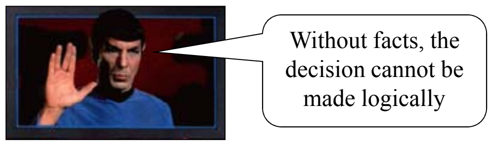
CS 331: Artificial Intelligence
Propositional Logic I



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Knowledge-based Agents

- Can represent knowledge
- And reason with this knowledge
- How is this different from the knowledge used by problem-specific agents?
  - More general
  - More flexible

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Outline

1. Knowledge-based Agents
2. The Wumpus World
3. Logic

Knowledge-based Agents

- Knowledge of problem solving agents is specific and inflexible
- Knowledge-based agents can benefit from knowledge expressed in very general forms, combining information in different ways to suit different purposes
- Knowledge-based agents can combine general knowledge with current percepts to infer hidden aspects of the current state

Knowledge-based Agents

Flexibility of knowledge-based agents:

- Accept new tasks in the form of explicitly described goals
- Achieve competence quickly by being told or learning new knowledge about the environment
- Adapt to changes in the environment by updating the relevant knowledge

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Knowledge is definite

- Knowledge of logical agents is always definite
- That is, each proposition is entirely true or entirely false
- Agent may be agnostic about some propositions
- Logic doesn't handle uncertainty well

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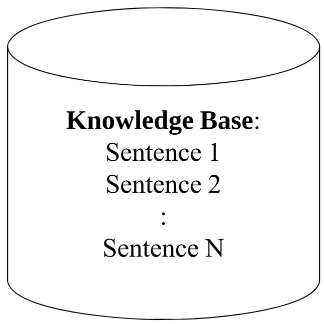
The Knowledge Base (KB)



- A knowledge base is a set of "sentences"
- Each sentence is expressed in a knowledge representation language and represents some assertion about the world

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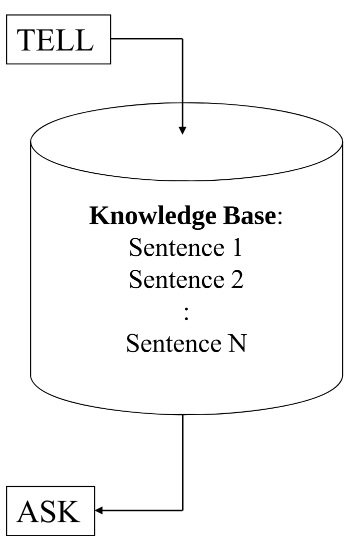
The Knowledge Base (KB)



- Need to add new sentences to the knowledge base (this task is called TELL)
- Need to query what is known (this task is called ASK)

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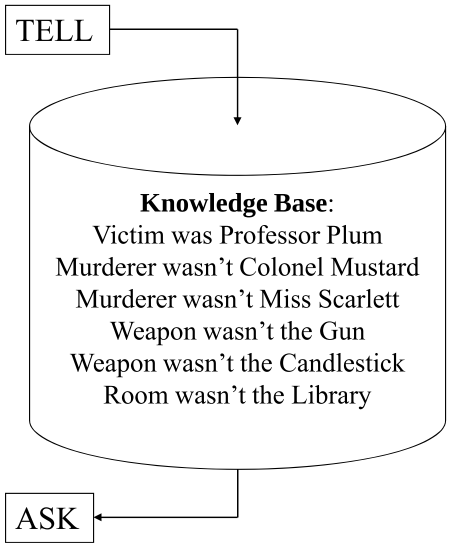
Knowledge Base Example



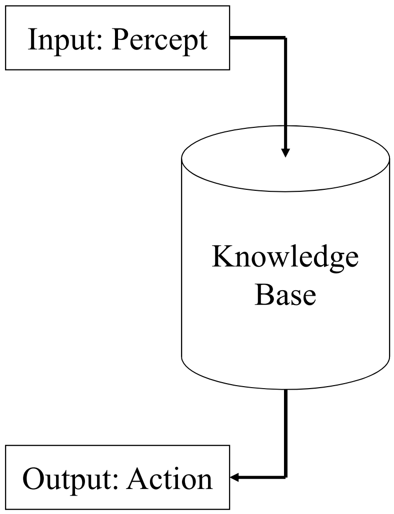
When you discover a new fact like "The murder room wasn't the study", you would TELL the KB

You can then ASK the KB what to ask next

Inference

- Inference: deriving new sentences from old ones
- Must obey fundamental requirement: when one ASKs a question of the knowledge base, answer should follow from what has been TELLed to the KB previously

A Generic Knowledge-based Agent



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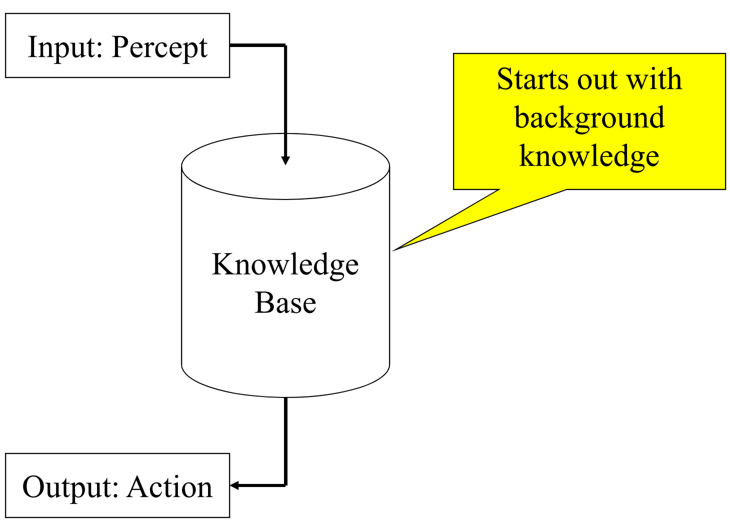
A Generic Knowledge-based Agent



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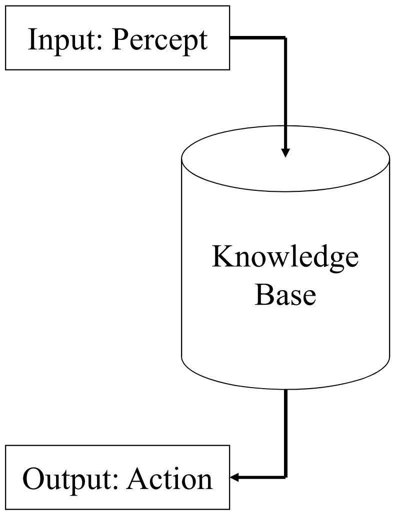
A Generic Knowledge-based Agent



1. TELL the KB what it perceives
2. ASK the KB what action it should perform
3. TELL the KB that the action was executed

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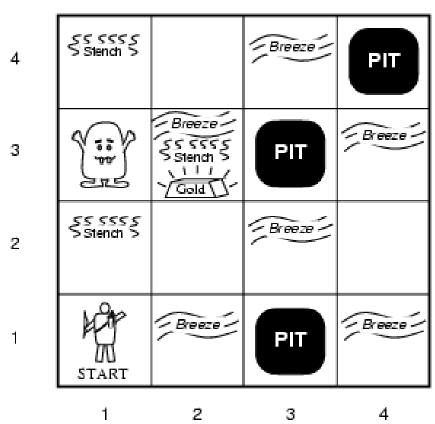
The Wumpus World



- Wumpus eats anyone that enters its room
- Wumpus can be shot by an agent, but agent has one arrow
- Pits trap the agent (but not the wumpus)
- Agent's goal is to pick up the gold

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The Wumpus World

- **Performance measure**:
  - +1000 for picking up gold, -1000 for death
  - -1 for each action taken, -10 for using arrow
- **Environment**:
  - 4x4 grid of rooms
  - Agent starts in (1,1) and faces right
  - Geography determined at the start:
    - Gold and wumpus locations chosen randomly
    - Each square other than start can be a pit with probability 0.2

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The Wumpus World

- **Actuators**:
  - Movement:
    - Agent can move forward
    - Turn 90 degrees left or right
    - Death for meeting a live wumpus or falling into a pit
  - Grab: pick up an object in same square
  - Shoot: fire arrow in straight line in the direction agent is facing

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The Wumpus World

- **Sensors**:
  - Returns a 5-tuple of five symbols eg. [stench, breeze, glitter, bump, scream] (note that in this 5-tuple, all five things are present. We indicate absence with the value None)
  - In squares adjacent to the wumpus, agent perceives a stench
  - In squares adjacent to a pit, agent perceives a breeze
  - In squares adjacent to the gold, agent perceives a glitter
  - When agent walks into a wall, it perceives a bump
  - When wumpus is killed, it emits a woeful scream that is perceived anywhere

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The Wumpus World

- Biggest challenge: Agent is ignorant of the configuration of the 4x4 world
- Needs logical reasoning of percepts in order to overcome this ignorance
- Note: retrieving gold may not be possible due to randomly generated location of pits
- Initial knowledge base contains:
  - Agent knows it is in [1,1]
  - Agent knows it is a safe square

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The Wumpus World Environment Properties

- Fully or Partially observable?
- Deterministic or stochastic (in terms of actions)?
- Episodic or sequential?
- Static or dynamic?
- Discrete or continuous?
- Single agent or multiagent?

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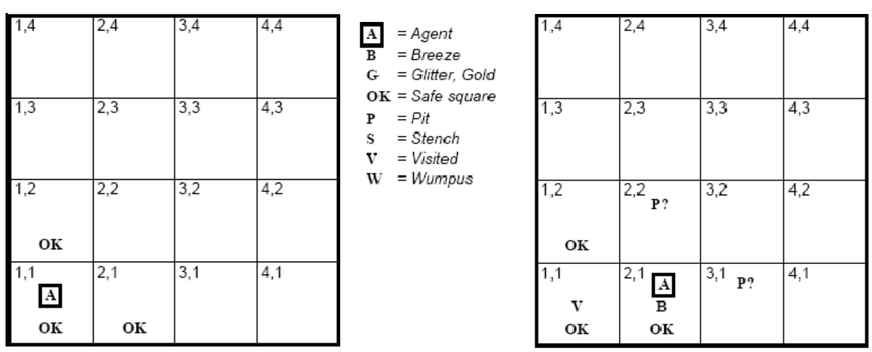
Wumpus World Example



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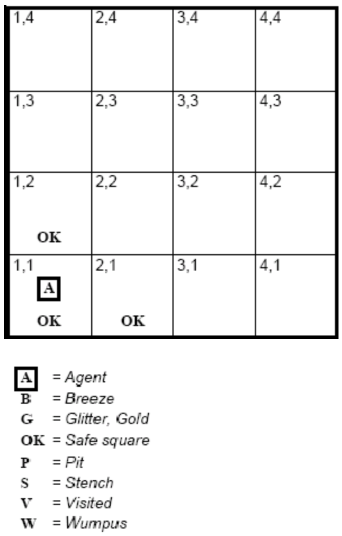
Wumpus World Example



1st percept is:

[None, None, None, None, None]

(Corresponding to [Stench, Breeze, Glitter, Bump, Scream])

Agent concludes squares [1,2], [2,1] are safe. We mark them with OK. A cautious agent will move only to a square that it knows is OK.

Agent now moves to [2,1]

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Wumpus World Example

2nd percept is:

[None, Breeze, None, None, None]

Must be a pit at [2,2] or [3,1] or both. We mark this with a P?.

Only one square that is OK, so the agent goes back to [1,1] and then to [1,2]

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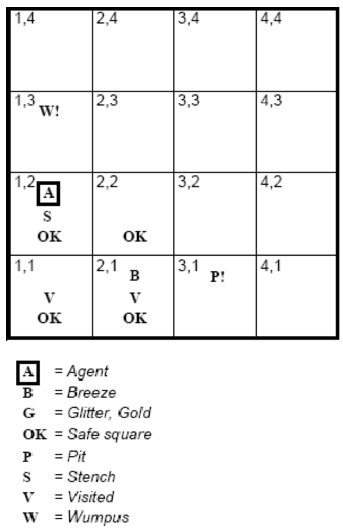
Wumpus World Example



3rd percept is:

[Stench, None, None, None, None]

Wumpus must be nearby. Can't be in [1,1] (by rules of the game) or [2,2] (otherwise agent would have detected a stench at [2,1])

Therefore, Wumpus must be in [1,3]. Indicate this by W!.

Lack of breeze in [1,2] means no pit in [2,2], so pit must be in [3,1].

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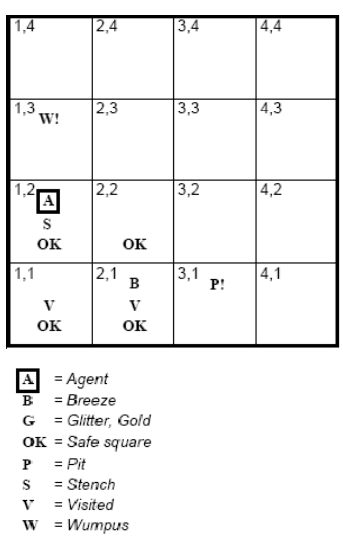
Wumpus World Example



Note the difficulty of this inference:

- Combines knowledge gained at different times and at different places.
- Relies on the lack of a percept to make one crucial step

At this point, the agent moves to [2,2].

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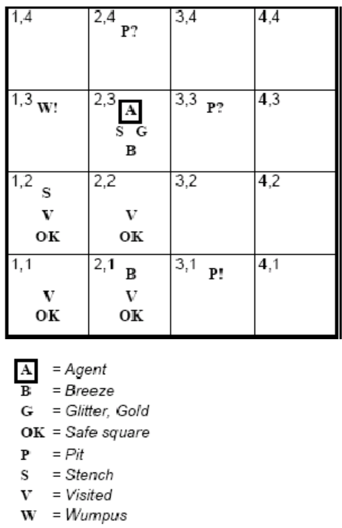
Wumpus World Example



We'll skip the agent's state of knowledge at [2,2] and assume it goes to [2,3].

Agent detects a glitter in [2,3] so it grabs the gold and ends the game

Note: In each case where the agent draws a conclusion from the available information, that conclusion is guaranteed to be correct if the available information is correct

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Logic

Logic must define:

1. Syntax of the representation language
   - Symbols, rules, legal configurations
2. Semantics of the representation language
   - Loosely speaking, this is the "meaning" of the sentence
   - Defines the truth of each sentence with respect to each possible world
   - Everything is either true or false, no in between

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Models

- We will use the word model instead of "possible world"
- "m is a model of α" means that sentence α is true in model m
- Models are mathematical abstractions which fixes the truth or falsehood of every relevant sentence
- Think of it as the possible assignments of values to the variables
  - Eg. the possible models for $x + y = 4$ are all possible assignments of numbers to x and y such that they add up to 4

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Entailment

$\alpha \models \beta$ means α entails β ie. β follows logically from α, where α and β are sentences

Mathematically, $\alpha \models \beta$ if and only if in every model in which α is true, β is also true.

Another way: if α is true, then β must also be true.

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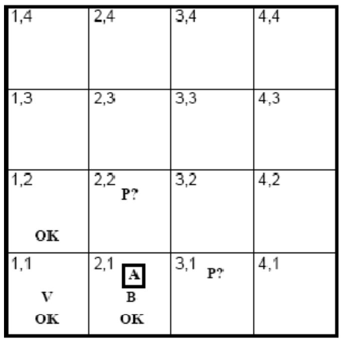
Entailment Applied to the Wumpus World



- Suppose the agent moves to [2,1]
- Agent knows there is nothing in [1,1] and a breeze in [2,1]
- These percepts, along with the agent's knowledge of the rules of the wumpus world constitute the KB
- Given this KB, agent is interested if the adjacent squares [1,2], [2,2] and [3,1] contain pits.

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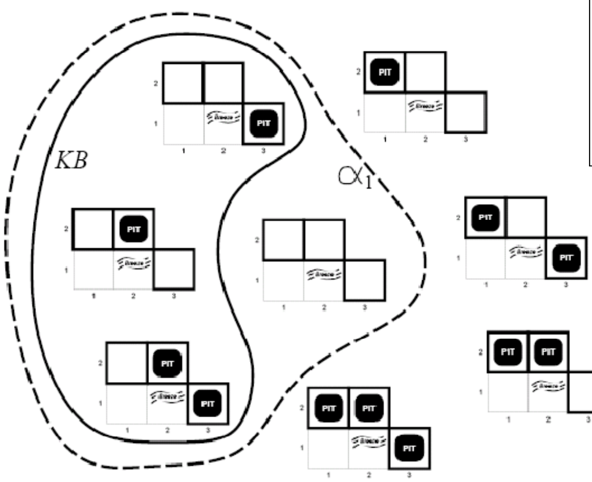
Entailment Applied to the Wumpus World



2^3 = 8 possible models because [1,2], [2,2] and [3,1] can take each take values true or false that there is a pit there

We do not show models that contradict the KB eg. models that say that [1,2] contains a pit

The 3 models inside the line marked KB are those in which the KB is true

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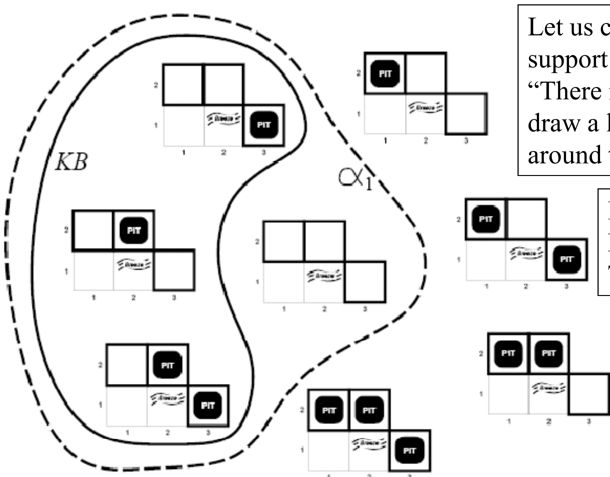
Entailment Applied to the Wumpus World



Let us consider the models that support the conclusion α_1 = "There is no pit in [1,2]." We draw a line marked with α_1 around these models

In every model in which KB is true, α_1 is also true. Therefore KB |= α_1

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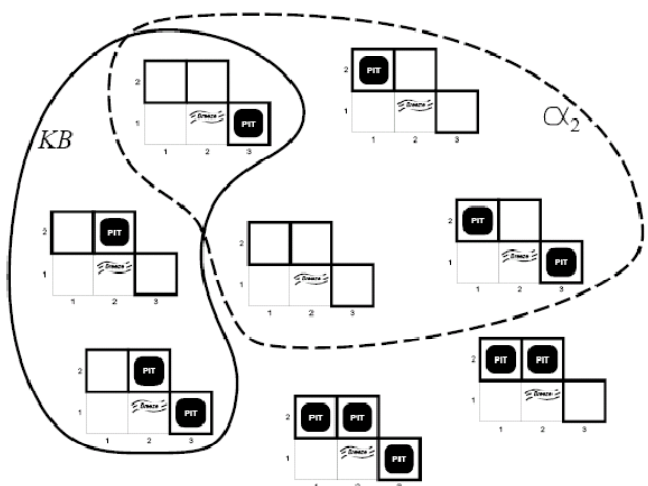
Entailment applied to the Wumpus World



Now let us consider the models that support the conclusion α_2 = "There is no pit in [2,2]." We draw a line marked with α_2 around these models

In some models in which KB is true, α_2 is false. Therefore KB |≠ α_2 and the agent cannot conclude that there is a pit in [2,2]

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Logical inference

- Entailment can be applied to derive conclusions (we call this carrying out logical inference)
- Model checking: enumerates all possible models to check that α is true in all models in which KB is true
- If an inference algorithm *i* can derive α from the KB, we write KB $\vdash_i$ α
- The above is pronounced "α is derived from KB by *i*" or "*i* derives α from KB"

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Soundness

- An inference algorithm that derives only entailed sentences is called sound or truth-preserving
- Soundness is a good thing!
- If an inference algorithm is unsound, you can make things up as it goes along and derive basically anything it wants to

This (unsoundness) is most illogical

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Completeness

- An inference algorithm is complete if it can derive any sentence that is entailed
- For some KBs, the number of sentences can be infinite
- Can't exhaustively check all of them, need to rely on proving completeness

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In Summary

- Soundness: *i* is sound if whenever KB $\vdash_i \alpha$, it is also true that KB $\models \alpha$
- Completeness: *i* is complete if whenever *KB* $\models \alpha$, it is also true that *KB* $\vdash_i \alpha$

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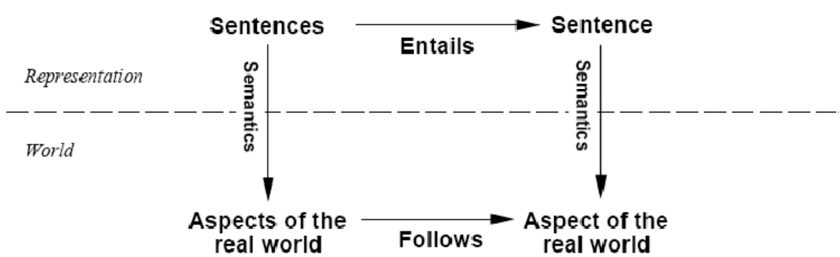
Correspondence to the Real World

If the KB is true in the real world, then any sentence α derived from the KB by a sound inference procedure is also true in the real world.



Grounding

- Defined as the connection, if any, between logical reasoning processes and the real environment in which the agent exists
- How do we know that the KB is true in the real world?
- Deep philosophical question
- We'll respond with the following:
  - Rely on sensors to accurately perceive the world
  - Learning produces general rules (derived from perceptual experience). Learning can be fallible but it has the potential to fix its mistakes.

Things you should know

- Properties of a knowledge-based agent
- What a knowledge-base is
- What entailment and inference mean
- Desirable properties of inference algorithms such as soundness and completeness

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