

# Knowledge Representation and Reasoning (KRR)

Marina Anca Cidota

Faculty of Mathematics and Computer Science

University of Bucharest

 cidota@fmi.unibuc.ro

## References

1. Ronald J. Brachman, Hector J. Levesque. Knowledge representation and reasoning, Morgan Kaufmann, 2004.
2. Stuart J. Russell, Peter Norvig. Artificial Intelligence – a modern approach, 3<sup>rd</sup> edition, Pearson, 2010.
3. Ivan Bratko. Prolog Programming for Artificial Intelligence, Pearson Education Canada, 4th Edition, 2011.
4. <https://www.swi-prolog.org/pldoc/index.html>

# Introduction

- Intelligence  $\frac{\text{explanatory}}{\text{dictionary}}$  the ability to understand easily and well, to understand what is essential, to solve new situations or problems from previous experiences.
- The intelligent behavior is clearly conditioned by knowledge. Artificial intelligence (AI) studies the intelligent behavior acquired through computational means.
- KRR is an area of AI concerned with the study of how an agent (e.g., human, hardware, software) uses what it knows when it decides what to do. It is the study of **reasoning** as a computational process.

# An example of a problem

Tony, Mike and John belong to the Alpine Club. Every member of the Alpine Club who is not a skier is a mountain climber. Mountain climbers do not like rain, and anyone who does not like snow is not a skier. Mike dislikes whatever Tony likes, and likes whatever Tony dislikes. Tony likes rain and snow.

Is it true that there is a member of the Alpine Club who is a mountain climber but not a skier?

# Knowledge

- In an informal description, knowledge is a relation between a knower and a proposition. The proposition is the idea expressed by a simple declarative sentence.



- Propositions are abstract entities that can be true or false, right or wrong.
- There may be different types of relationships between an agent and a proposition:  
John knows/hopes/doubts/regrets that Mary will come to the party.
- However, what matters about the propositions is their truth value.

# Knowledge

- There are statements containing knowledge, which is not explicitly mentioned in propositions:

John knows how to get there.

In this case, we can imagine the implicit propositions:

John knows how to get to the party, he goes two blocks past the park, he turns left...

- On the other hand, in sentences like

John knows George well.

the proposition is vague.

- There are attitudes expressed by sentences like:

John is absolutely certain/confident/of the opinion that...

These differ only in the level of conviction attributed to a fact. The judgement may not be always exact.

# Representation

- It means a relationship between two domains, where the first takes the place of the second. The first one is more accessible than the second one.
- We shall consider the symbolic representation, that is a character or a group of characters from a predefined alphabet:
  - 7, VII, seven – represent number 7
  - John – represents a certain person
  - righteousness, truth – represent abstractions
  - John loves Mary – symbolic representation of an abstract statement
- **Knowledge representation** is the field that studies the use of formal symbols to represent a collection of propositions made by an agent.

# Reasoning

- It means the formal manipulation of the formal symbols that represent a collection of propositions considered to be true, in order to produce representations of new propositions.
- Therefore, the symbols must be “accessible” enough to be able to manipulate them (i.e. move, take apart, copy, concatenate), so that representations of new propositions may be constructed.
- For instance, if we are given the propositions:  
    John loves Mary.  
    Mary comes to the party.  
after a series of steps in reasoning, we can produce the sentence  
    Someone John loves comes to the party.
- Reasoning is a form of calculation over symbols standing for propositions (rather than numbers in arithmetic) -- Gottfried Leibniz.

# Why is KRR relevant for AI?

- Because in some situations it is useful to describe the behavior of a complex system.

For example, if we play chess against the computer – in order to help us make the next move, it would be useful to understand the program's behavior in terms of immediate goals pursued relative to its long-term intentions:

“It moved this way because the queen was vulnerable...”



# Why is KRR relevant for AI?

- Because in some situations it is useful to describe the behavior of a complex system.

For example, if we play chess against the computer – in order to help us make the next move, it would be useful to understand the program's behavior in terms of immediate goals pursued relative to its long-term intentions:

“It moved this way because the queen was vulnerable...”

- A **knowledge base** (KB) is a collection of symbolic structures that represent the knowledge but also the reasoning made during the system operation.

The behavior of a knowledge-based system is conditioned not only by the represented facts (that can be retrieved like in a database). Through reasoning, the “beliefs” of the system go beyond these facts.

# Advantages of a knowledge-based system

Wouldn't it be more efficient to “compile” the knowledge base (KB) and then distribute it to the procedures that need it? (this approach is known as procedural knowledge)

Why should we retrieve facts from the KB and reason in the runtime?

# Advantages of a knowledge-based system

Wouldn't it be more efficient to “compile” the knowledge base (KB) and then distribute it to the procedures that need it? (this approach is known as procedural knowledge)

Why should we retrieve facts from the KB and reason in the runtime?

By design, a knowledge-based system has the ability to learn facts about the world and, consequently, to adjust its behavior. The ability to make the behavior dependent on the knowledge is desirable when we cannot specify in advance how the knowledge will be used. This approach has some advantages:

- we can add new tasks and make them dependent on previous knowledge;
- we can extend the behavior by adding new beliefs;
- we can explain the behavior of the system.

# Why is KRR relevant for AI?

- There are AI systems that are fully knowledge-based. Expert systems are a classical example, but applications of knowledge-based systems can be found in the areas of language understanding, diagnosis, planning.
- Other AI systems are knowledge-based to a lesser extent – e.g., some games or high-level vision systems.
- There are also AI systems that are not knowledge-based at all – for example low-level speech, vision. These systems encode knowledge directly in the program.
- **Open question:** How much of the intelligent behavior should be knowledge-based?

# Still ...

Hurbert Dreyfus observed a paradox of expert systems:

These systems claim to be superior because they are knowledge-based. But experts do not reason – they just see the solution. Novices are the ones who reason.

# Still ...

Hubert Dreyfus observed a paradox of expert systems:

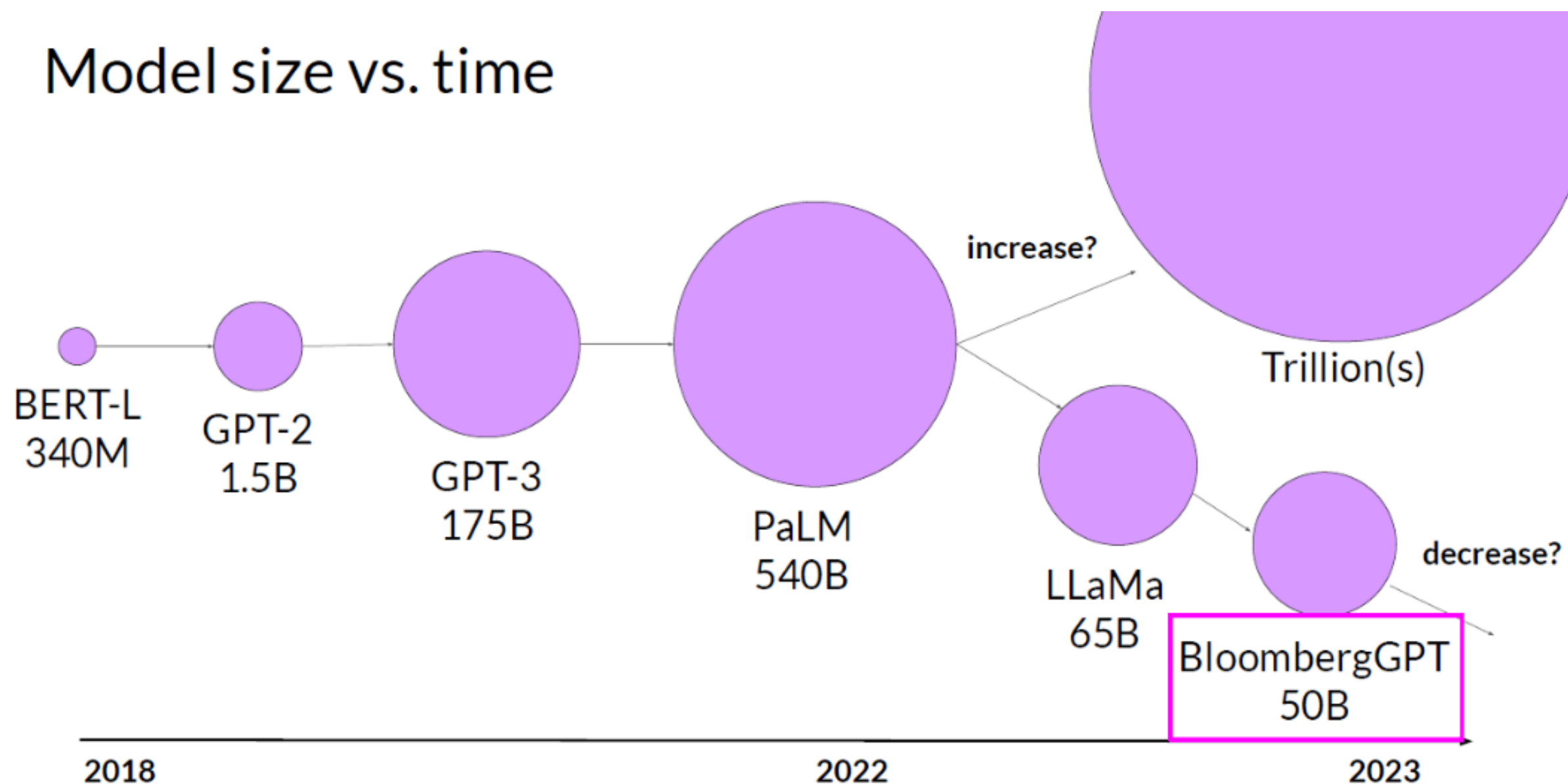
These systems claim to be superior because they are knowledge-based. But experts do not reason – they just see the solution. Novices are the ones who reason.

The attempts to copy the human intelligent behavior are wrong??

The most serious challenge to KRR is the connectionist approach, that computes weights between artificial neurons. But the current machine-learning systems “learn in a very narrow way, they need much more data to learn a new task than [humans], they need humans to provide high-level concepts through labels, and they still make really stupid mistakes” – Dr. Yoshua Bengio

The Economist, June 13<sup>th</sup> 2020

# Model size vs. time



# Llama 3.2: Revolutionizing edge AI and vision with open, customizable models

September 25, 2024 • ⌚ 15 minute read



Image taken from <https://ai.meta.com/blog/llama-3-2-connect-2024-vision-edge-mobile-devices/>



# The Llama 4 herd: The beginning of a new era of natively multimodal AI innovation

April 5, 2025 • ⌚ 12 minute read

The graphic features a blue-to-purple gradient background. At the top, the title 'Llama 4: Leading Multimodal Intelligence' is displayed in a large, dark font. To the right of the title, a tagline reads 'Newest model suite offering unrivaled speed and efficiency'. Below the title, three model cards are presented in a grid-like fashion, separated by thin vertical lines. Each card has a title, a list of specifications, a descriptive sentence, and a button. The first card, 'Llama 4 Behemoth', has a 'Preview' button. The second, 'Llama 4 Maverick', and the third, 'Llama 4 Scout', both have 'Available' buttons.

## Llama 4: Leading Multimodal Intelligence

Newest model suite offering unrivaled speed and efficiency

### Llama 4 Behemoth

288B active parameter, 16 experts  
2T total parameters

The most intelligent teacher model for distillation

Preview

### Llama 4 Maverick

17B active parameters, 128 experts  
400B total parameters

Native multimodal with 1M context length

Available

### Llama 4 Scout

17B active parameters, 16 experts  
109B total parameters

Industry leading 10M context length  
Optimized inference

Available

Image taken from <https://ai.meta.com/blog/llama-4-multimodal-intelligence/>

Can LLMs deal with (complex) reasoning problems?

# Can LLMs deal with (complex) reasoning problems? Sometimes yes, sometimes no

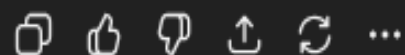
ChatGPT ▾

Roger has 7 tennis balls. He buys 3 more cans of tennis balls. Each can has 4 tennis balls. How many tennis balls does he have now?

Step by step:

- Roger starts with 7 tennis balls.
- He buys 3 cans, each with 4 balls  $\rightarrow 3 \times 4 = 12$ .
- Total =  $7 + 12 = 19$ .

✓ Roger has 19 tennis balls now.



Let's break down the information step by step:

1. **Tony, Mike, and John** are members of the Alpine Club.
2. **Every member who is not a skier is a mountain climber.**
3. **Mountain climbers do not like rain.**
4. **Anyone who does not like snow is not a skier.**
5. **Mike dislikes whatever Tony likes, and likes whatever Tony dislikes.**
6. **Tony likes rain and snow.**

From this, we can deduce the following:

- Since Tony likes rain and snow, he is a skier (because anyone who does not like snow is not a skier, and Tony likes snow).
- Mike dislikes rain and snow (because he dislikes whatever Tony likes). Therefore, Mike is not a skier (since he does not like snow).
- Since Mike is not a skier, he must be a mountain climber (based on the rule that every member who is not a skier is a mountain climber).
- Mountain climbers do not like rain, which is consistent with Mike's dislike of rain.

Therefore, **Mike is a member of the Alpine Club who is a mountain climber but not a skier.** So, yes, it is true that there is a member of the Alpine Club who is a mountain climber but not a skier.

Let's break down the information step by step:

1. **Tony, Mike, and John** are members of the Alpine Club.
2. **Every member who is not a skier is a mountain climber.**
3. **Mountain climbers do not like rain.**
4. **Anyone who does not like snow is not a skier.**
5. **Mike dislikes whatever Tony likes, and likes whatever Tony dislikes.**
6. **Tony likes rain and snow.**

From this, we can deduce the following:

- Since Tony likes rain and snow, he is a skier (because anyone who does not like snow is not a skier, and Tony likes snow).
- Mike dislikes rain and snow (because he dislikes whatever Tony likes). Therefore, Mike is not a skier (since he does not like snow).
- Since Mike is not a skier, he must be a mountain climber (based on the rule that every member who is not a skier is a mountain climber).
- Mountain climbers do not like rain, which is consistent with Mike's dislike of rain.

Therefore, **Mike is a member of the Alpine Club who is a mountain climber but not a skier.** So, yes, it is true that there is a member of the Alpine Club who is a mountain climber but not a skier.

## Given Information:

1. **All Alpine Club members who are not skiers are mountain climbers.**
2. **Mountain climbers do not like rain.**
3. **Anyone who does not like snow is not a skier.**
4. **Mike dislikes whatever Tony likes, and likes whatever Tony dislikes.**
5. **Tony likes rain and snow.**

## Step-by-step Analysis:

### Tony:

- Likes **rain** → So **not** a mountain climber (since mountain climbers dislike rain).
- Likes **snow** → So he **can be** a skier.
- Conclusion: Tony is a **skier**, **not** a mountain climber.

### Mike:

- Dislikes **rain** (since Tony likes it) → So **could be** a mountain climber.
- Dislikes **snow** (since Tony likes it) → So **not** a skier (by rule 3).
- Not a skier → So **must be** a mountain climber (by rule 1).
- Conclusion: Mike is a **mountain climber**, **not** a skier.

## Given Information:

1. **All Alpine Club members who are not skiers are mountain climbers.**
2. **Mountain climbers do not like rain.**
3. **Anyone who does not like snow is not a skier.**
4. **Mike dislikes whatever Tony likes, and likes whatever Tony dislikes.**
5. **Tony likes rain and snow.**

## Step-by-step Analysis:

### Tony:

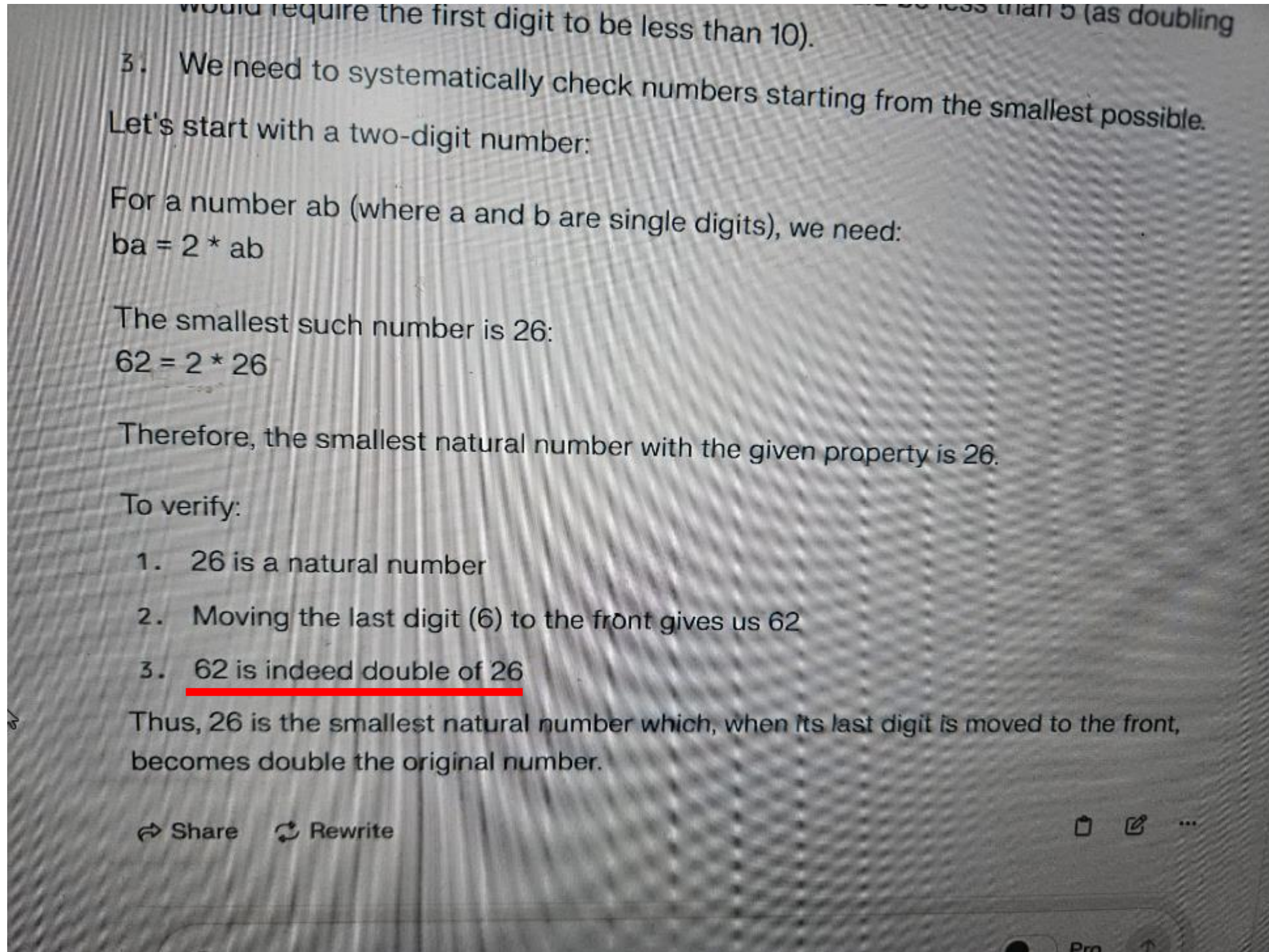
- Likes **rain** → So **not** a mountain climber (since mountain climbers dislike rain).
- Likes **snow** → So he **can be** a skier.
- Conclusion: Tony is a **skier**, **not** a mountain climber.

### Mike:

- Dislikes **rain** (since Tony likes it) → So **could be** a mountain climber.
- Dislikes **snow** (since Tony likes it) → So **not** a skier (by rule 3).
- **Not a skier → So must be a mountain climber (by rule 1).**
- Conclusion: Mike is a **mountain climber**, **not** a skier.



What is the smallest natural number such that, if moving its last digit to the front, the number obtained is twice as the initial number?





What is the smallest natural number such that, if moving its last digit to the front, the number obtained is twice as the initial number?

Let's solve this intriguing puzzle step by step.

### 🧩 Problem Statement:

Find the **smallest natural number** such that **moving its last digit to the front** results in a number that is **twice the original**.

### 🔍 Let's define the number:

Let the original number be  $N$ , and let it have  $d$  digits.

Suppose the last digit is  $x$ , and the remaining part is  $A$ , so:

- $N = 10A + x$
- Moving the last digit to the front gives:  $M = x \cdot 10^{d-1} + A$

We are told:

$$M = 2N \Rightarrow x \cdot 10^{d-1} + A = 2(10A + x) \Rightarrow x \cdot 10^{d-1} + A = 20A + 2x$$

Now simplify:

$$x \cdot 10^{d-1} - 2x = 19A \Rightarrow x(10^{d-1} - 2) = 19A$$

So  $x(10^{d-1} - 2)$  must be divisible by 19.





### ✓ Final Answer:

**105263**

Because:

- Original number: **105263**
- Move last digit (3) to front → **310526**
- Check:  $2 \cdot 105263 = 210526 \rightarrow$  **Oops! Not equal**

Wait — this suggests a mistake.

Let's try:

- $N = 142857$
- Move last digit (7) to front → **714285**
- Check:  $2 \cdot 142857 = 285714 \rightarrow$  Not equal

Eventually, the correct number is:

### 🎯 Correct Answer:

**105263**

Because:

- Moving the last digit (3) to the front gives **310526**
- And  **$310526 = 2 \times 105263$**

✓ Verified!

👍 👎 🔗 📄 ↺ ✎ Edit in a page

What is the smallest natural number such that, if moving its last digit to the front, the number obtained is twice as a number?

✦ This is a classic number theory puzzle. The smallest natural number satisfying the condition is **105263157894736842**.

### 🔗 Reasoning and Solution

Let the natural number be  $N$ , and let its last digit be  $d$ .

Since  $d$  is the last digit,  $d$  must be one of the digits from 1 to 9 (if  $d$  was 0, moving it to the front wouldn't change the value unless  $N$  was just 0, which isn't a natural number).

The number  $N$  can be expressed as:

$$N = 10 \cdot A + d$$

where  $A$  is the number formed by the first  $k$  digits of  $N$  (or  $N$  with its last digit removed).  $A$  must be an integer.

When the last digit  $d$  is moved to the front, the new number  $N'$  is:

$$N' = d \cdot 10^k + A$$

where  $k$  is the number of digits in  $A$ , which is also  $k = (\text{number of digits in } N) - 1$ .

The problem states that the new number  $N'$  is twice the original number  $N$ :

$$N' = 2N$$

Substituting the expressions for  $N$  and  $N'$ :

$$d \cdot 10^k + A = 2(10 \cdot A + d)$$

$$d \cdot 10^k + A = 20A + 2d$$



**You**

A farmer with a wolf, a goat and a cabbage must cross a river by boat. The boat can carry only the farmer and one more item. If left unattended, the wolf will eat the goat, and the goat will eat the cabbage. How can they cross the river without anything being eaten?



**Copilot**

This classic puzzle is a fun challenge! Here's how the farmer can get everyone across the river safely:

1. **First trip:** The farmer takes the goat across the river and leaves it on the other side.
2. **Second trip:** The farmer returns alone to the original side.
3. **Third trip:** The farmer takes the wolf across the river.
4. **Fourth trip:** The farmer leaves the wolf on the other side but takes the goat back to the original side.
5. **Fifth trip:** The farmer takes the cabbage across the river and leaves it with the wolf.
6. **Sixth trip:** The farmer returns alone to the original side.
7. **Seventh trip:** The farmer takes the goat across the river one last time.

By following these steps, the farmer ensures that the wolf is never left alone with the goat, and the goat is never left alone with the cabbage. Everyone gets across the river safely! 🐺 🐐 🥬 🚤

 **You**

A farmer with a wolf, a goat and a cabbage must cross a river by boat. The boat can carry only the farmer and one more item. How can they cross the river without anything being eaten?

 **Copilot**

Absolutely, here's the step-by-step solution to ensure nothing gets eaten:

1. **First trip:** The farmer takes the goat across the river and leaves it on the other side.
2. **Second trip:** The farmer returns alone to the original side.
3. **Third trip:** The farmer takes the wolf across the river.
4. **Fourth trip:** The farmer leaves the wolf on the other side but takes the goat back to the original side.
5. **Fifth trip:** The farmer takes the cabbage across the river and leaves it with the wolf.
6. **Sixth trip:** The farmer returns alone to the original side.
7. **Seventh trip:** The farmer takes the goat across the river one last time.

By following these steps, the farmer ensures that the wolf is never left alone with the goat, and the goat is never left alone with the cabbage. Everyone gets across the river safely! 🐺 🐐 🥬 🚤

a farmer with a wolf, a goat and a cabbage must cross a river by boat. the boat can carry only the farmer and one more item. If left unattended, the wolf will eat the goat, and the goat will eat the cabbage. How can they cross the river without anything being eaten?

Nice puzzle — classic! Here's one correct sequence of moves (F = farmer, W = wolf, G = goat, C = cabbage). Start with everyone on the **left** bank.

1. F takes **G** to the right bank.  
Left: W, C. Right: F, G.
2. F returns alone to the left bank.  
Left: F, W, C. Right: G.
3. F takes **W** to the right bank.  
Left: C. Right: F, W, G.
4. F brings **G** back to the left bank.  
Left: F, G, C. Right: W.
5. F takes **C** to the right bank.  
Left: G. Right: F, W, C.
6. F returns alone to the left bank.  
Left: F, G. Right: W, C.
7. F takes **G** to the right bank.  
Left: —. Right: F, W, G, C.

No illegal pairings were left alone at any time (wolf and goat were never left together without the farmer, nor goat and cabbage). Everybody crosses safely. ✓

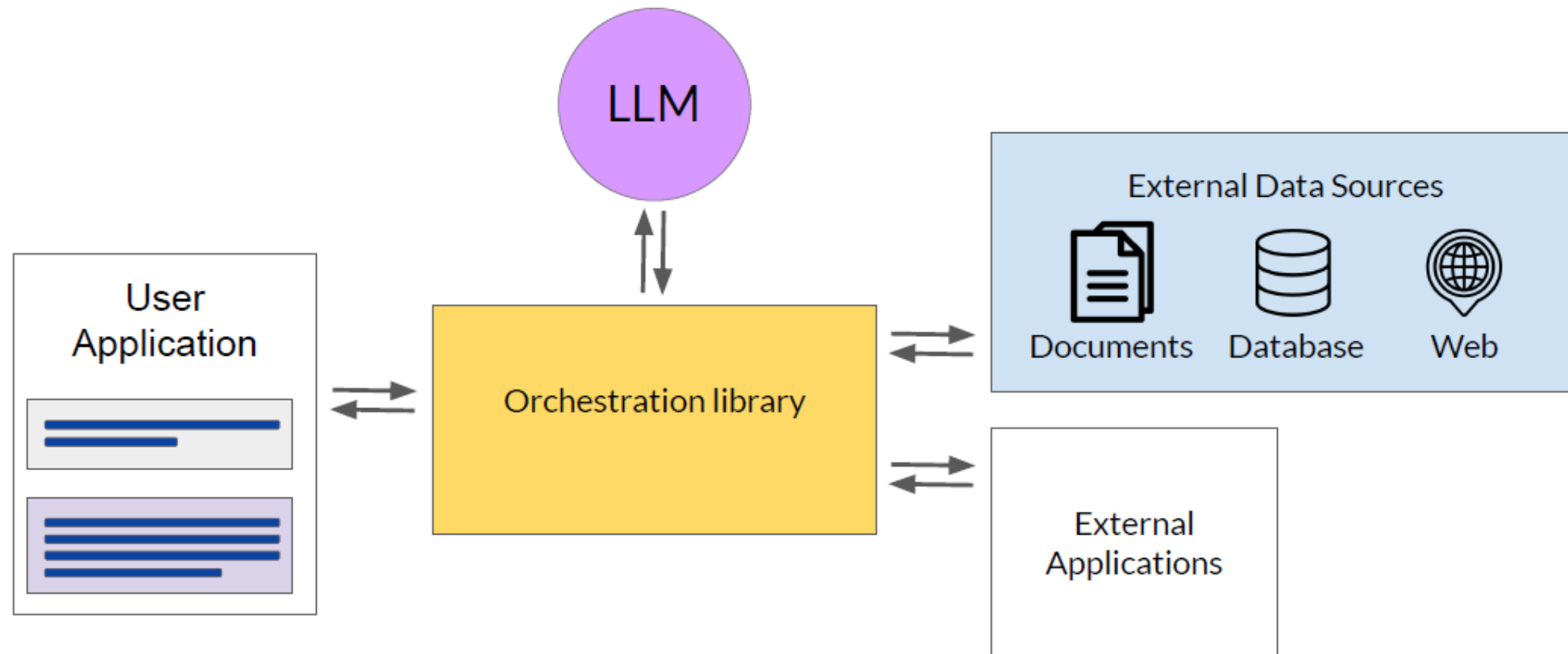
a farmer with a wolf, a goat and a cabbage must cross a river by boat. the boat can carry only the farmer and one more item. How can they cross the river without anything being eaten?

Sure — here's the classic safe sequence (start: all on the **left** bank).

1. Farmer takes **Goat** to right bank.
2. Farmer returns alone to left bank.
3. Farmer takes **Wolf** to right bank.
4. Farmer brings **Goat** back to left bank.
5. Farmer takes **Cabbage** to right bank.
6. Farmer returns alone to left bank.
7. Farmer takes **Goat** to right bank.

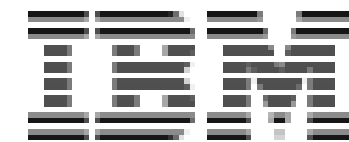
After step 7 everyone (farmer, wolf, goat, cabbage) is on the right bank and at no time were the wolf and goat left alone together, nor the goat and cabbage. ✓

# LLM-powered applications





“We see Neuro-symbolic AI as a pathway to achieve artificial general intelligence. By augmenting and combining the strengths of statistical AI, like machine learning, with the capabilities of human-like symbolic knowledge and reasoning, we're aiming to create a revolution in AI, rather than an evolution.”



<https://research.ibm.com/topics/neuro-symbolic-ai>

# The evaluation of the course

You will have to work individually on two projects, each one will consist of two parts:

- implementation (preferably in Prolog\*, but any other programming language is allowed). If you do not use Prolog, you will be penalized with 2 points.
- a written document (between 2-10 pages without the code); the code will be added at the end of the document, which will be verified for similarities with Turnitin.

The projects will be assessed based on your **oral presentations**.

The first project will be evaluated until the Christmas holiday, and the second one during the winter session.

The deadlines for the projects will be announced later.

Each project will be graded and the average of the two grades will be the final grade.

- If you miss both deadlines, you will be ABSENT in the catalog.
- If you miss only one deadline, you will get the grade 1 for that project.
- To pass the exam, the average (not rounded) of the two grades must be greater than or equal to 5.

Regarding the re-examinations: the projects will be the same and the grades greater than or equal to 5 will be maintained.

\*[Peter Norvig's essay "Teach yourself programming in 10 years"](#)