GDP SMU SSP with UBD, 9-23 June 2024

Artificial Intelligence (AI)

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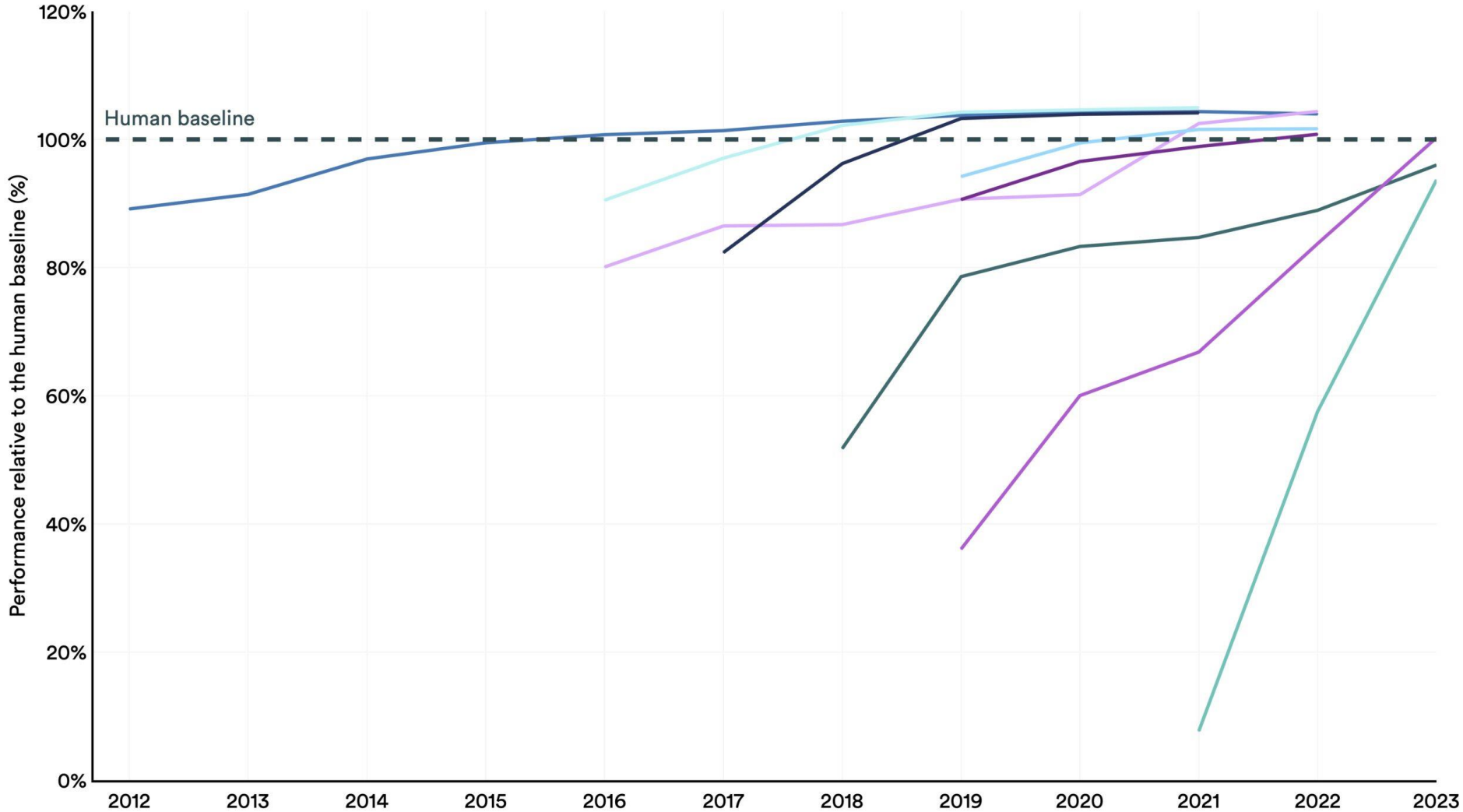
https://ailab.space/teaching/gdp-smu-ssp-with-ubd/

Everyone knows AI

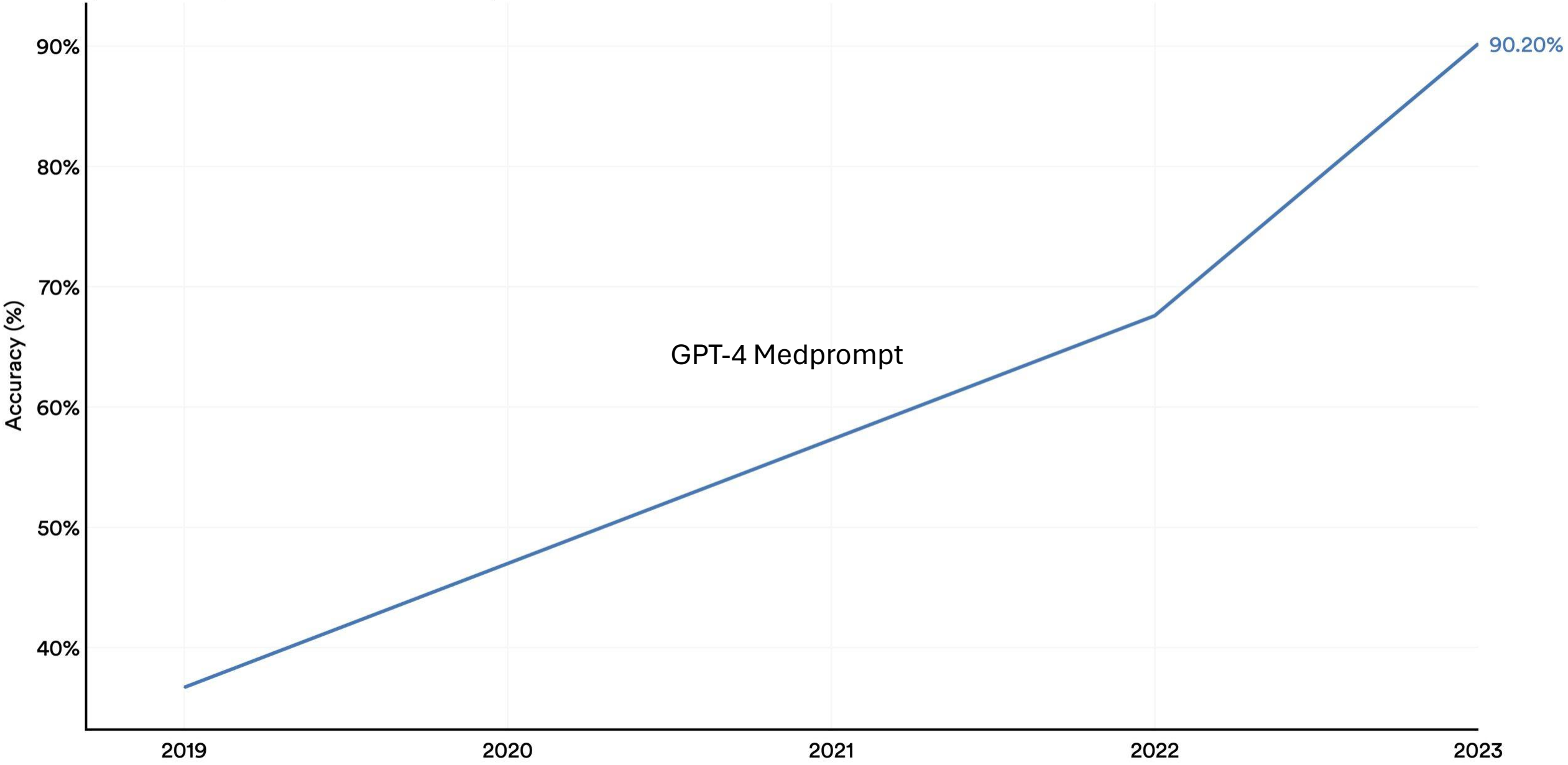
Select AI Index technical performance benchmarks vs. human performance

Source: AI Index, 2024 | Chart: 2024 AI Index report



MedQA: accuracy

Source: Papers With Code, 2023 | Chart: 2024 AI Index report



Timeline of images generated by artificial intelligence

These people don't exist. All images were generated by artificial intelligence.

Our World in Data

2014

Goodfellow et al. (2014) – Generative Adversarial Networks

2015

Radford, Metz, and Chintala (2015) – Unsupervised Representation Learning with Deep Convolutional GANs

2016

Liu and Tuzel (2016) – Coupled GANs

2017

Karras et al. (2017) – Progressive Growing of GANs for Improved Quality, Stability, and Variation

2018

Karras, Laine, and Aila (2018) – A Style-Based Generator Architecture for Generative Adversarial Networks

2019

Karras et al. (2019) – Analyzing and Improving the Image Quality of StyleGAN

2020

Ho, Jain, & Abbeel (2020) – Denoising Diffusion Probabilistic Models

2021

Image generated with the prompt: *"a couple of people are sitting on a wood bench"*

Ramesh et al. (2021) – Zero-Shot Text-to-Image Generation (OpenAI's DALL-E 1)

2022

Image generated with the prompt: *"A Pomeranian is sitting on the King's throne wearing a crown. Two tiger soldiers are standing next to the throne."*

Saharia et al. (2022) – Photorealistic Text-to-Image Diffusion Models with Deep Language Understanding (Google's Imagen)

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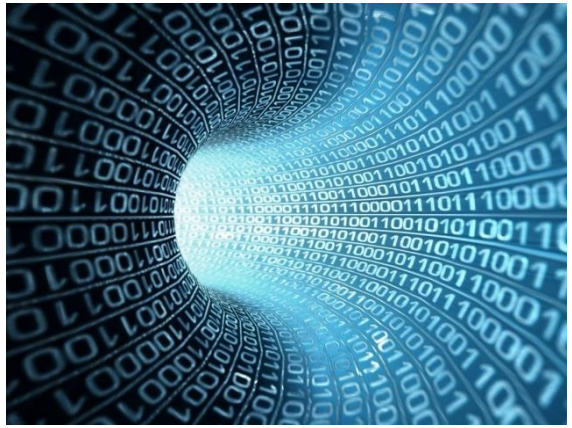
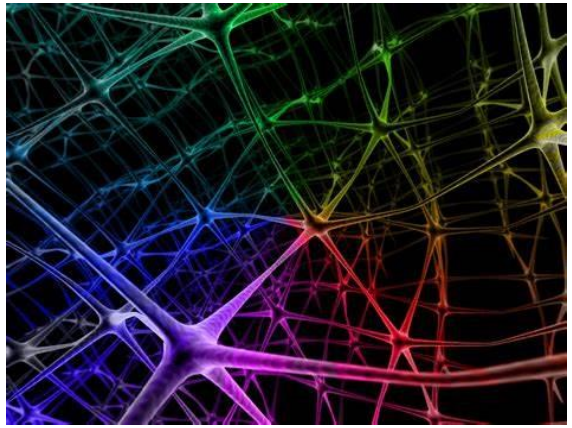
What drive AI’s growth?



Big data

Powerful compute



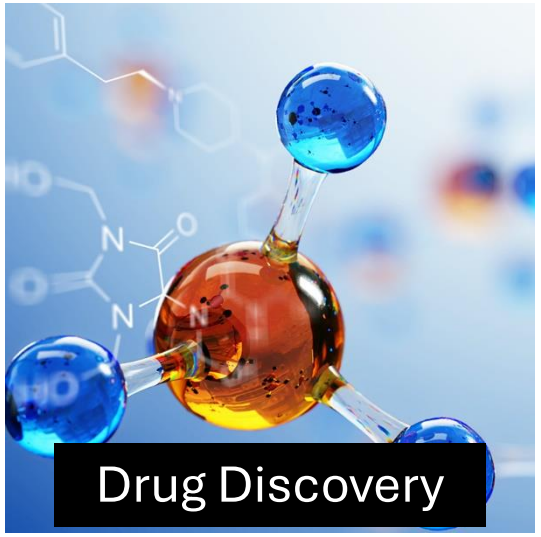
Advance algorithms

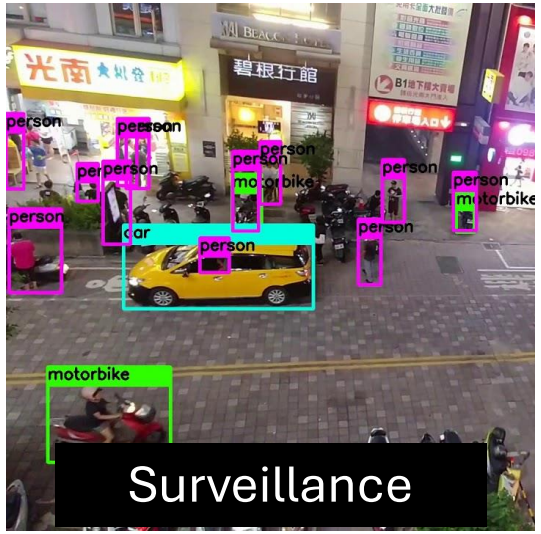
AI applications

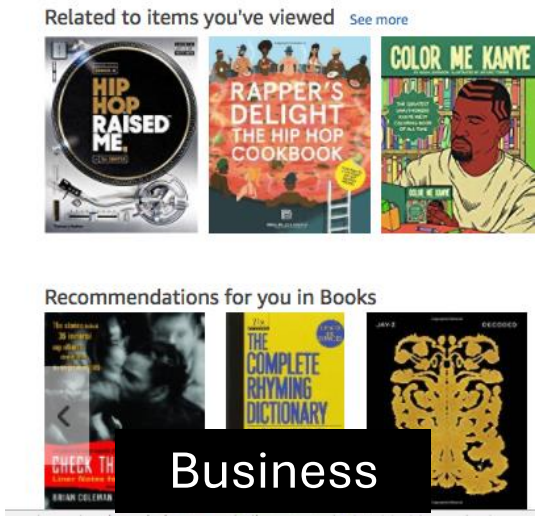
Healthcare | Automobile | Business | Finance | Entertainment

Education | Gaming | Manufacturing | Transportation

Robotics | Space Exploration | Surveillance | Agriculture







What is AI?

Intelligence exhibited by artificial systems: machines or software.

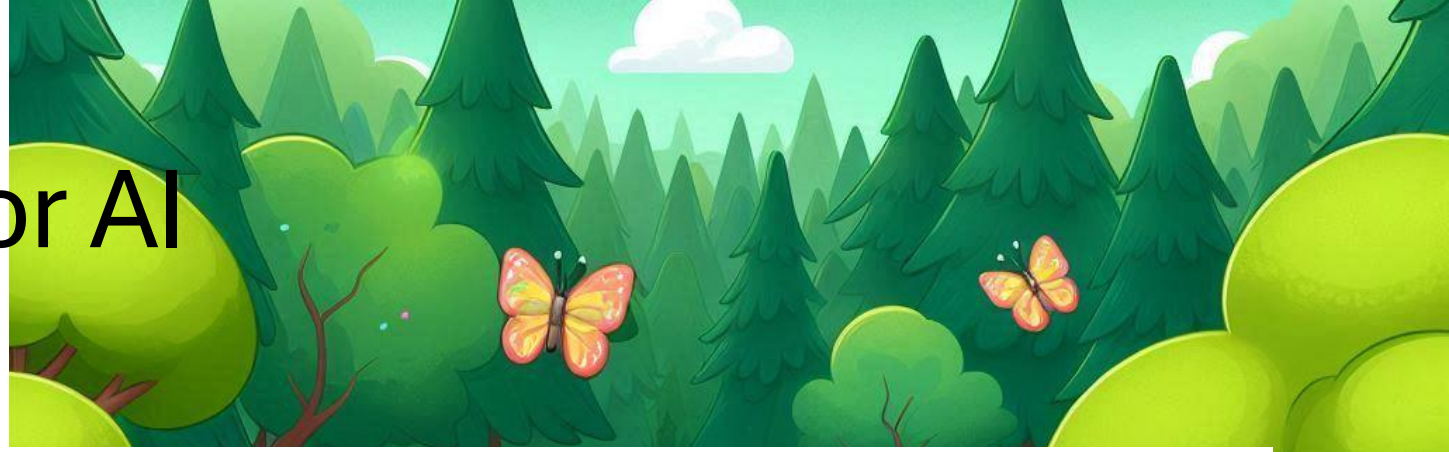
The study of AI is about the **creation of intelligence** similar to human (and animals).

Is calculator AI?

$$(2^3.5^2) - \frac{100}{2} + \sqrt{144} + \log_{10}(1000) = ?$$

Image credit: Wikipedia

A simple problem for AI



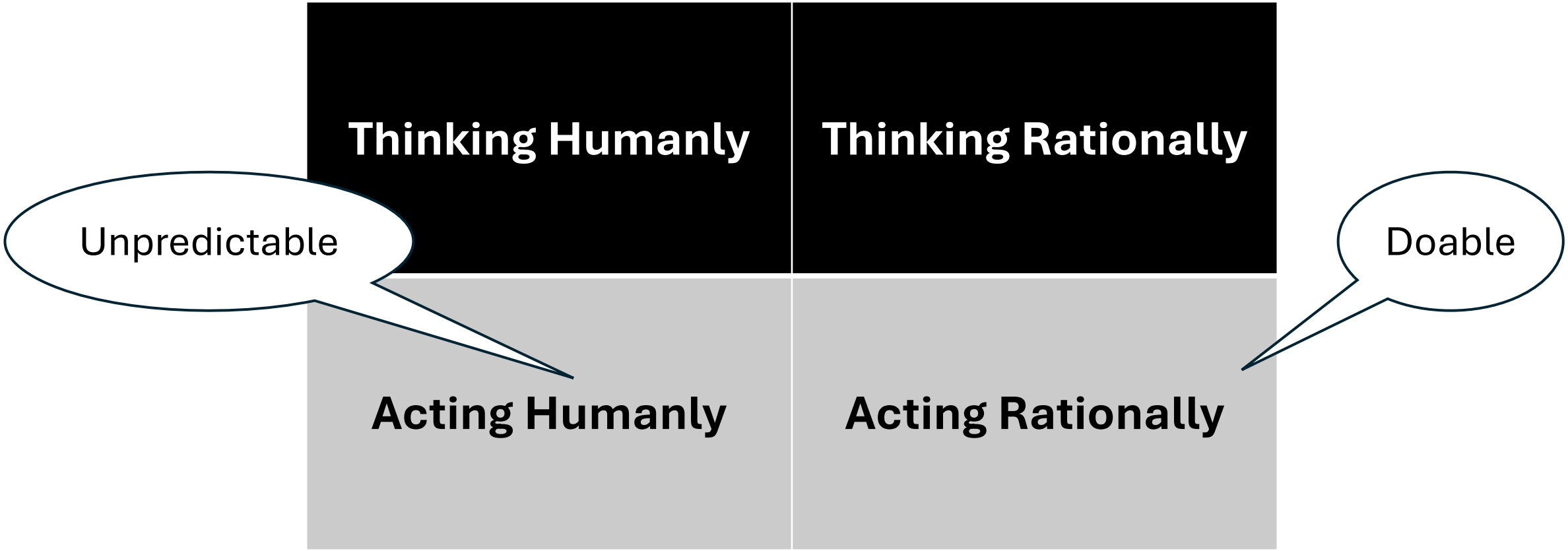
You’re planning a road trip and want to calculate the total cost of gas. Your car’s fuel efficiency is 25 miles per gallon, and the distance to your destination is 300 miles. If gas costs $3.50 per gallon, how much will the gas for the trip cost?

$$Cost = \$3.50 \times \frac{300}{25}$$

More problems for AI

- Prove a theorem
- Play chess
- Plan a surgical operation
- Diagnose a disease
- Navigate in a building
- …

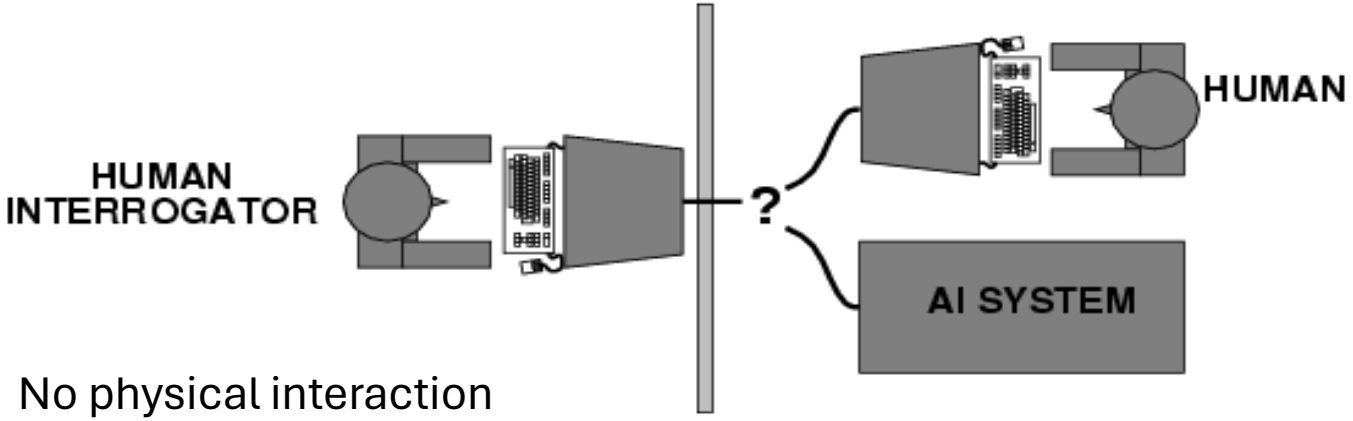
Four views of AI



1950

Turing Test

"A computer would deserve to be called intelligent if it could **deceive a human into believing that it was human**.“ (Acting humanly)



No physical interaction

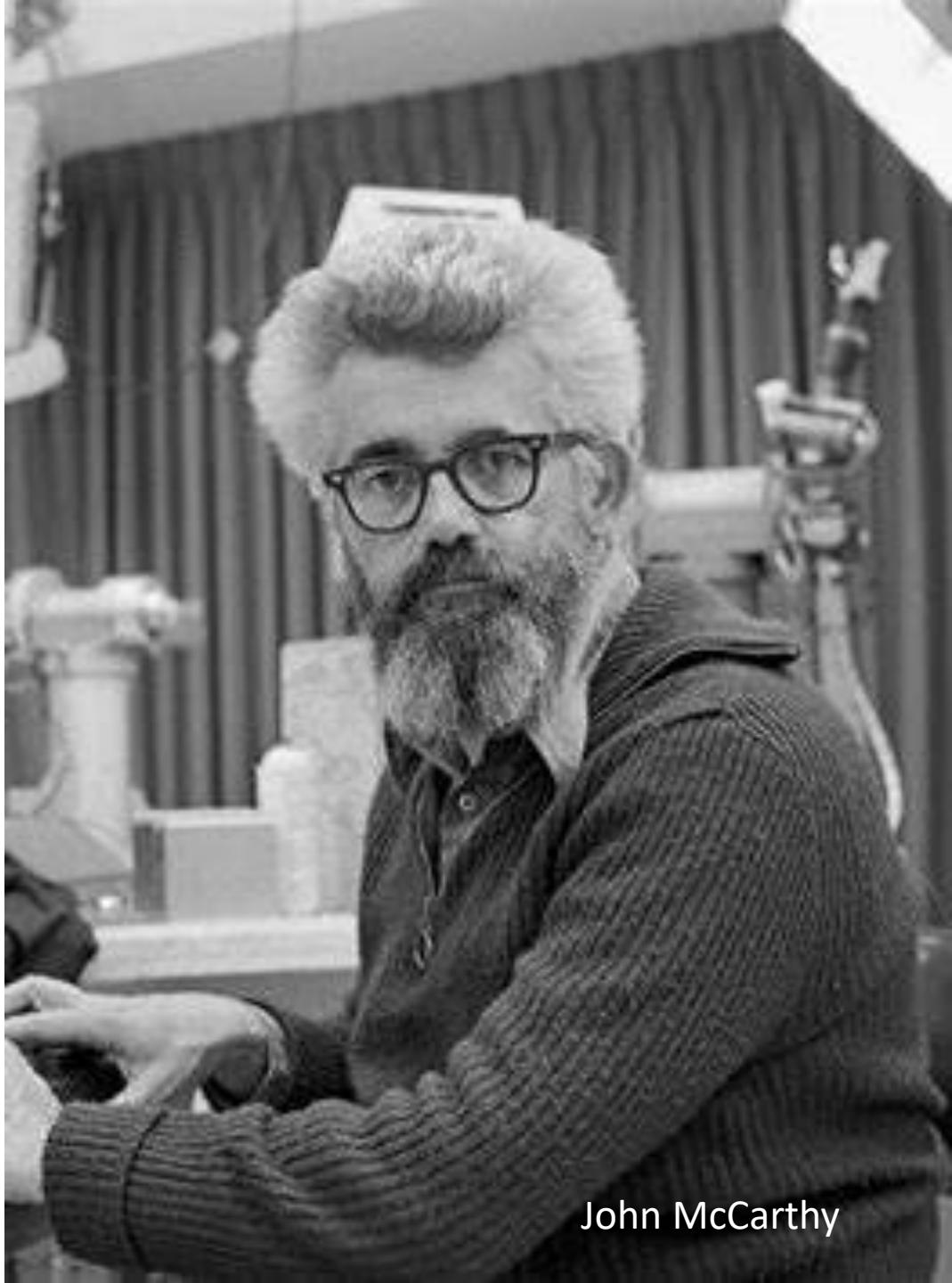
Alan Turing.

Image credits: NPL / Science Museum

1956

Birth of AI

"The ultimate goal of artificial intelligence is to create computer programs that can **solve problems** and achieve goals **without needing explicit instructions for each step**."



John McCarthy

Capabilities of AI

- Knowledge **representation**
- Natural **language** processing (NLP)
- Automated **reasoning** and **problem solving**
- Machine **learning**
- **Perception** (vision, audio, etc)
- **Robotics**

for intelligence

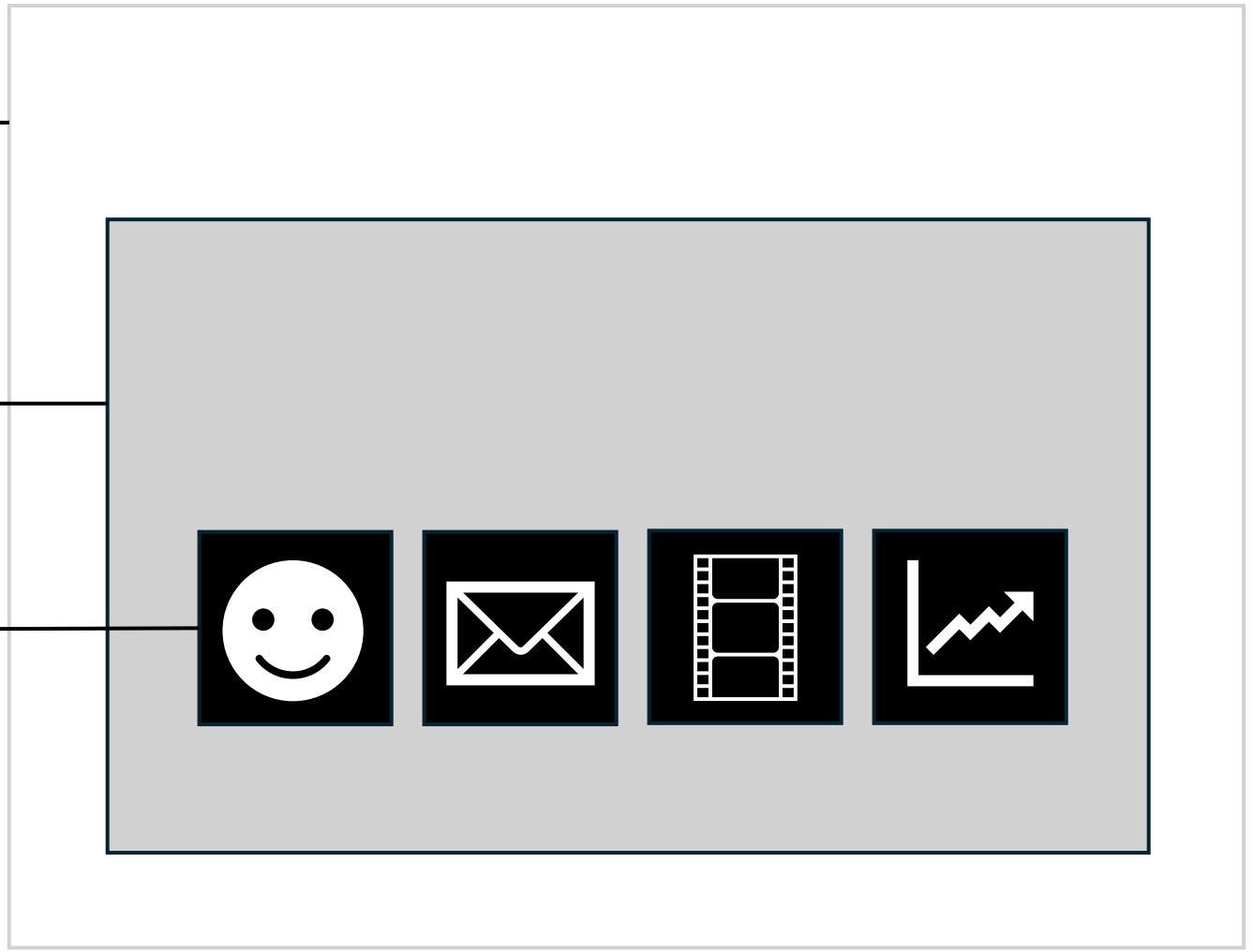
for interaction
(Total Turing Test)

Levels of AI

Artificial Superintelligence

Artificial General AI (AGI) (Strong AI)

Weak (Narrow) AI



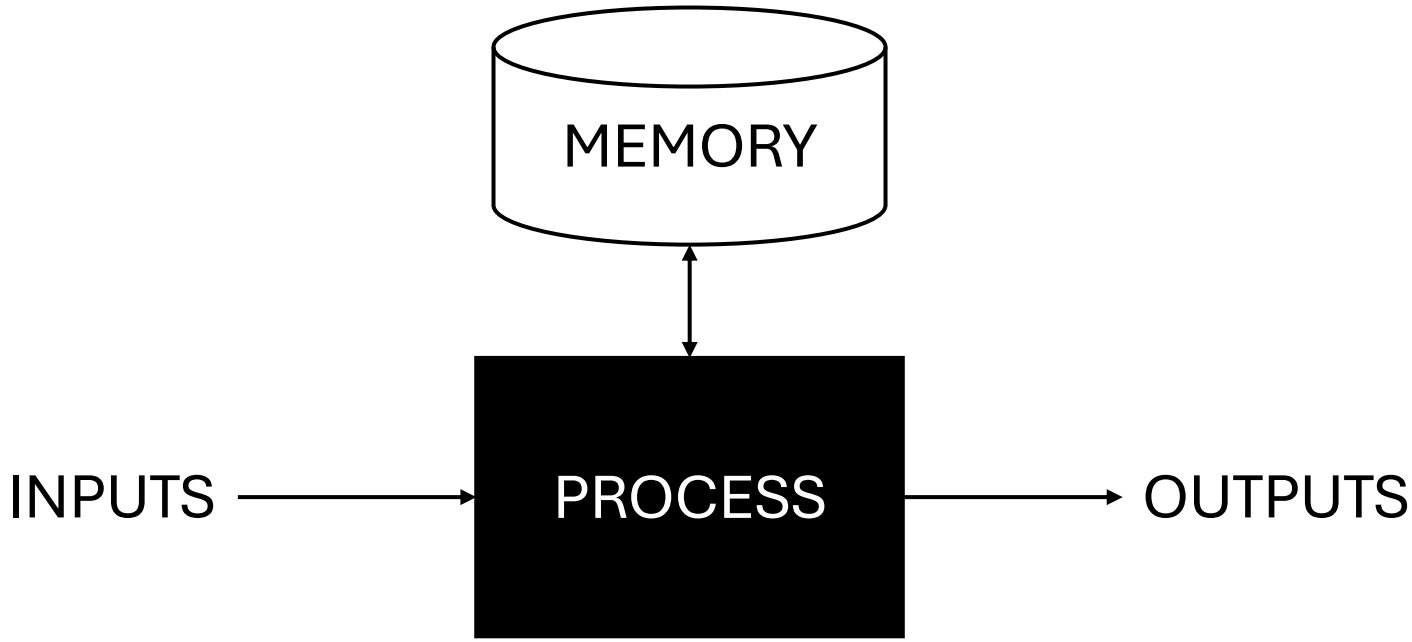
AI system

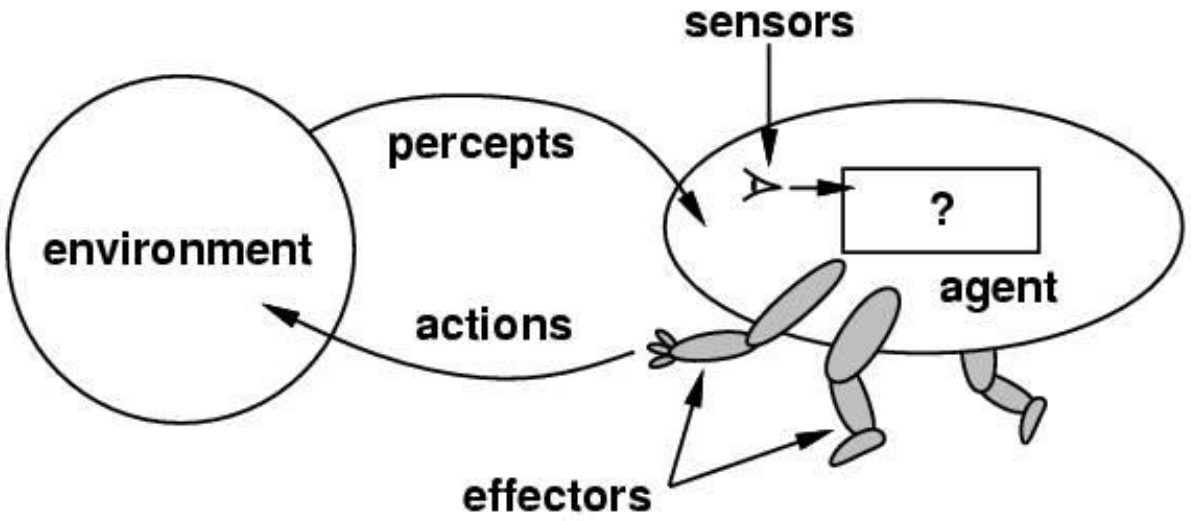
Artifact

+

Intelligence

AI Programs



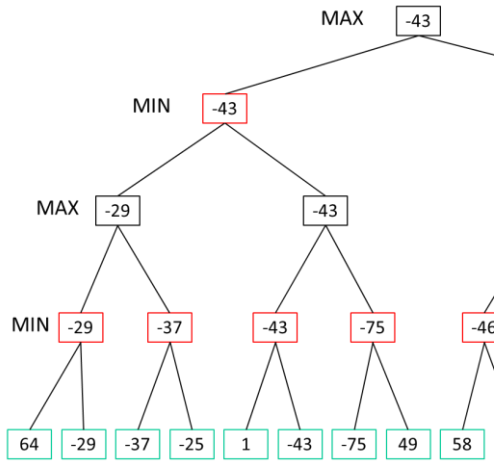


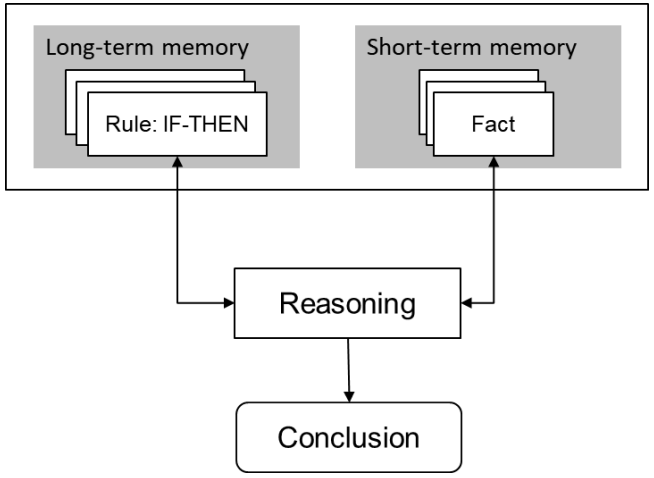
Two paradigms of AI techniques

Dominates

Symbolic AI

aka Interpretational AI, Good Old Fashion AI (GOFAI), Traditional AI

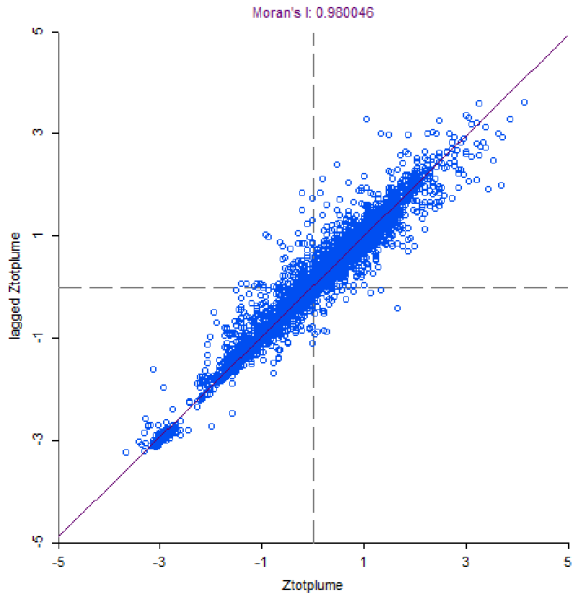


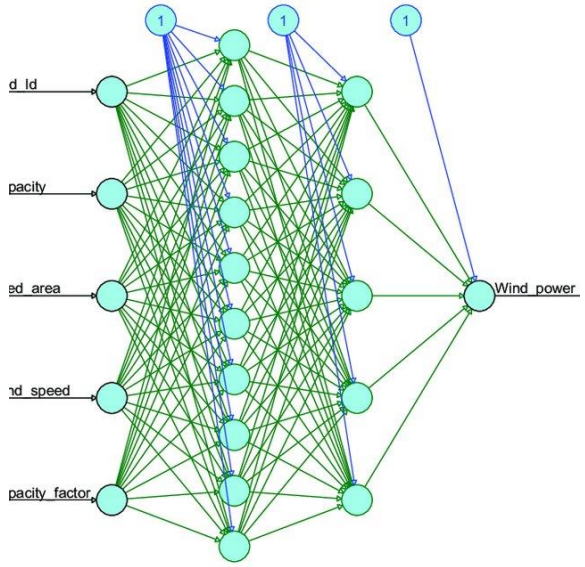


Non-symbolic AI

aka Sub-symbolic, Modern AI

- Comprises of **Statistical AI** and **Neural (Connectionist) AI**
- Data driven





AI techniques

Dominates

Symbolic AI

aka Interpretational AI, Good Old Fashion AI (GOFAI), Traditional AI

- Problem solving by search
- Knowledge-based system

Non-symbolic AI

aka Sub-symbolic, Modern AI

- Machine Learning
  - Linear regression
  - Logistic regression
  - Artificial Neural Network
  - K-Means clustering

AI techniques

Symbolic AI

aka Interpretational AI, Good Old Fashion AI (GOFAI), Traditional AI

- Problem solving by search
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Non-symbolic AI

aka Sub-symbolic, Modern AI

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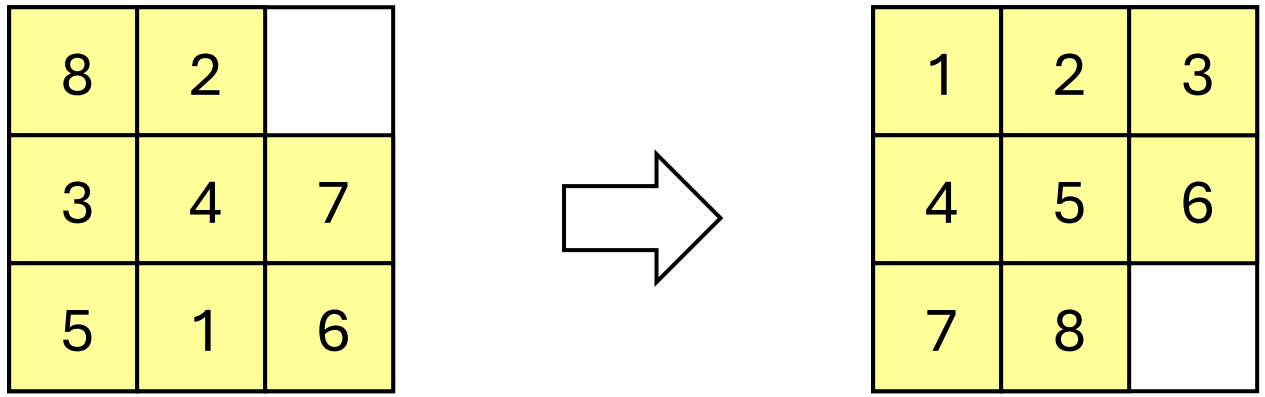
Problem solving by Search

When we don’t know much, we just try

Problem solving by Search



Initial state

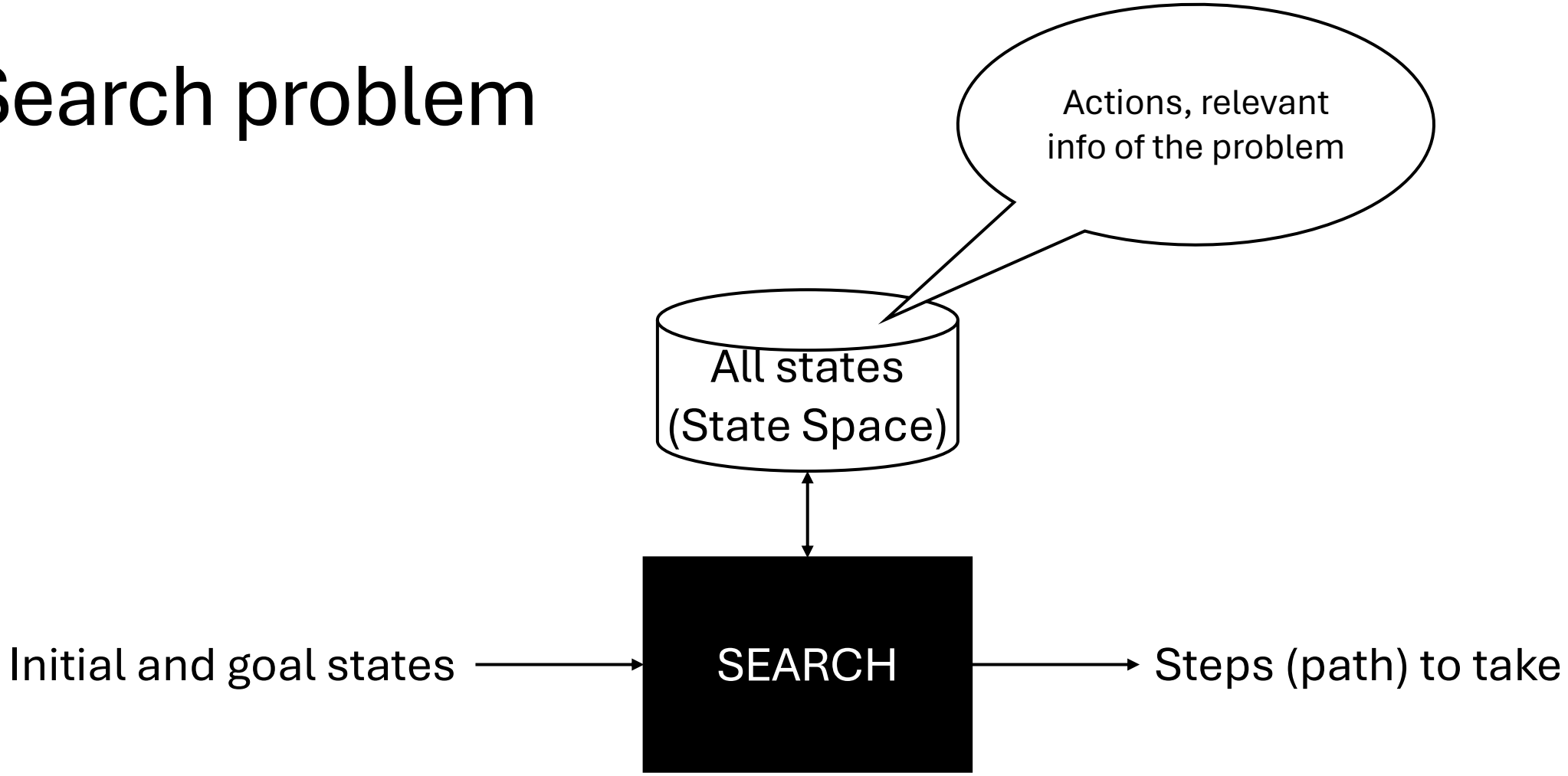
Goal state

Finding answer (to reach a goal) by trials and errors; **exploring alternatives**

Real-world Search problems

- Route finding: airline travel, computer networks, map navigation, tour plan
- Information search (e.g. web search engine)
- Game playing (e.g. boardgames)
- Electronic ICs (VLSI) layout
- Assembly sequencing
- Packaging arrangement
- Parameters (variables) optimization
- …

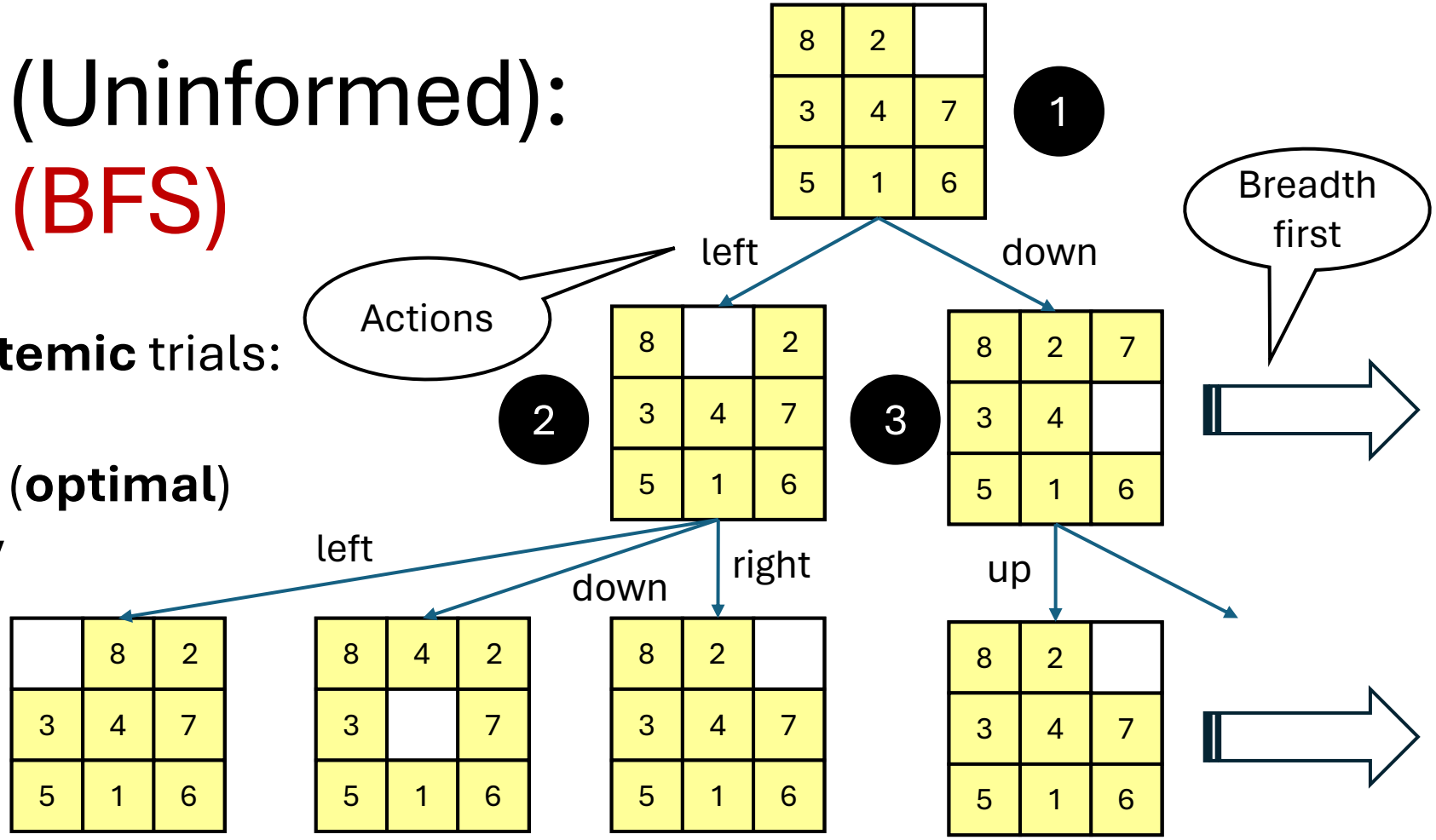
Search problem



Blind Search (Uninformed):
Breadth-first (BFS)

Finding answer by **systemic** trials:
try “side” way first

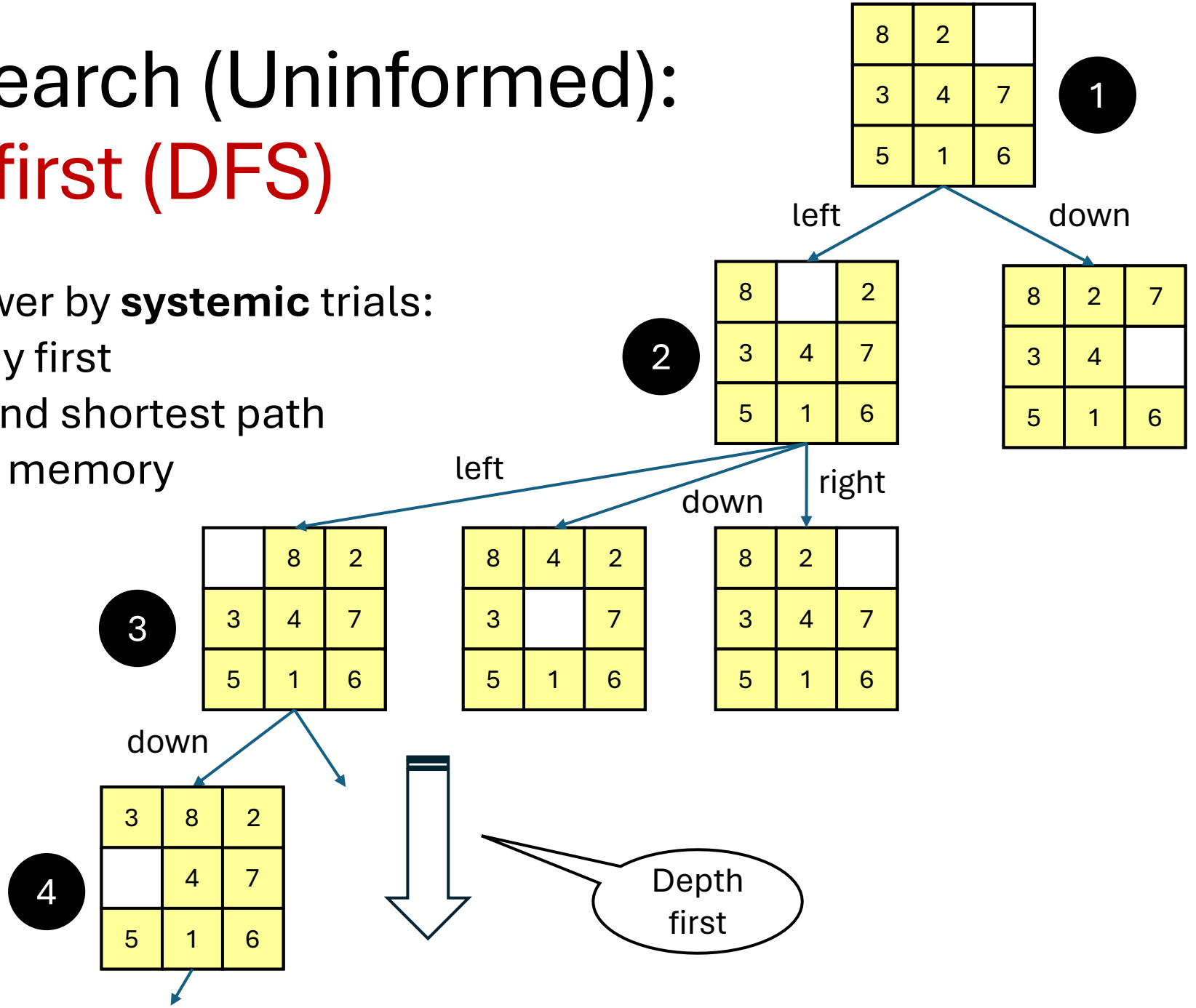
- Finds shortest path (**optimal**)
- Uses more memory



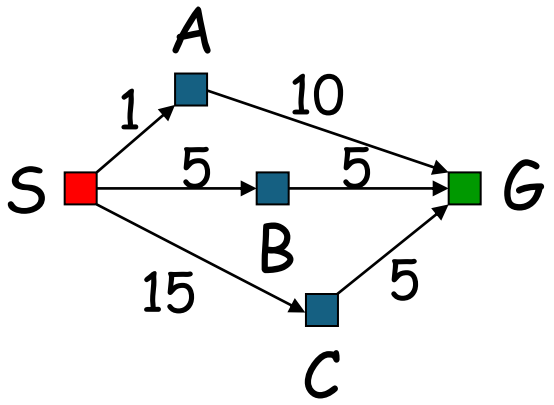
Blind Search (Uninformed):
Depth-first (DFS)

Finding answer by **systemic** trials:
try “side” way first

- May not find shortest path
- Uses less memory



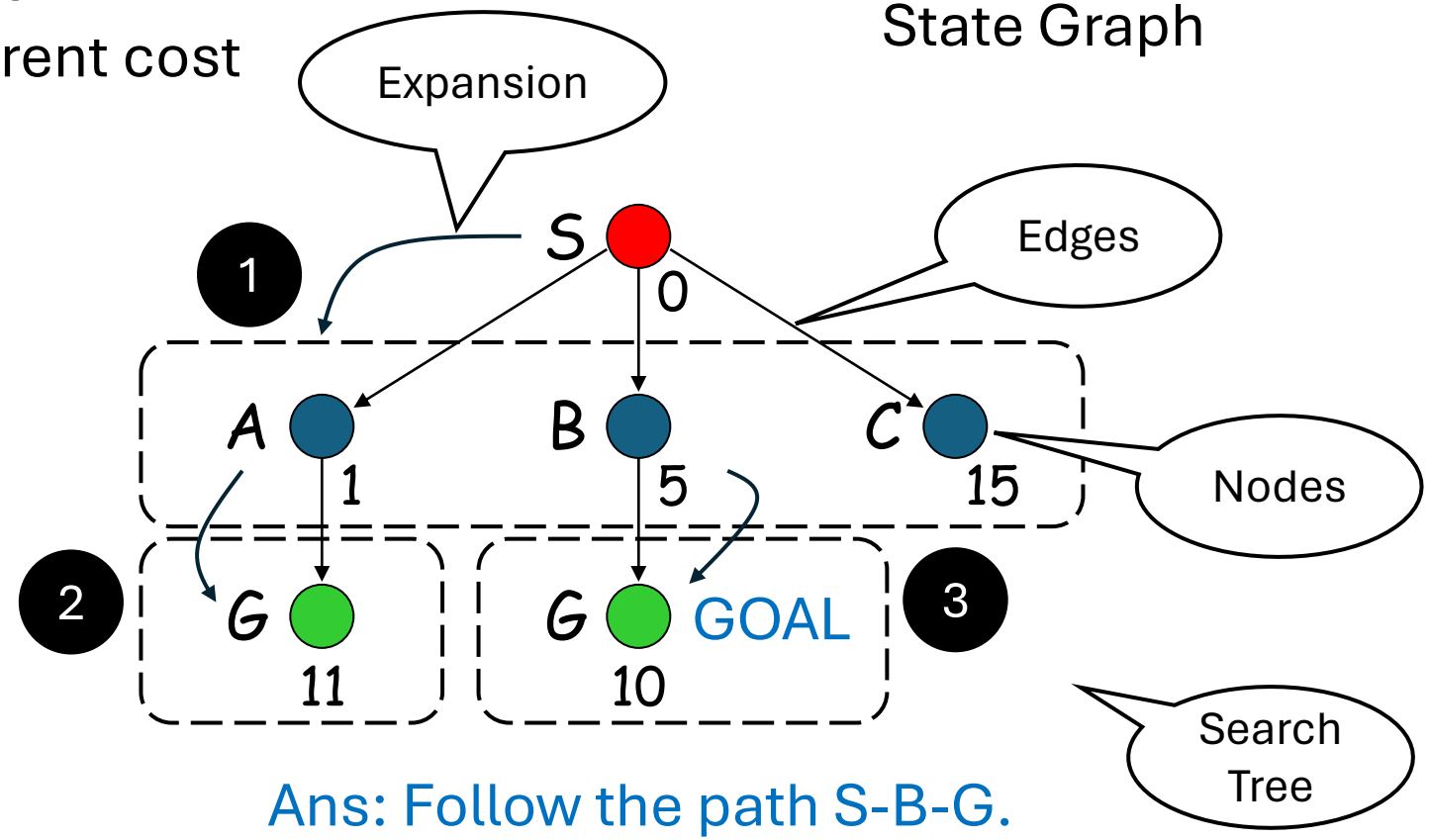
Blind Search (Uninformed):
Uniform-cost (UCS)



State Graph

Finding answer by **systemic** trials:
try "cheapest" (so far) way first
- When each action has different cost
- Finds shortest path

Test goal before **expansion**,
stop if goal reached
(likewise, in BFS and DFS)



Ans: Follow the path S-B-G.

Blind vs informed Search

Blind

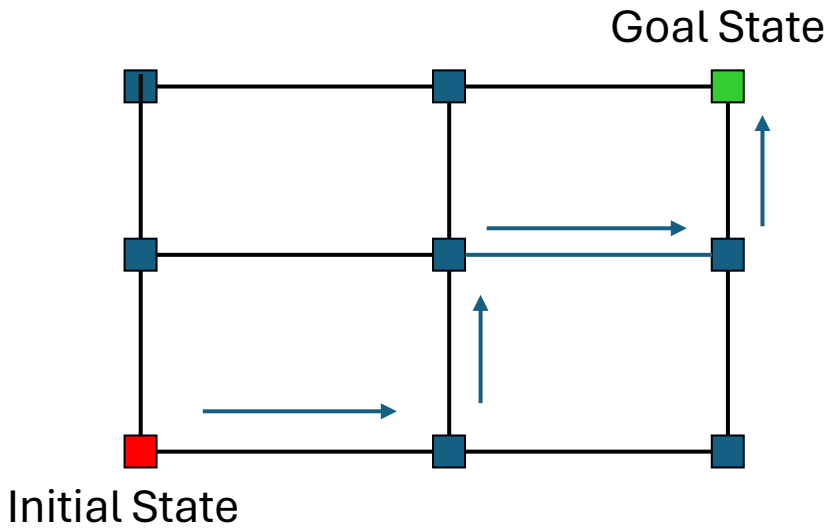
Informed

Heuristic Search (Informed):
Greedy best-first

Finding answer by **smart** trials: try "closest or best" (estimate) way first

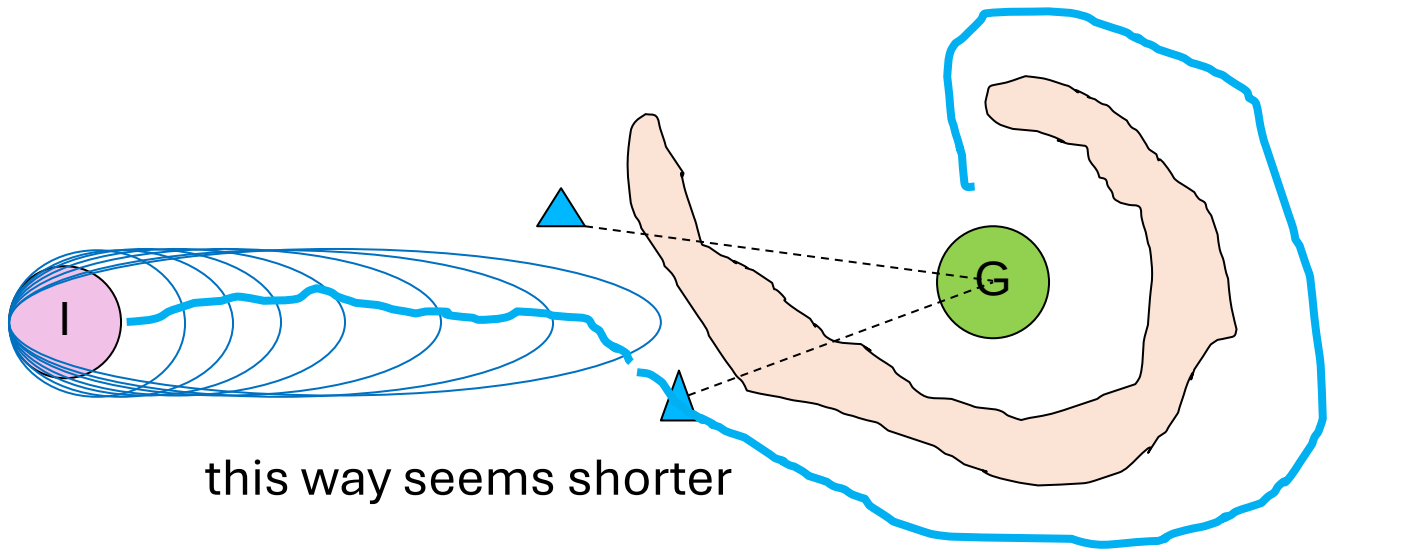
- Uses a **heuristic** $h(n)$ to estimate "distance" to goal
- Greedy, may reach solution fast
- Performs badly with poor estimates

Heuristic $h(n)$ = Straight line distance



Greedy best-first not optimal

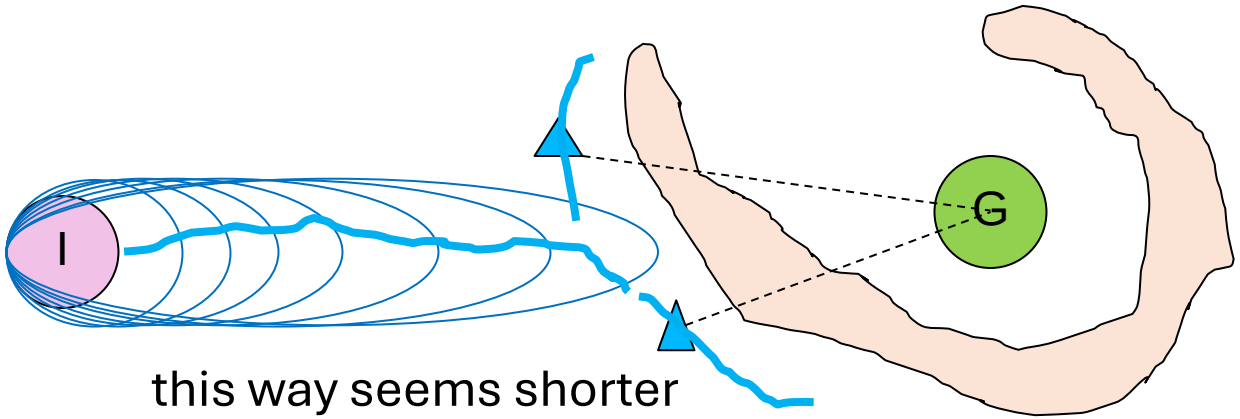
Heuristic: straight line distance (ignore barriers, actual route/path)



Heuristic Search (Informed):
A-star (A*)

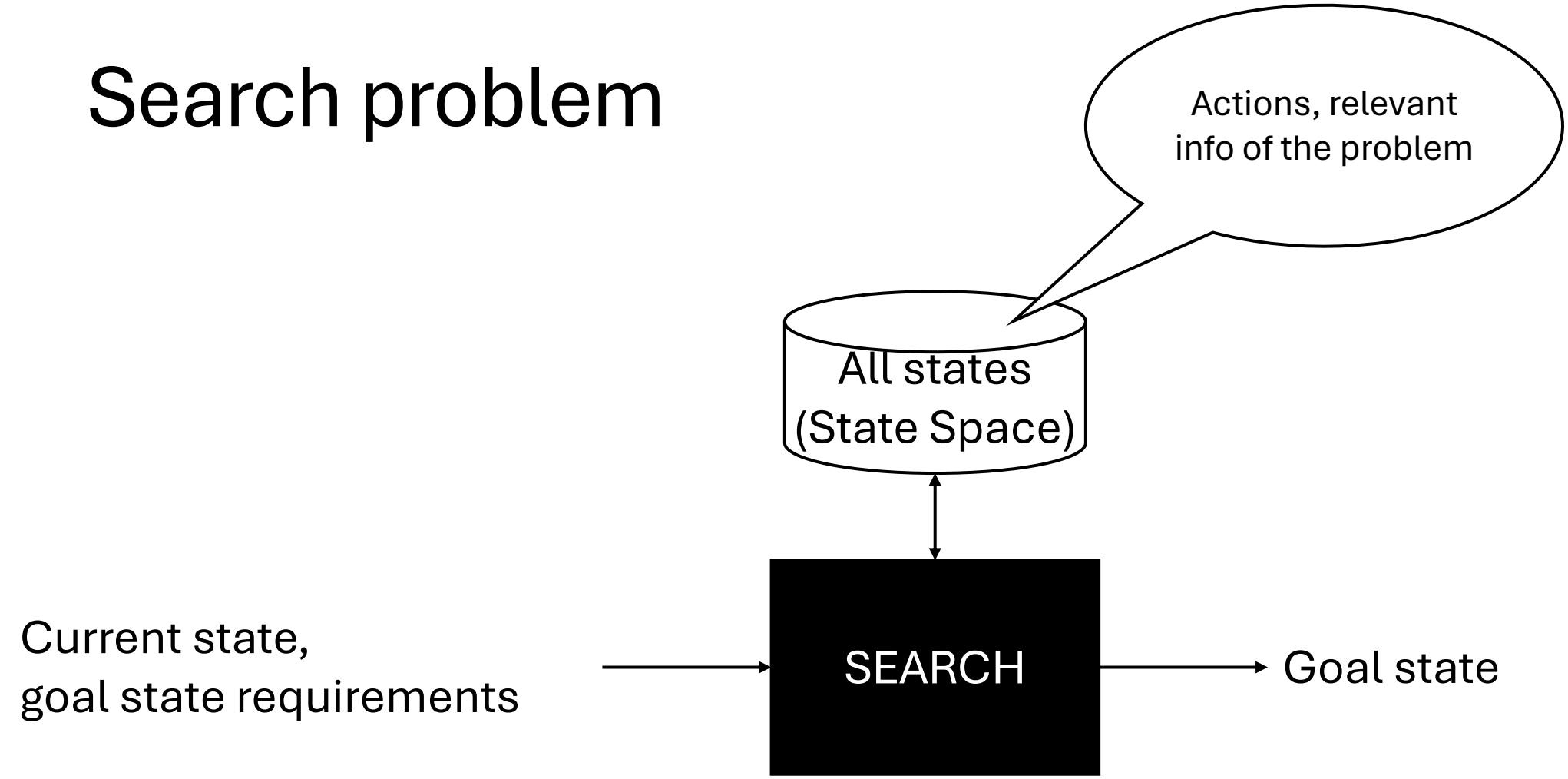
Finding answer by **smart** trials: try “closest ” (estimate) and “cheapest” (so far) way first

- Uses a heuristic $h(n)$ to estimate “distance” to goal, and the path cost $g(n)$ travelled so far
- Optimal, most popular search



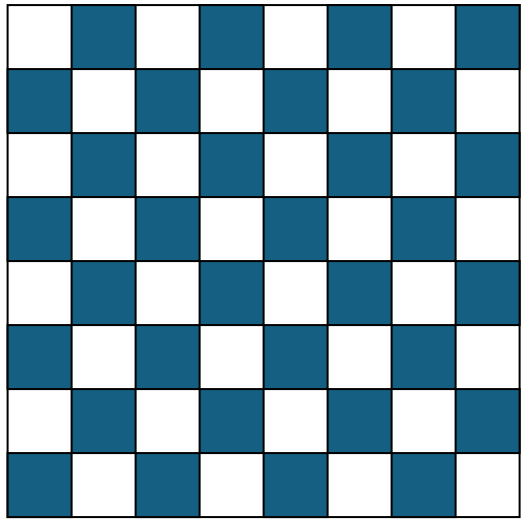
Evaluation of state n, $f(n) = g(n) + h(n)$

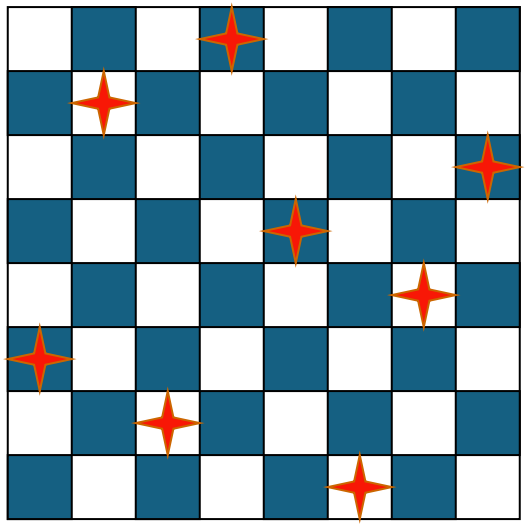
Search problem



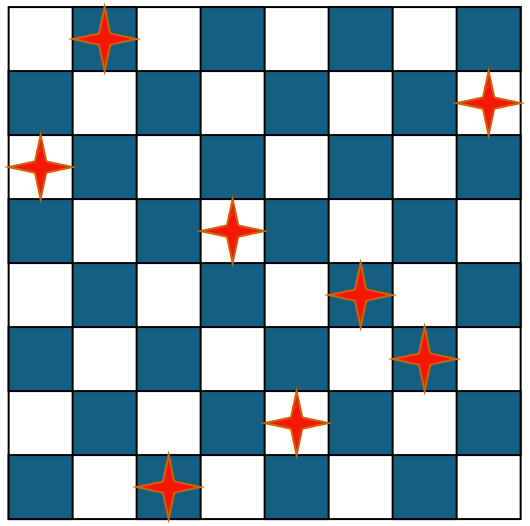
8-Queens problem

Problem: Place 8 queens on the chess board without any conflicts





A solution



Not a solution

Other search algorithms

- Improvement over basic search algorithms
- Local search
- Beam search
- Adversarial search (game)
- …

Knowledge-base systems

When we have knowledge, we reason (think) with our knowledge

Rules are knowledge

- IF the 'fuel tank' is empty THEN the car is dead

- IF the car is dead AND the 'fuel tank' is empty
- THEN the action is 'refuel the car’

- IF the spill is liquid AND the 'spill PH' < 6 AND the 'spill smell' is vinegar
- THEN the 'spill material' is 'acetic acid'

Rules expresses our logics

Rules are knowledge

- IF the 'fuel tank' is empty THEN the car is dead

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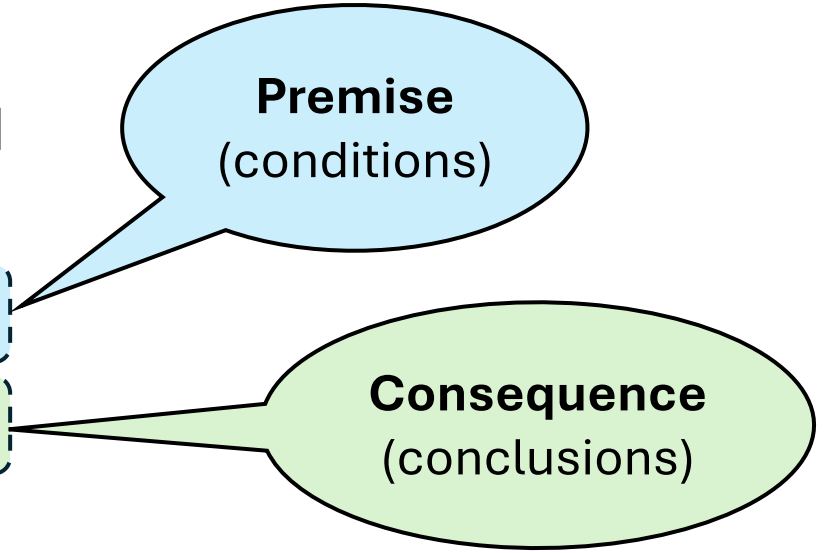

- IF the spill is liquid AND the 'spill PH' < 6 AND the 'spill smell' is vinegar
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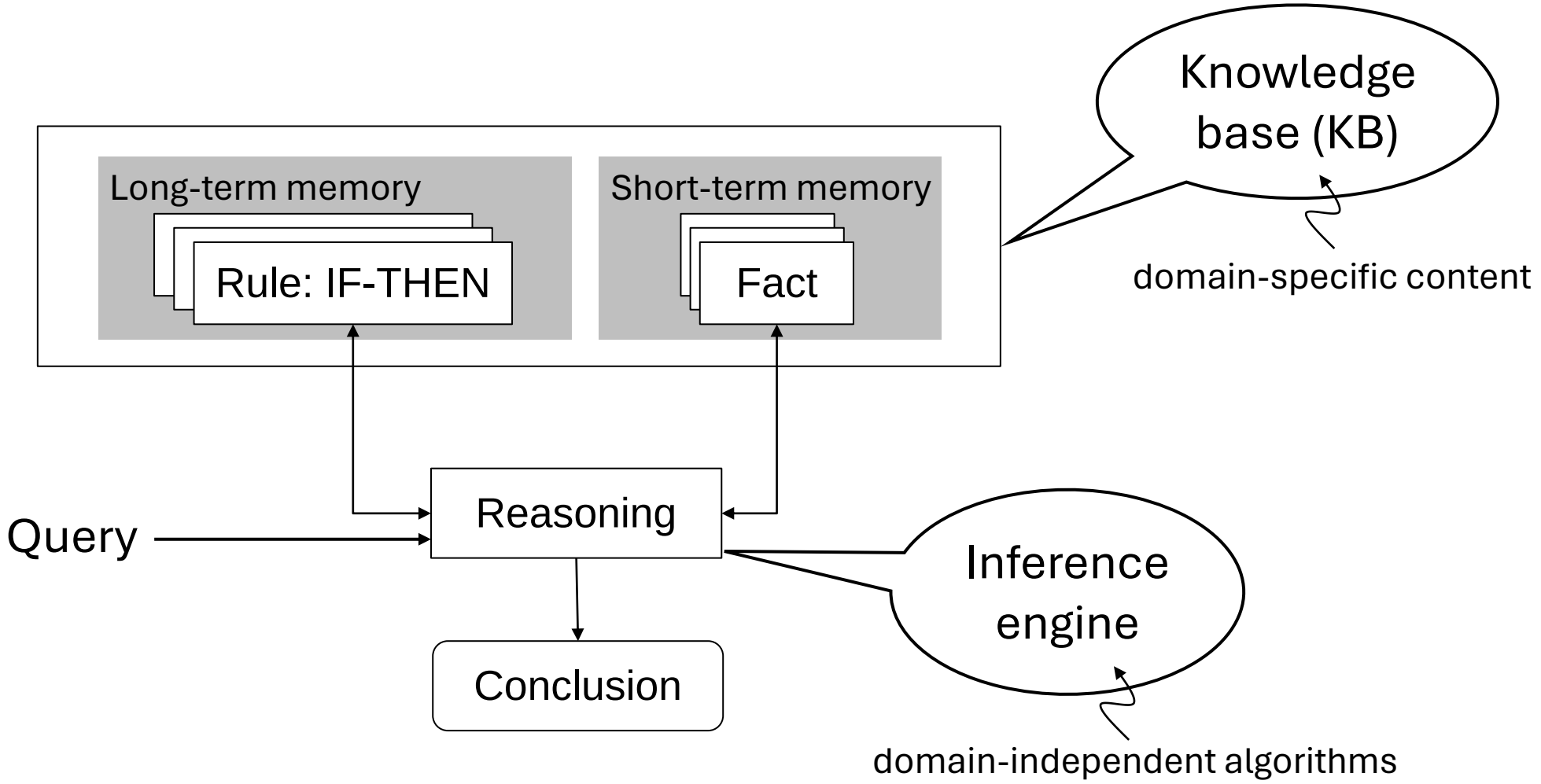
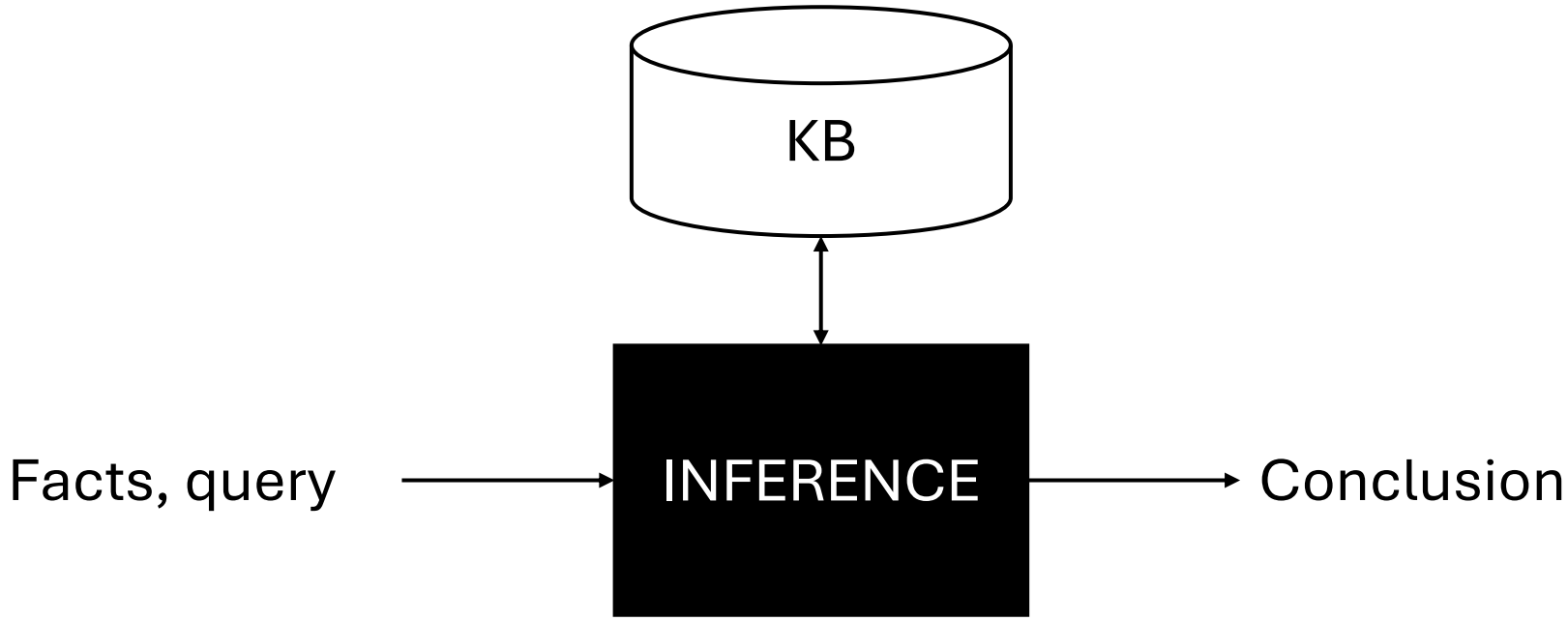
Rules expresses our logics

Rule-based expert system

Expert system is one type of KB systems, targeting specific domain



Knowledge-base system



Inference approaches

- Proof by enumeration (check all rules with all facts)
- Inference rules (algebraic manipulation)
- Forward reasoning
- Backward reasoning
- Proof by resolution

Forward reasoning

- Given the following rules:
  - R1: IF A OR B THEN C
  - R2: IF D AND E AND F THEN G
  - R3: IF C AND G THEN H
- And the following facts:
  - B, D, E, F
- Goal: Prove H

Facts:
B, D, E, F

Rules:
R1: IF A OR B THEN C
R2: IF D AND E AND F THEN G
R3: IF C AND G THEN H

Forward reasoning

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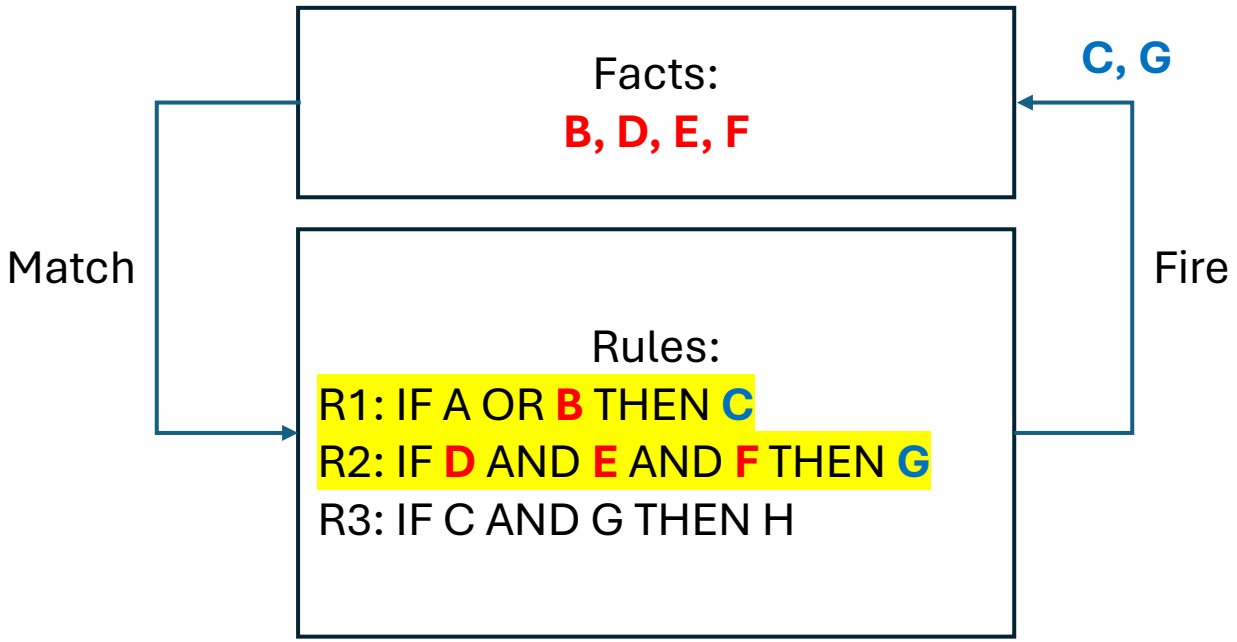

Steps (**match-fire** cycles):

- Check each rule with facts
- If facts **match** premise, **fires** the rule, generate **new** fact(s) from the consequence
- Repeat the match-fire cycle with the updated facts
- Stop when goal achieved

Forward reasoning

- Given the following rules:
  - R1: IF A OR B THEN C
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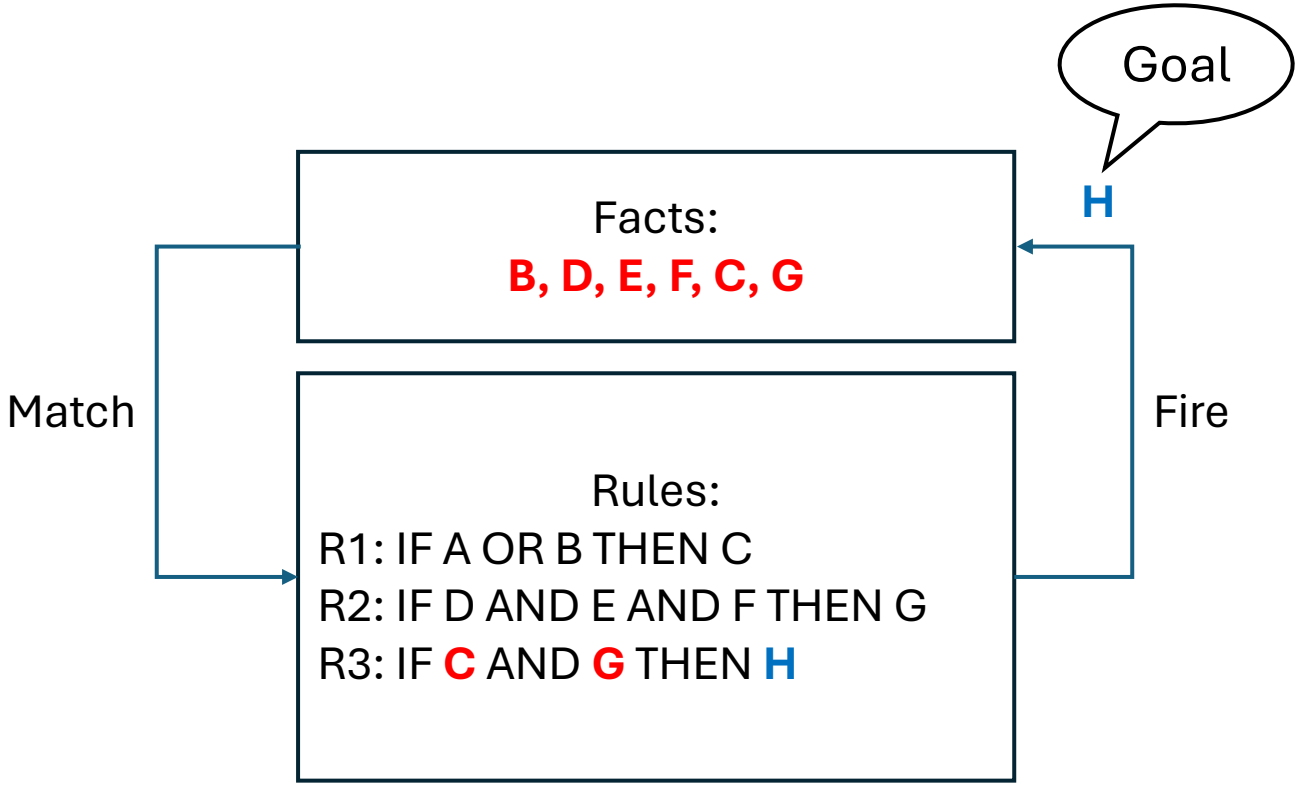

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- Check each rule with facts
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Knowledge representation

- We can't program the computer in our languages (yet)
- **Formal logic** is designed to representation knowledge (rules and facts)
- Propositional logic
- First order logic
- …

$C \wedge G \Rightarrow H$

IF C AND G THEN H

$\exists y \forall x \big(Loves(x, y)\big)$

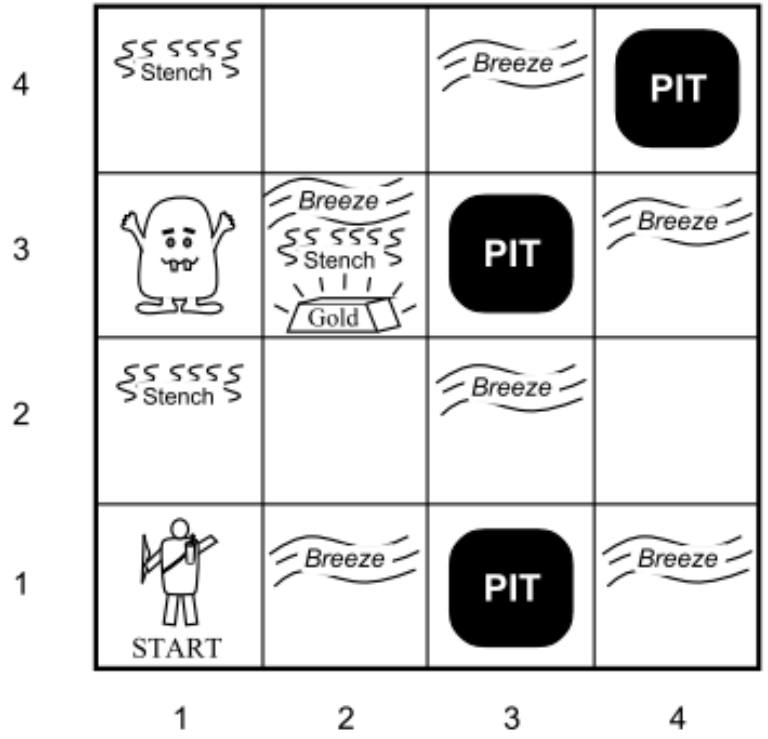
Says there is someone who is loved by everyone in the universe.

Exploring Wumpus world with KB

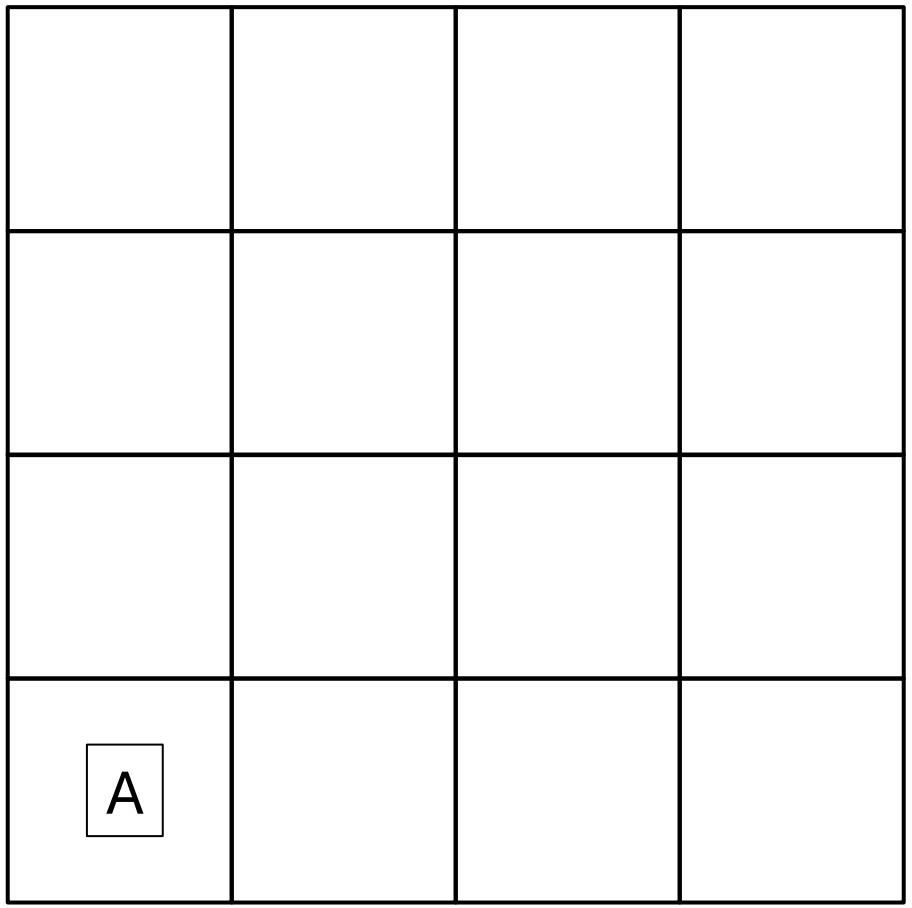
Knowledge base:
- Squares adjacent to Wumpus are smelly
- Squares adjacent to pit are breezy
- Glitter iff gold is in the same square
- Shooting kills Wumpus if you are facing it
- Shooting uses up the only arrow
- Grabbing picks up gold if in same square
- Releasing drops the gold in same square

Actions:
- Left turn, Right turn, Forward, Grab, Release, Shoot

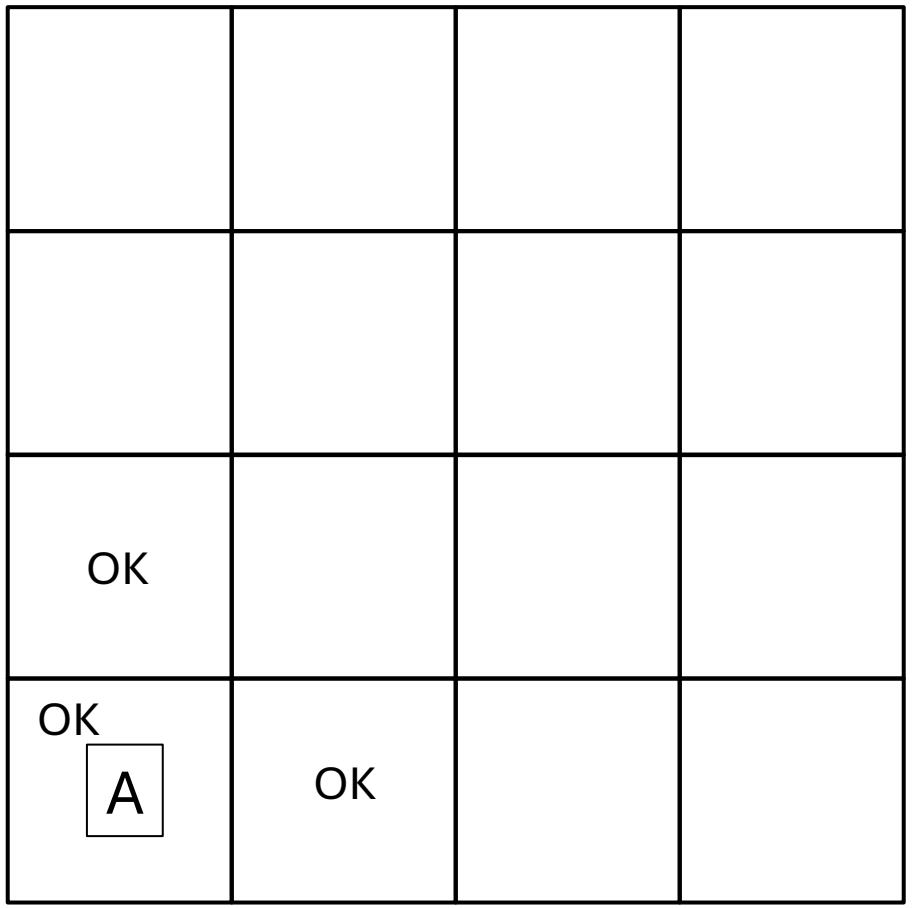
Senses:
- Breeze, Glitter, Smell



Wumpus and Pits don’t move
Agent die if meet Wumpus or Pit
Agent can sense its current cell

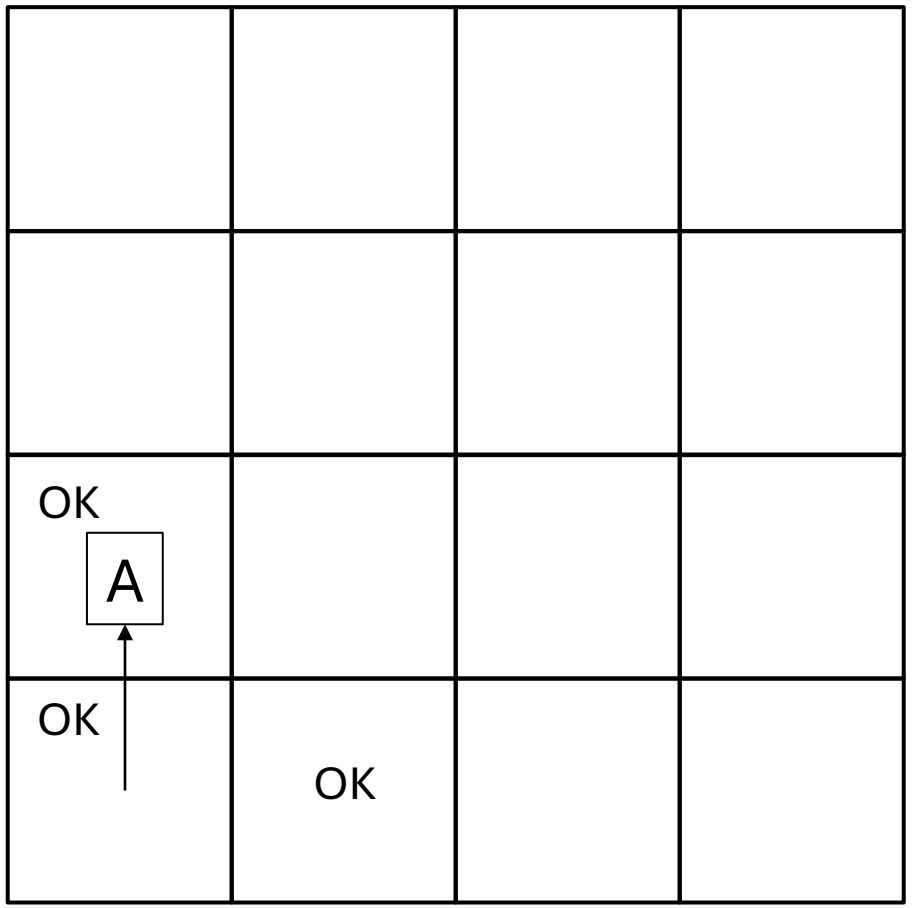


Agent start at (1,1)
Senses nothing

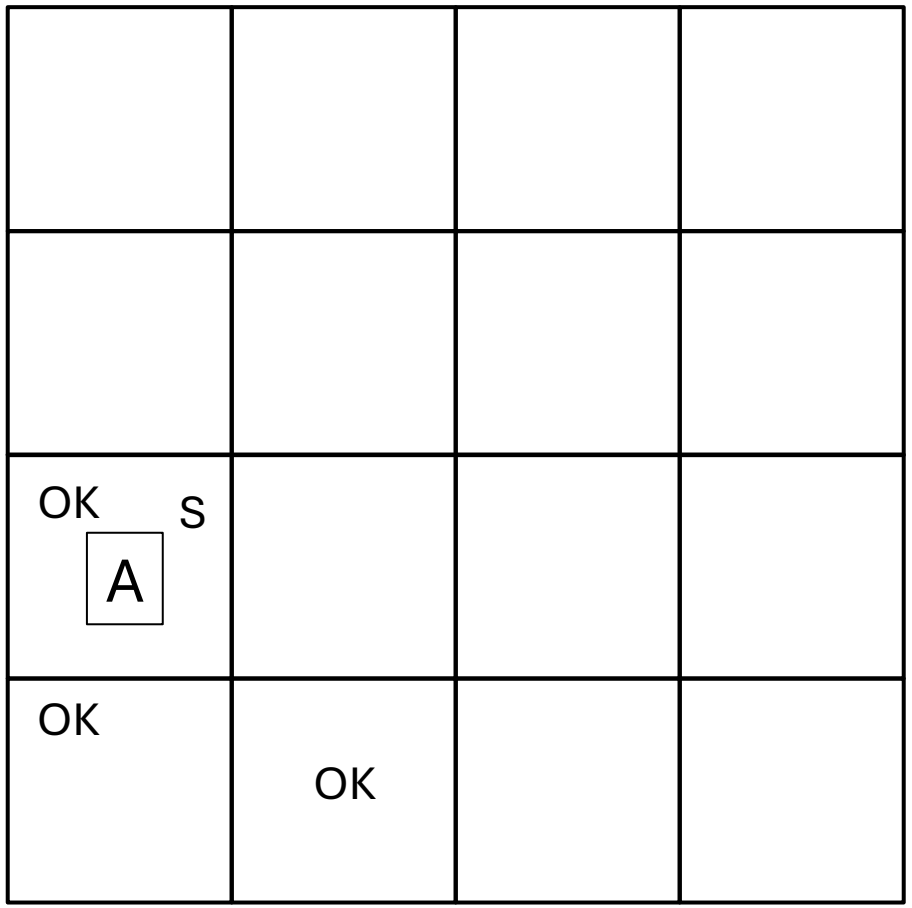


Agent start at (1,1)
Senses nothing

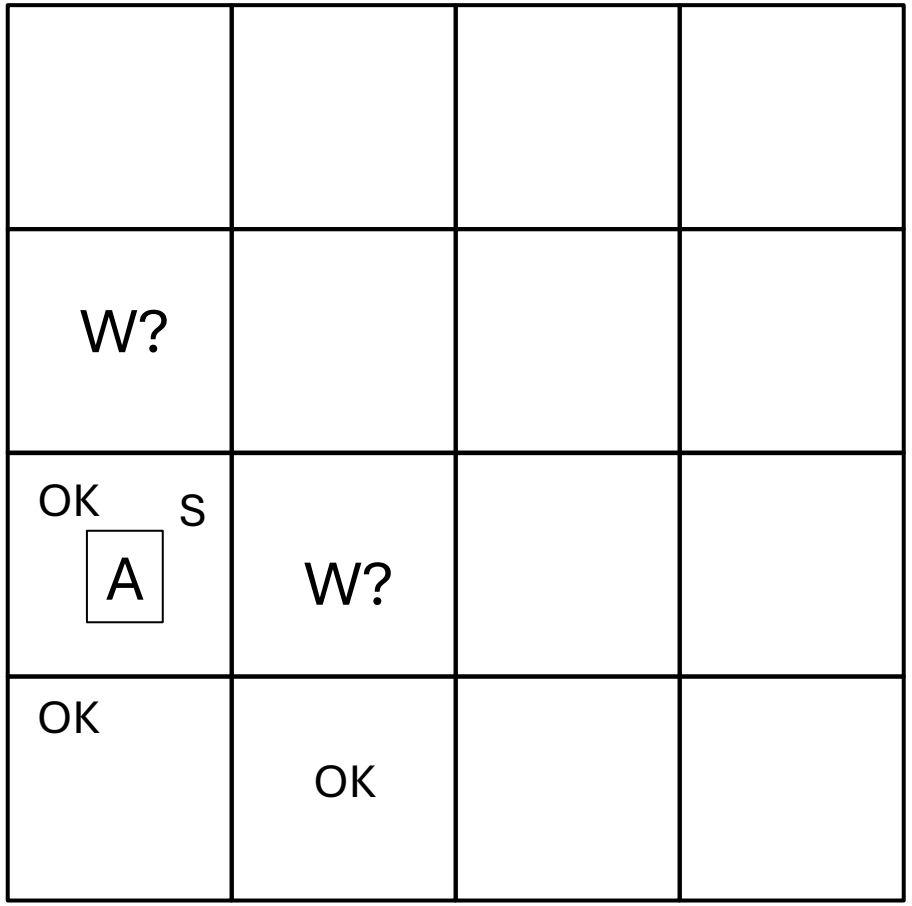
Conclude (1,1), (1,2),
(2,1) are OK (safe)



Agent moves to (1,2)

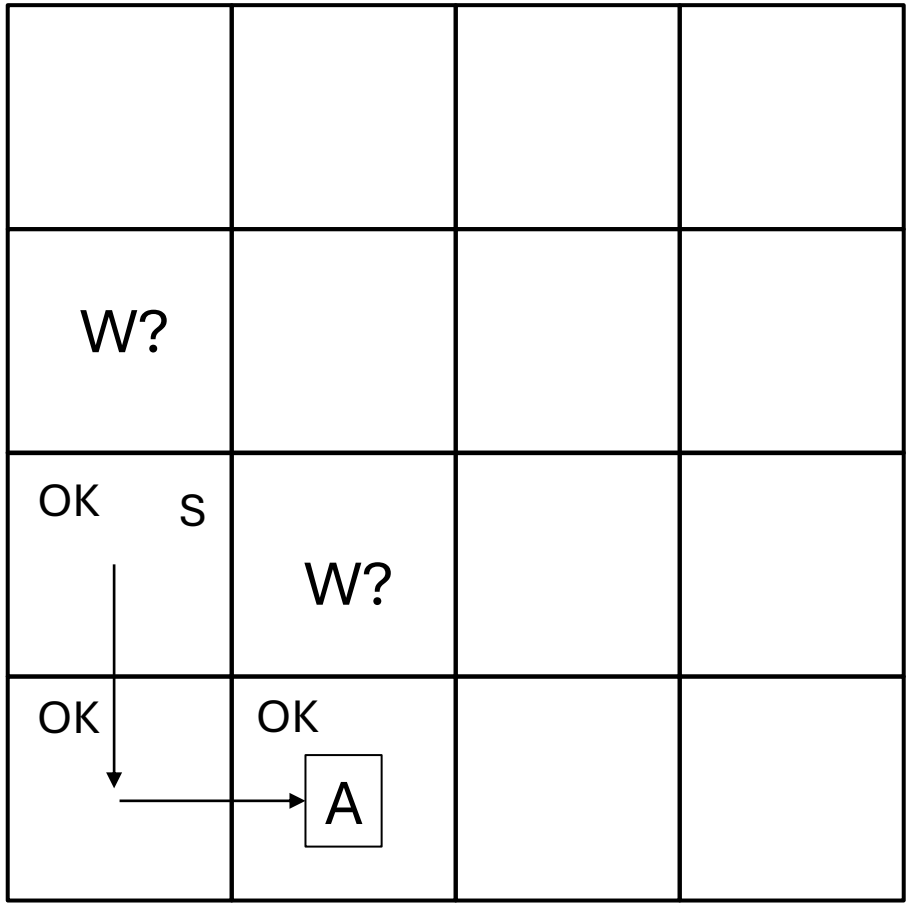


Agent moves to (1,2)
Senses stench

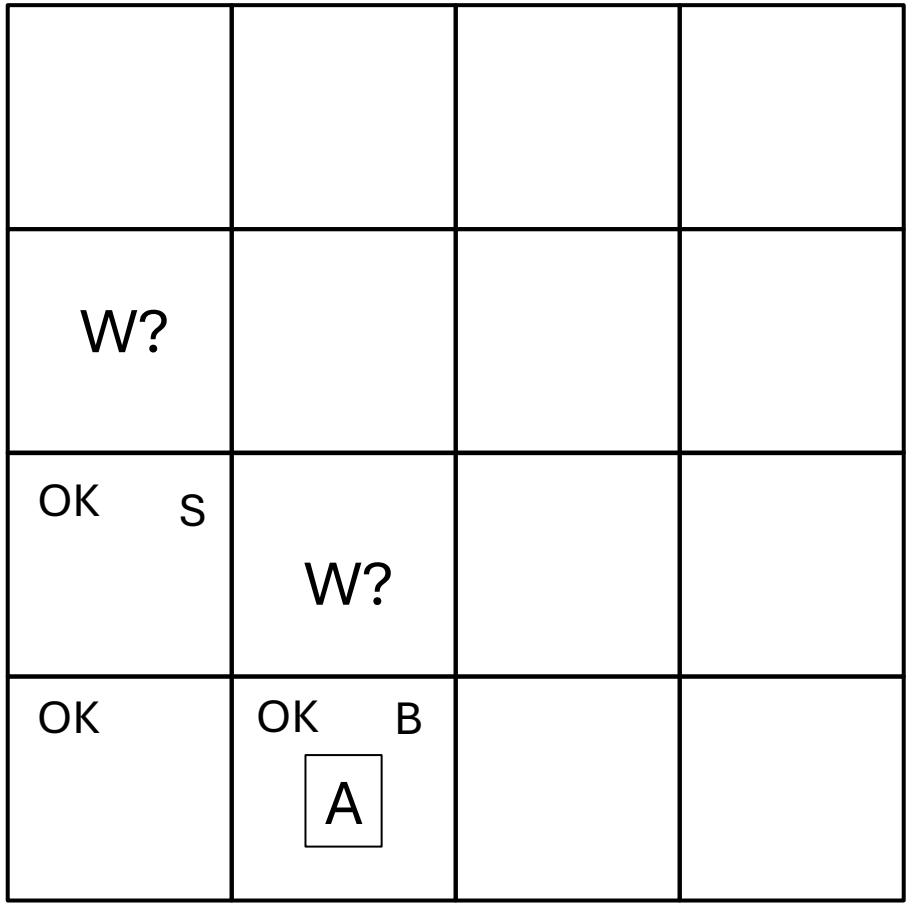


Agent moves to (1,2)
Senses stench

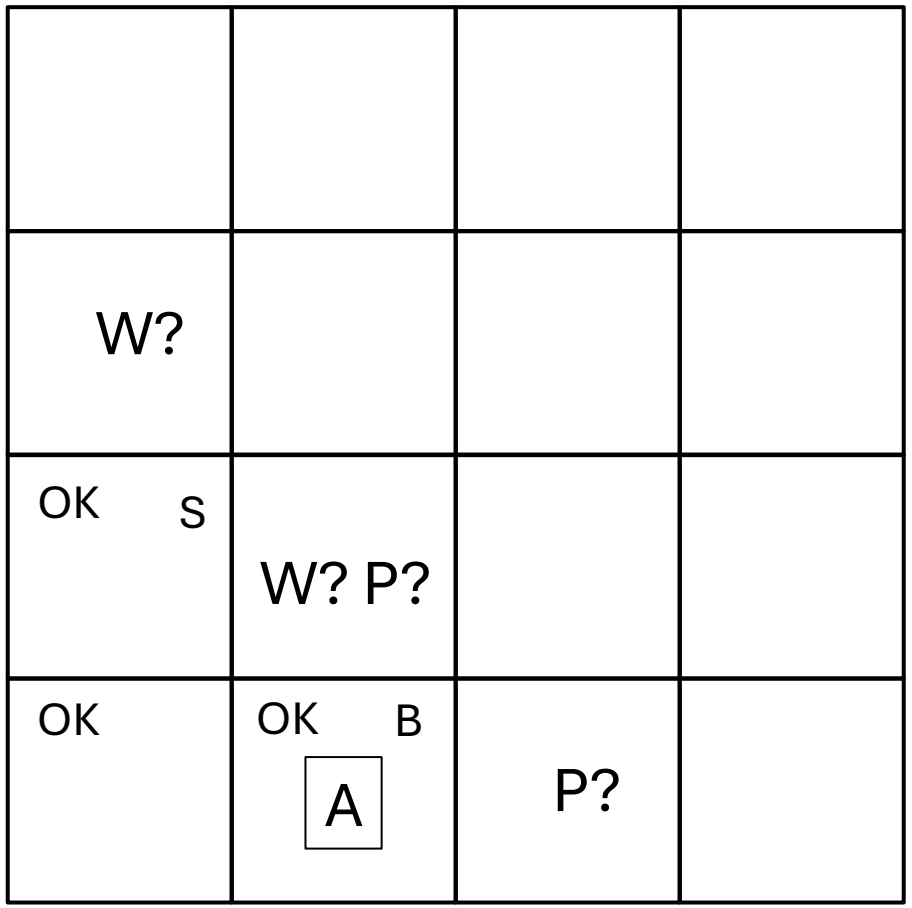
Conclude there is Wumpus either in (1,3) or (2,2) or both.



Agent moves back and heads to (2,1)

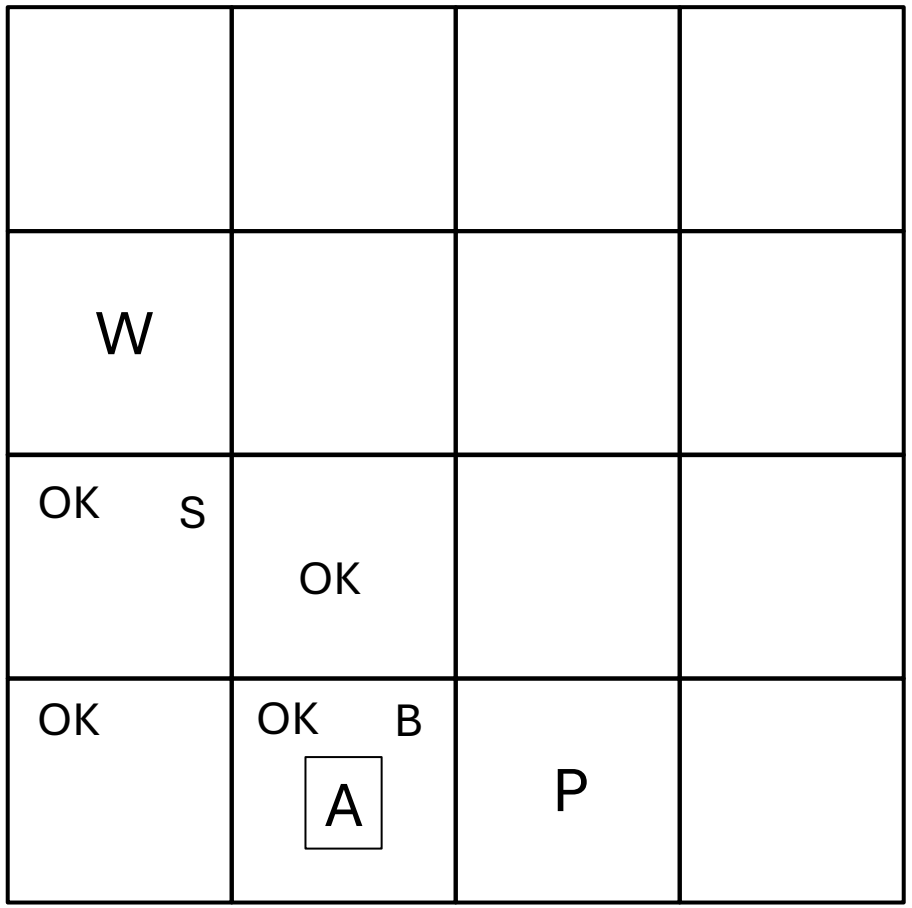


Agent moves back
and heads to (2,1)
Senses breeze



Agent moves back and heads to (2,1)
Senses breeze

Conclude that there is Pit in either (2,2) or (3,1) or both.



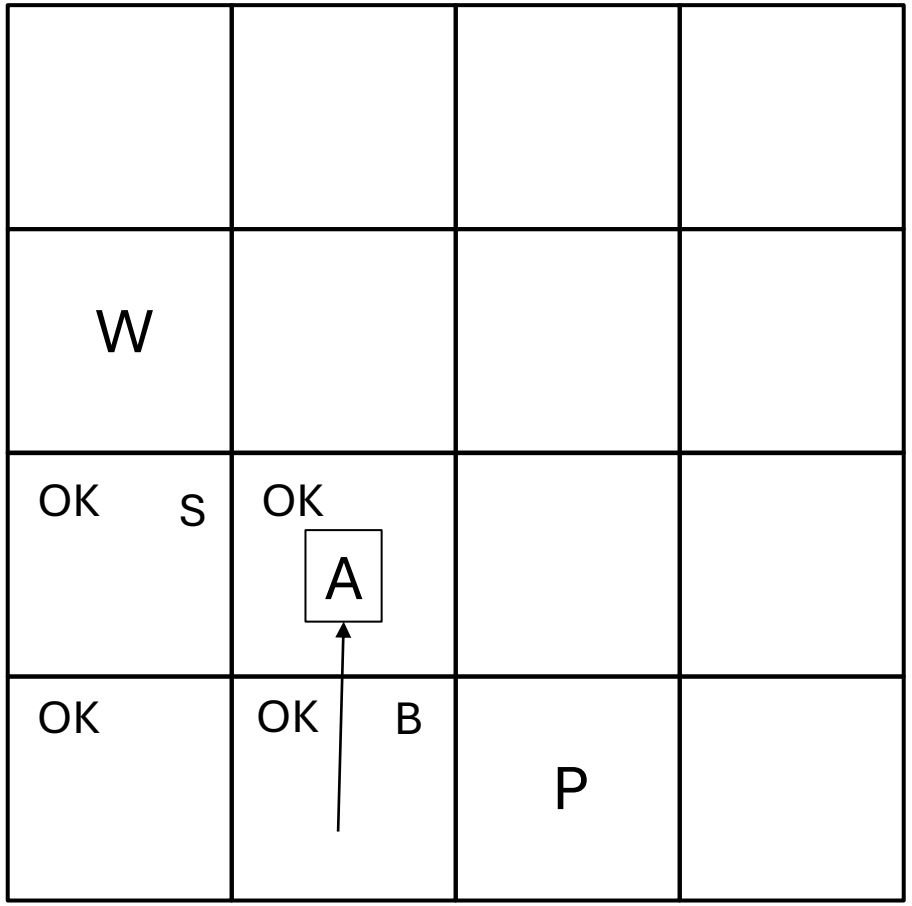
Agent moves back
and heads to (2,1)
Senses breeze

Conclude that there is
Pit in either (2,2) or
(3,1) or both.

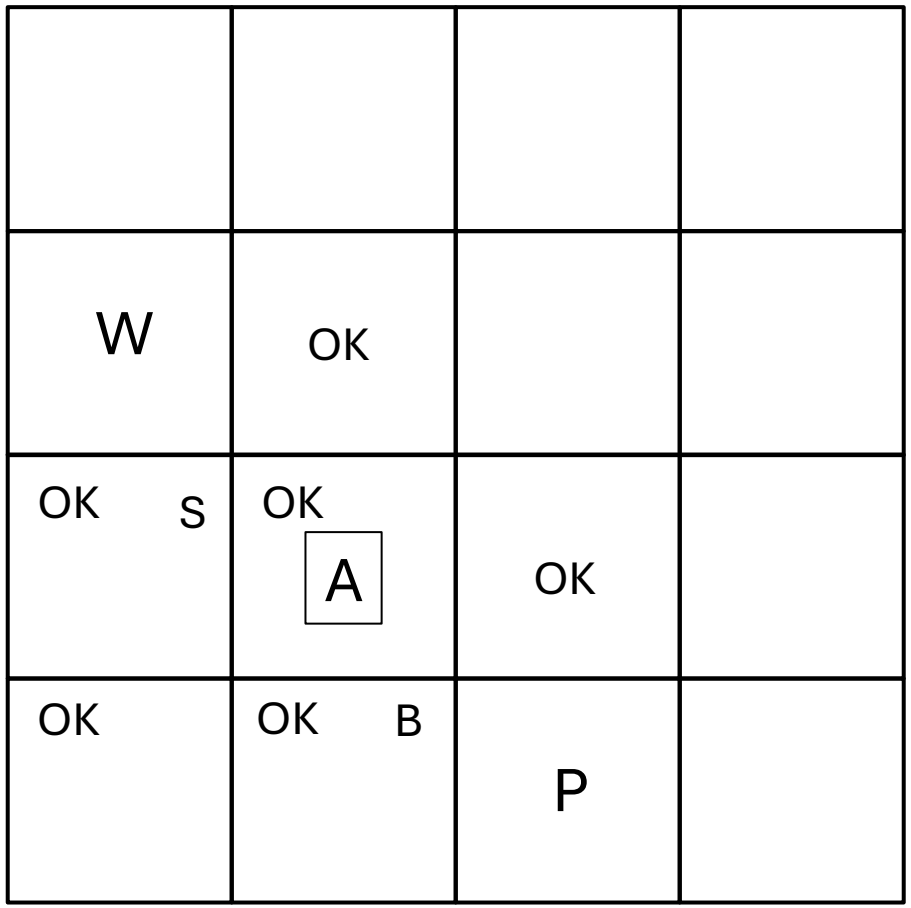
However, if (2,2) has Pit, there
should be breeze at (1,2), but
there wasn't.

So, there is Pit in (3,1).

Further, since there is no stench
in (2,1), there is no Wumpus in
(2,2), Then the Wumpus must
be in (1,3).

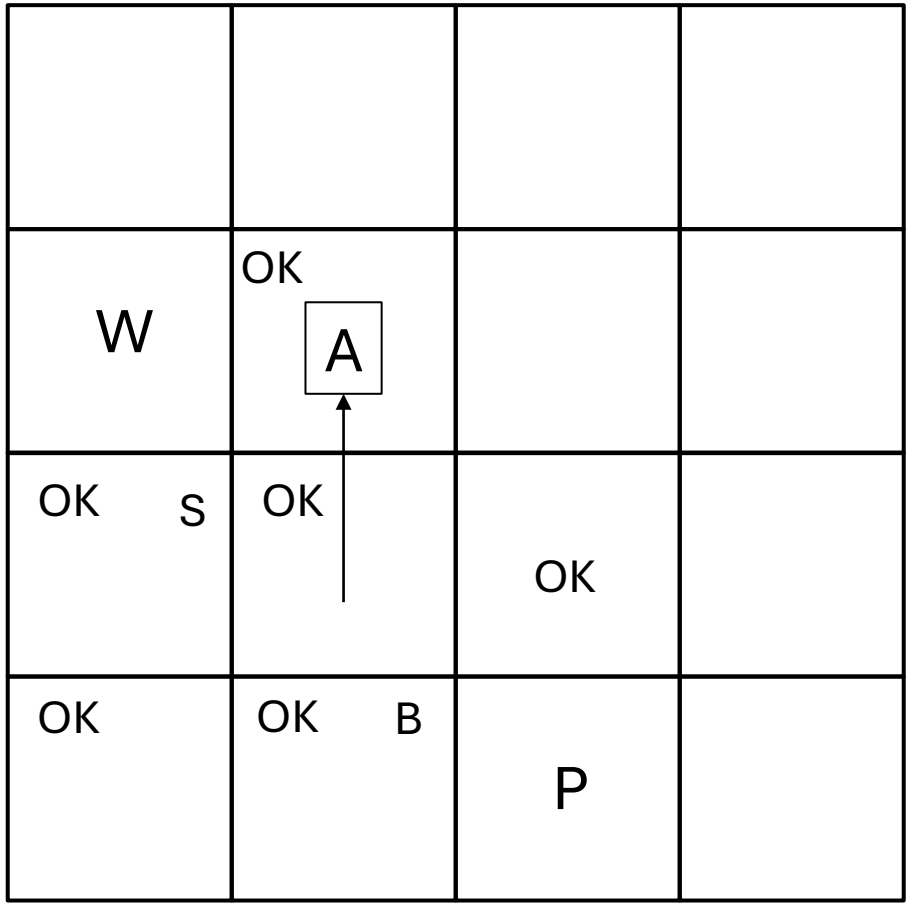


Agent moves to (2,2)

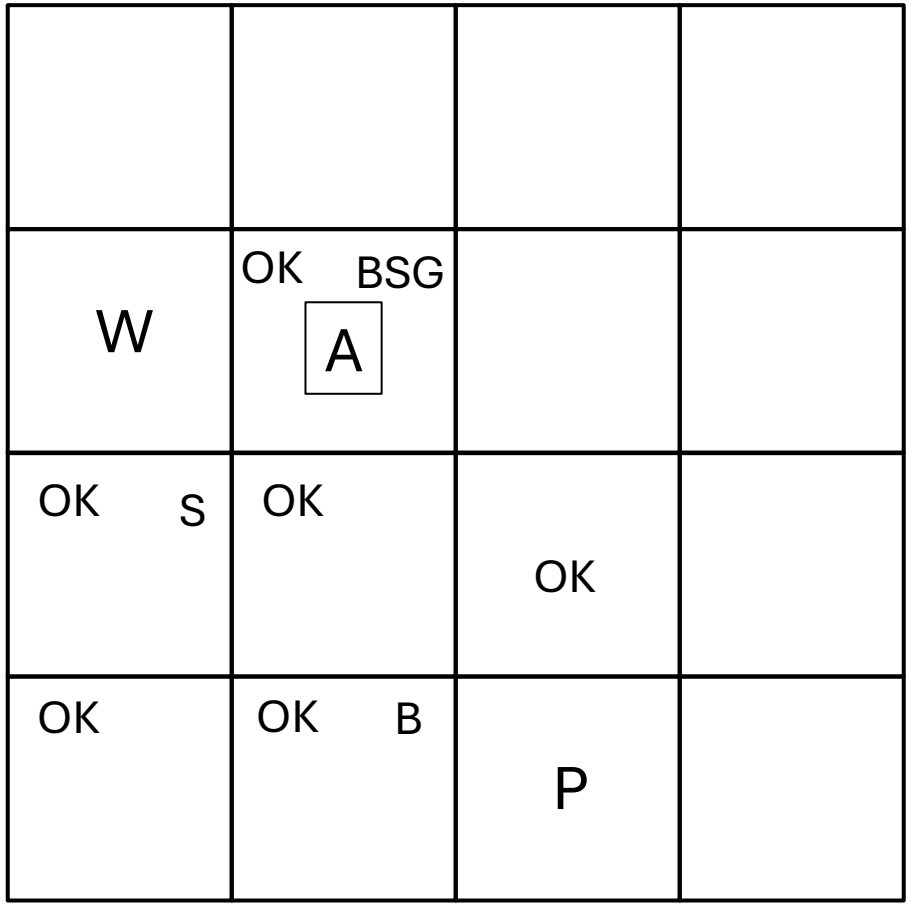


Agent moves to (2,2)
Senses nothing

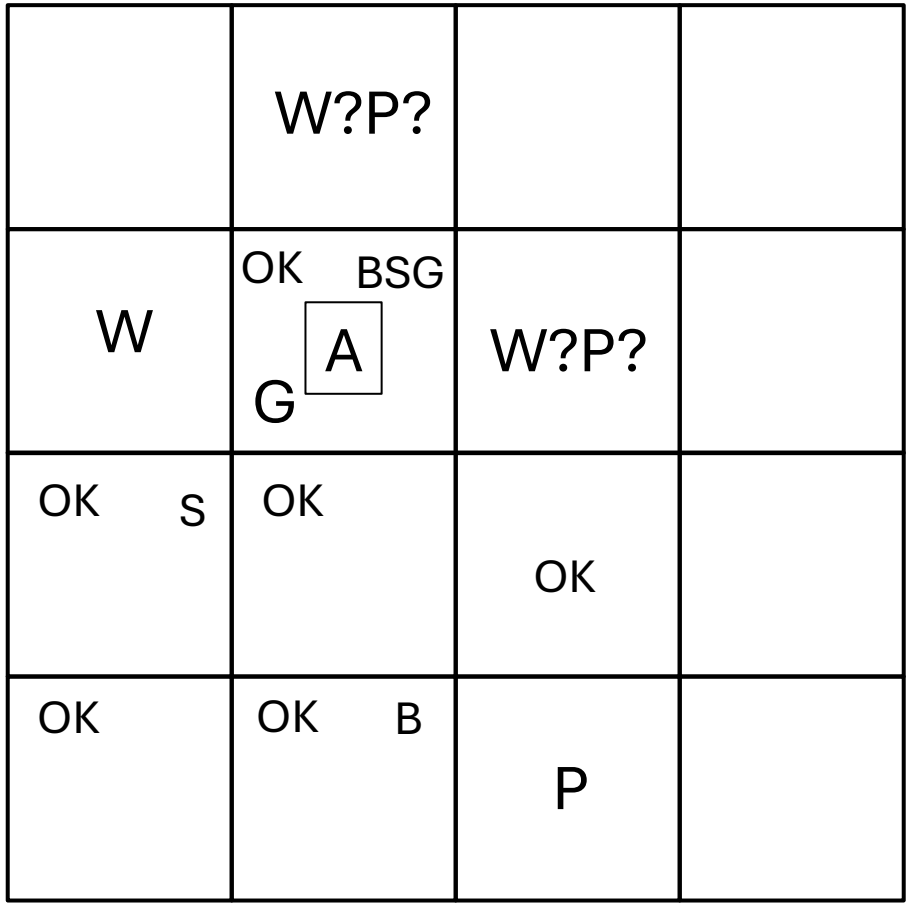
Conclude (2,3) and
(3,2) are safe



Agent moves to (2,3)



Agent moves to (2,3)
Senses breeze, stench and glitter



Agent moves to (2,3)
Senses breeze, stench and glitter

Conclude that there are Wumpus and Pits Around (2,3), and there is Gold in (2,3)

Gold found

AI techniques

Symbolic AI

aka Interpretational AI, Good Old Fashion AI (GOFAI), Traditional AI

- Problem solving by search
- Knowledge-based system

Non-symbolic AI

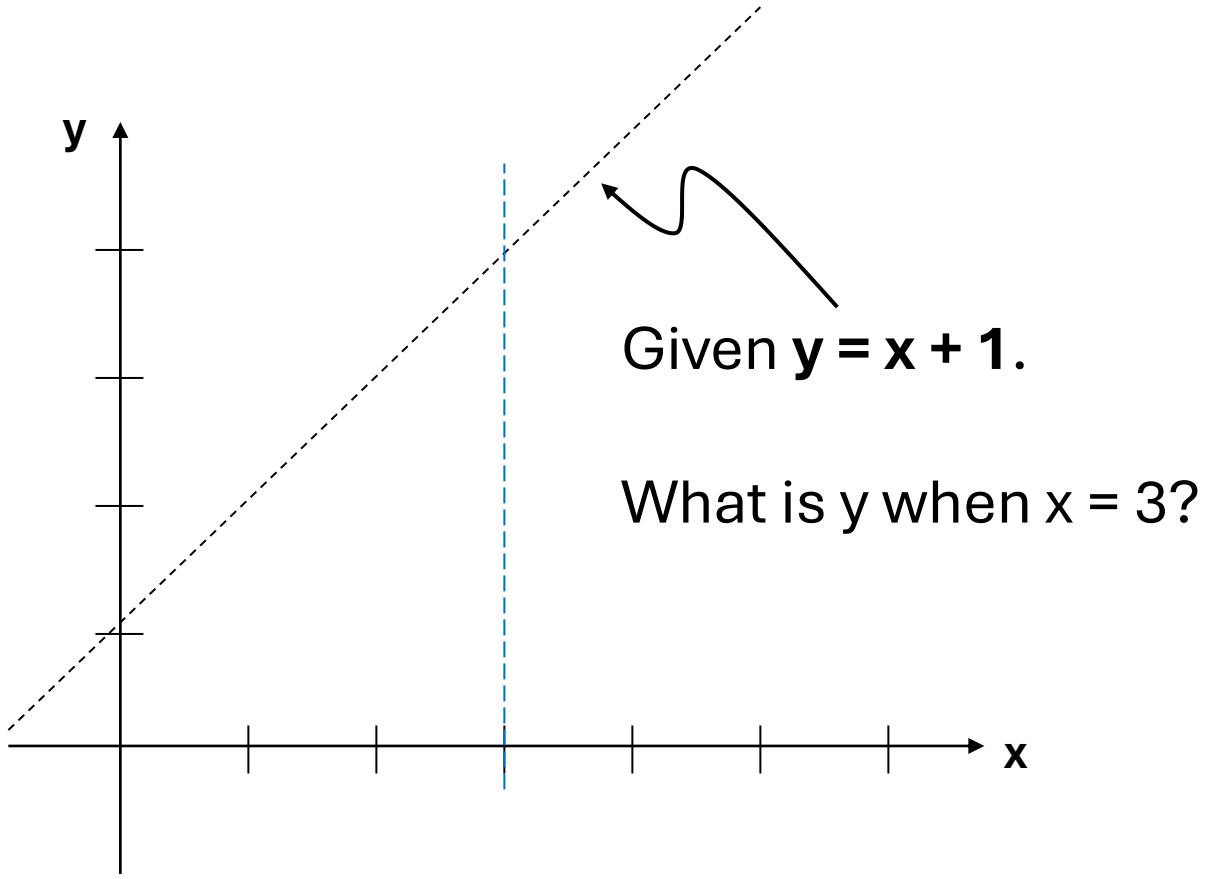
aka Sub-symbolic, Modern AI

- Machine Learning
  - Linear regression
  - Logistic regression
  - Artificial Neural Network
  - K-Means clustering

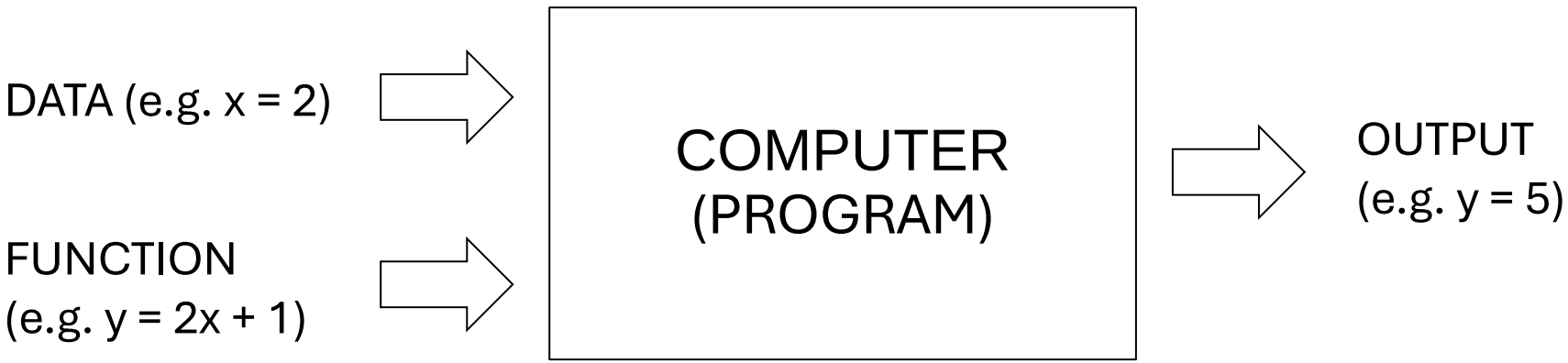
Machine Learning

It’s impossible to encode all knowledge in the world, can machines learn from observations?

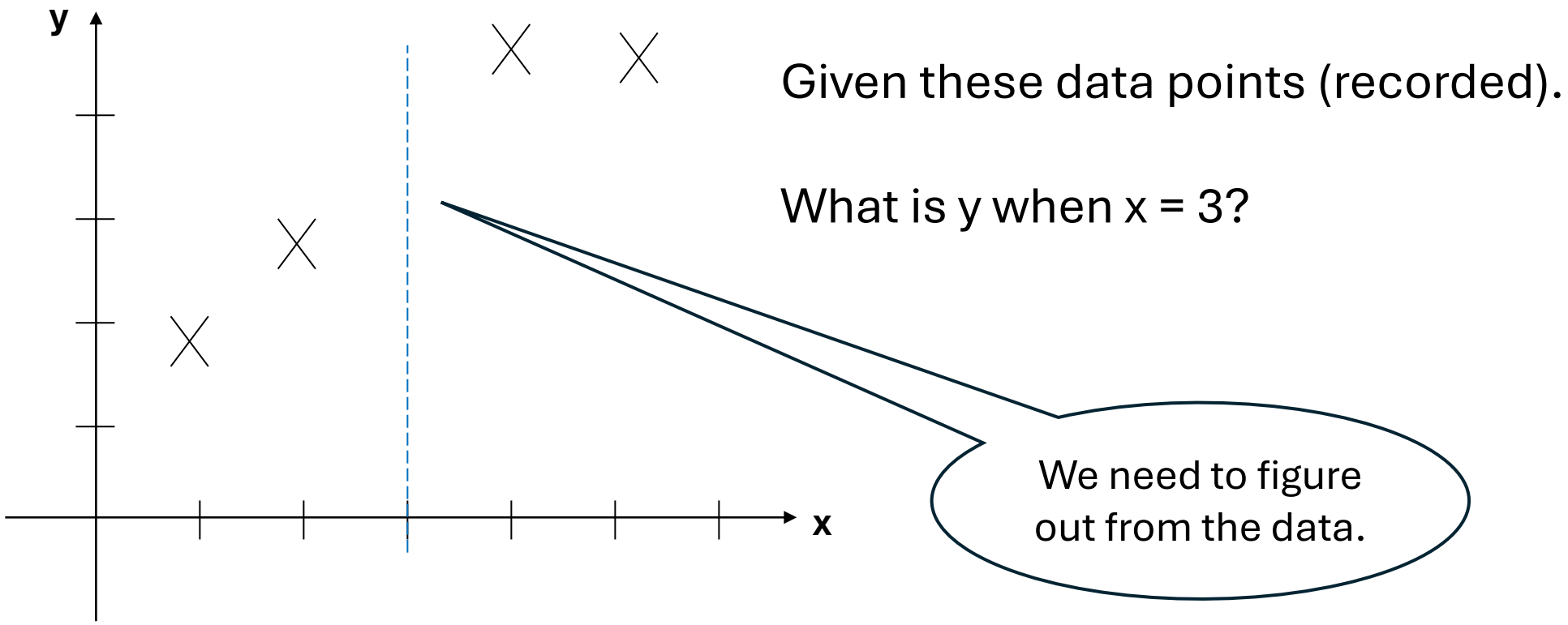
No learning required



Traditional computer science



Learning required

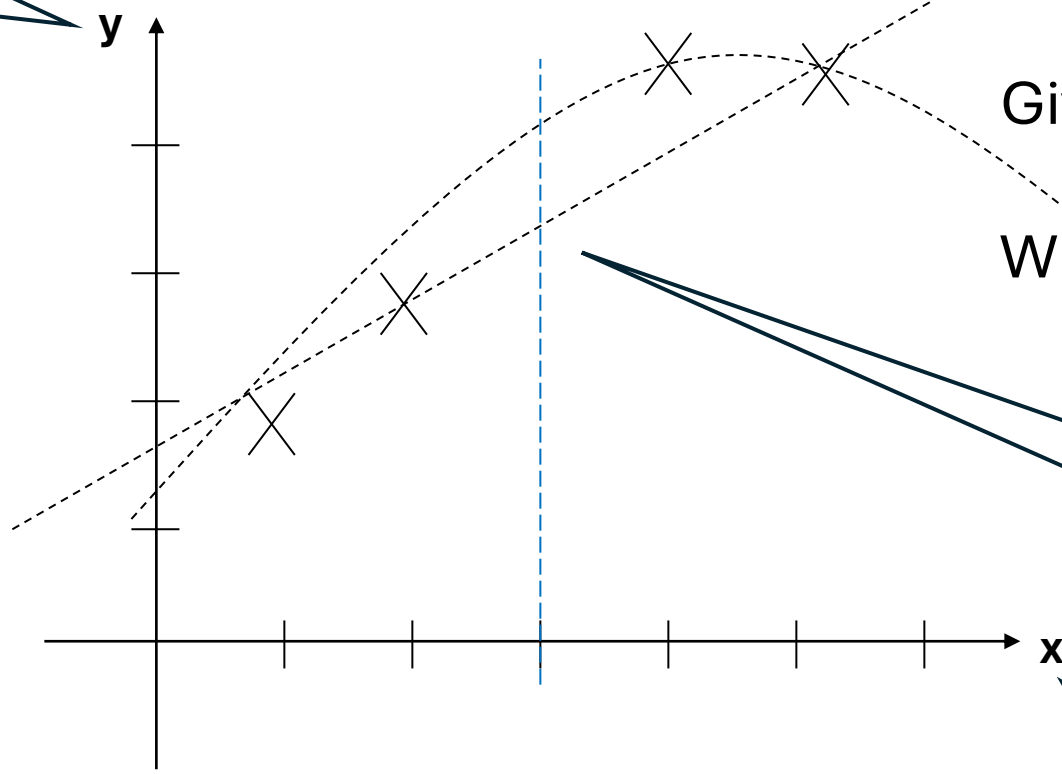


What do we learn?

Model

$y = f(x)$

Output **label**



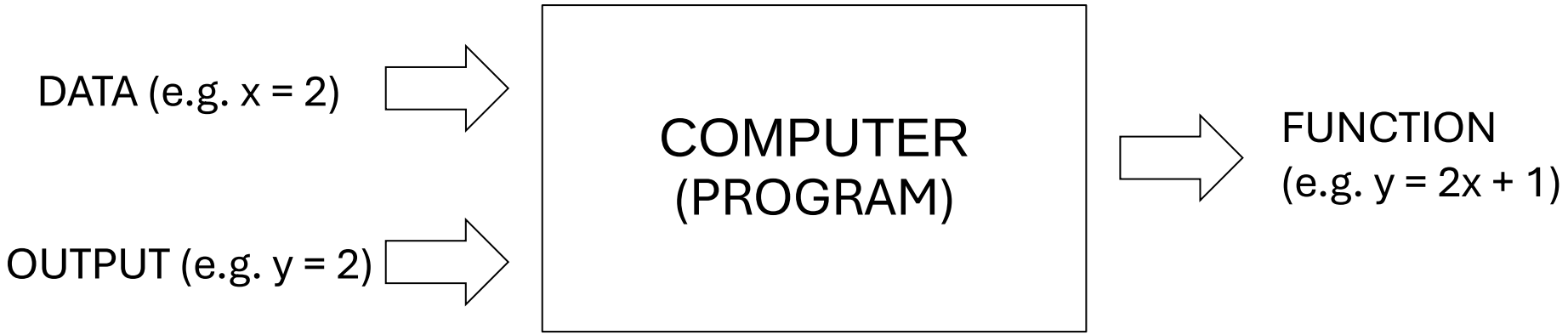
Given these data points (recorded).

What is y when x = 3?

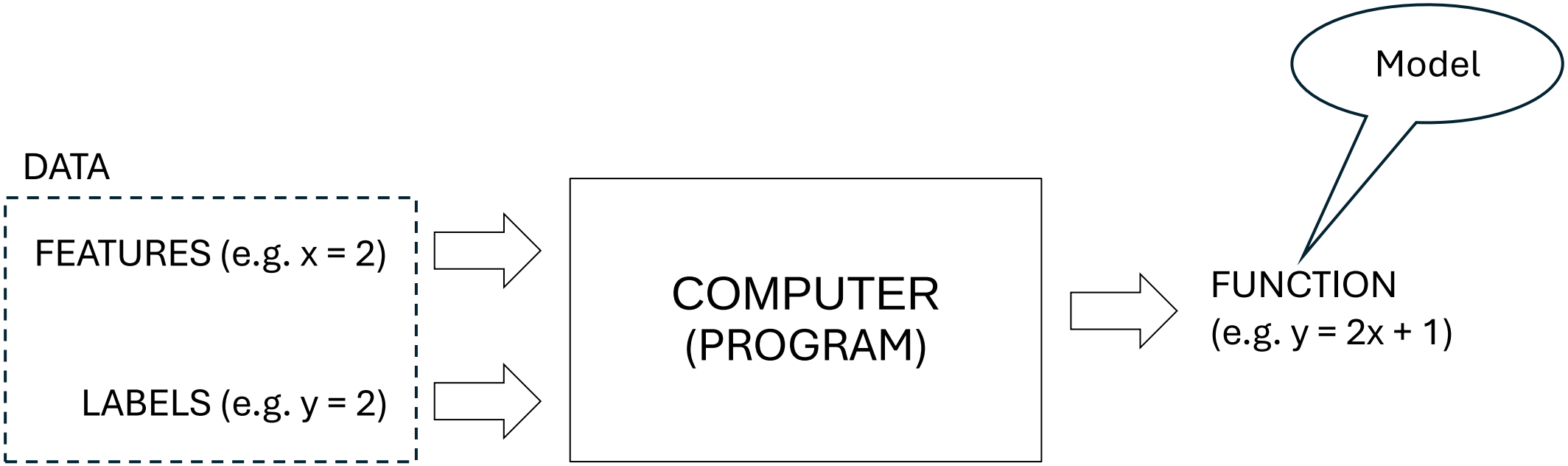
We need to learn the **function y** from the data.

Input variable or **feature**

Machine learning



Machine learning



Can you figure out?

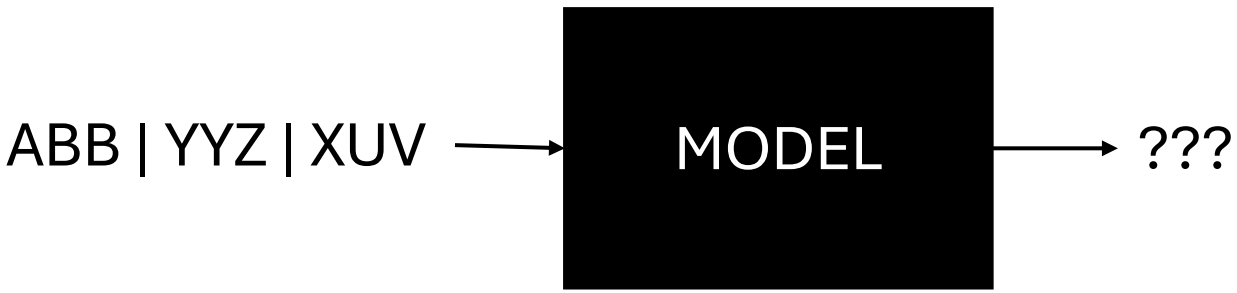


ABB | YYZ | XUV = ???

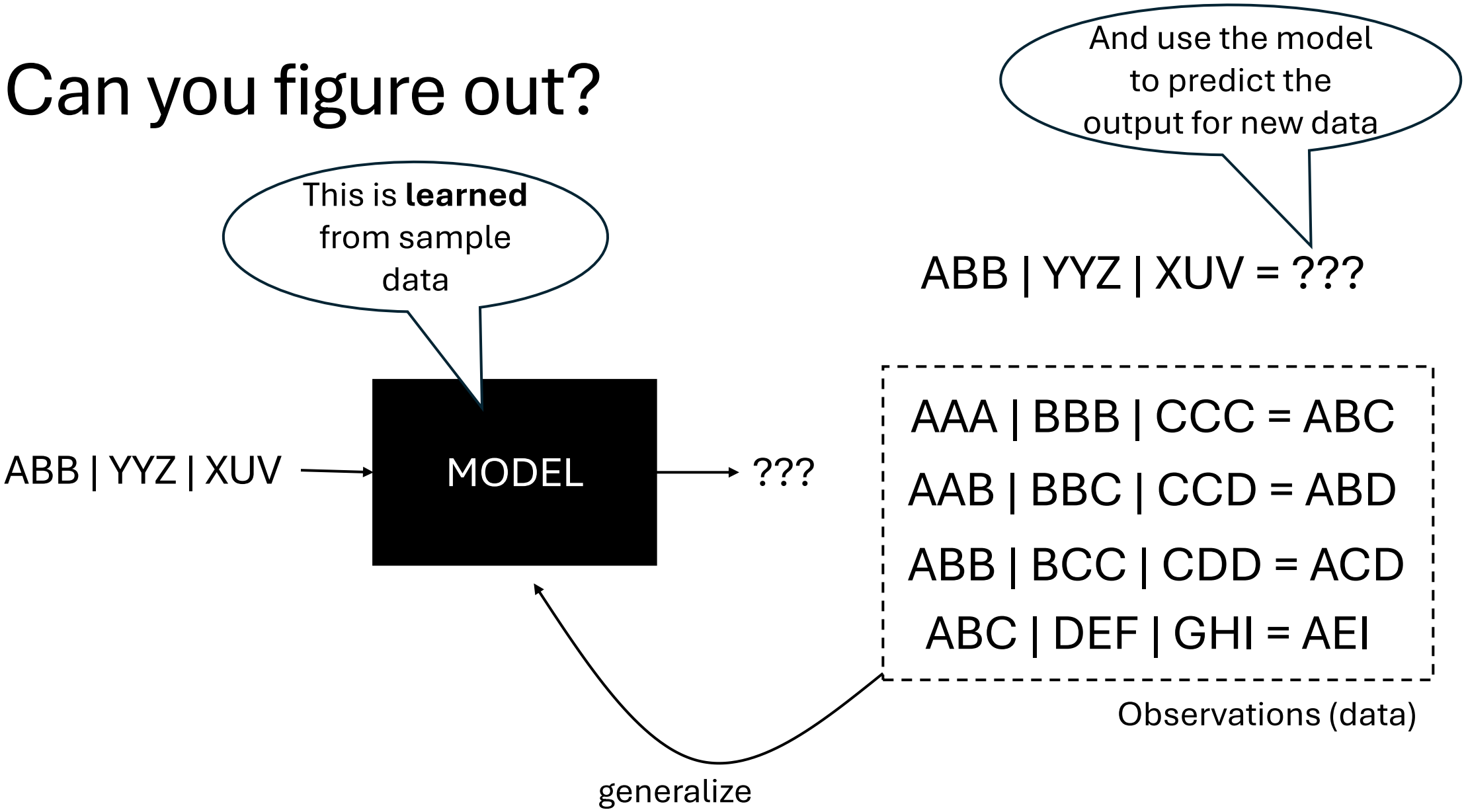
AAA | BBB | CCC = ABC

AAB | BBC | CCD = ABD

ABB | BCC | CDD = ACD

ABC | DEF | GHI = AEI

Can you figure out?



Ways of machine learning

- Supervised learning
- Unsupervised learning
- Semi-supervised learning
- Self-supervised learning
- Reinforcement learning

Supervised learning

$230,000

$510,000

$670,000

$190,000

Age, area, rooms, …

$340,000

Ground truth

Labeled Examples

Supervised Learning

Learning algorithm

Predictor e.g. model

New data

$??????

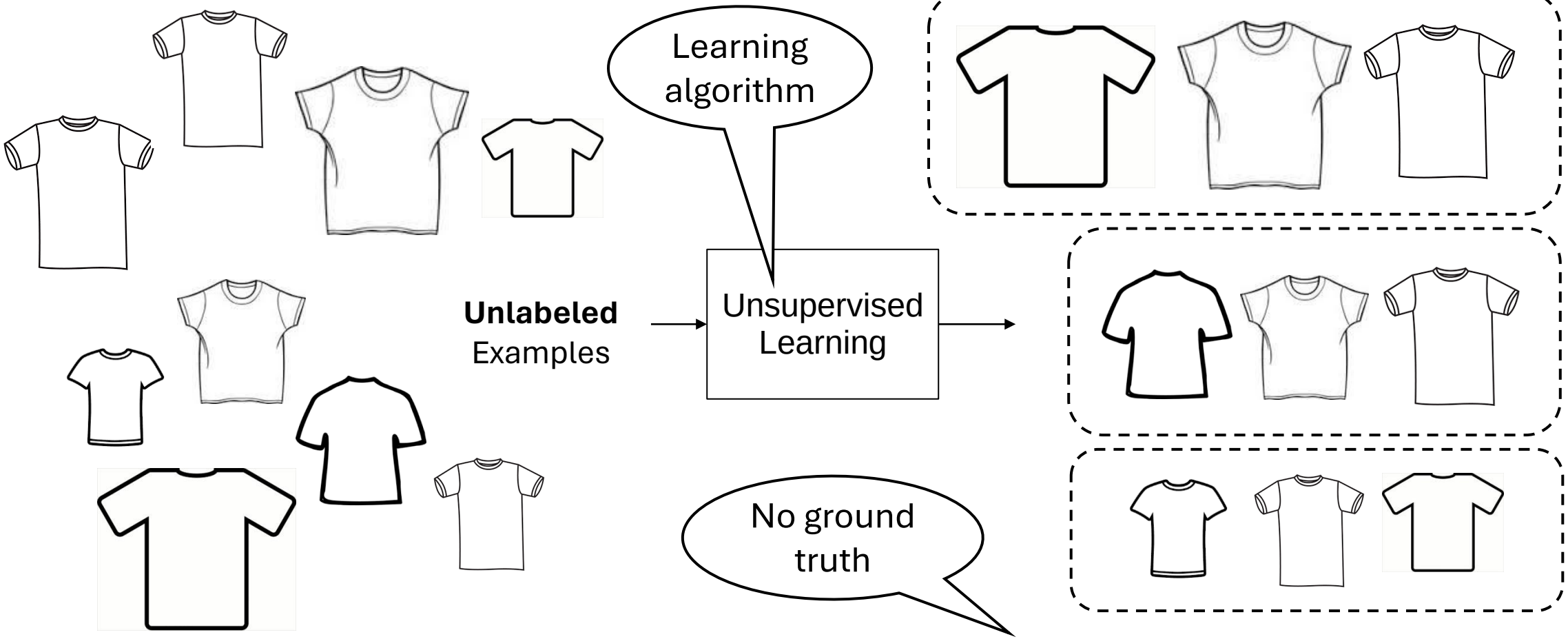
Predicted label (price)

Have ground truth, right or wrong

Training set: data (or observations or examples) **with label**.

Predict label (e.g. price, object) of new data.

Unsupervised learning

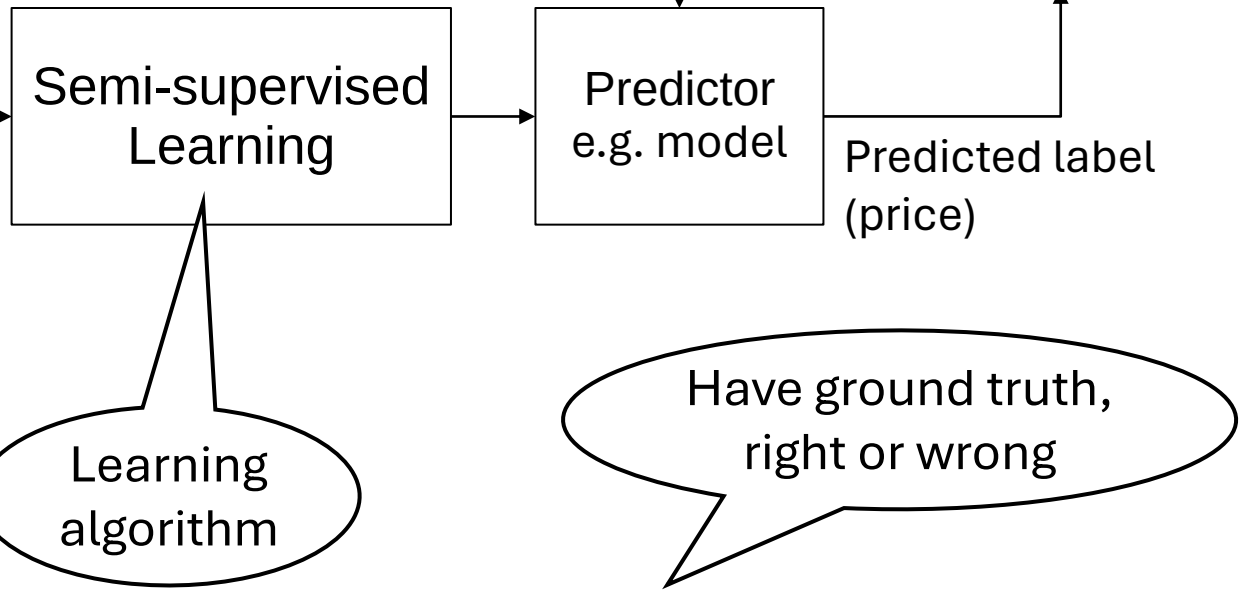


Learning set: data (or observations) **without label**.

Discover properties (e.g. size groups) in the data.

Semi-supervised learning

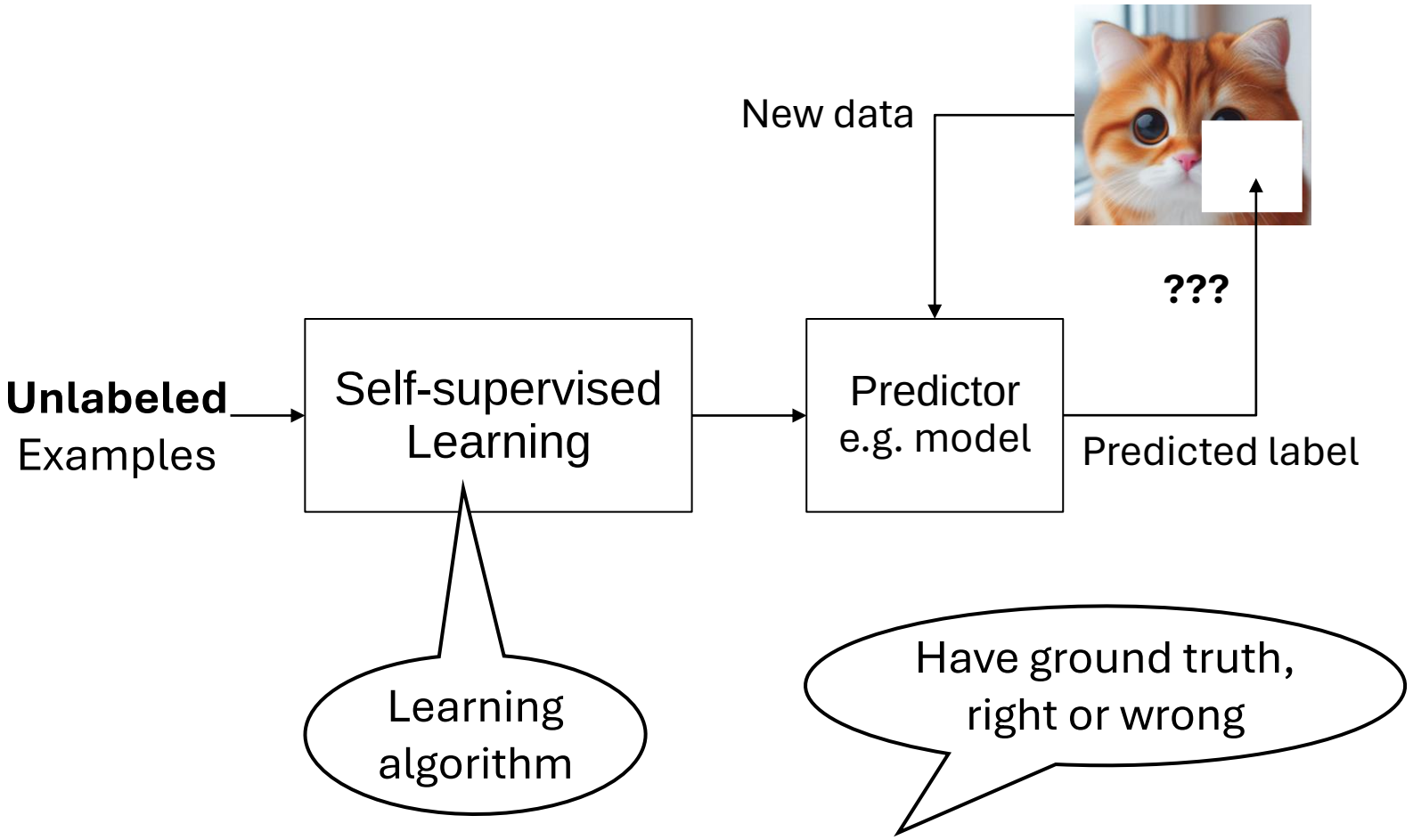
Labeled and unlabeled Examples



Training set: data (or observations or examples) **with label** and **without label**.

Predict label (e.g. price, object) of new data.

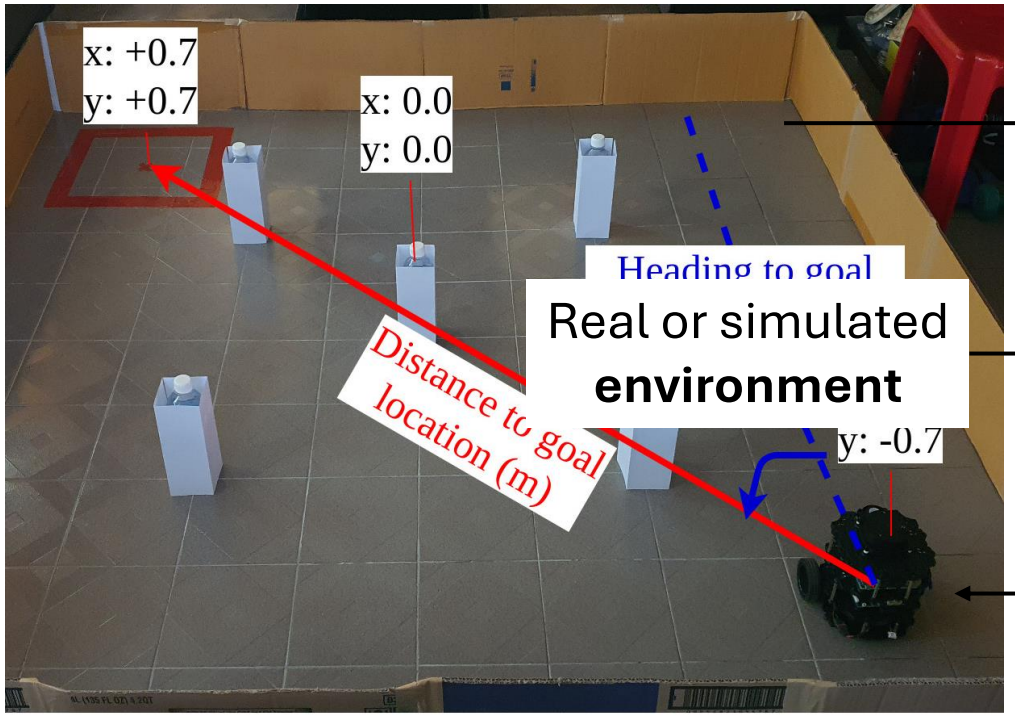
Self-supervised learning



Training set: data (or observations or examples) **without label**.

Predict "label" (e.g. object) of new data.

Reinforcement learning



Real or simulated **environment**

Learning algorithm

Reinforcement Learning

Policy

Action

Learning from trials and errors

Training set: real or simulated environment, i.e. real-time observations (data)

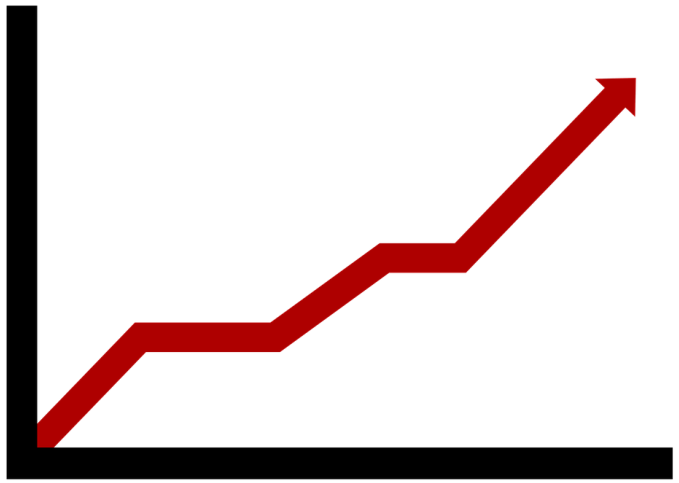
Policy maps environment conditions to suitable actions

Supervised machine learning

Supervised learning: two types of problems

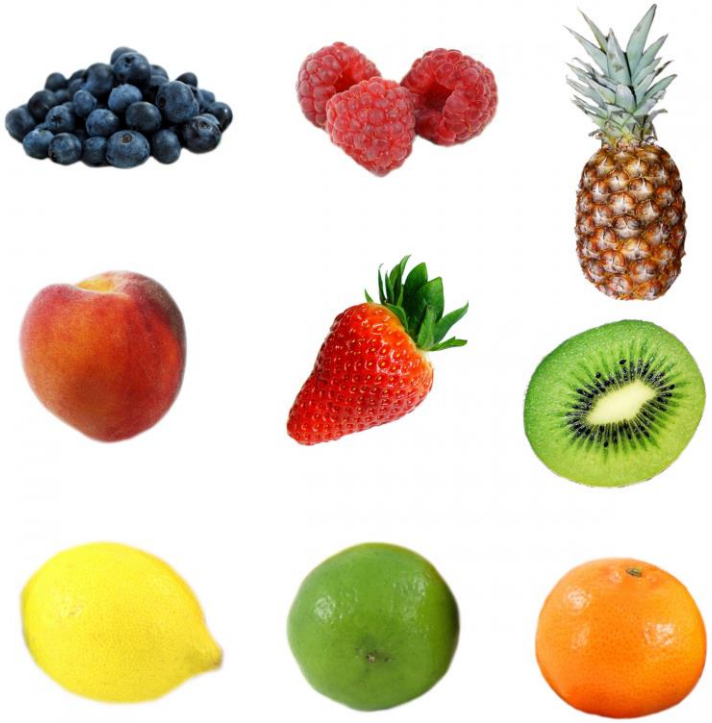
Regression

- Output Y is **continuous**



Classification

- Output Y is **discrete**

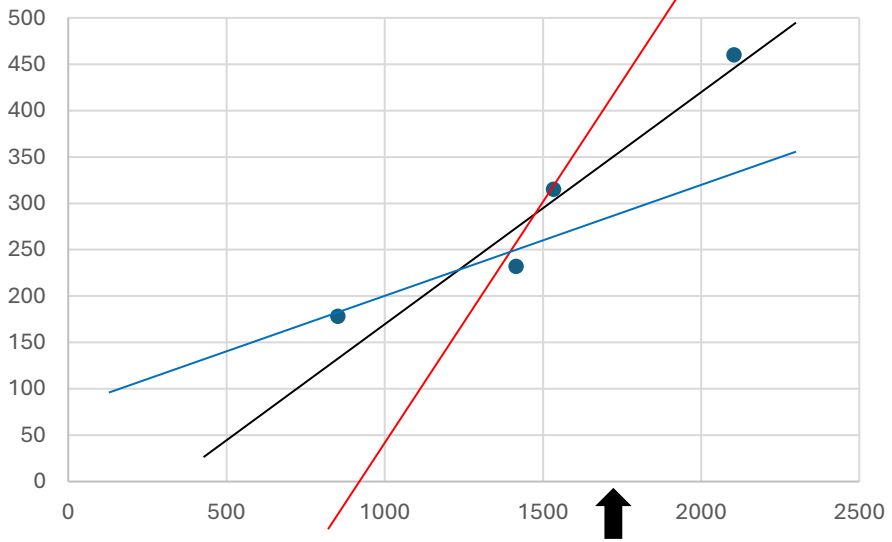


Linear regression

Training Set *D*

Size in feet² (x)	Price ($) in 1000's (y)
2104	460
1416	232
1534	315
852	178
…	…

training data points



If x = 1750, y =?

Guess of model type

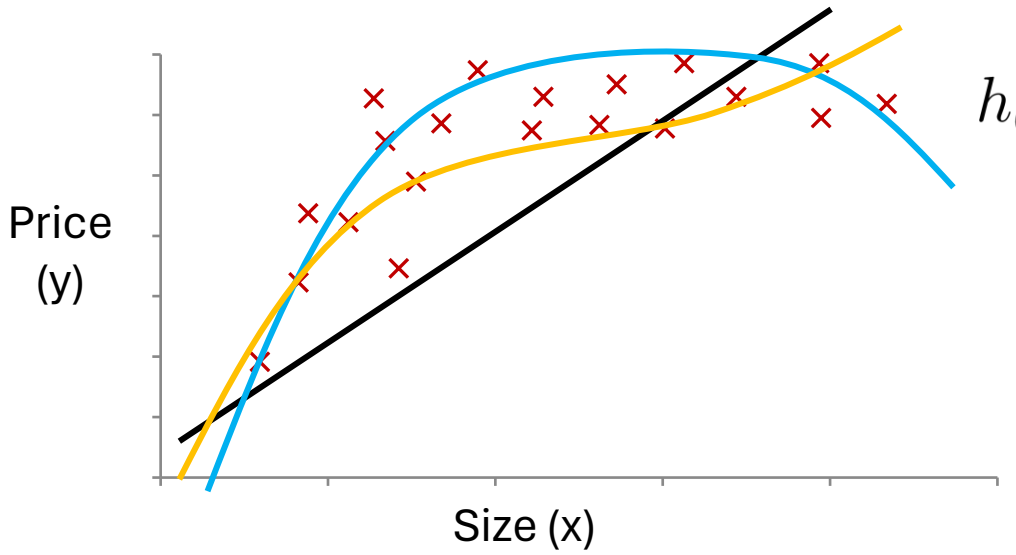
Hypothesis h: $h(x) = h_\theta(x) = \theta_0 + \theta_1 x$

Note: Straight line eqn $y = mx + c$

What are the appropriate values of θ_0 and θ_1?

parameters of *h*

Not just straight line: polynomial regression



$$h_\theta(x) = \theta_0 + \theta_1 x$$
$$\theta_0 + \theta_1 x + \theta_2 x^2$$
$$\theta_0 + \theta_1 x + \theta_2 x^2 + \theta_3 x^3$$

$$h_\theta(x) = \theta_0 + \theta_1 x_1 + \theta_2 x_2 + \theta_3 x_3$$
$$= \theta_0 + \theta_1 (size) + \theta_2 (size)^2 + \theta_3 (size)^3$$

$$x_1 = (size)$$
$$x_2 = (size)^2$$
$$x_3 = (size)^3$$

Prediction error

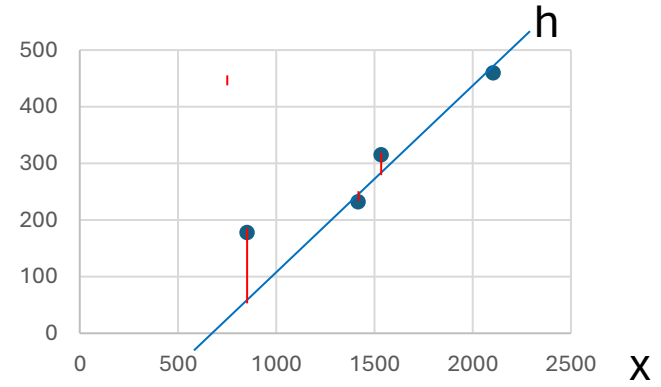
Lets try different values for the parameters and compute the prediction error:

$$error = h(x) - y$$

$\theta_0 = -234, \theta_1 = 0.33$

$h(x) = -234 + 0.33x$

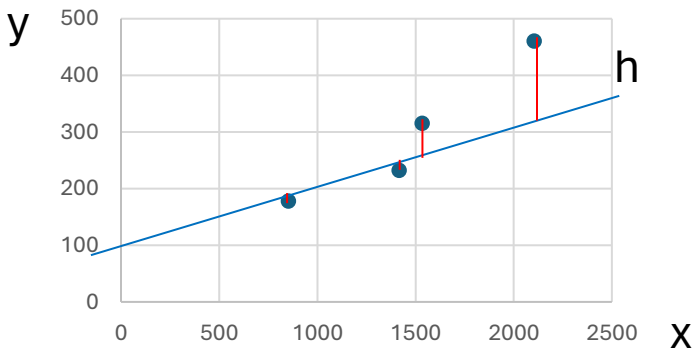
	x	y	h	Error
1	2104	460	460.32	0.32
2	1416	232	233.28	1.28
3	1534	315	272.22	-42.78
4	852	178	47.16	-130.84



$\theta_0 = 92.8, \theta_1 = 0.1$

$h(x) = 92.8 + 0.1x$

	x	y	h	Error
1	2104	460	303.2	-156.8
2	1416	232	234.4	2.4
3	1534	315	246.2	-68.8
4	852	178	178	0



... keep trying different values.

Cost function = Mean Square Error (MSE)
(or Root Mean Square Error (RMSE)

Prediction error

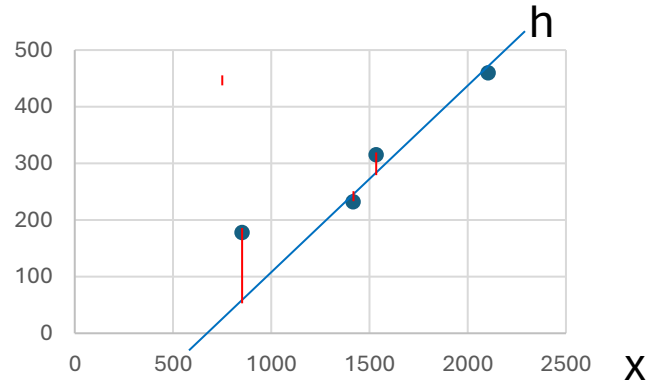
Lets try different values for the parameters and compute the prediction error:

$$error = h(x) - y$$

$\theta_0 = -234, \theta_1 = 0.33$

$h(x) = -234 + 0.33x$

	x	y	h	Error
1	2104	460	460.32	0.32
2	1416	232	233.28	1.28
			272.22	-42.78
				-130.84

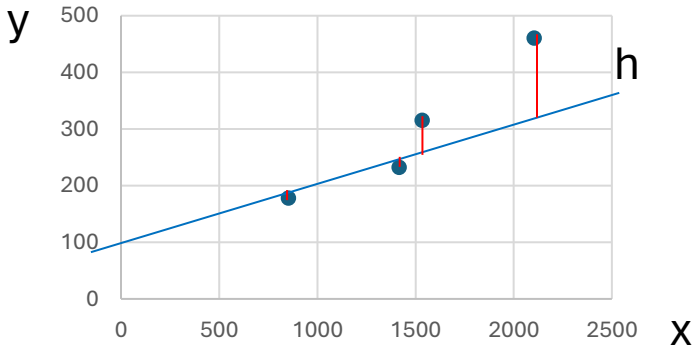


Use **gradient descent** to find parameters that minimizes the cost function

$\theta_0 = 92.8, \theta_1 = 0.1$

$h(x) = 92.8 + 0.1x$

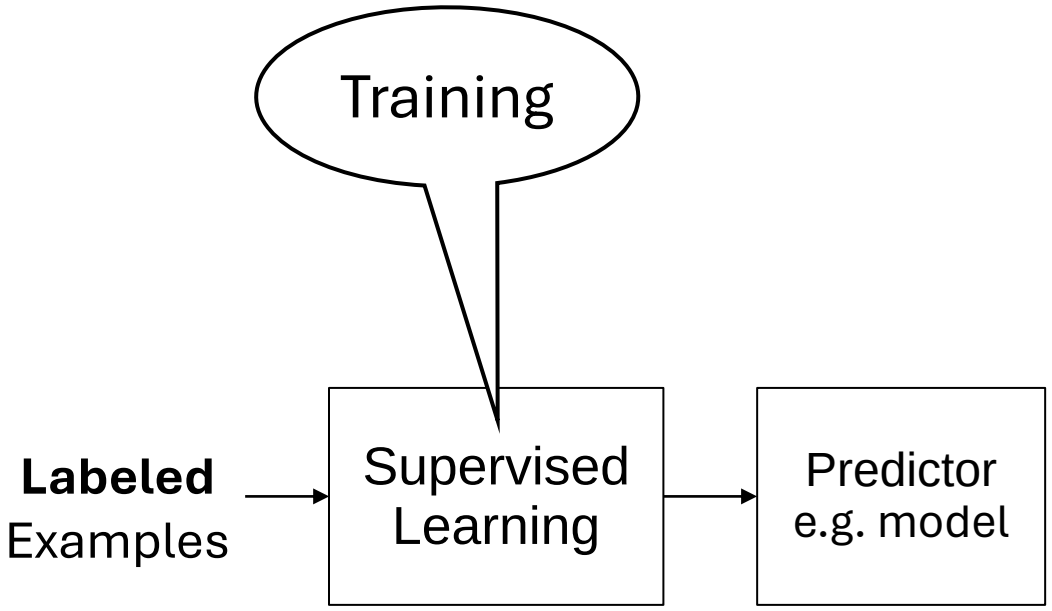
				Error
1	2	460	303.2	-156.8
2	14	232	234.4	2.4
3	153	315	246.2	-68.8
4	852	178	178	0



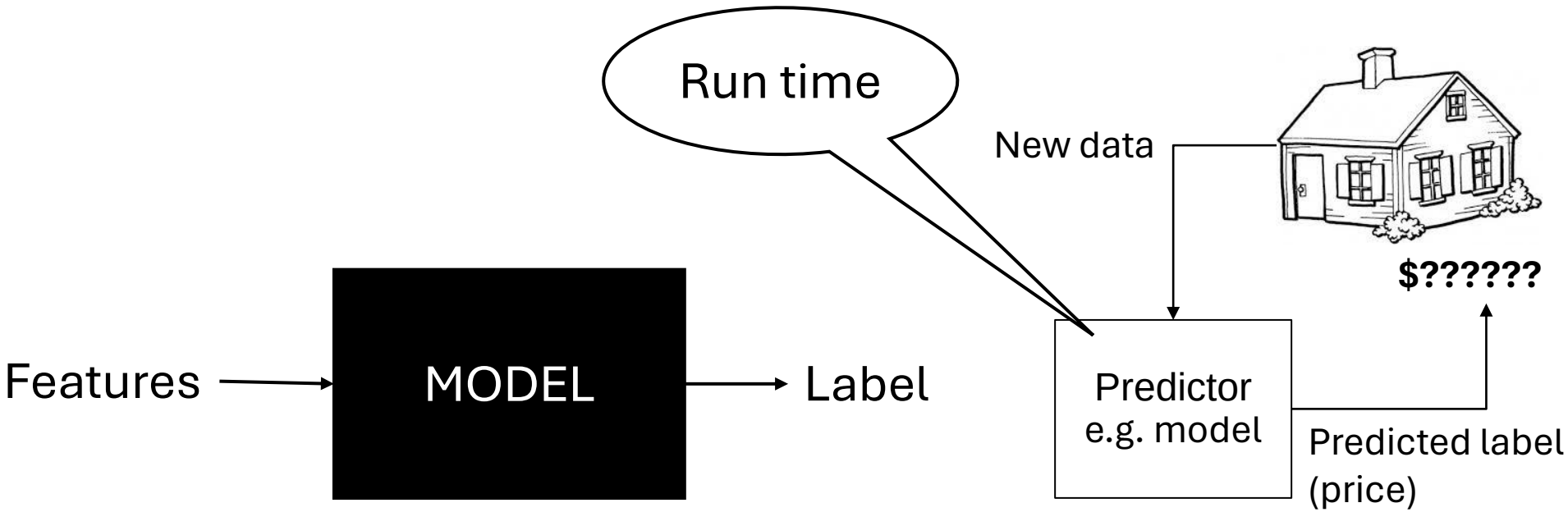
... keep trying different values.

Cost function = Mean Square Error (MSE)
(or Root Mean Square Error (RMSE)

Two phases of supervised ML



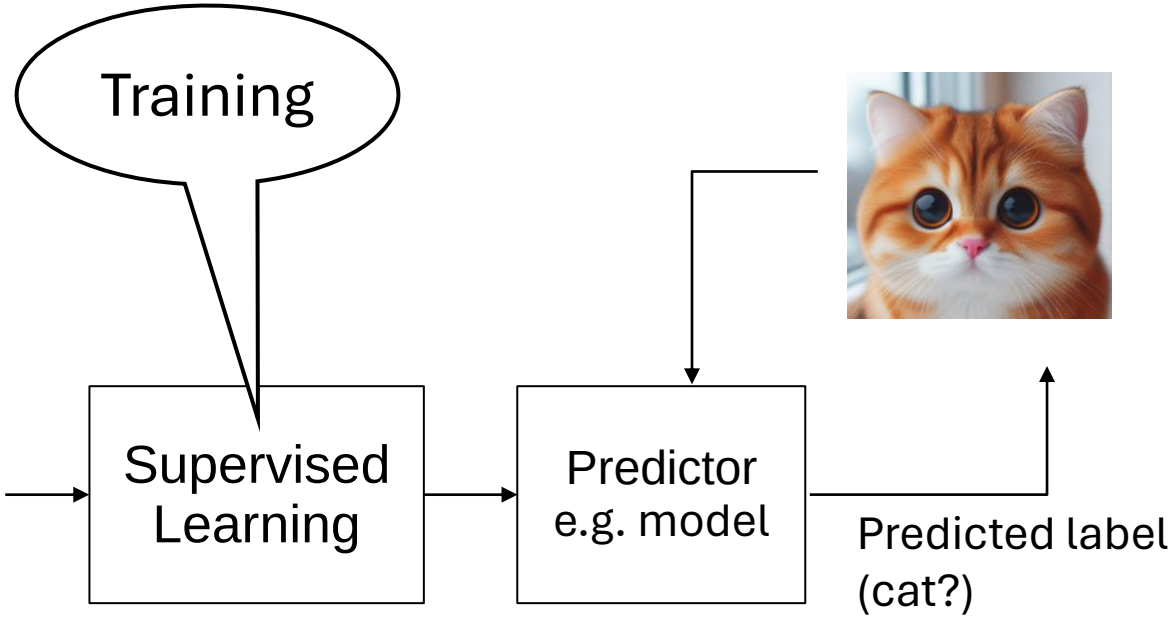
Two phases of supervised ML



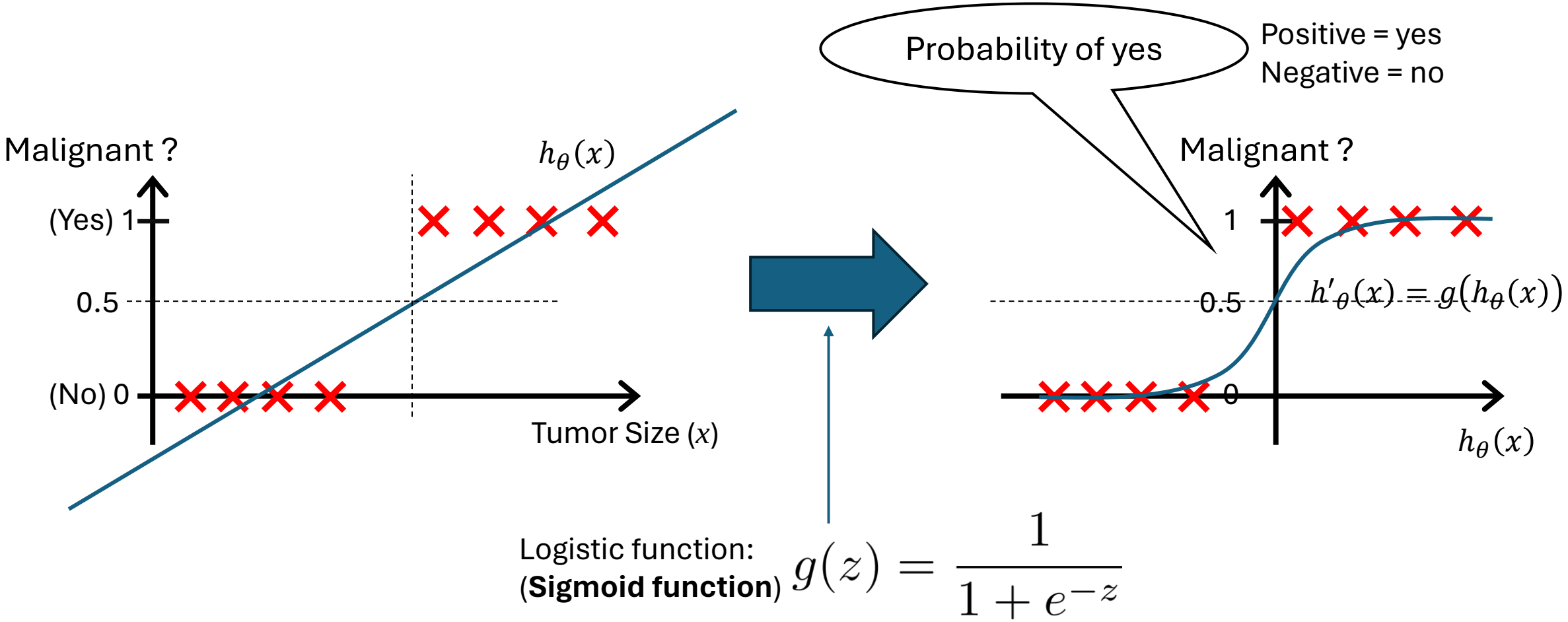
Classification

Cat

Not cat



Classification: logistic regression

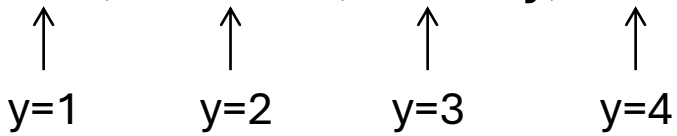


Logistic function:
(**Sigmoid function**) $g(z) = \dfrac{1}{1+e^{-z}}$

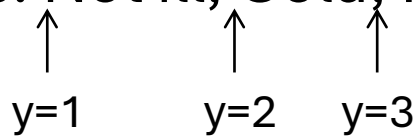
Multiclass classification

(Cat vs Not Cat is a binary classification)

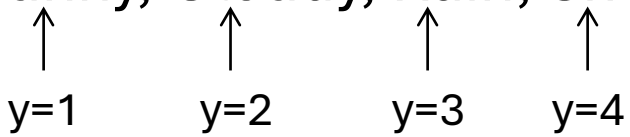
Email labeling/tagging: Work, Friends, Family, Hobby



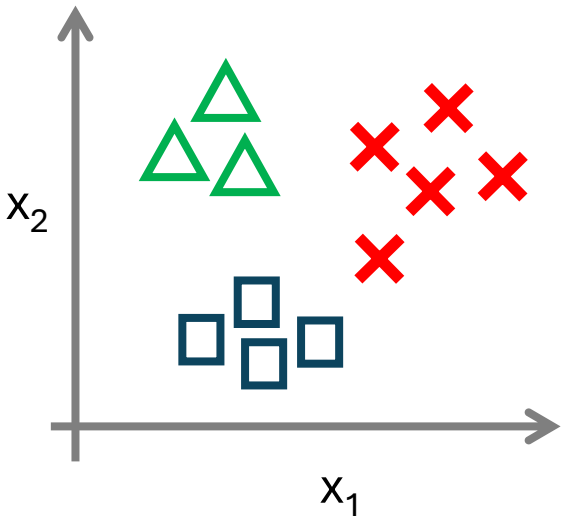
Medical diagrams: Not ill, Cold, Flu



Weather: Sunny, Cloudy, Rain, Snow



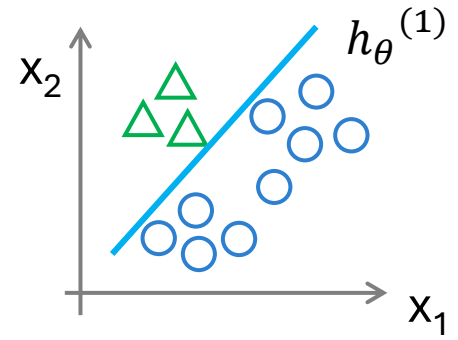
One-vs-all

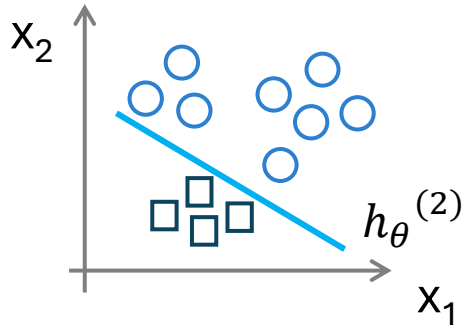


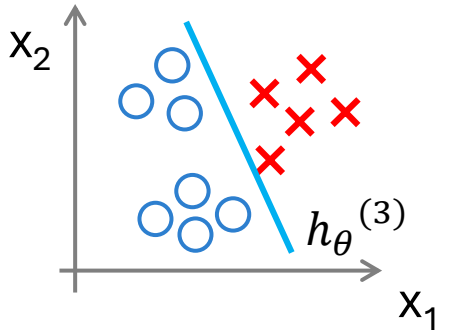
Class 1: △

Class 2: □

Class 3: ×



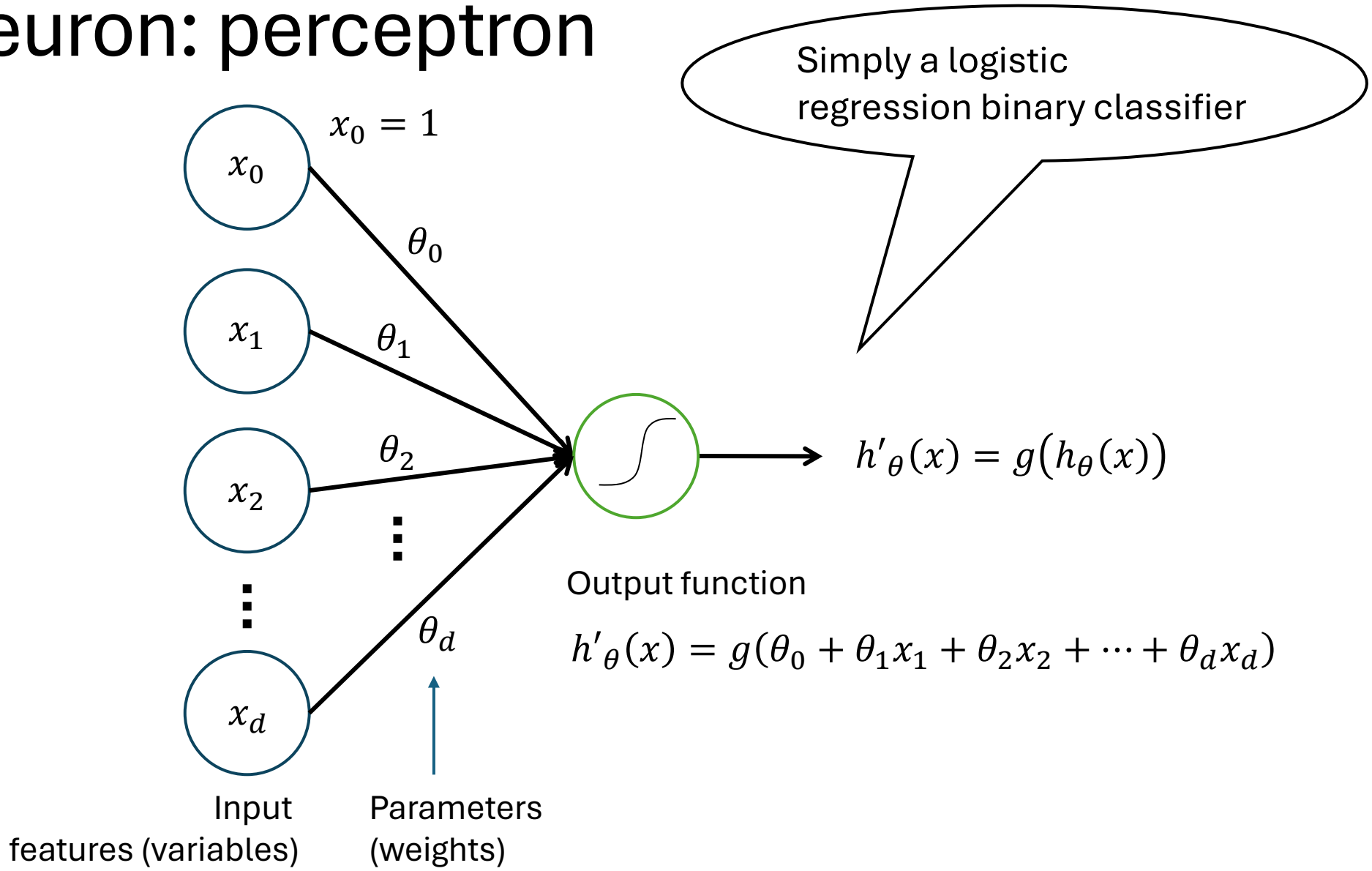




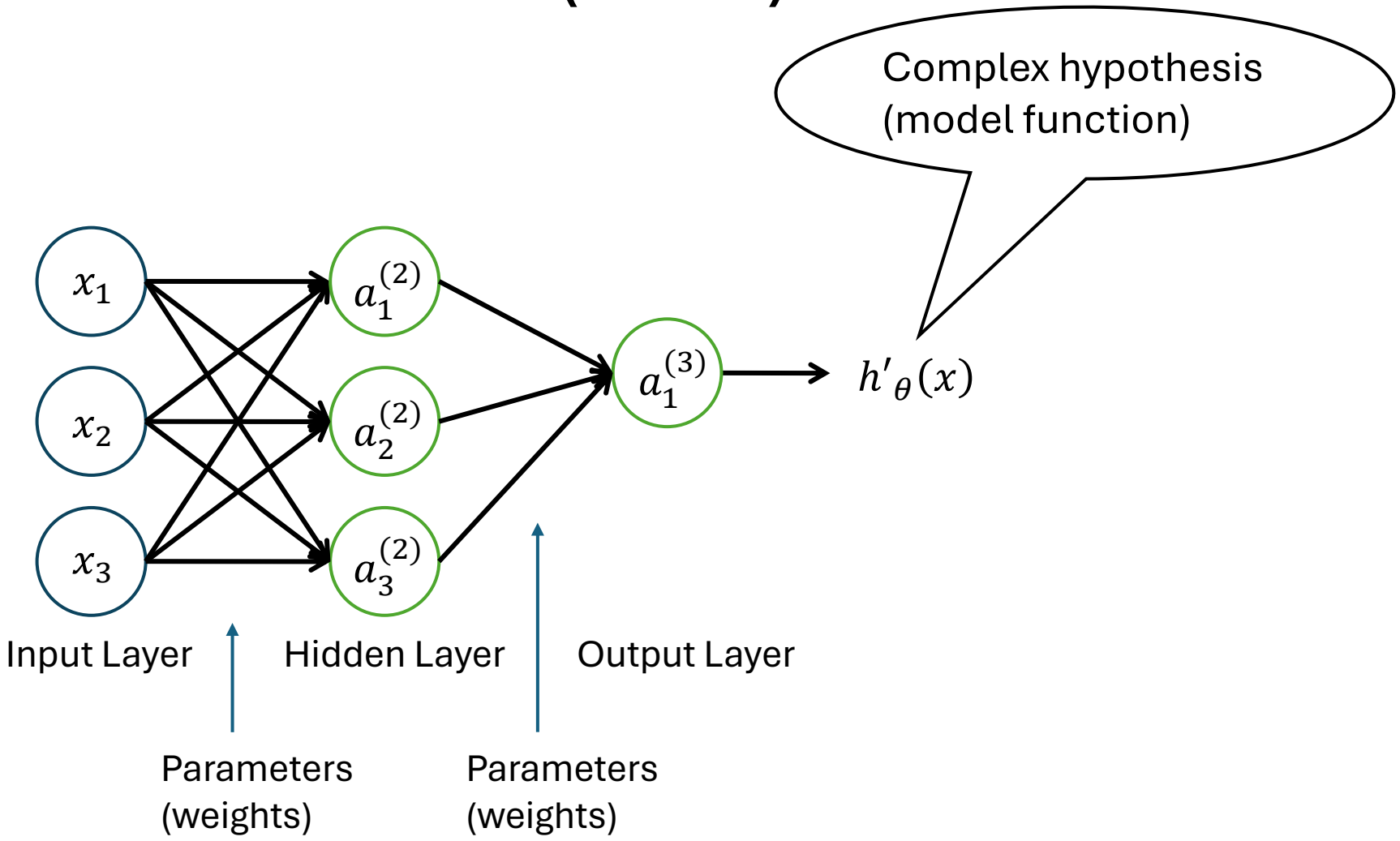
Select label with highest probability

Train the same way as linear regression

A neuron: perceptron



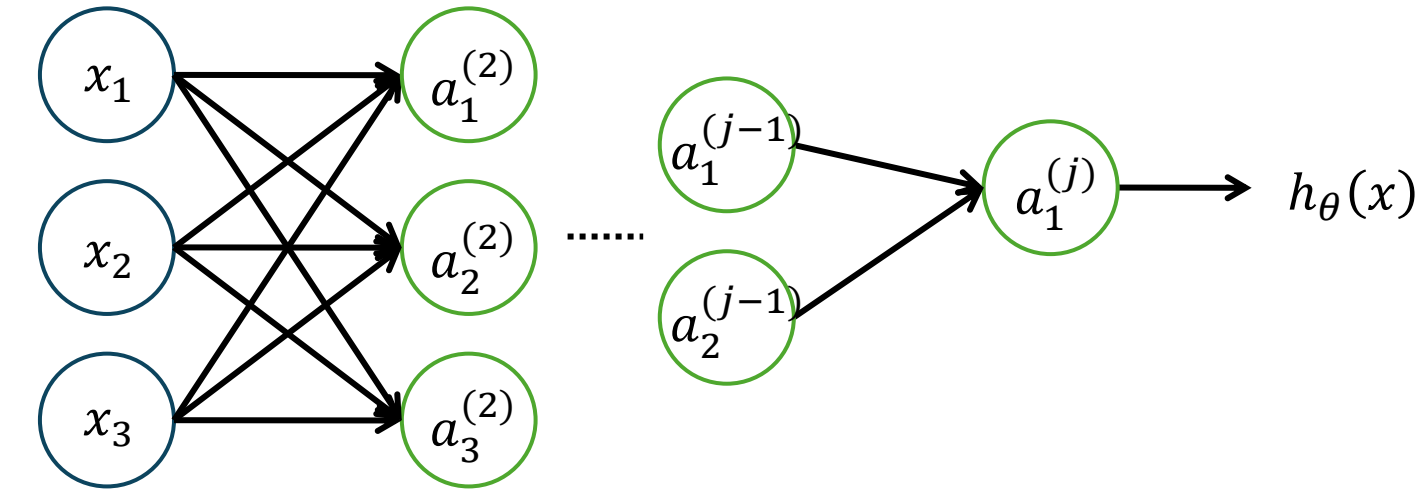
Artificial Neural Network (ANN)



Deep Neural Network (DNN)

Deep learning (DL)

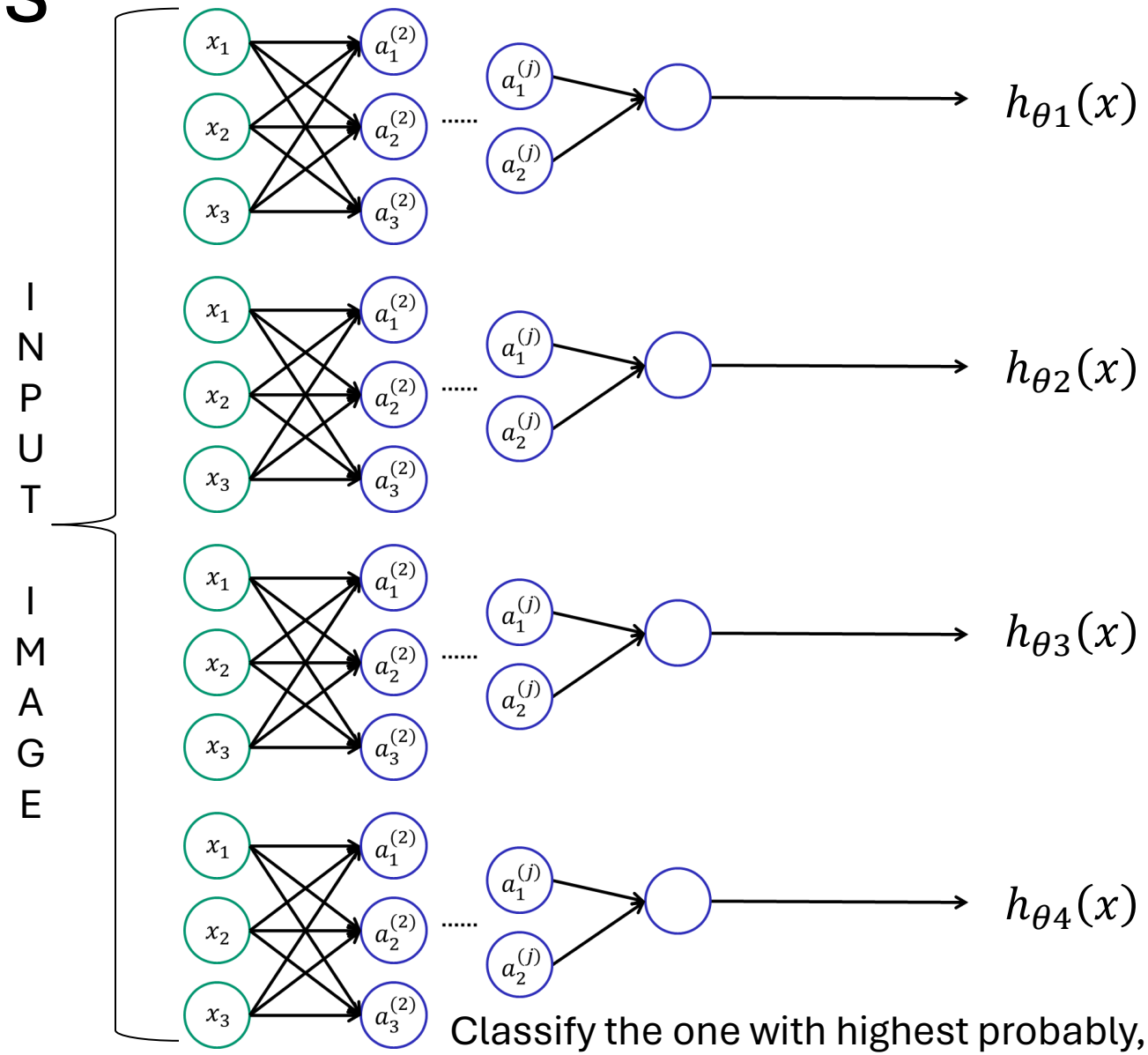
There may be more than one hidden layer.



Input Layer **Hidden Layers** Output Layer

Considered **DNN**
when >1 hidden layer

Multiclass ANN



Pedestrian

Car

Motorcycle

Truck

Classify the one with highest probably, i.e. h value.

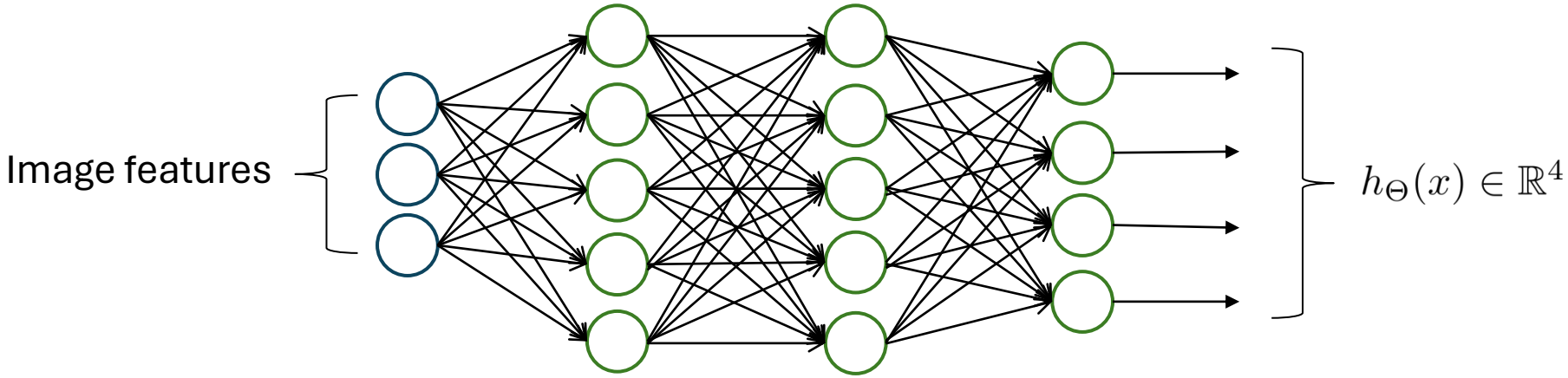
Multiclass ANN

Pedestrian

Car

Motorcycle

Truck



We want $h_\Theta(x) \approx \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$, $h_\Theta(x) \approx \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$, $h_\Theta(x) \approx \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}$, etc.

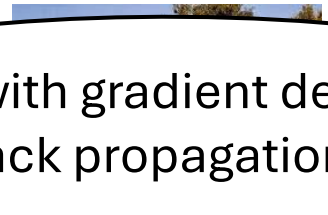
when pedestrian when car when motorcycle

Multiclass ANN

Pedestrian

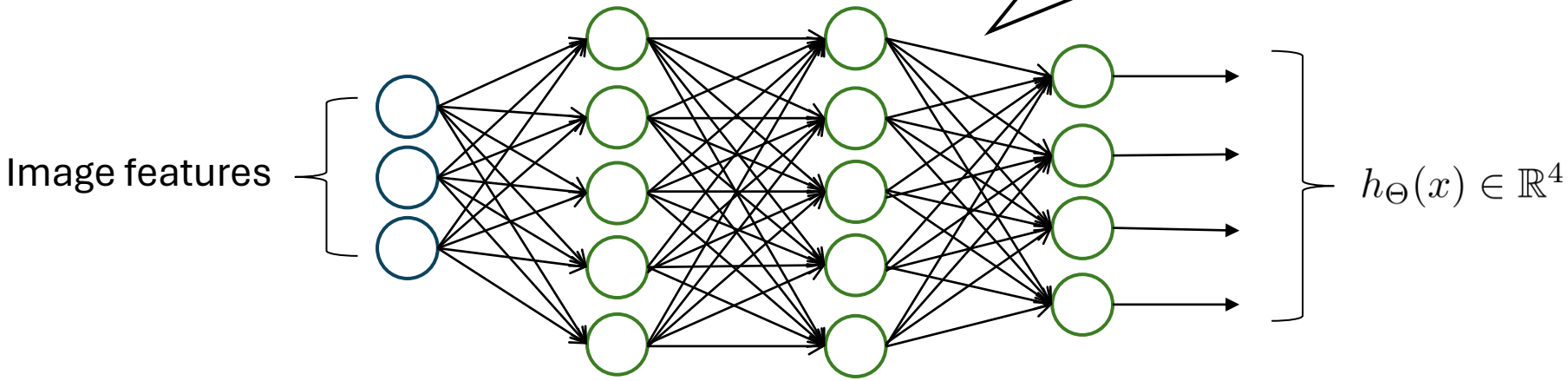
Car

Motorcycle



Truck

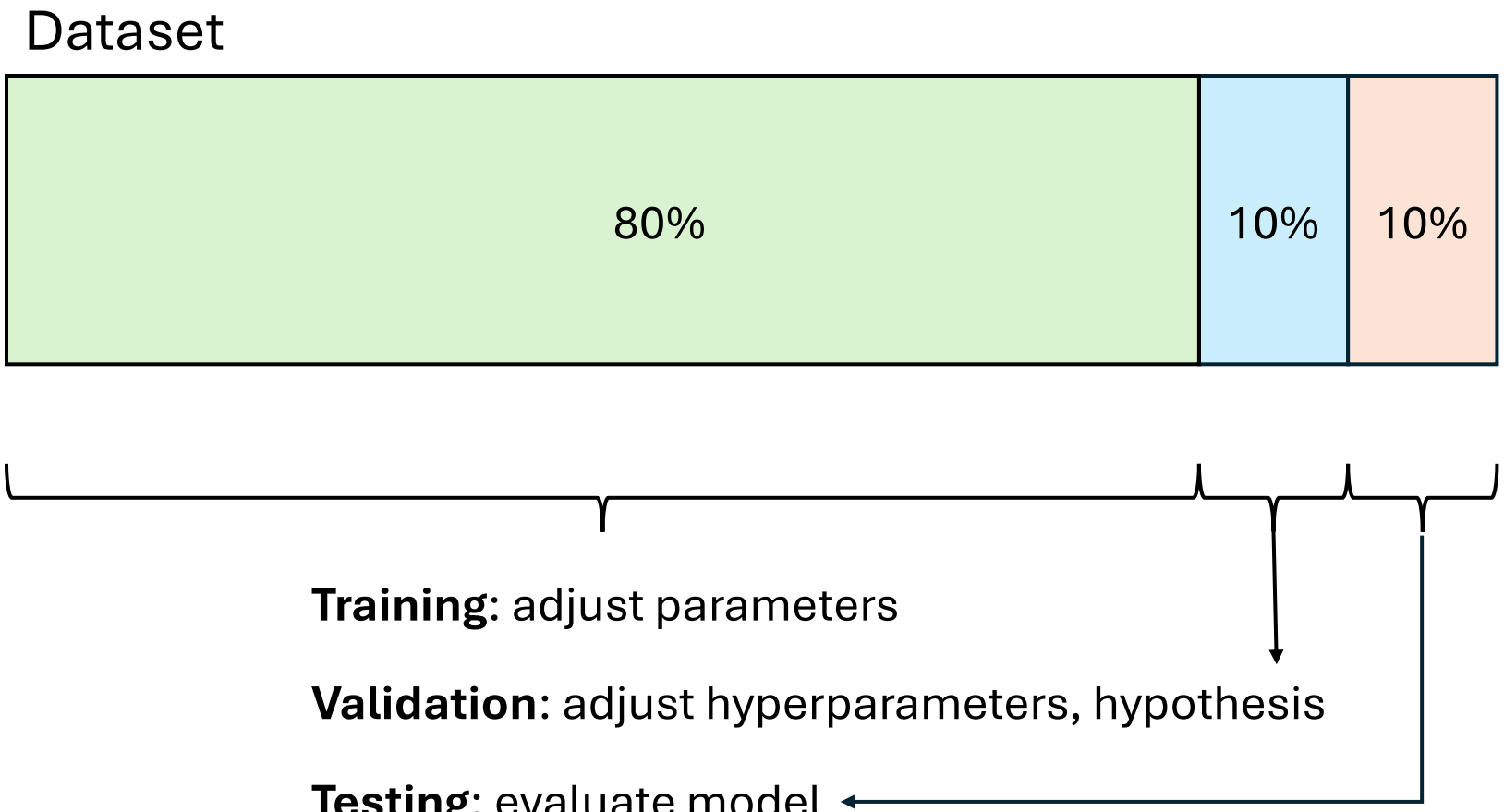
Train with gradient descent and back propagation



We want $h_\Theta(x) \approx \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$, $h_\Theta(x) \approx \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$, $h_\Theta(x) \approx \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}$, etc.

when pedestrian when car when motorcycle

Train, validate and test

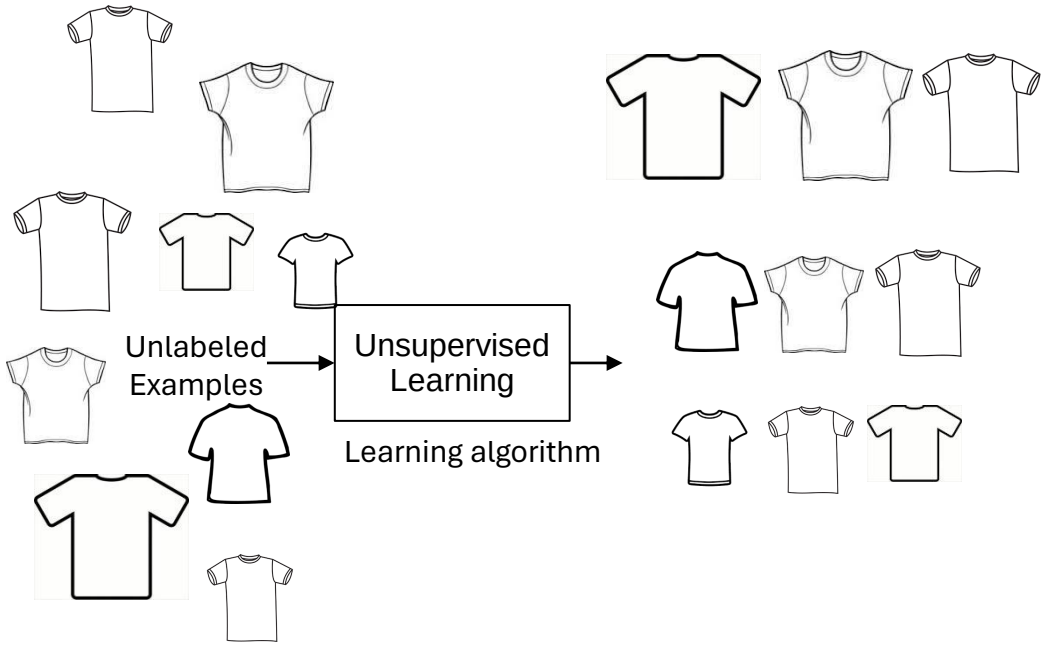


Unsupervised machine learning

Unsupervised learning: two types of problems

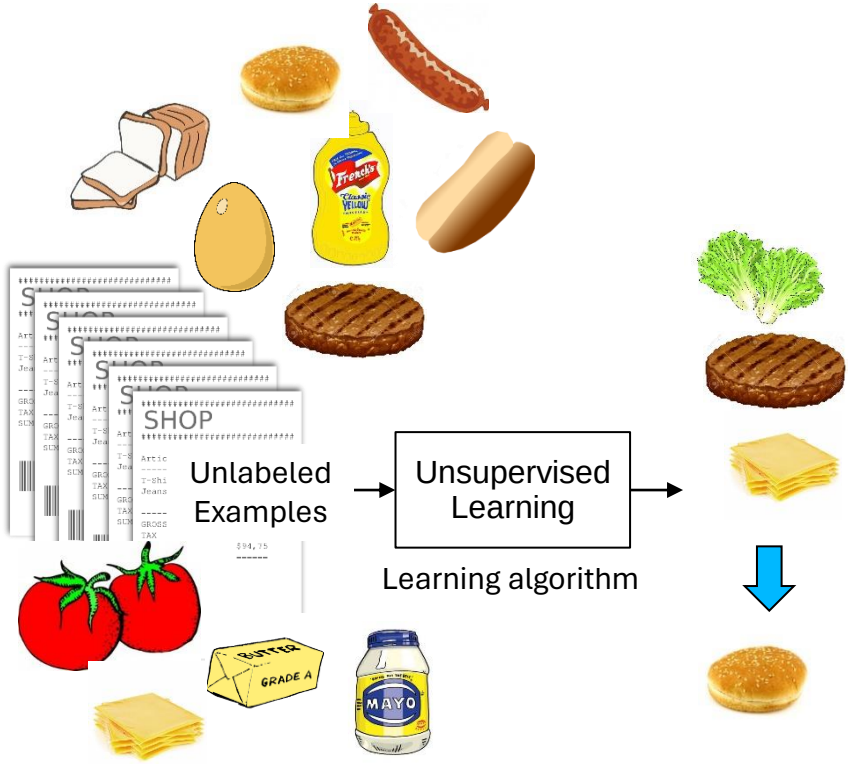
Clustering

- discover **groupings**

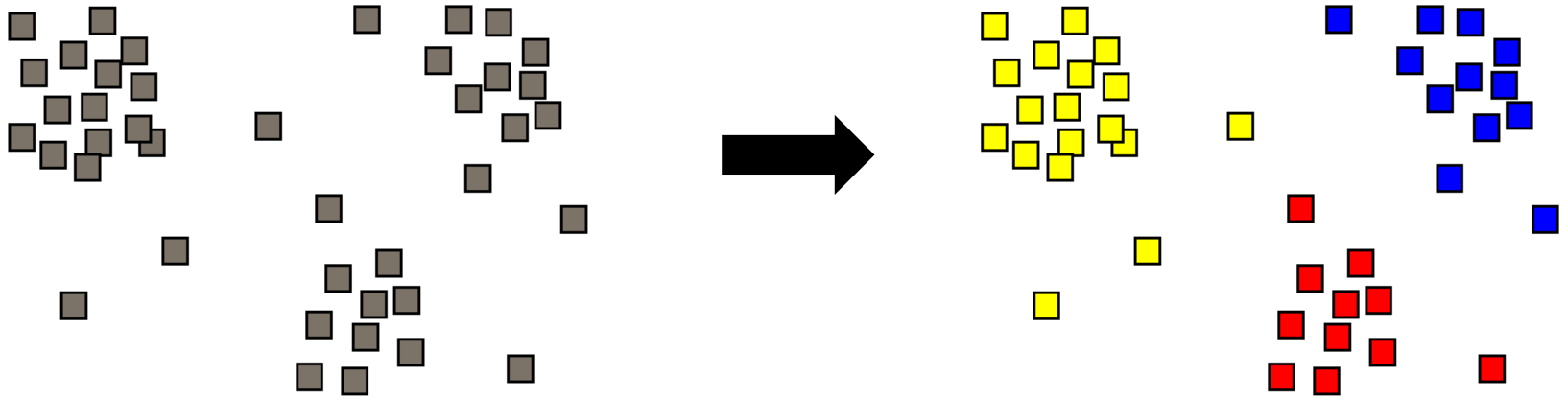


Association

- discover **rules, relations**



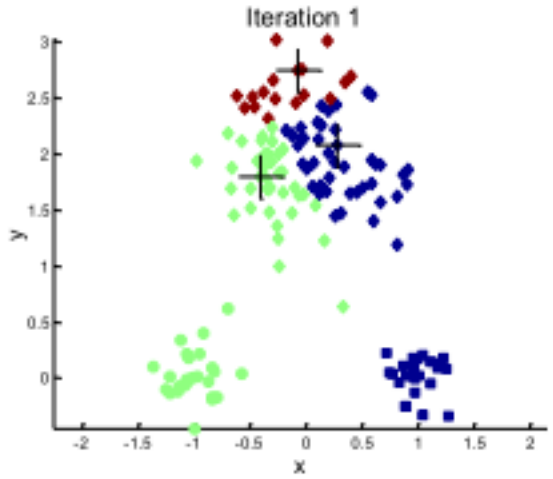
K-Means clustering



Each group is a **cluster**

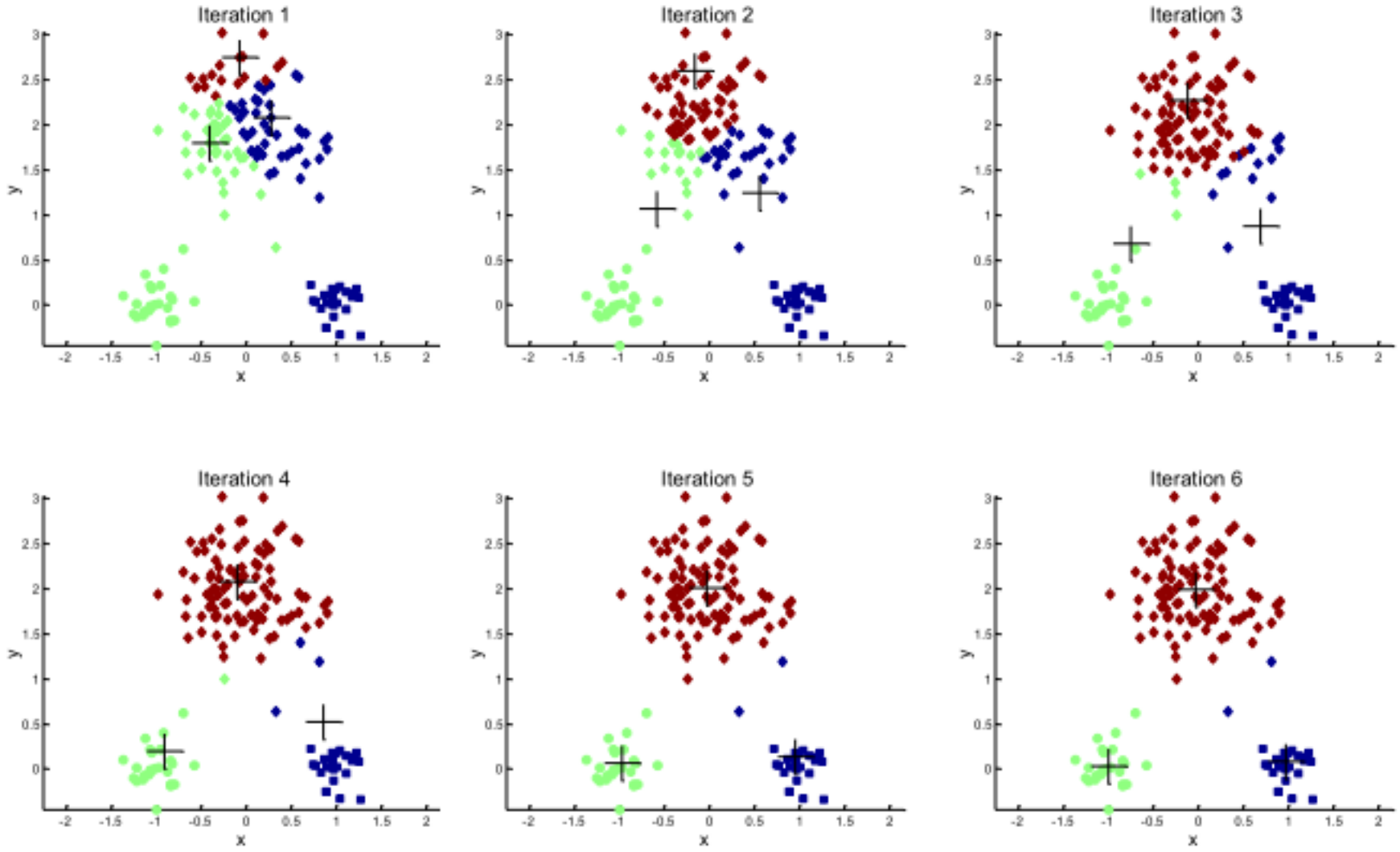
K-Means clustering steps

K=3



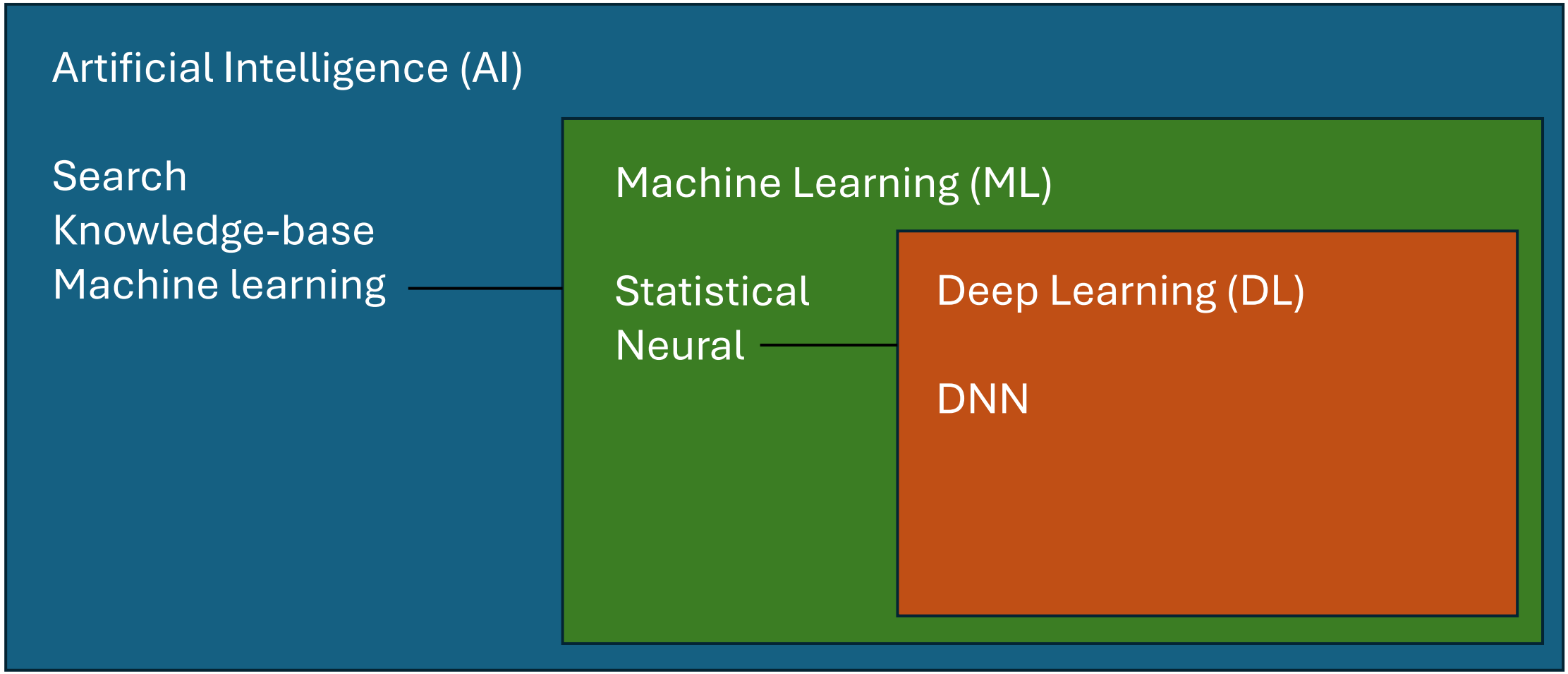
K-Means clustering steps

K=3



AI, ML, DL

AI, ML, DL


Artificial Intelligence (AI)
Search
Knowledge-base
Machine learning
Machine Learning (ML)
Statistical
Neural
Deep Learning (DL)
DNN

Evaluation

https://forms.gle/ZWHTNJw3m5qDgR277

Feedback

https://forms.gle/o7adMBRjhdnLb2d6A

Thank you!