ARTIFICIAL INTELLIGENCE PROGRAM · LECTURE 01

Introduction to Knowledge Representation & Reasoning

How a machine stores what it knows — and uses it to work out what it was never told.

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THE PIPELINE

Information

↓

Knowledge

↓

Representation

↓

Knowledge Base

↓

Reasoning

↓

Action

The Grandfather Question

EVERYTHING THE SYSTEM STORES

```
parent(Ali, Sara)
parent(Sara, Omar)
```

WHAT WE ASK IT

Is Ali the grandfather of Omar?

> You answered in under a second. The database returns **nothing at all**.

The Missing Rule

Nothing was missing from the facts. What was missing was a statement of what the word **grandfather** means — written in a form the machine can use.

THE RULE WE ADD

$$\text{parent}(X, Y) \wedge \text{parent}(Y, Z) \rightarrow \text{grandparent}(X, Z)$$

Representation

Writing the rule down in a language with precise meaning.

Reasoning

Chaining the rule with the facts to produce one nobody typed in.

This course

Both halves — and how to build systems that use them.

Roadmap for today

01 What knowledge representation and reasoning means

02 Data, information, knowledge — and why the difference matters

03 Inside a knowledge-based system

04 Why the field matters in the age of large language models

05 Applications, and what you will be able to build

I

Foundations

Representation, reasoning, and the line between data and knowledge.

What is knowledge?

An agent's understanding of the world, expressed as **statements it takes to be true**.

Grass is green.	If it rains, the ground becomes wet.	Ahmed is allergic to penicillin.

> **Key idea.** Knowledge is not raw numbers — it is **meaningful structure** about the world.

المعرفة هي فهم لحالة العالم، مش مجرد أرقام.

From data to knowledge

One measurement, four levels of meaning.

DATA

`38.9`

A raw symbol. No units, no subject, no meaning.

INFORMATION

`38.9 °C, patient A`

The symbol in context: what it measures, and of whom.

KNOWLEDGE

`temp > 38 → fever`

A general rule that holds beyond this patient and licenses new conclusions.

DECISION

order blood culture

Knowledge applied to a case, with a justification the clinician can audit.

المعلومة بتوصف، والمعرفة بتفسّر، والقرار بيتصرف.

Data vs knowledge

DIMENSION	DATA	KNOWLEDGE
Form	Records, measurements, symbols	Concepts, relations, rules, constraints
Scope	About one instance	General over all instances
Answers	Only what was stored	Also what follows from what was stored
Grows by	Adding rows	Adding rules and definitions
Typical home	Database, log file, spreadsheet	Knowledge base, ontology, rule set

Knowledge is structured meaning

Facts alone ≠ intelligence

Facts + relations + rules = knowledge

What exists?

How are things connected?

What is always true?

RELATIONS IN THE WILD

A doctor treats patients

A city contains hospitals

If a sensor fails, trust decreases

Knowledge representation

A **formal, machine-usable encoding** of what is true about a domain — its objects, their properties, and the relations between them.

EXPRESSIVE

Rich enough to state what experts actually mean — exceptions and uncertainty included.

TRACTABLE

Restricted enough that a machine can draw conclusions in acceptable time.

UNAMBIGUOUS

One reading only. Meaning does not depend on who is looking at it.

> Expressiveness and tractability pull against each other. Choosing where to sit on that trade-off is **the designer's job** .

Reasoning

The process of deriving statements that were **never stored** , using only what is stored and the rules of the representation.

Known facts + rules	→	Inference procedure	→	New fact + its justification

> Because every conclusion is derived by a traceable step, the system can also say **why** — and that explanation is what makes such systems usable in medicine, law and engineering.

The map and the traveller

A map is not the city. It keeps the few things a traveller must reason about — and deliberately **throws the rest away** .

THE MAP

Representation

Streets, distances, one-way arrows.

THE TRAVELLER

Reasoner

Plans a route the mapmaker never drew.

THE OMISSIONS

Design choice

What is left out decides which questions can still be answered.

> Knowledge is the map; reasoning is the navigation. Without reasoning you hold the facts and cannot use them.

II

Writing Knowledge Down

Propositions, symbols, the knowledge base — and the families of formalism we will study.

What is a proposition?

A statement that can be **true** or **false**.

“The library is closed on Sunday.”

“Ahmed is allergic to penicillin.”

Propositions are the **building blocks** of knowledge.

Without truth-evaluable statements, there is no reasoning.

القضية جملة ينفع نقول عليها صح أو غلط.

Why symbols?

Machines cannot reason over English sentences directly. Words carry ambiguity; symbols carry **commitments**.

> "The library is closed on Sunday."
>
> →
>
> `Closed(Library, Sunday)`

> **Key idea.** Representation is using symbols to stand for facts about the world — symbols make meaning **computable**.

التمثيل بيحوّل المعنى لرموز يفهمها الكمبيوتر.

Encoding beliefs in a formal language

```
Allergic(Ahmed, Penicillin)
Allergic(x, Penicillin) ⟶ Allergic(x, Amoxicillin)
```

The first line is a **fact** about one patient.

The second is a **rule** about every patient.

Representation determines what can be inferred.

بنكتب اللي نعرفه بطريقة تخلّي النظام يفكّر بيه.

The Knowledge Base (KB)

A structured collection of **explicitly represented** knowledge — the shelves of our library.

KB

```
Allergic(Ahmed, Penicillin)
Allergic(x, Penicillin) ⟶ Avoid(x, Penicillin)
```

> **Key idea.** The KB is everything the system **explicitly** knows.

قاعدة المعرفة هي كل اللي النظام عارفه ومكتوب قدامه.

Explicit vs implicit knowledge

EXPLICIT

Written in the KB.

IMPLICIT

Not written — but it logically follows.

IF

Ahmed is allergic to Penicillin

Allergic patients must avoid the drug

→

THEN

`Avoid(Ahmed, Penicillin)`

This conclusion was never stored — it was derived.

في حاجات بيستنتجها... مش كل اللي النظام يعرفه مكتوب.

Families of representation

Logic
Propositional and first-order. Precise meaning, provable conclusions.

Rules
If–then production systems, readable by a domain expert.

Semantic networks
Concepts as nodes, relations as edges. Inheritance comes for free.

Frames and objects
Stereotyped situations with slots, defaults and exceptions.

Ontologies
Shared vocabularies with formal semantics — RDF, OWL, description logics.

Probabilistic models
Bayesian networks, when the world is known only to a degree.

III

Reasoning

A knowledge base that cannot reason is a filing cabinet.

Reasoning in one example

All humans are mortal.

Socrates is human.

Therefore: Socrates is mortal.

Reasoning **extends** knowledge.

It does not add random facts.

It reveals **consequences**.

الاستدلال هو استخراج نتيجة من معرفة موجودة.

One scene, read three ways

Wet grass in the morning.

CERTAIN

Deduction

It rained, and rain wets grass — so the grass is wet. If the premises hold, the conclusion must.

GENERALISING

Induction

The grass was wet after every rain we recorded — so rain wets grass. This is where machine learning lives.

BEST EXPLANATION

Abduction

The grass is wet — perhaps it rained. Plausible, not guaranteed. Every diagnosis is an abduction.

Logical inference & entailment

LOGICAL INFERENCE

If the premises are true, the conclusion **must** be true.

ENTAILMENT

A conclusion true in **every** situation where the premises hold.

$$KB \models \alpha$$

Key idea. Logic constrains truth. It defines what **must** follow.

المنطق بيحدّد إيه اللي لازم يطلع من اللي نعرفه.

What reasoning buys you

Drawing conclusions

Making decisions

Answering unseen questions

A REASONER ANSWERS

What follows from what I know?

What must be true?

What is likely?

IV

Inside a Knowledge-Based System

Architecture, and why the same output can mean very different intelligence.

Anatomy of a knowledge-based system

01
Knowledge base
Facts about the case plus general rules about the domain.

02
Inference engine
Applies the rules to the facts — forward or backward.

03
Explanation module
Reports the chain of steps behind every answer.

04
Acquisition interface
How experts add knowledge without writing code.

Analogy. The knowledge base is the recipe book; the inference engine is the cook. Replace recipes freely — the cook never needs retraining.

Hard-coded vs knowledge-based

HARD-CODED

```
if x == grass: print("green")
```

Behaviour lives in the code. Every new case is a new line.

KNOWLEDGE-BASED

Stores facts

Applies rules

Derives answers

Behaviour lives in the knowledge. New cases are new facts.

Same behaviour. Very different intelligence.

النظام الذكي بيتصرف بناءً على اللي يعرفه، مش بس اللي مبرمج عليه.

Knowledge level vs symbol level

KNOWLEDGE LEVEL

What does the system know?

What follows logically?

SYMBOL LEVEL

How is it computed?

Which algorithm is used?

> This course begins at the **knowledge level**. Understand meaning first — optimise later.

The big mental pipeline

01	02	03	04	05	06
Information	**Knowledge**	**Representation**	**Knowledge Base**	**Reasoning**	**Action**

> Memorise this flow — it is the architecture of intelligent systems.

المعرفة تتخزن في قاعدة… والاستدلال يحوّلها لقرار.

From reality to decisions

Real world

↓

Symbols — facts, rules, relations

↓

Reasoning engine

↓

Decision · explanation · action

Machines don't understand reality. They understand **representations** of reality.

KRR ASKS

How do we represent reality correctly?

How do we reason without contradictions?

How do we automate thinking?

V

Motivation & Applications

Whenever rules, logic, explanation or structure matter — KRR is involved.

Why this course matters now

Statistical models predict; they do not know

A fluent answer can still be false. Without an explicit model of the domain there is nothing to check it against.

Regulated decisions require reasons

Medicine, finance, aviation and law require a decision trail an auditor can follow. Inference chains provide one.

Knowledge outlives the model

Curated ontologies and rule bases are reused across decades; a trained network retires with its data.

The strongest systems being built today combine both: **learning to perceive**, and **represented knowledge to constrain and explain** .

Representation is power

Intelligence requires **structure**.

Representation determines **reasoning power**.

Different representations allow different inferences.

AI is not only learning — it is reasoning.

FOUNDATION OF

- Expert systems
- Ontologies and knowledge graphs
- Explainable AI
- Logical agents
- Even the limits of deep learning

طريقة تمثيلك للمعرفة بتحدّد قوة تفكيرك.

Intelligence is not just learning

AI becomes **interpretable**

Systems become **trustworthy**

Decisions become **logical, auditable, reusable**

Smart behaviour vs **Intelligent thinking**

KRR is the line between the two.

Where it is already used

HEALTHCARE

Clinical decision support

Drug-interaction checking, guideline-based triage, coded diagnosis vocabularies.

WEB AND SEARCH

Knowledge graphs

Entity-level answers, linked open data, retrieval grounded in structured facts.

ROBOTICS

Task and motion planning

Symbolic goals and preconditions over a world model the robot maintains.

INDUSTRY

Diagnosis and configuration

Fault trees for plant equipment; configurators that enforce compatibility.

LAW AND FINANCE

Compliance reasoning

Regulations encoded as rules, checked against transactions with an audit trail.

SMART SYSTEMS

Digital twins

Sensor streams interpreted against a model of how the plant should behave.

And three more

Cybersecurity

Attack reasoning

Policy enforcement

Smart cities

Traffic rules

Resource allocation

Explainable AI

Why did the model decide this?

Whenever **rules, logic, explanation or structure** matter → KRR is involved.

Programming says how. KRR says what it means.

ALGORITHMS

how fast

DATA STRUCTURES

how stored

KRR

how understood

> This course upgrades you from **code writers** to **system thinkers**.

Foundations that make KRR click

REQUIRED MINDSET

Logical thinking

Comfort with abstraction

HELPFUL COURSES

Discrete mathematics

Logic / Boolean algebra

Data structures

Basic AI concepts

If you can reason about **conditions, rules and consequences** — you are ready.

This course is a backbone

Artificial Intelligence	Machine Learning — interpretability	Expert Systems	Natural Language Processing
Semantic Web	Multi-Agent Systems	Decision Support Systems	…and the limits of deep learning

> Many advanced AI courses **assume you already think this way**.

What you will be able to do

By the end of the semester.

01 Model a real domain as objects, relations and constraints.

02 Encode that model in propositional and first-order logic, and check it.

03 Build a rule-based system with forward and backward chaining.

04 Design an ontology and query a knowledge graph over it.

05 Judge which representation fits a problem — and defend the choice.

Three things to take away

01 Data records instances; knowledge states what holds in general.

02 Representation without reasoning is storage; reasoning without representation is guessing.

03 A system that can justify its answer can be trusted with a consequential one.

NEXT LECTURE

Propositional logic: syntax, semantics, and how to **prove** that Ali is Omar's grandfather.

The whole lecture in five lines

Knowledge describes the world.

Representation encodes it.

The **Knowledge Base** stores it.

Reasoning extends it.

Logic constrains it.