Artificial Intelligent

Sem. Ganjil 2024/2025

07. Logical Agent

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Overview

- Knowledge-Based Agent
- The Wumpus World
- Propositional Logic
- Method Checking
- Theorem Proving
- Intro. to First Order Logic

Preliminaries

Problems with Problem-Solving Agent:

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- A sentence is an assertion about the world.

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Logical AI

"The idea is that an agent can represent knowledge of its world, its goals and the current situation by sentences in logic and decide what to do by inferring that a certain action or course of action is appropriate to achieve its goals."

John McCarthy

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```
function KB-AGENT(percept) returns an action
   persistent: KB, a knowledge base
               t, a counter, initially 0, indicating time

   TELL(KB, MAKE-PERCEPT-SENTENCE(percept, t))
   action ← ASK(KB, MAKE-ACTION-QUERY(t))
   TELL(KB, MAKE-ACTION-SENTENCE(action, t))
   t ← t + 1
   return action
```

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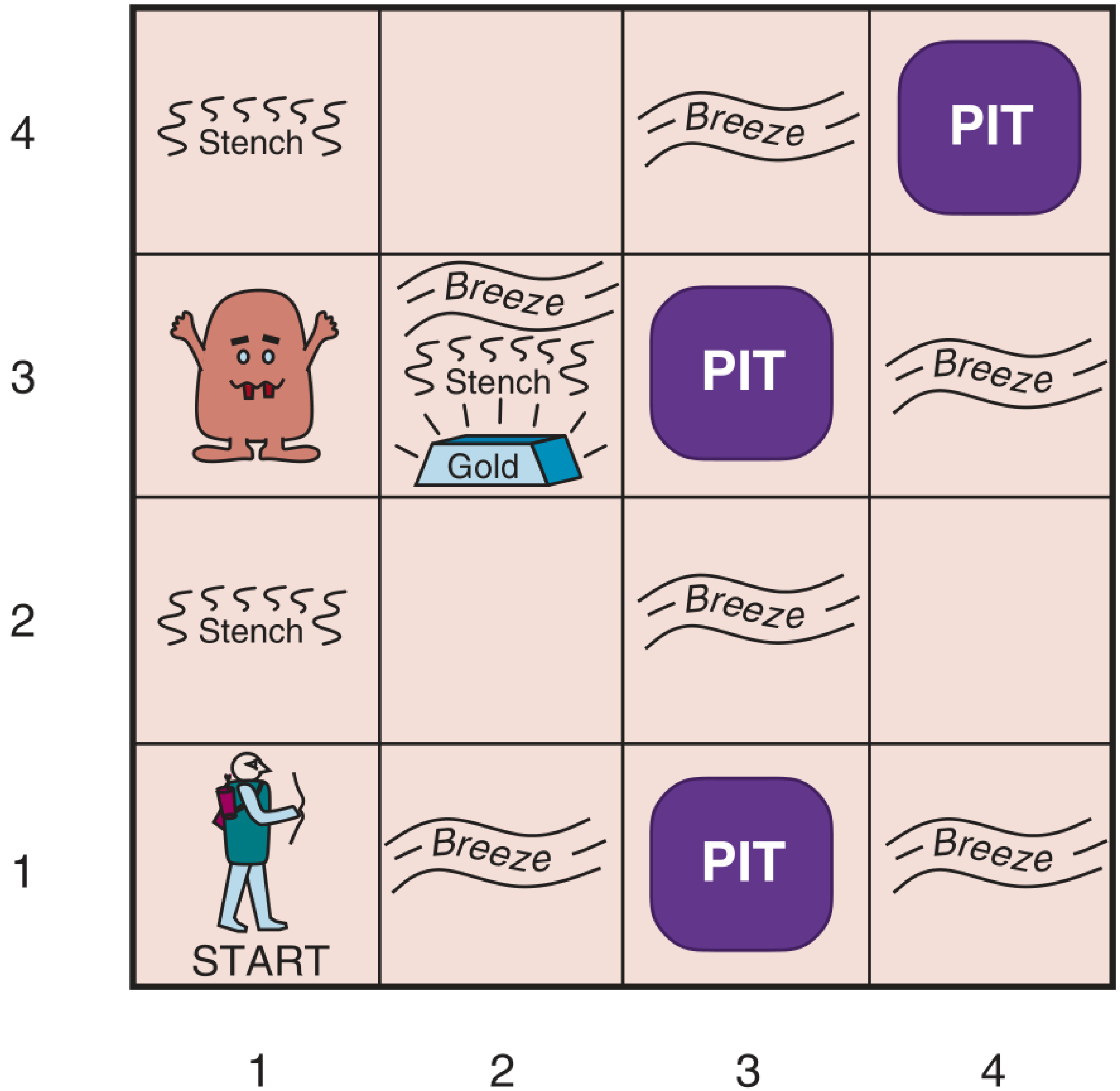
The Wumpus World



PEAS of the Wumpus world

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Performance: +1000 take the gold and climb out the cave. -1000 for falling into a pit or being eaten by the wumpus. -10 for using the arrow and -1 for each action taken. The game ends either when the agent dies or when the agent climbs out of the cave.

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Environment: 4x4 grid rooms (walls surrounding the grid), Start in [1,1], facing east. The locations of the gold and the Wumpus are chosen randomly (not at [1,1]) with a uniform distribution. Each square (not at [1,1]) can be a pit with probability 0.2.

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Sensors: *Stench* and *Breeze*: adjacent to the wumpus and a pit, respectively. *Glitter*: square with gold. *Bump*: walks into a wall. *Scream*: the wumpus is killed. Given to the agent as a list of five symbols, ex.: [Stench, Breeze, None, None, None].

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Properties: Partially Observable, Static, Discrete, Single-agent, Deterministic, Sequential

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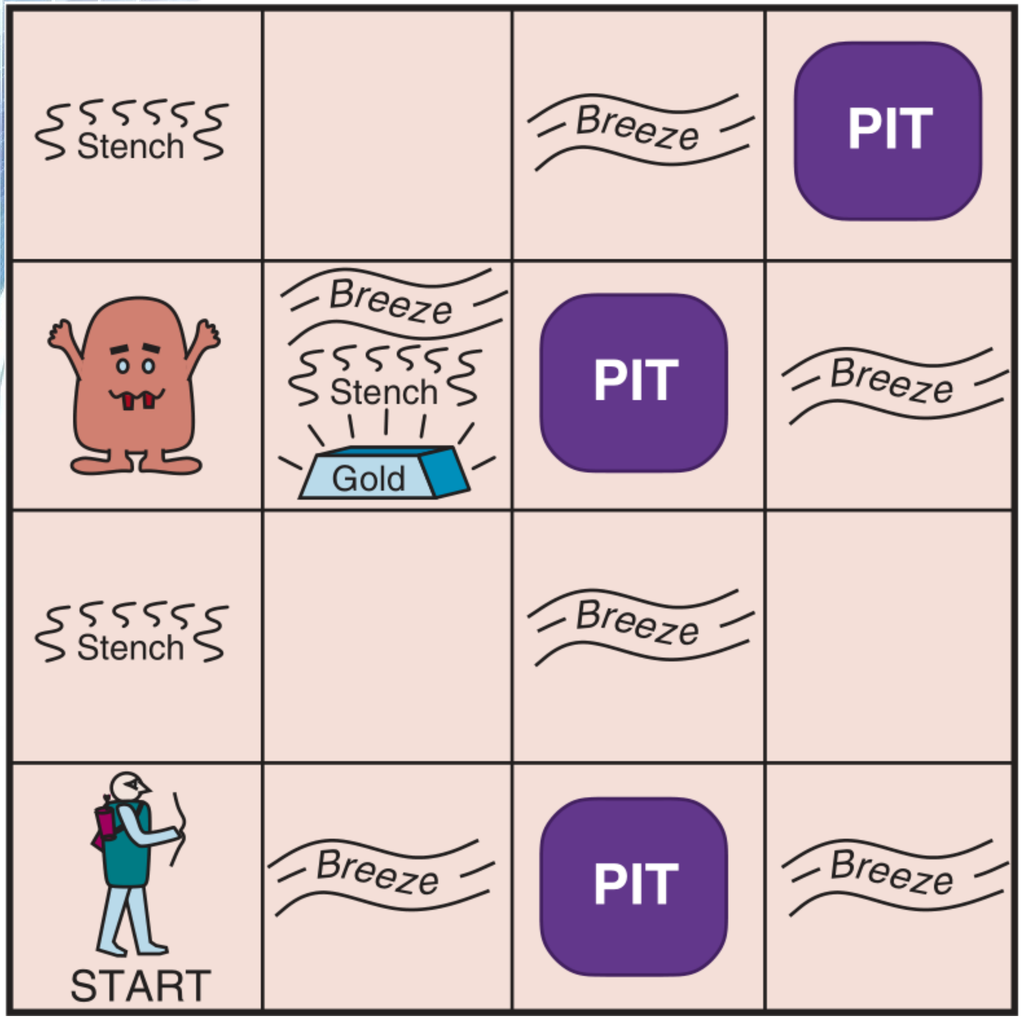
Exploring the Wumpus world



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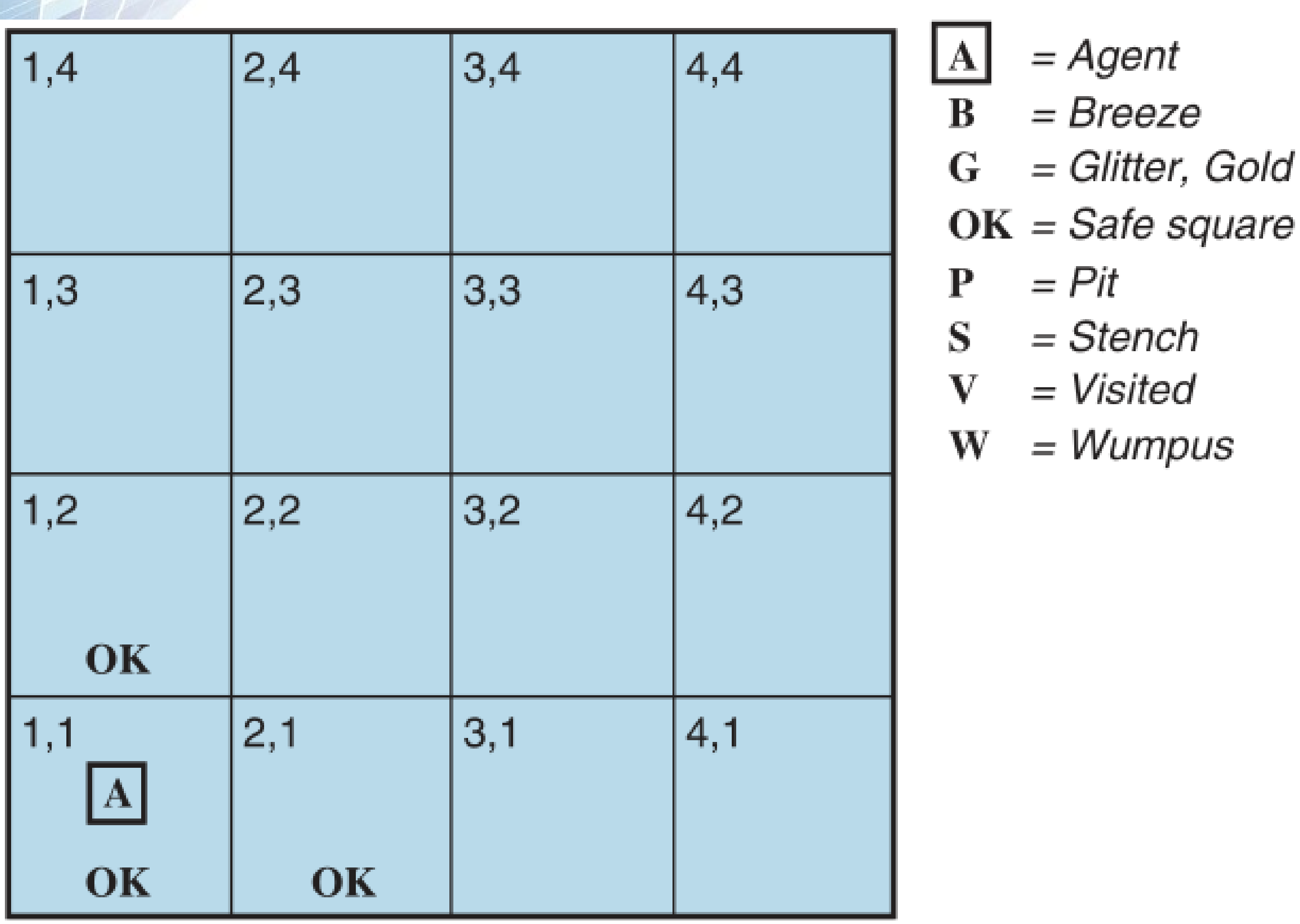

The initial situation: after percept [*None, None, None, None, None*]

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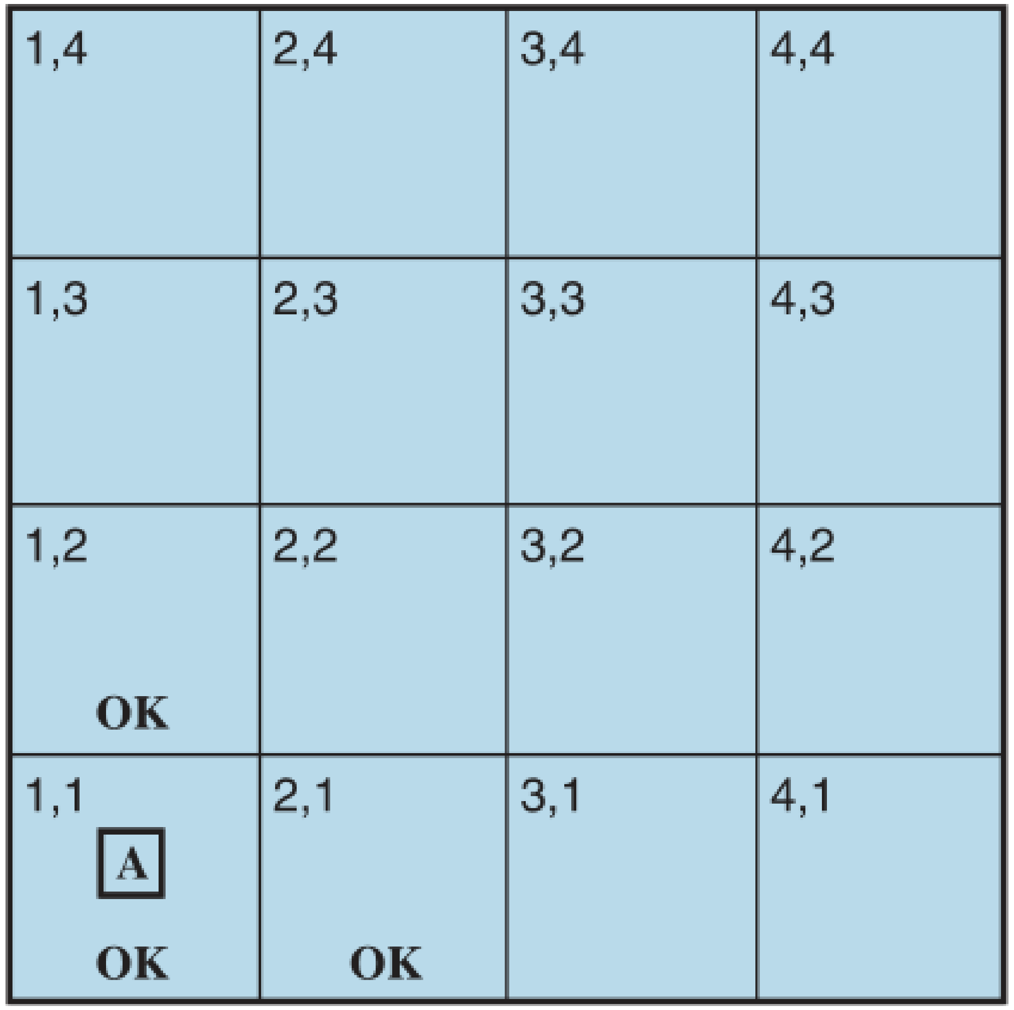
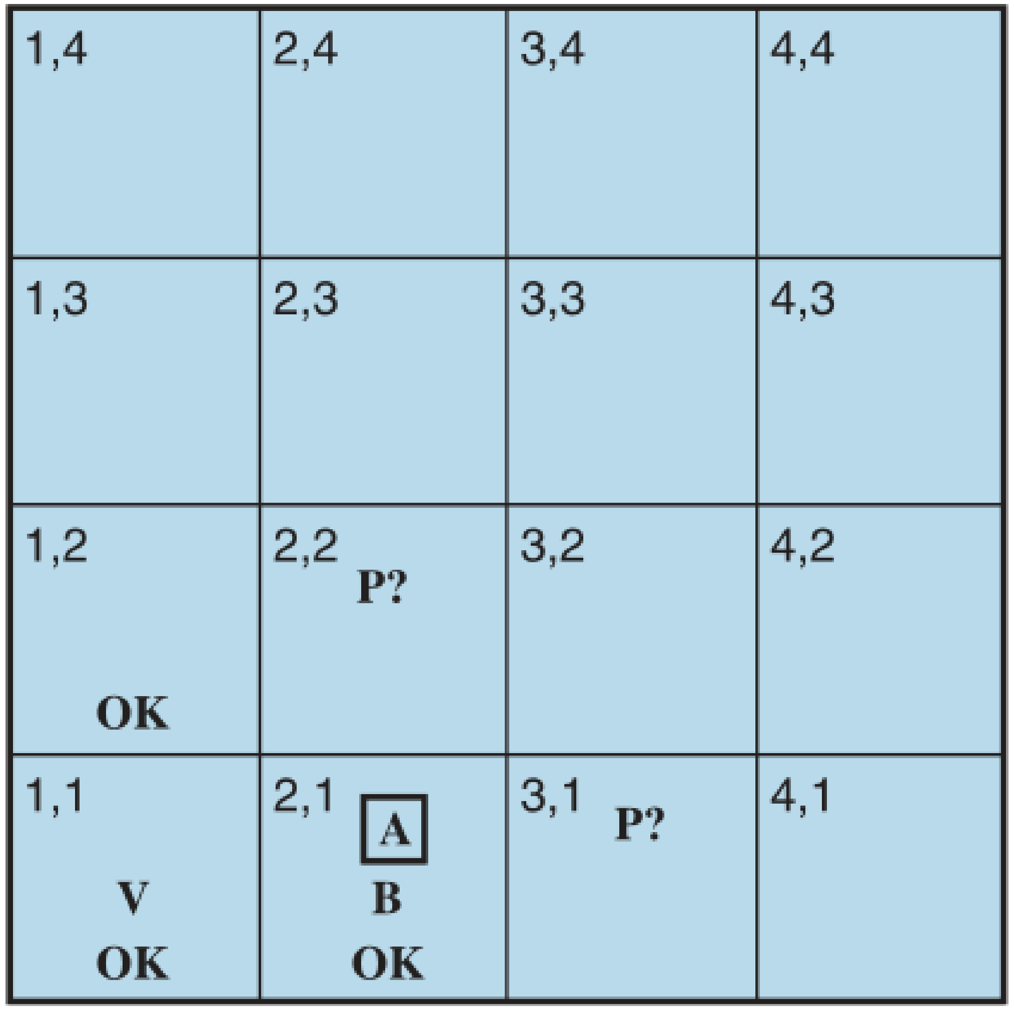


A = *Agent*
B = *Breeze*
G = *Glitter, Gold*
OK = *Safe square*
P = *Pit*
S = *Stench*
V = *Visited*
W = *Wumpus*



After moving to [2,1] and perceiving [*None, Breeze, None, None, None*]

Exploring the Wumpus world

1,4	2,4	3,4	4,4
1,3 **W!**	2,3	3,3	4,3
1,2 $\boxed{\text{A}}$ **S** **OK**	2,2 **OK**	3,2	4,2
1,1 **V** **OK**	2,1 **B** **V** **OK**	3,1 **P!**	4,1

- $\boxed{\text{A}}$ = *Agent*
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After moving to [1,1] and then [1,2], and perceiving [*Stench, None, None, None, None*]

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After moving to [2,2] and then [2,3], and perceiving [*Stench, Breeze, Glitter, None, None*]

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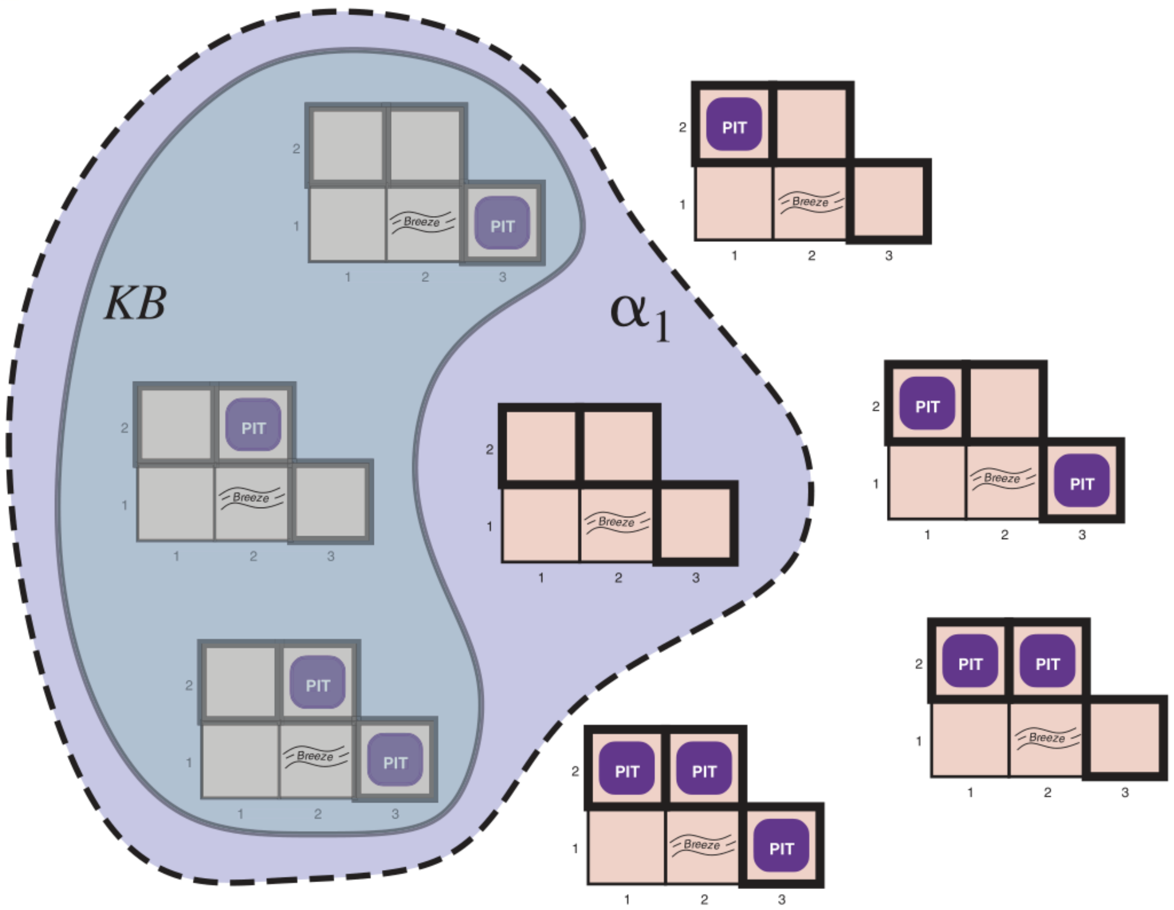

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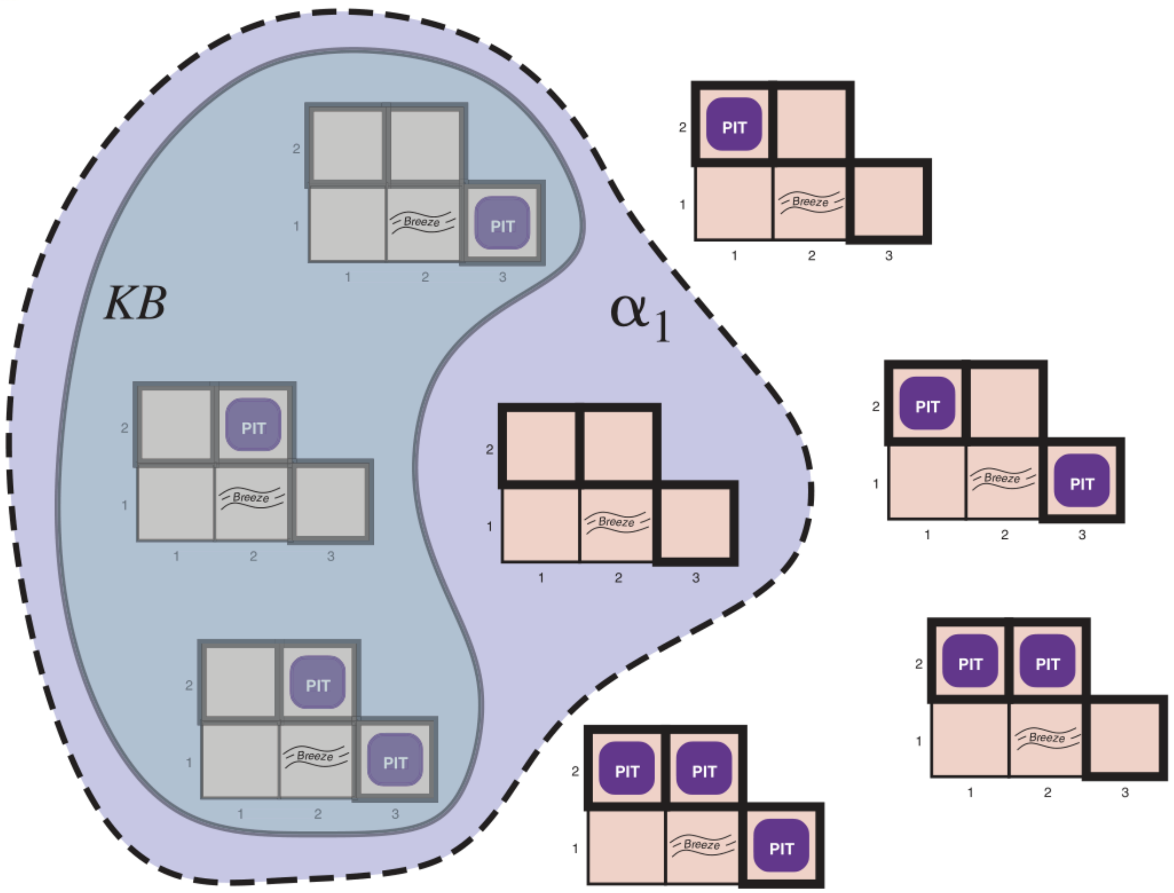

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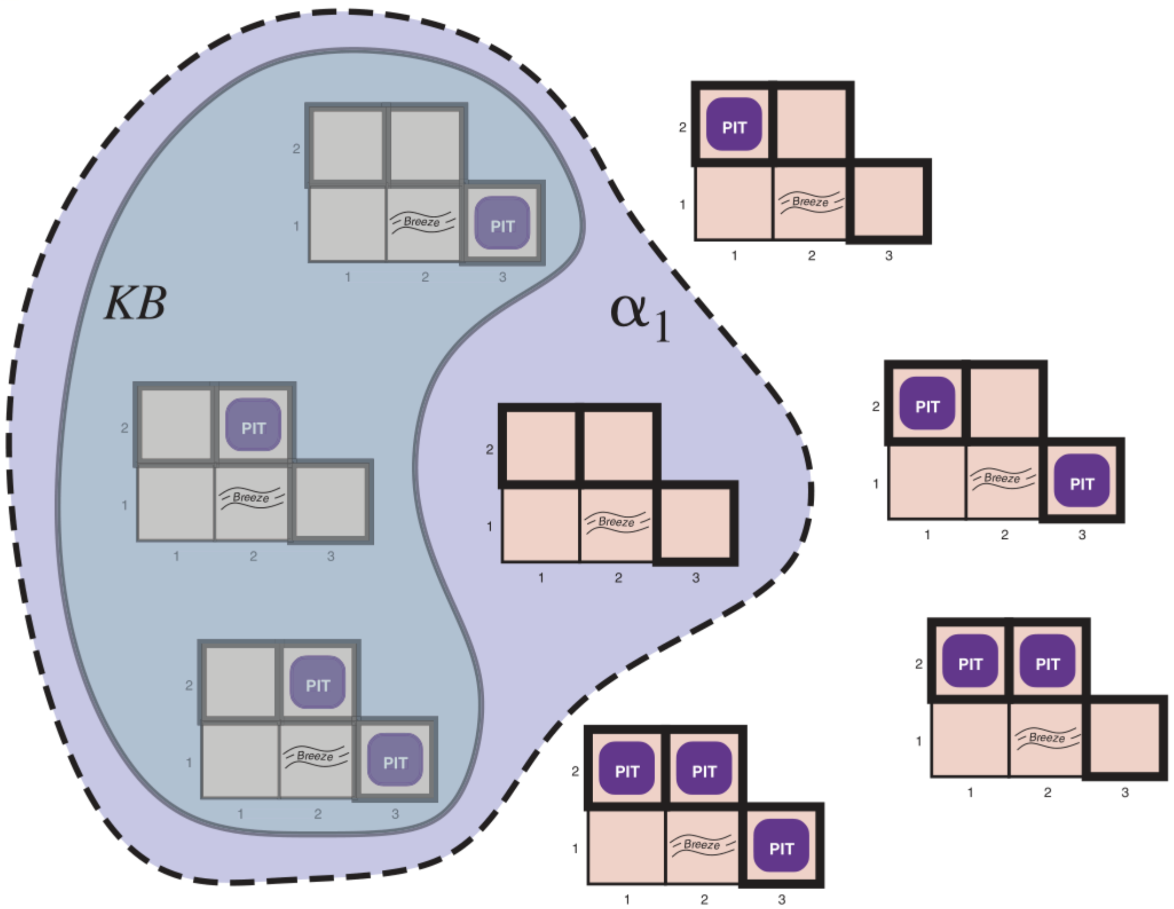

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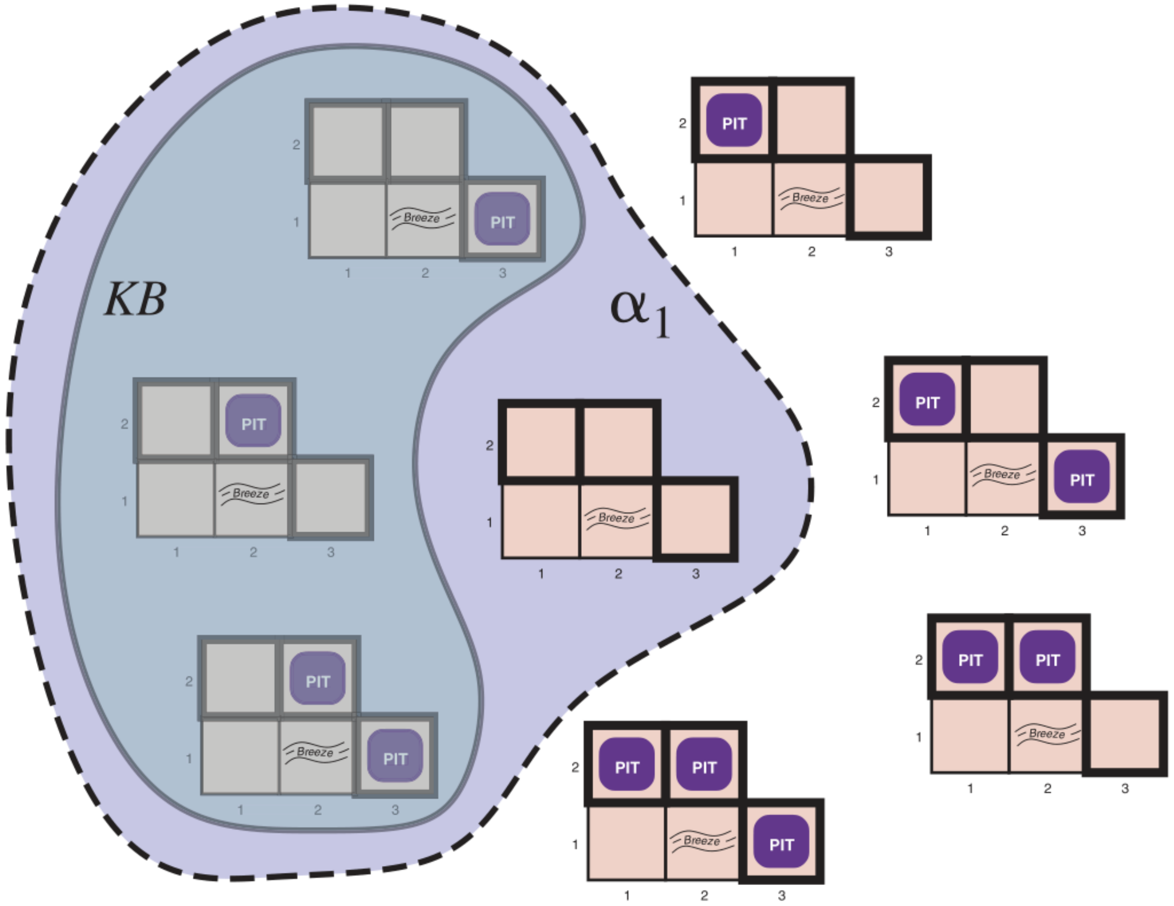

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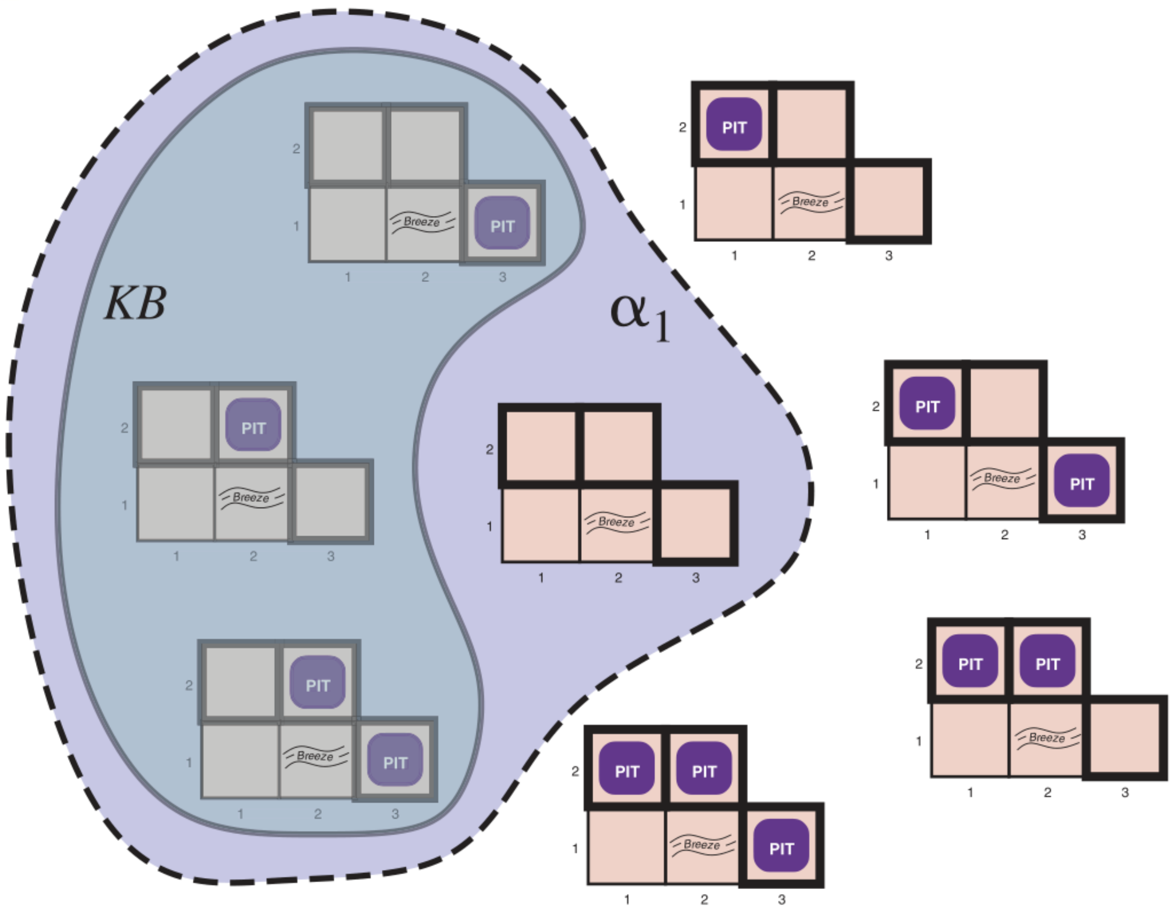

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- in every model in which $\mathcal{KB}$ is true, so does α_1
- hence, $\mathcal{KB} \vDash \alpha_1$

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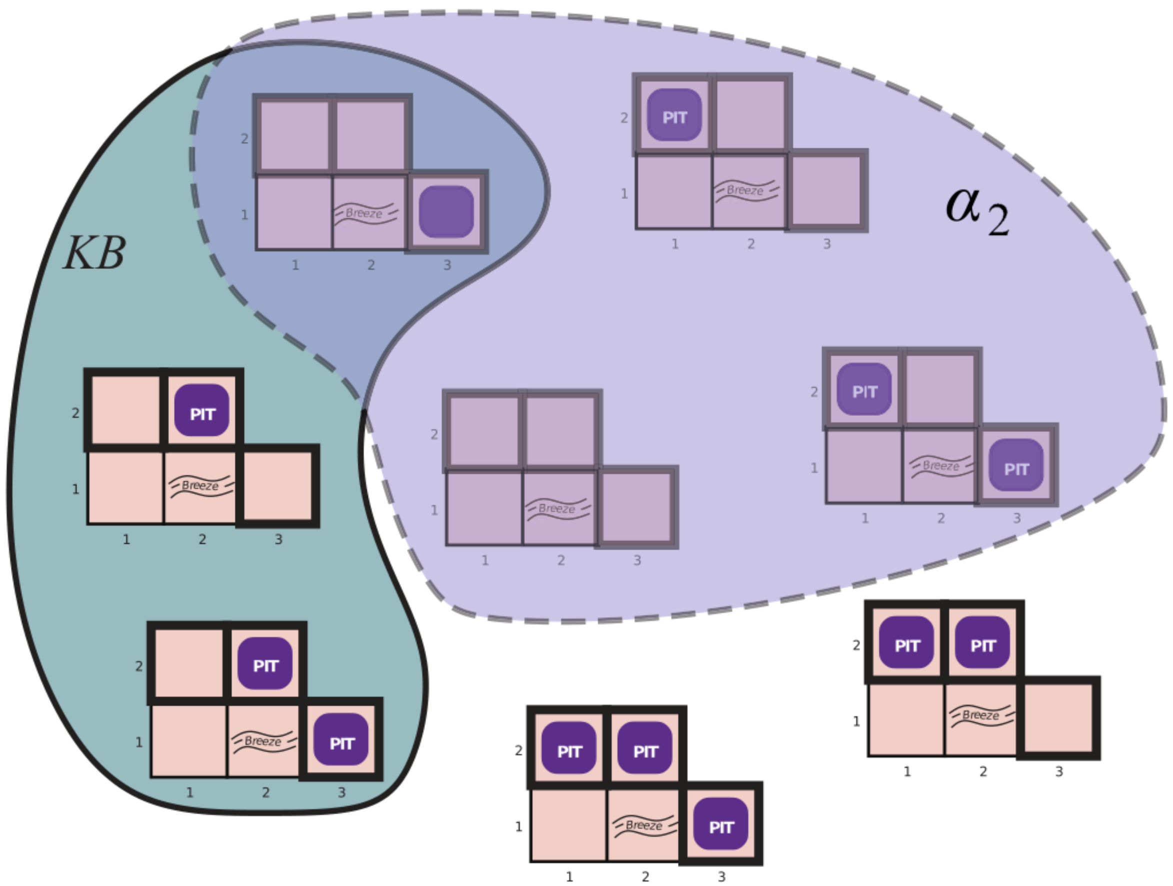

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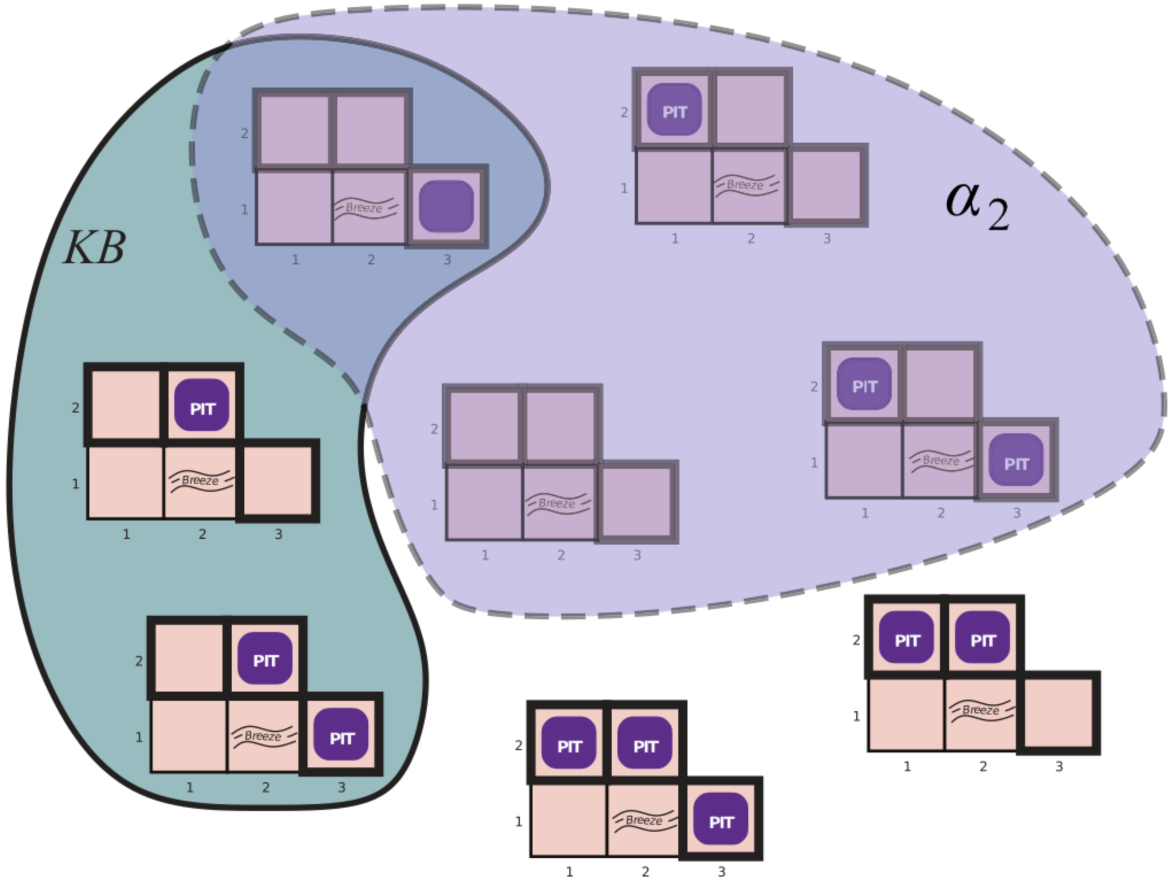

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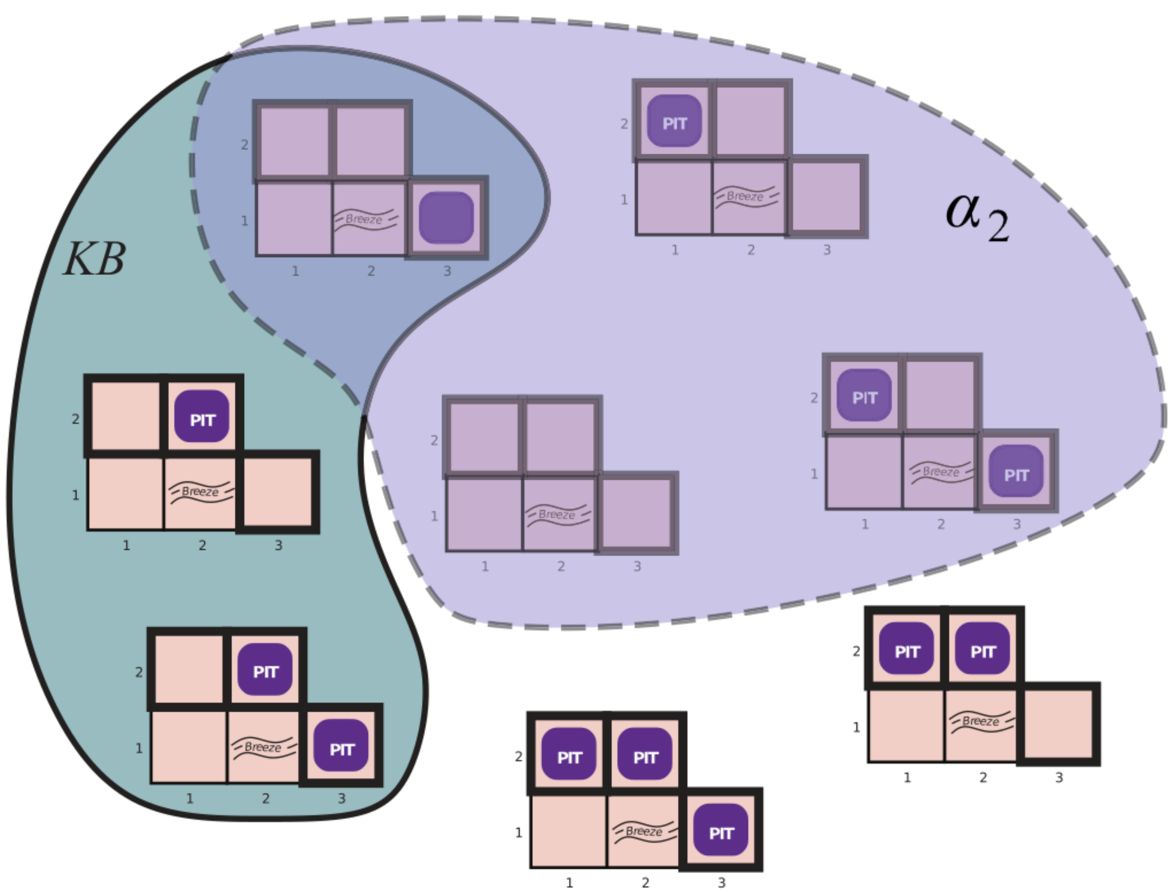

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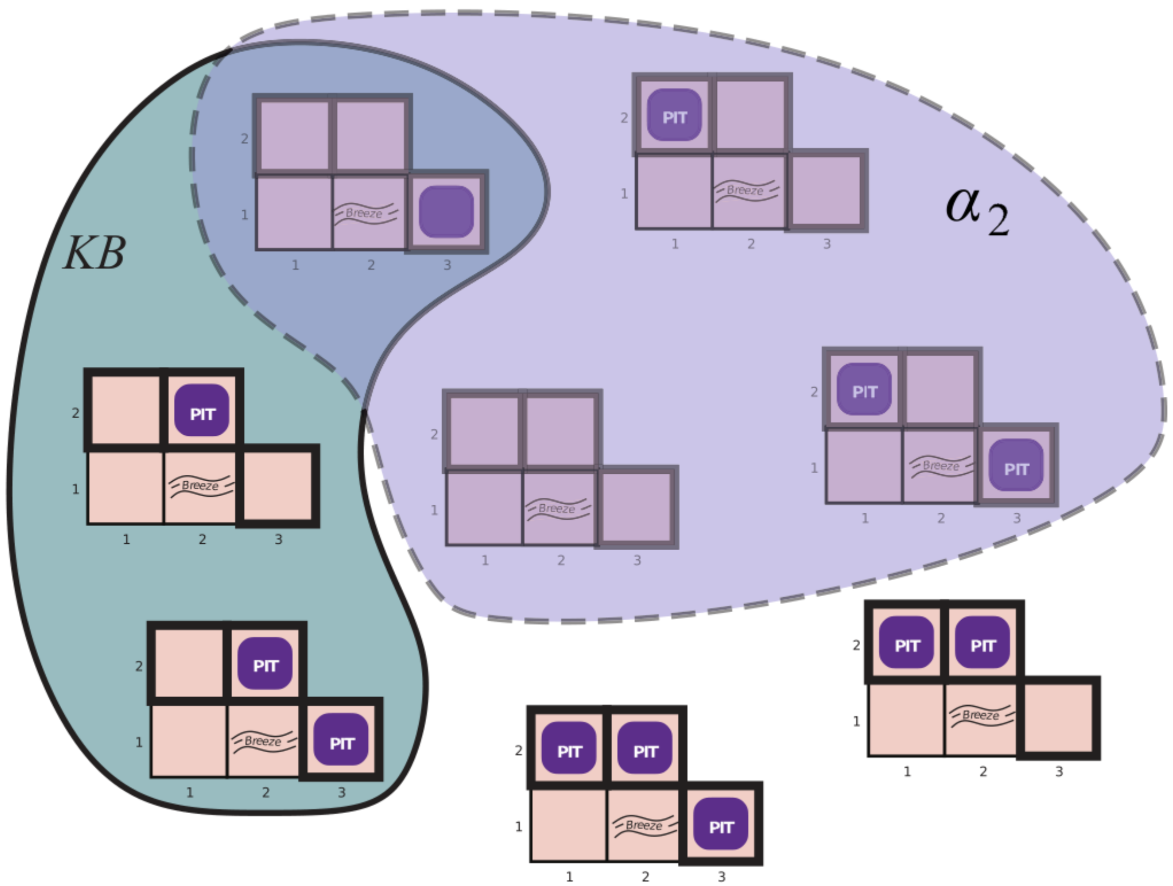

- α_2 = "There is no pit in [2,2]"
- in some model in which $\mathcal{KB}$ is true, α_2 is false
- hence, $\mathcal{KB}$ does not entail α_2

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The basic rules (background knowledge) can be produced from *learning*

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A **BNF (BackusâNaur Form)** grammar of sentences in propositional logic:

$$
\begin{array}{rcl}
Sentence & \rightarrow & AtomicSentence \mid ComplexSentence \\
AtomicSentence & \rightarrow & True \mid False \mid P \mid Q \mid R \mid \ldots \\
ComplexSentence & \rightarrow & (\ Sentence\ ) \\
& \mid & \neg\ Sentence \\
& \mid & Sentence \land Sentence \\
& \mid & Sentence \lor Sentence \\
& \mid & Sentence \Rightarrow Sentence \\
& \mid & Sentence \Leftrightarrow Sentence \\
& & \\
\text{OPERATOR PRECEDENCE} & : & \neg, \land, \lor, \Rightarrow, \Leftrightarrow
\end{array}
$$

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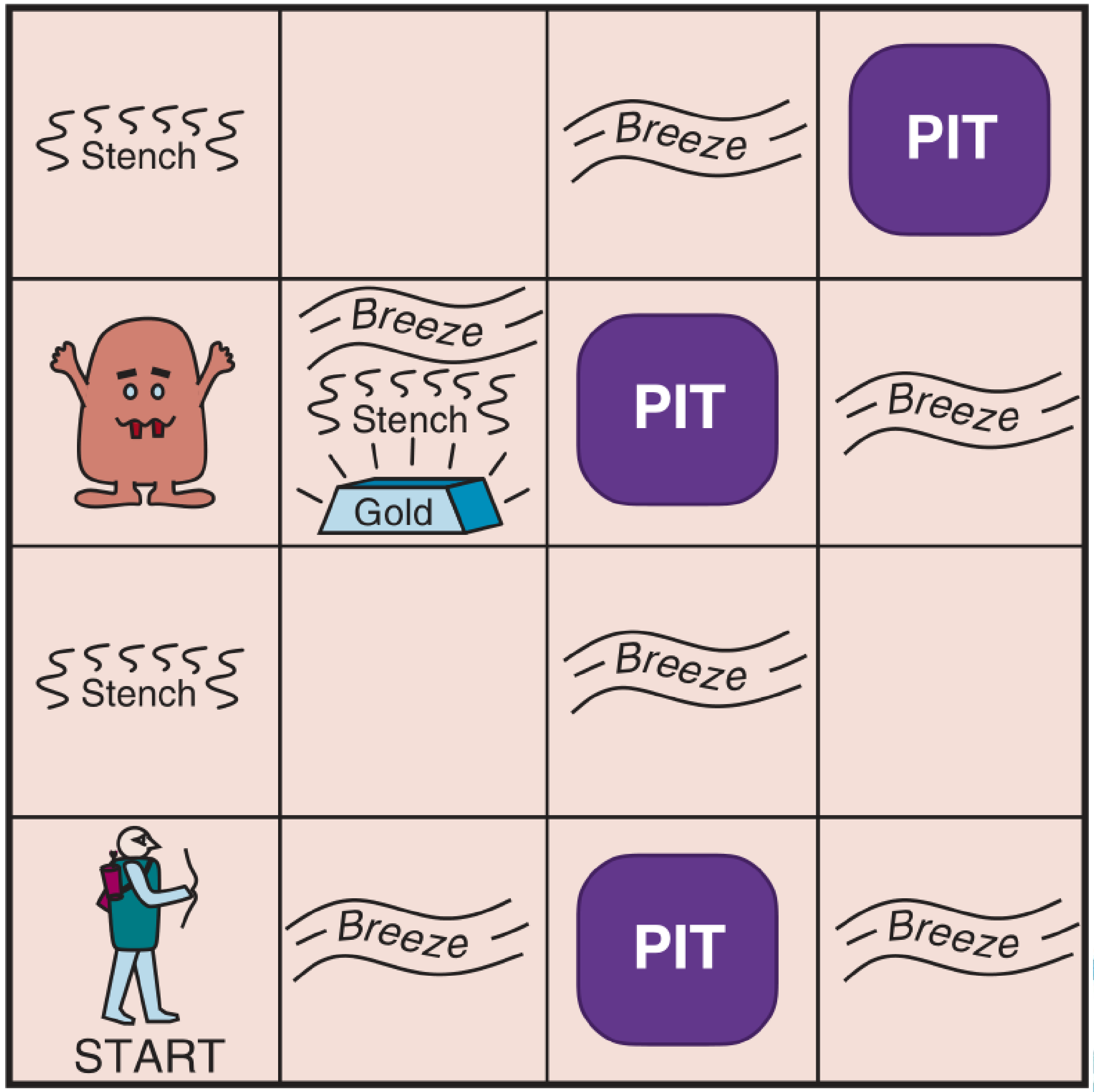
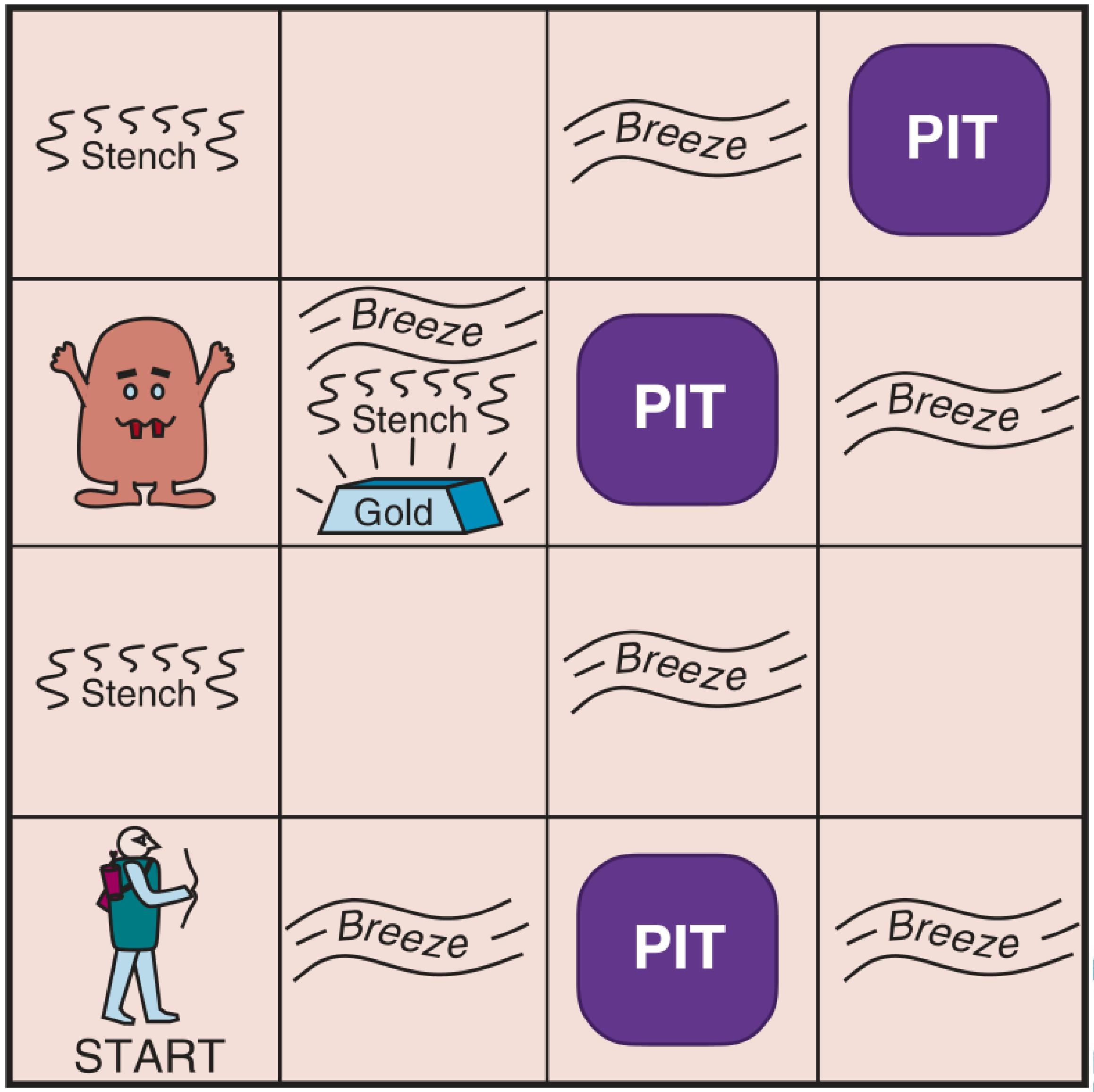


The Wumpus world $\mathcal{KB}$

Symbols for each $[x, y]$:



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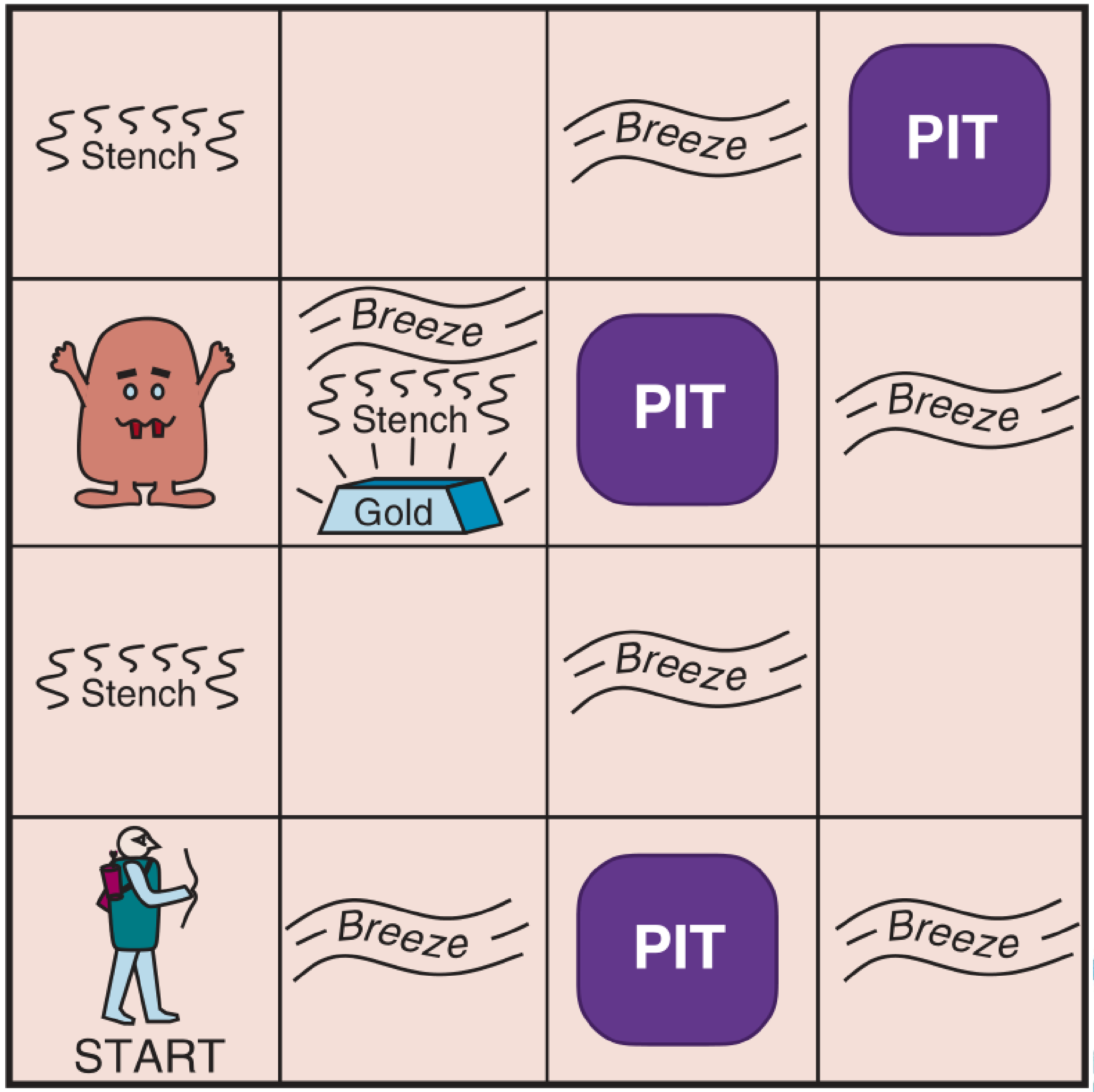

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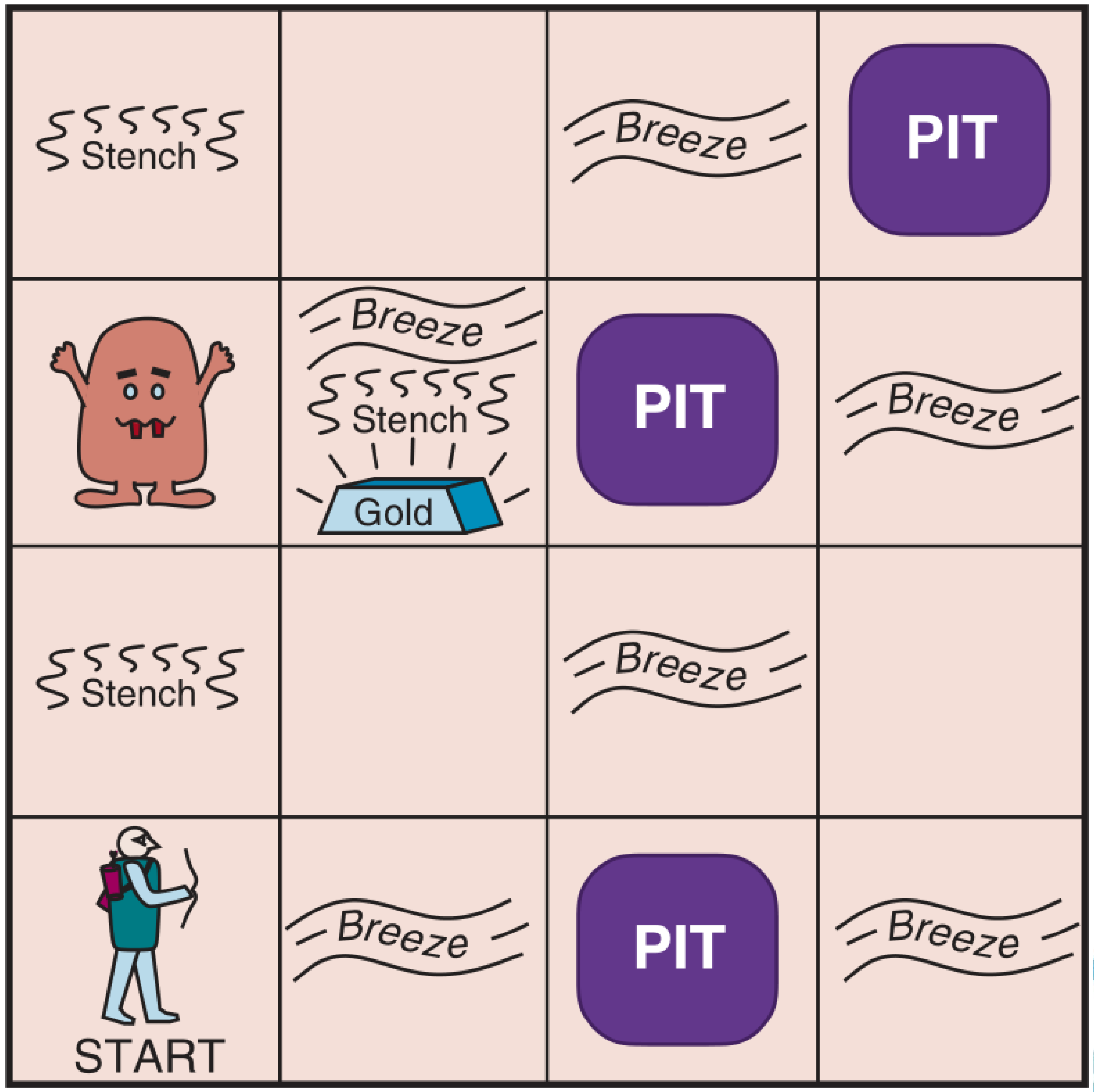

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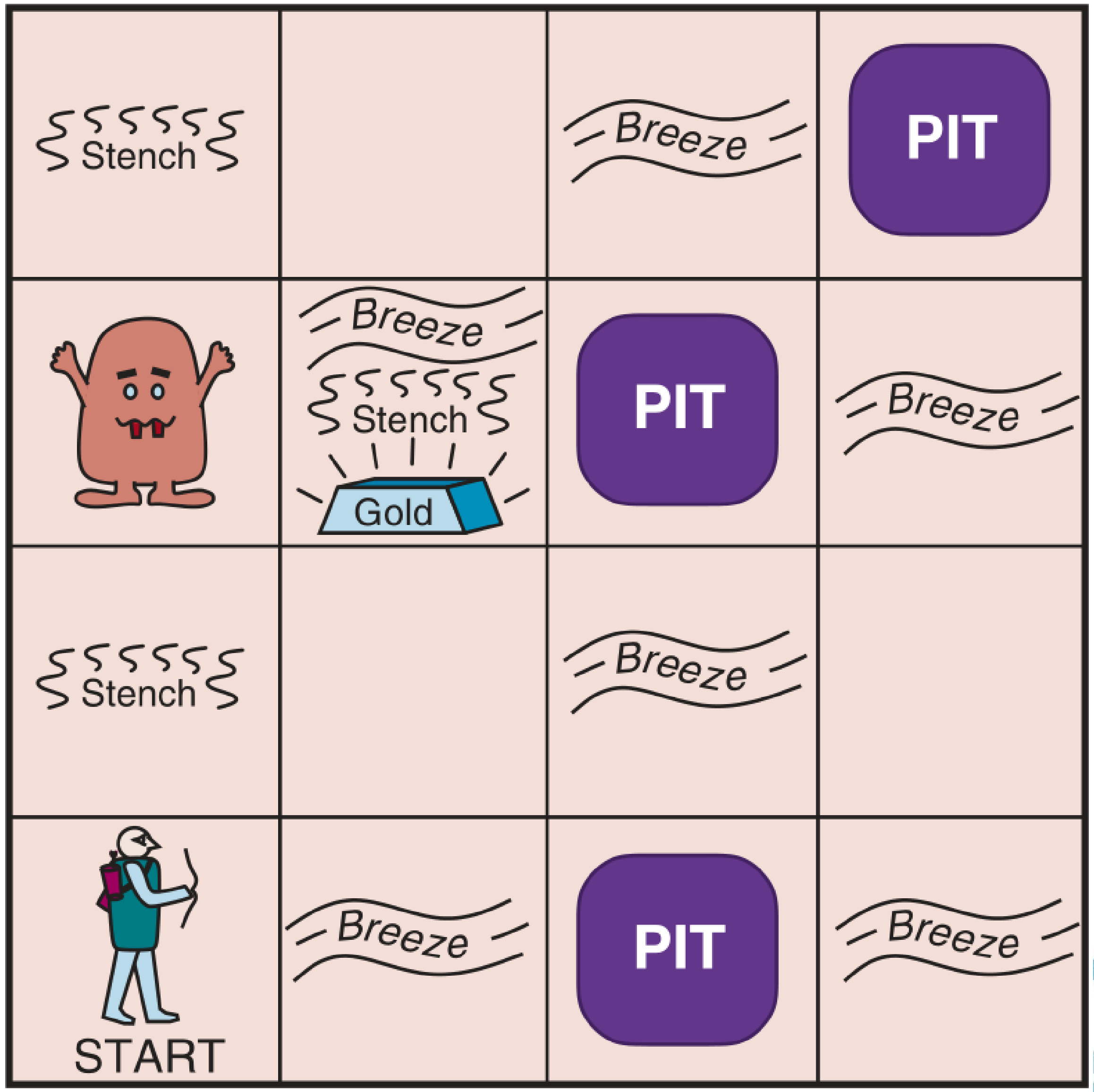

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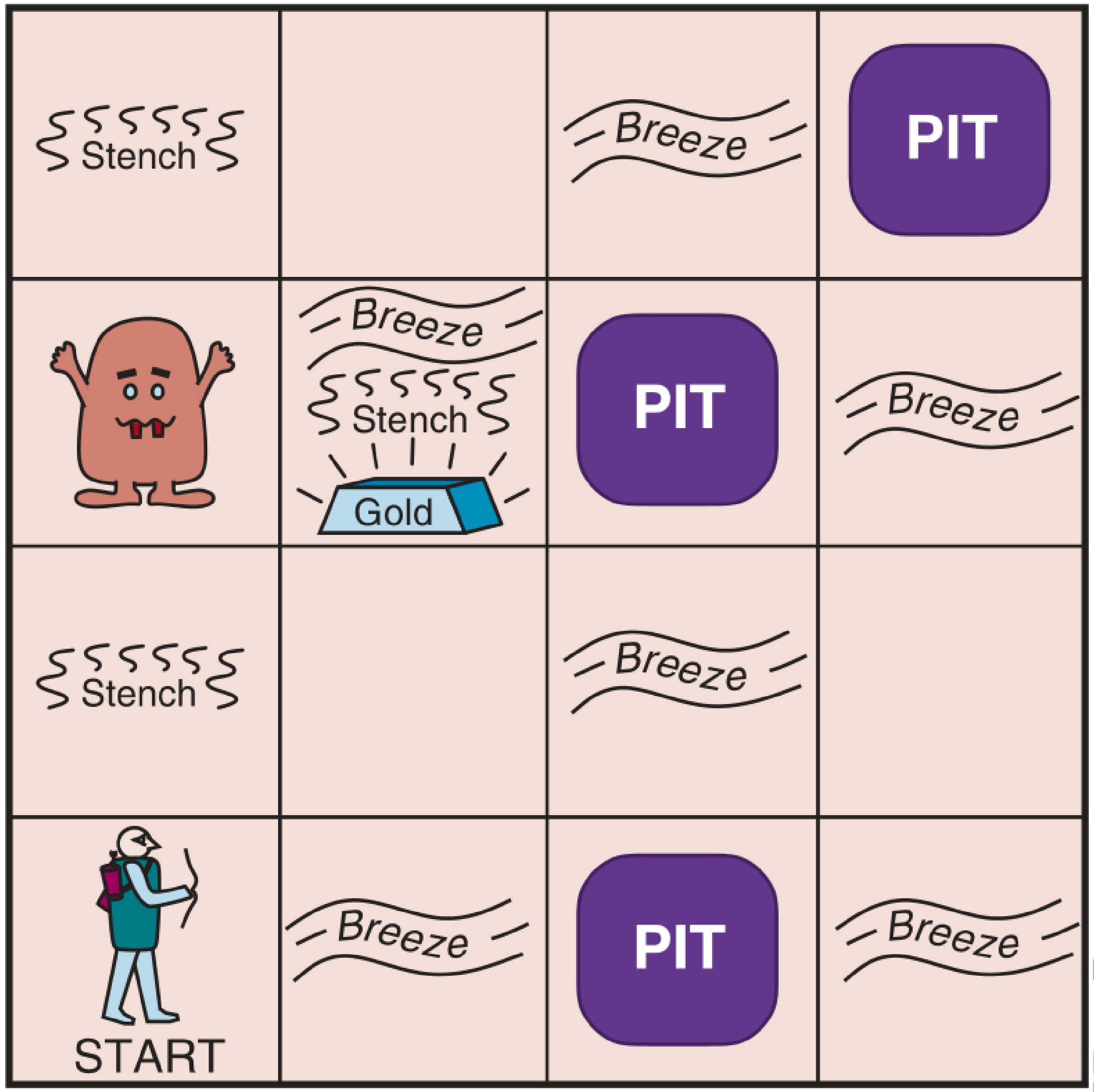

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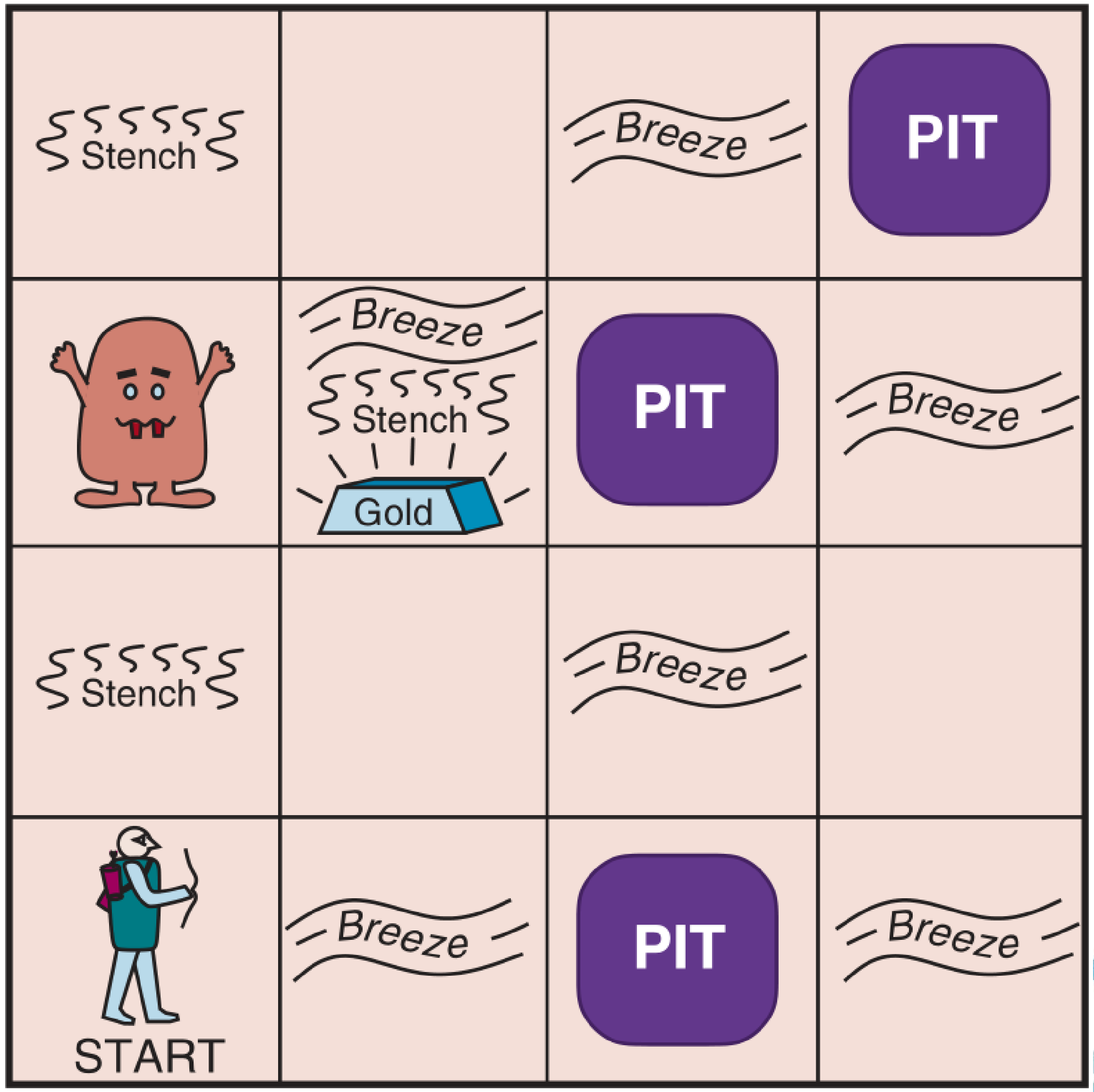

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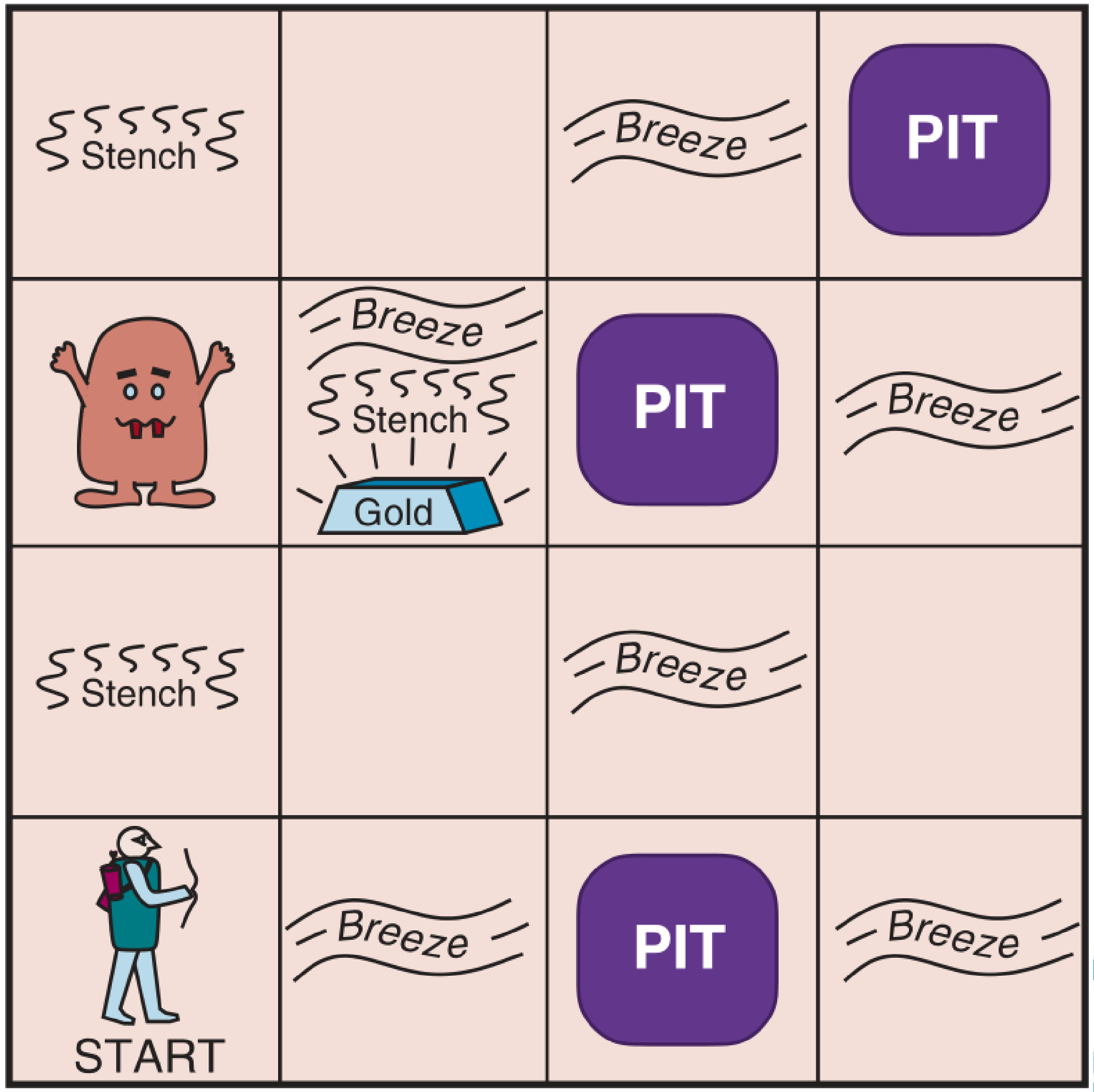

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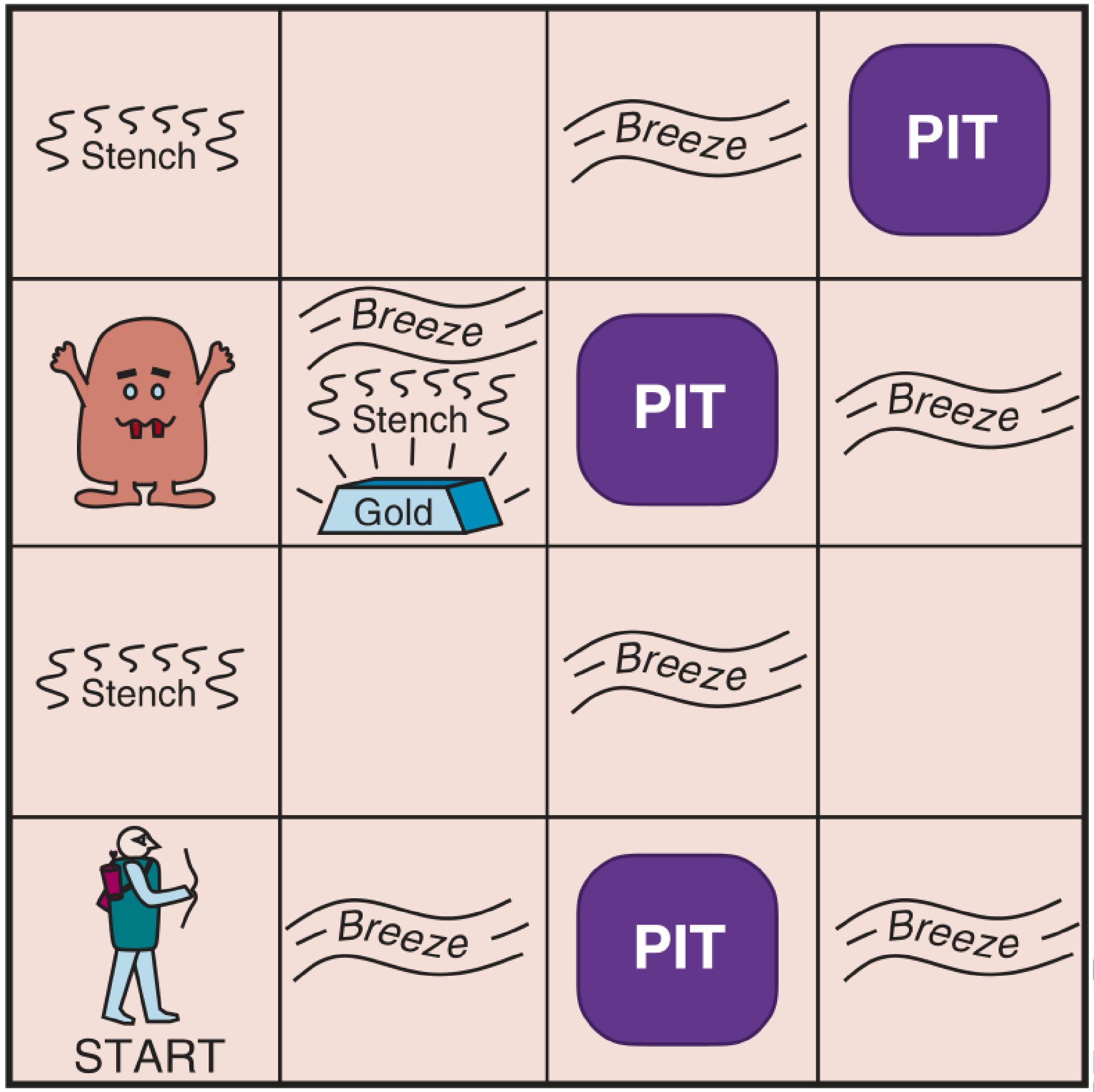

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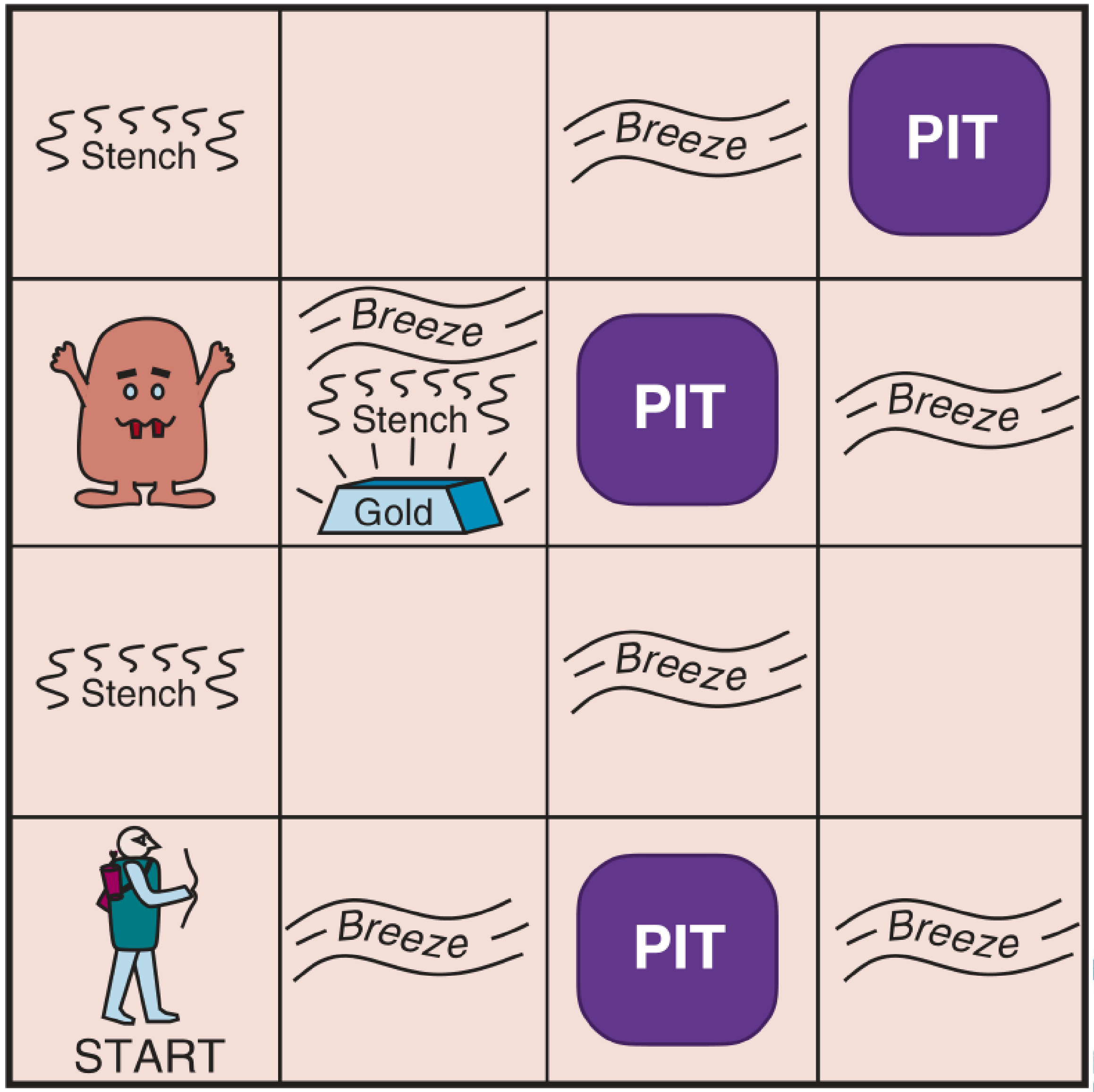

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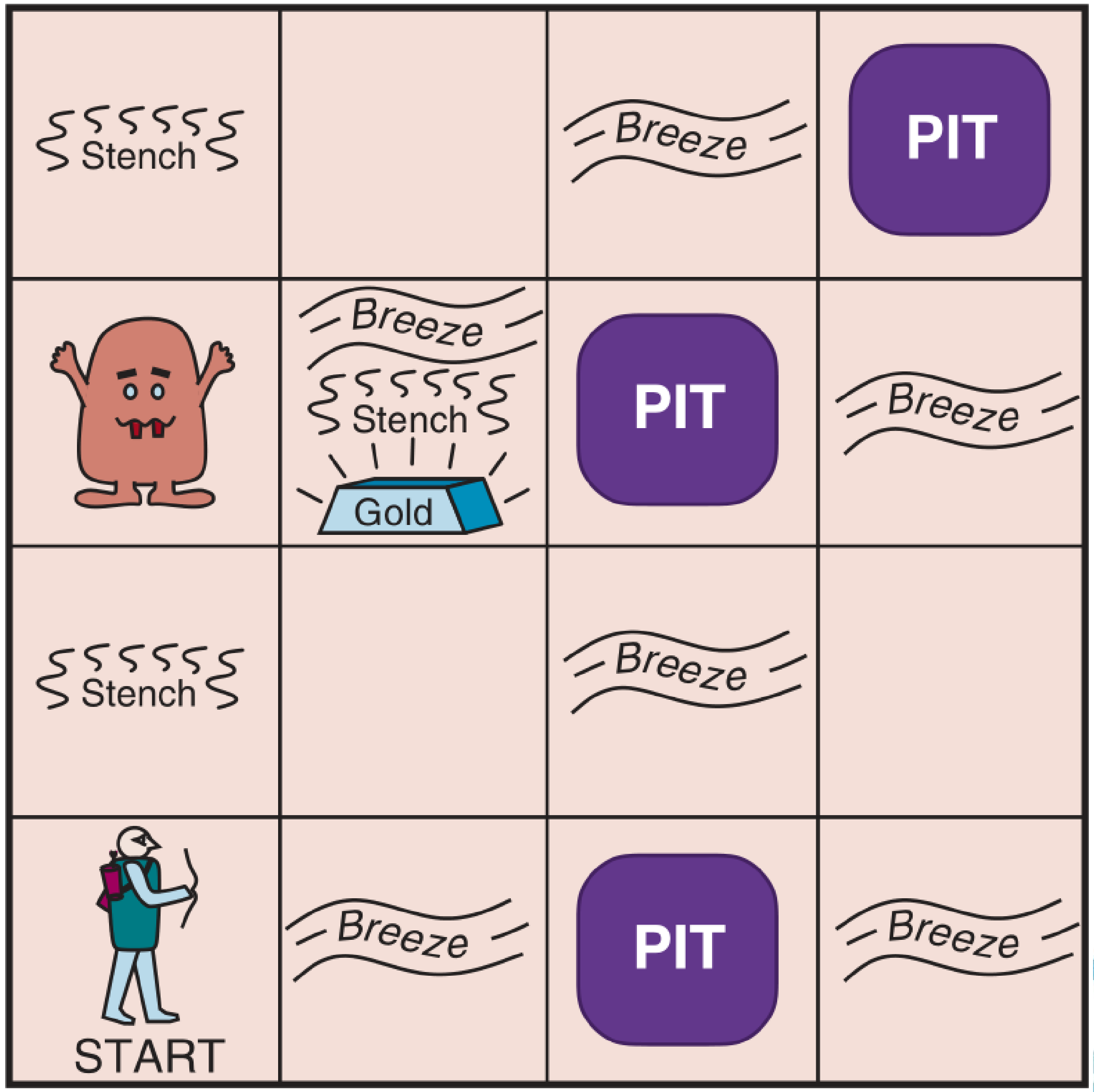

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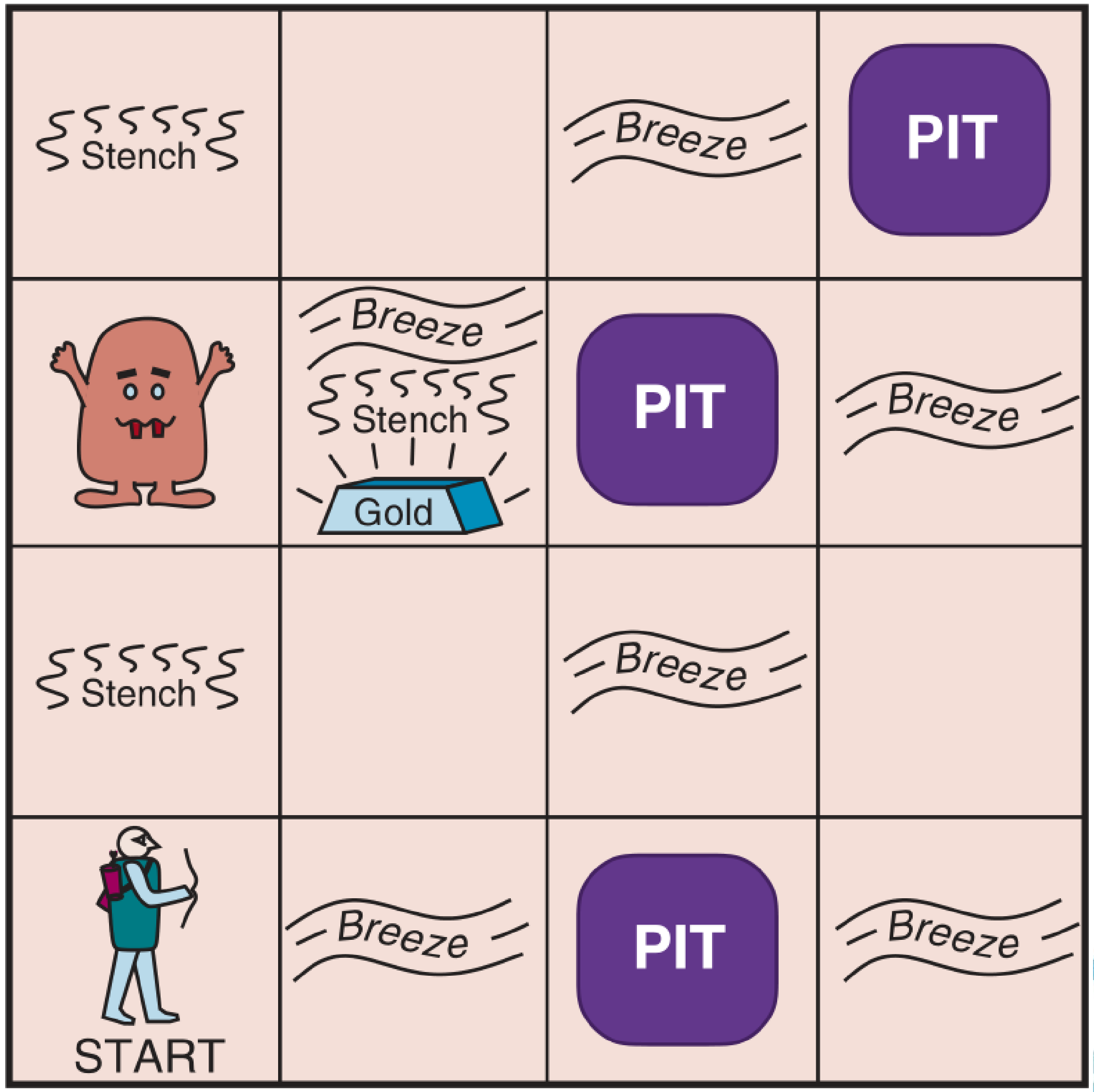

Questions (based on above $\mathcal{KB}$):

- $\mathcal{KB} \models: P_{1,2}$
- $\mathcal{KB} \models: P_{2,2}$

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$B_{1,1}$	$B_{2,1}$	$P_{1,1}$	$P_{1,2}$	$P_{2,1}$	$P_{2,2}$	$P_{3,1}$	R_1	R_2	R_3	R_4	R_5	KB
false	*false*	*false*	*false*	*false*	*false*	*false*	*true*	*true*	*true*	*true*	*false*	*false*
false	*false*	*false*	*false*	*false*	*false*	*true*	*true*	*true*	*false*	*true*	*false*	*false*
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
false	*true*	*false*	*false*	*false*	*false*	*false*	*true*	*true*	*false*	*true*	*true*	*false*
false	*true*	*false*	*false*	*false*	*false*	*true*	*true*	*true*	*true*	*true*	*true*	*true*
false	*true*	*false*	*false*	*false*	*true*	*false*	*true*	*true*	*true*	*true*	*true*	*true*
false	*true*	*false*	*false*	*false*	*true*	*true*	*true*	*true*	*true*	*true*	*true*	*true*
false	*true*	*false*	*false*	*true*	*false*	*false*	*true*	*false*	*false*	*true*	*true*	*false*
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
true	*true*	*true*	*true*	*true*	*true*	*true*	*false*	*true*	*true*	*false*	*true*	*false*

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$B_{1,1}$	$B_{2,1}$	$P_{1,1}$	$P_{1,2}$	$P_{2,1}$	$P_{2,2}$	$P_{3,1}$	R_1	R_2	R_3	R_4	R_5	KB
false	*false*	*false*	*false*	*false*	*false*	*false*	*true*	*true*	*true*	*true*	*false*	*false*
false	*false*	*false*	*false*	*false*	*false*	*true*	*true*	*true*	*false*	*true*	*false*	*false*
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
false	*true*	*false*	*false*	*false*	*false*	*false*	*true*	*true*	*false*	*true*	*true*	*false*
false	*true*	*false*	*false*	*false*	*false*	*true*	*true*	*true*	*true*	*true*	*true*	<u>*true*</u>
false	*true*	*false*	*false*	*false*	*true*	*false*	*true*	*true*	*true*	*true*	*true*	<u>*true*</u>
false	*true*	*false*	*false*	*false*	*true*	*true*	*true*	*true*	*true*	*true*	*true*	<u>*true*</u>
false	*true*	*false*	*false*	*true*	*false*	*false*	*true*	*false*	*false*	*true*	*true*	*false*
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
true	*true*	*true*	*true*	*true*	*true*	*true*	*false*	*true*	*true*	*false*	*true*	*false*

If $\mathcal{KB}$ and α contain n symbols, then there are 2^n models and the complexity of the enumeration (algorithm) is $O(2^n)$

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4. Apply Modus Ponens with R_8 and the percept R_4 (i.e., $\neg B_{1,1}$), to obtain

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5. Apply De Morgan's rule, giving the conclusion

$$R_{10}: \quad \neg P_{1,2} \wedge \neg P_{2,1}.$$

That is, neither [1,2] nor [2,1] contains a pit.

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- *Forward or Backward chaining*: use of modus ponens on a restricted form of propositions (Horn clauses)

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Unit resolution rule:

$$\frac{\ell_1 \vee \ldots \vee \ell_i \vee \ldots \vee \ell_k, \quad m}{\ell_1 \vee \ldots \vee \ell_{i-1} \vee \ell_{i+1} \vee \ldots \vee \ell_k}$$

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The $\mathcal{KB}$ must be transformed to CNF (Conjunctive Normal Form): Conjunction of disjunction of literals. Example: $(A \vee B \vee \neg C) \wedge (C \vee \neg D)$

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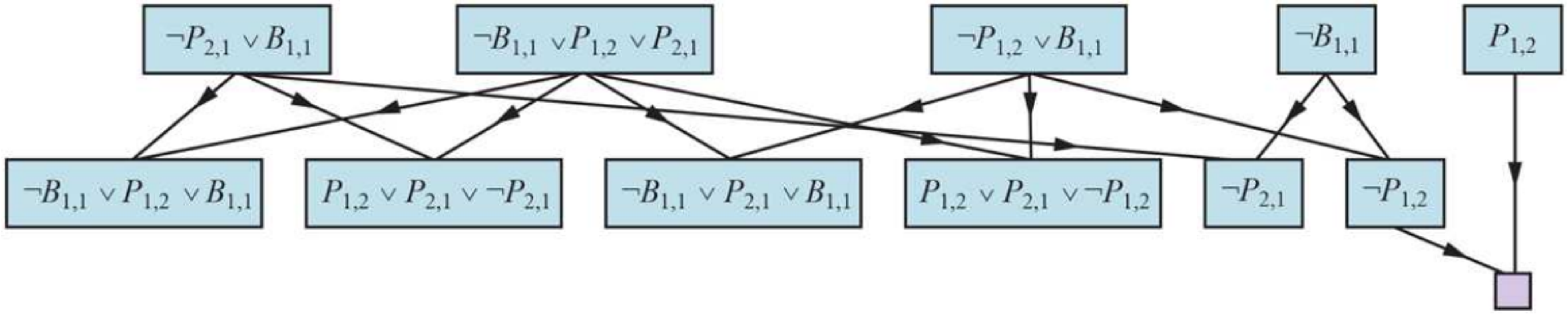

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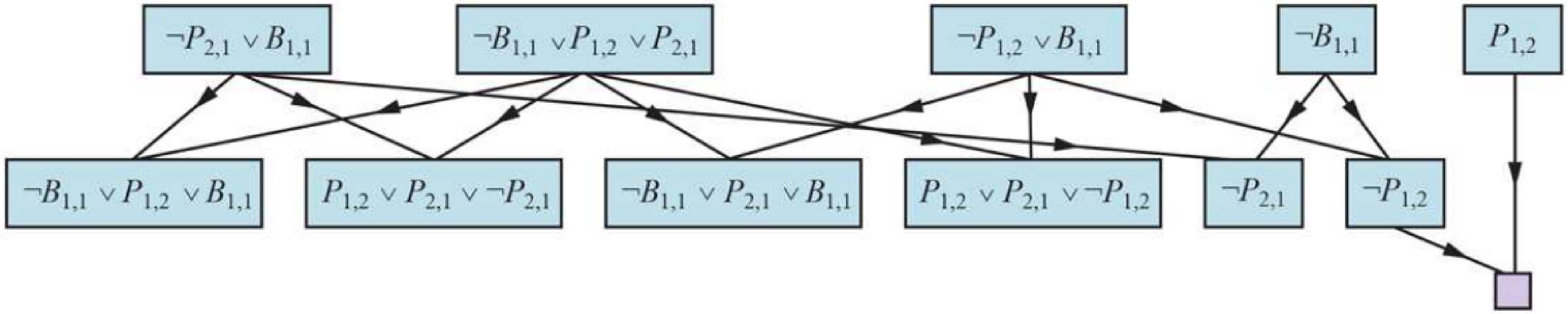

- An empty clause is yielded, meaning the query is proven

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Horn clause is a disjunction of literals of which at most one is positive

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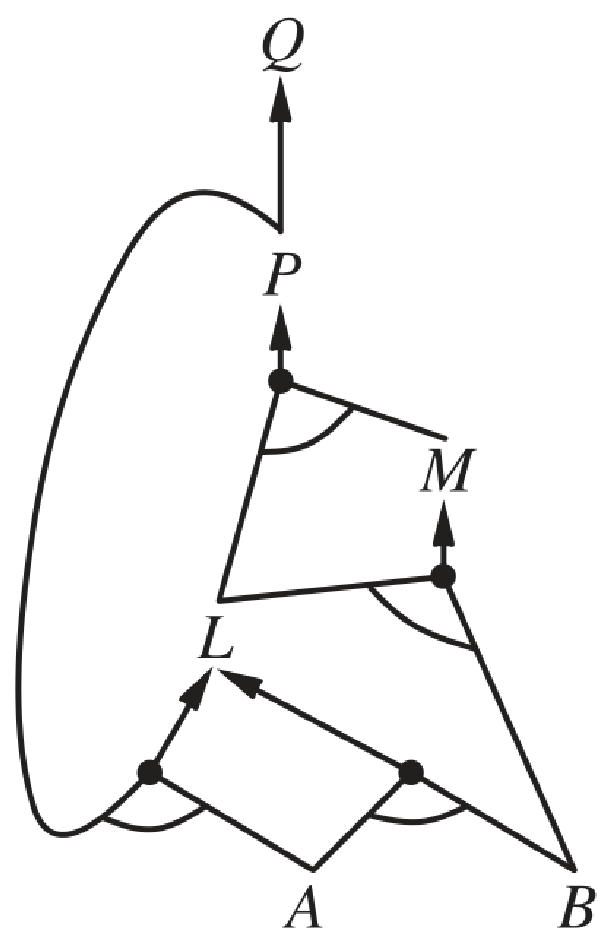
Example:

$$P \Rightarrow Q$$
$$L \wedge M \Rightarrow P$$
$$B \wedge L \Rightarrow M$$
$$A \wedge P \Rightarrow L$$
$$A \wedge B \Rightarrow L$$
$$A$$
$$B$$



Representation Languages

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- All birds except dodo fly: $\forall\, x\ bird(x) \wedge \neg dodo(x) \implies fly(x)$
- Some wombat like ice-cream: $\exists\, x\ wombat(x) \wedge likes(x, ice - cream)$

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- *Universal Instantiation* and *Existential Instantiation* with *Unification*
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Note on natural language:

Conversion between natural language and logical expressions is possible due to the expressiveness of FOL. This is very valuable in many areas, such as development of virtual assitants like Alexa, Cortana, Siri, and many more.

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Logic is used to represent the environment of the agent and reason about that env.

While models are encoded explicitly, there are some limitations:

- It is difficult to model every aspect of the world
- rule-based and do not use data like machine learning
- do not handle uncertainty like probability, although fuzzy logic allows for degree of truth

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