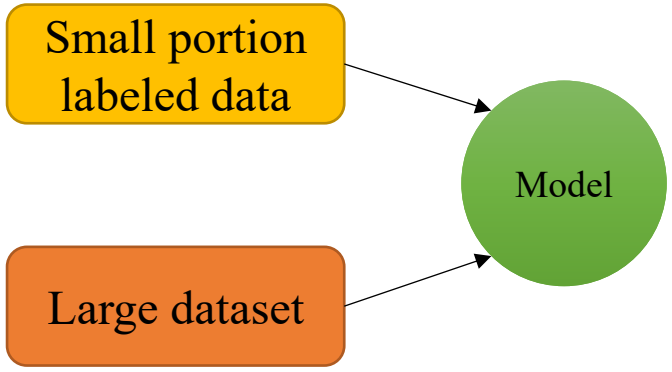


Which one is harder?

Semi-Supervised learning

- ✓ **Semi-Supervised learning** is **mixture** of the supervised and unsupervised learning
- ✓ The models that **combine** labeled and unlabeled data and **make guess for unlabeled data.**
- ✓ Useful for self-training, so that we can use it to annotate unlabeled data.

For example: dataset of images with only some images having labels.



Reinforcement Learning

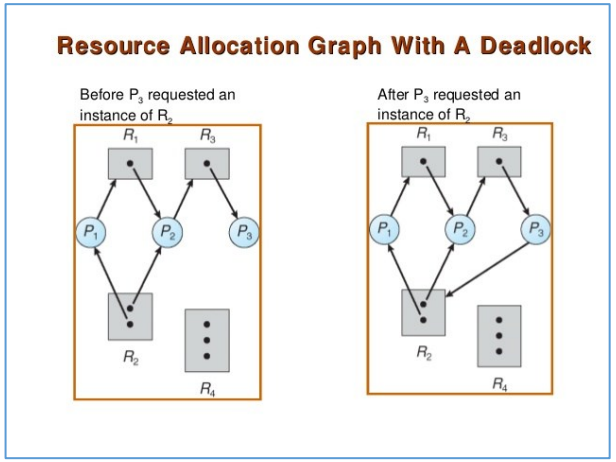
- ✓ The agent learns how to move from **initial state** to **Goal state** or (target state) and what is the best Action in each state.

With dynamic nature!

Reinforcement Learning

- ✓ **RL:** A type of learning that is very **useful** in robotics because the robot learns exactly **which action is best in each state**.

- ✓ **Applications:** From resource allocation in the operating system to unmanned helicopter control and ...



Reinforcement learning

History of Reinforcement Learning

Three concurrent threads

1) Learning by trial and error:

- ✓ Originated in the psychology of animal learning
- ✓ Earliest work in AI resulted revealing of RL (early 1980s).

2) The optimal control problem and its solution using **Dynamic Programming (DP)**

- ✓ The research in 'optimal control' began in the 1950's

3) Temporal Differences Learning Methods

- ✓ Inspired from mathematical differentiation
- ✓ Aiming to derive a prediction from a set of known variables

Reinforcement learning application examples

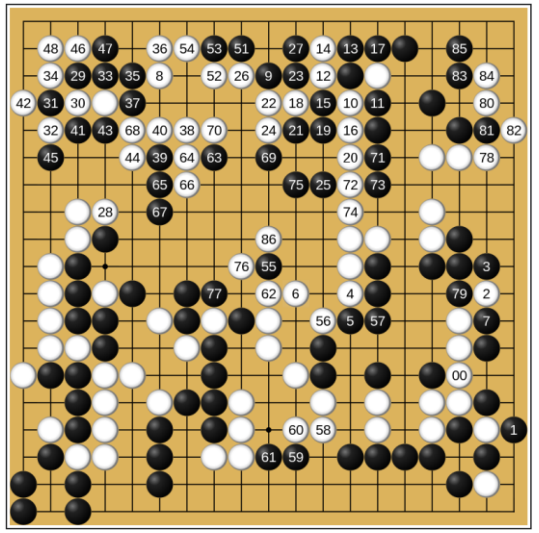
Game Playing

✓ **AlphaGo** and **AlphaGo Zero** RL algorithm play the **board game Go!**

(DeepMind, Google).

In March 2016, RL beat Lee Sedol in a five-game match.

Environment?	Board and player
Agent?	Player
State?	Board Configuration
Action?	Placing a stone
Reward?	✓ Wining or Losing
	✓ Current evaluation



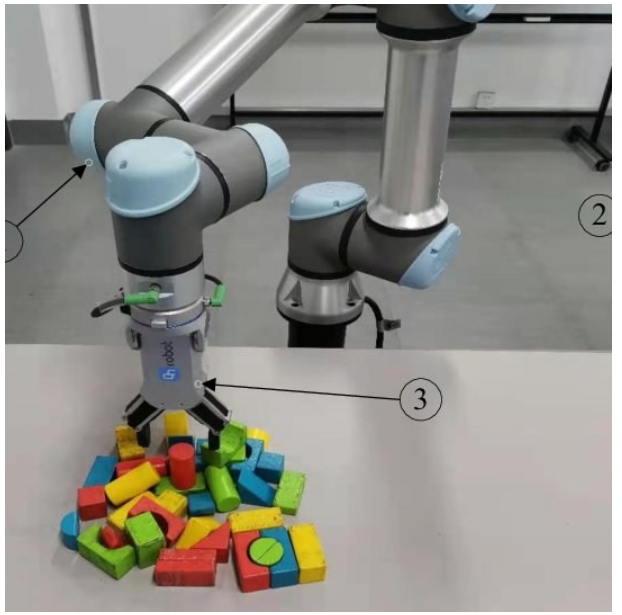
https://www.youtube.com/watch?v=WXuK6gekU1Y

Reinforcement learning application examples

Robotics

- ✓ The robot to have ability to grasp various objects
- ✓ Almost in **all kind of robots we can use RL**

Environment?	Objects and robot's work space
Agent?	Robot
State?	Robot Joint's position and Object Pose
Action?	Robot's arm movements
Reward?	?



Reinforcement learning

✓Reinforcement learning is for learning:

- **What to do**
- **How to map each state to actions** (long and short term reward)

✓ The learner is not told which actions to take, but instead **must discover** which **actions** yield the **most reward** by **trying them**.

✓ Actions may **affect not only the immediate reward** but also the **next situations** and all **subsequent rewards**.

Machine Learning Advances

The latest remarkable advances in Machine Learning (ML):

1. Transfer Learning
2. Generative Adversarial Networks (GANs)
3. Multi-task Learning
4. Explainability and Interpretability
5. Reinforcement Learning (RL)

Machine Learning Advances

1. Transfer Learning

✓ A technique where a **pre-trained ML model is adapted** for a new task.

✓ **Reducing** data and **computation** requirements compared to training from scratch.

Applications of Transfer Learning:

1. **Computer Vision:** Image classification, object detection, and segmentation.
2. **Natural Language Processing (NLP):** Sentiment analysis, recognition, and machine translation.
3. **Speech Recognition:** Speaker identification and language recognition.
4. **Robotics:** Reinforcement learning and control.

Machine Learning Advances

2. Generative Adversarial Networks (GANs):

✓ A popular deep learning algorithm for generating new data similar to a training dataset.

Applications of GANs:

1. **Image Synthesis:** GANs are used to generate entirely new images that are similar to a training dataset, such as **creating novel photo-realistic images** or applying **style transfer**.
2. **Text Generation:** GANs can generate text, such as writing novel stories or poetry.
3. **Audio Generation:** GANs can generate new audio samples, including speech and music.

Machine Learning Advances

Applications of GANs:

5. **Image-to-Image Translation:**

   GANs can translate images from one domain to another, such as converting sketches to photographs or changing the weather in an image.

5. **Anomaly Detection:** GANs can identify instances in a dataset that are different from the norm, used for detecting anomalies in areas such as fraud detection.

6. **Data Augmentation:** GANs can generate additional training data for other machine learning models, especially useful in domains with limited labeled data.

What is the Regression

3. Multi-task Learning (MLT):

- ✓ Multi-task learning is a technique where **a single ML model is trained on multiple tasks simultaneously**.
- ✓ It is to **improve the performance of multiple related tasks** by learning shared information and knowledge among these tasks.
- ✓ Multi-task learning improves performance of related tasks **by learning a shared representation**, reducing data and computation needs compared to training each task separately in traditional ML.

Example:

- ✓ This can be effective where there is **shared information between tasks**, such as **NLP** and **computer vision**.
- ✓ For instance we have **Unified Language and Vision Pre-training (UniLV)** model.

Uses unified encoder

What is the Regression

More Applications of Multi-Task Learning:

1. **NLP** (Sentiment analysis, Recognition, Part-of-speech tagging)
2. **Computer Vision** (Object detection, Semantic segmentation, Depth estimation)
3. **Speech Processing** (Speech recognition, Speaker verification, Language identification)
4. **Healthcare** (Disease diagnosis, Treatment recommendation)
5. **Recommender Systems** (User behavior-based recommendation, Item metadata-based recommendation, Content-based recommendation)
6. **Robotics** (Object recognition, Grasping, Navigation)

Machine Learning Advances

4. Explainability and Interpretability:

- ✓ As ML models become more complex, it becomes increasingly important to understand how they make decisions (**Transparency**).
- ✓ Explainability refers to the **ability to provide an explanation** of how a model **arrived at its predictions**.
- ✓ Understanding how **individual features influence predictions**, and being able to identify biases or other **sources of error** in the model.

Machine Learning Advances

4. Explainability and Interpretability:

Example method:

LIME (Local Interpretable Model-Agnostic Explanations):

- ✓ LIME can be used to provide a human-understandable explanation for why the model made a specific prediction.
- ✓ LIME is a algorithm for interpreting and explaining the predictions of machine learning models, regardless of their type or complexity.
- ✓ LIME has been used to explain the predictions of a wide range of deep learning models:
  - Convolutional Neural Networks (CNNs)
  - Recurrent Neural Networks (RNNs)
  - Deep Belief Networks (DBNs) - for unsupervised learning

What is the Regression

- ✓ Regression is **a method that we try to understand the relationship between:**
  - ✓ Independent variables or features
  - ✓ Dependent variable or features
- ✓ Regression is a type of supervised learning method

- We use regression mainly **for prediction, time series modeling, and extracting relationship between variables.**

So we plot a graph between the variables for best fits, then we can make predictions about new data.

Summery

- ✓ We discussed what is the Machine Learning concepts
- ✓ History of Machine learning
- ✓ We discussed Supervised, Unsupervised, RL and Semi-Supervised definitions
- ✓ We mentioned the latest general advances in Machine Learning