Artificial Intelligent

Sem. Ganjil 2023/2024

09. Logical Agent

Lionov

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.

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*))
  $t \leftarrow t + 1$
  return *action*

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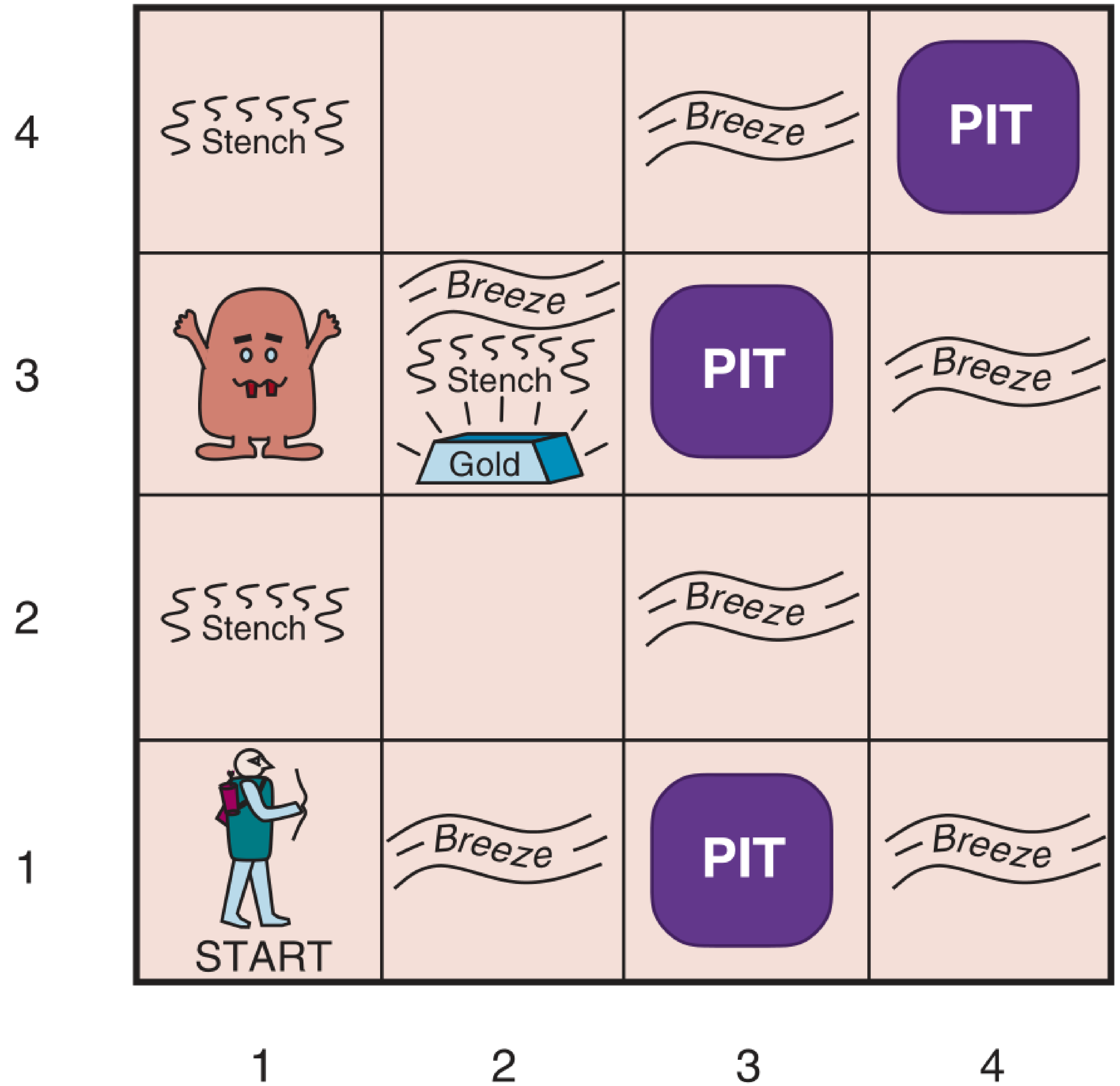
The Wumpus World



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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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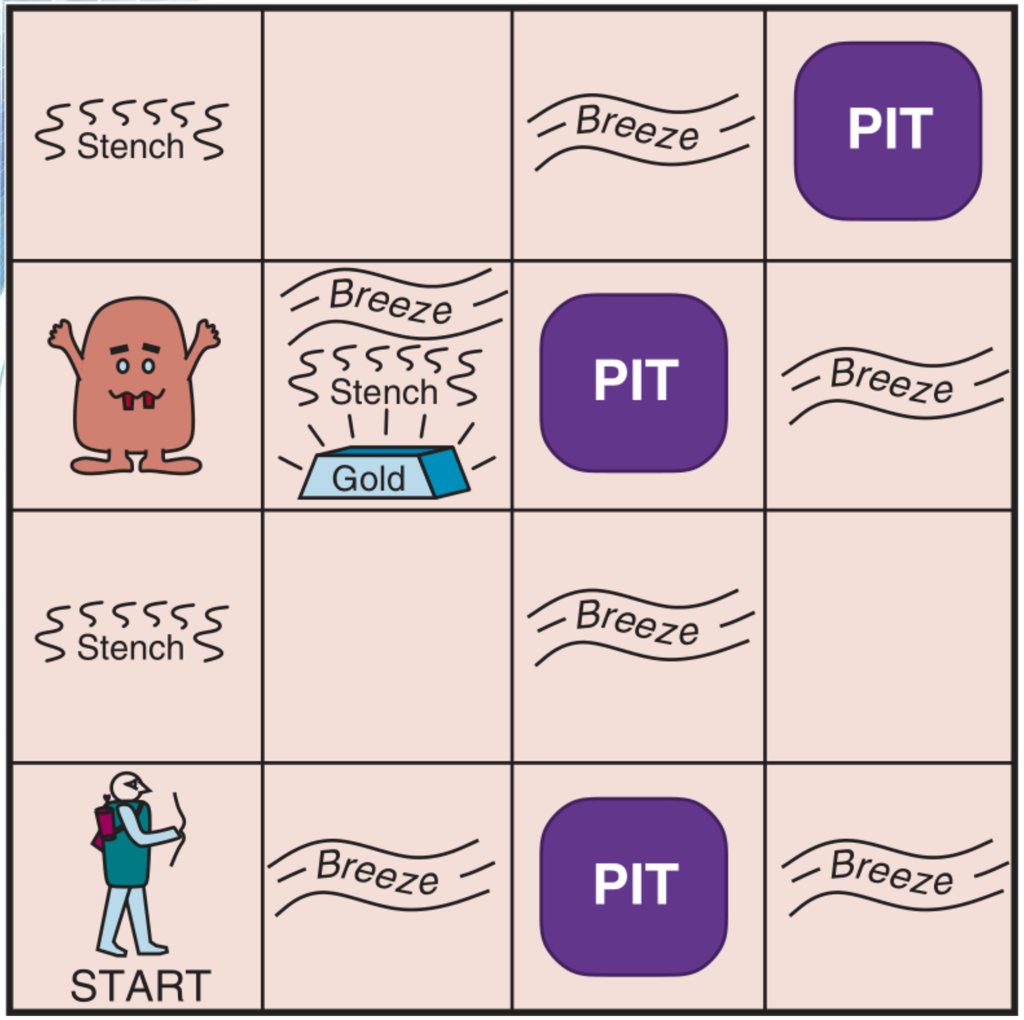

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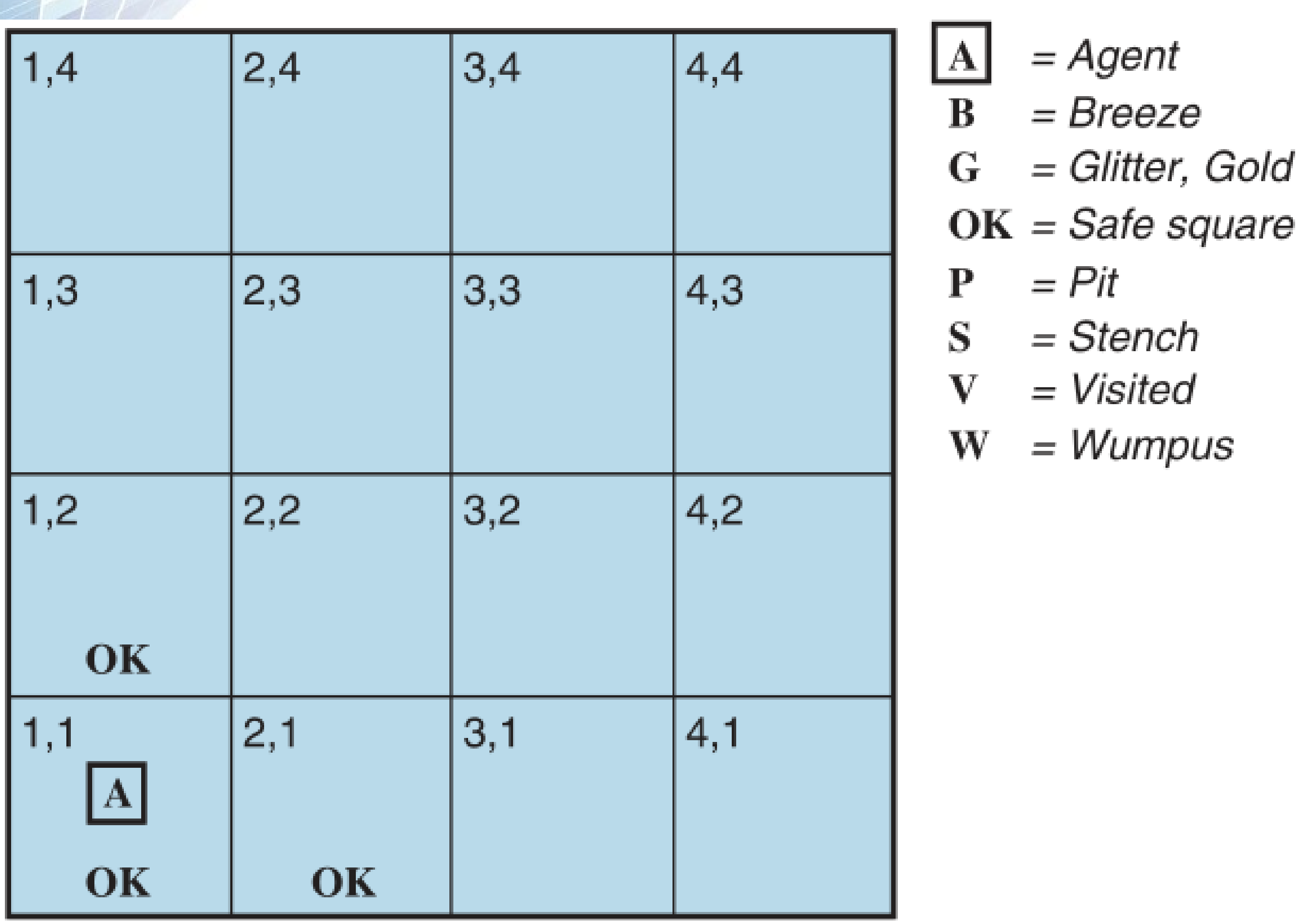

The initial situation: after percept [*None, None, None, None, None*]

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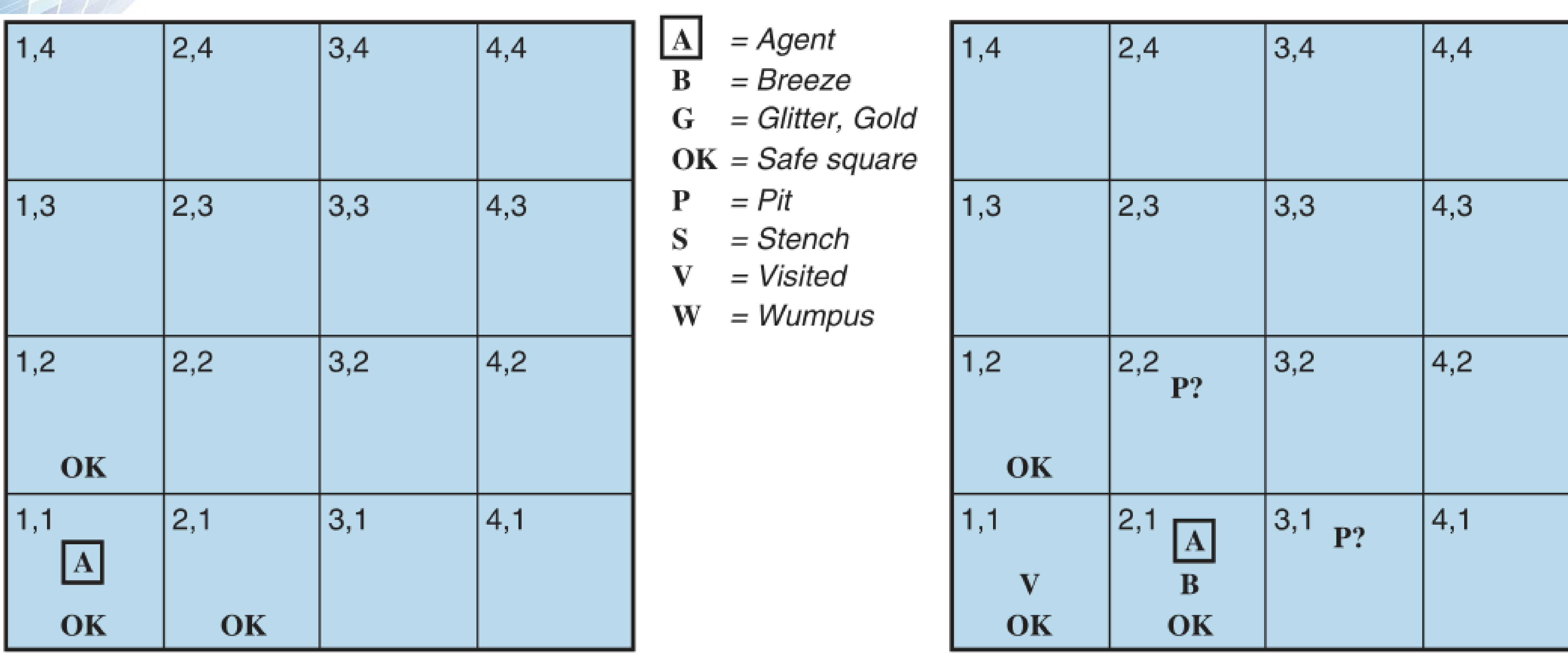

After moving to [2,1] and perceiving [*None, Breeze, None, None, None*]

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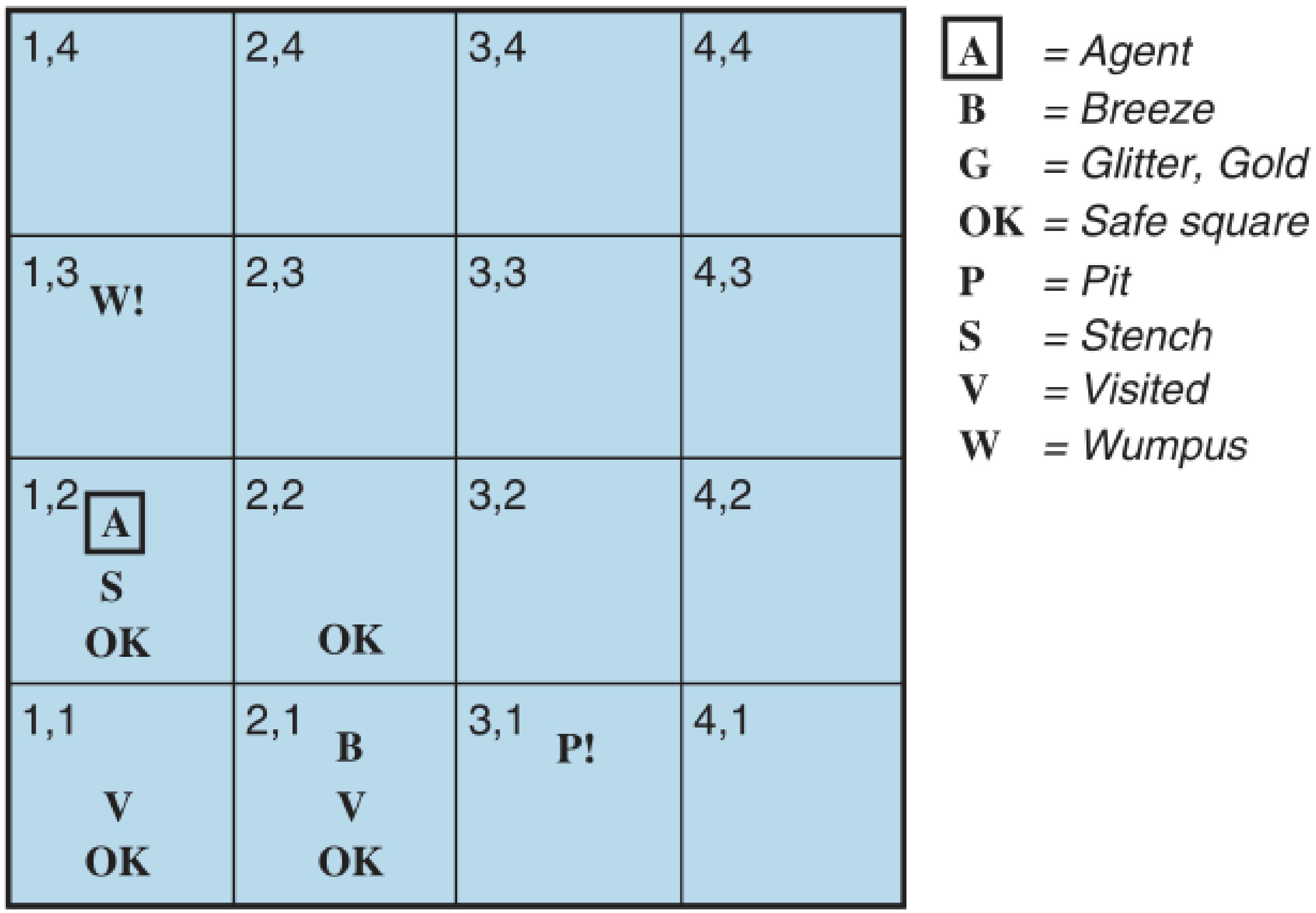

After moving to [1,1] and then [1,2], and perceiving [*Stench, None, None, None, None*]

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

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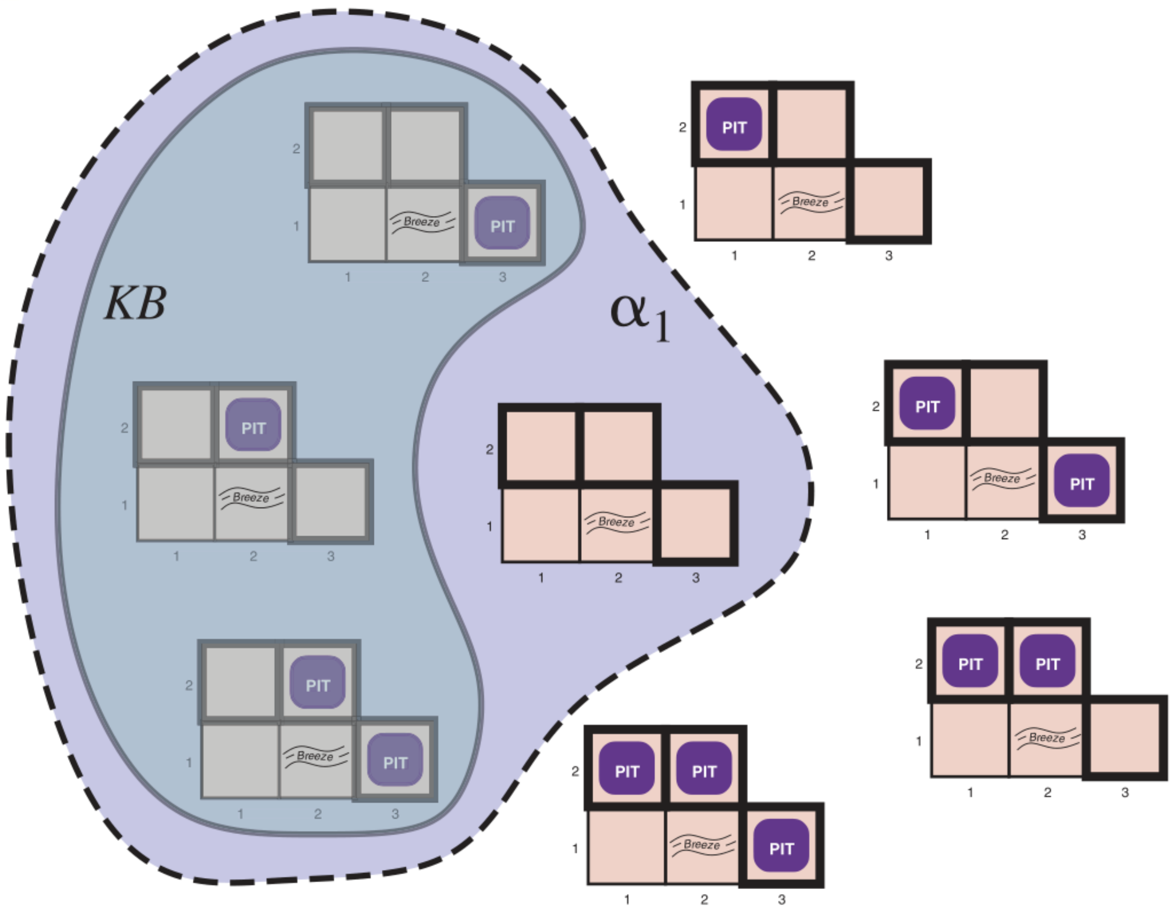

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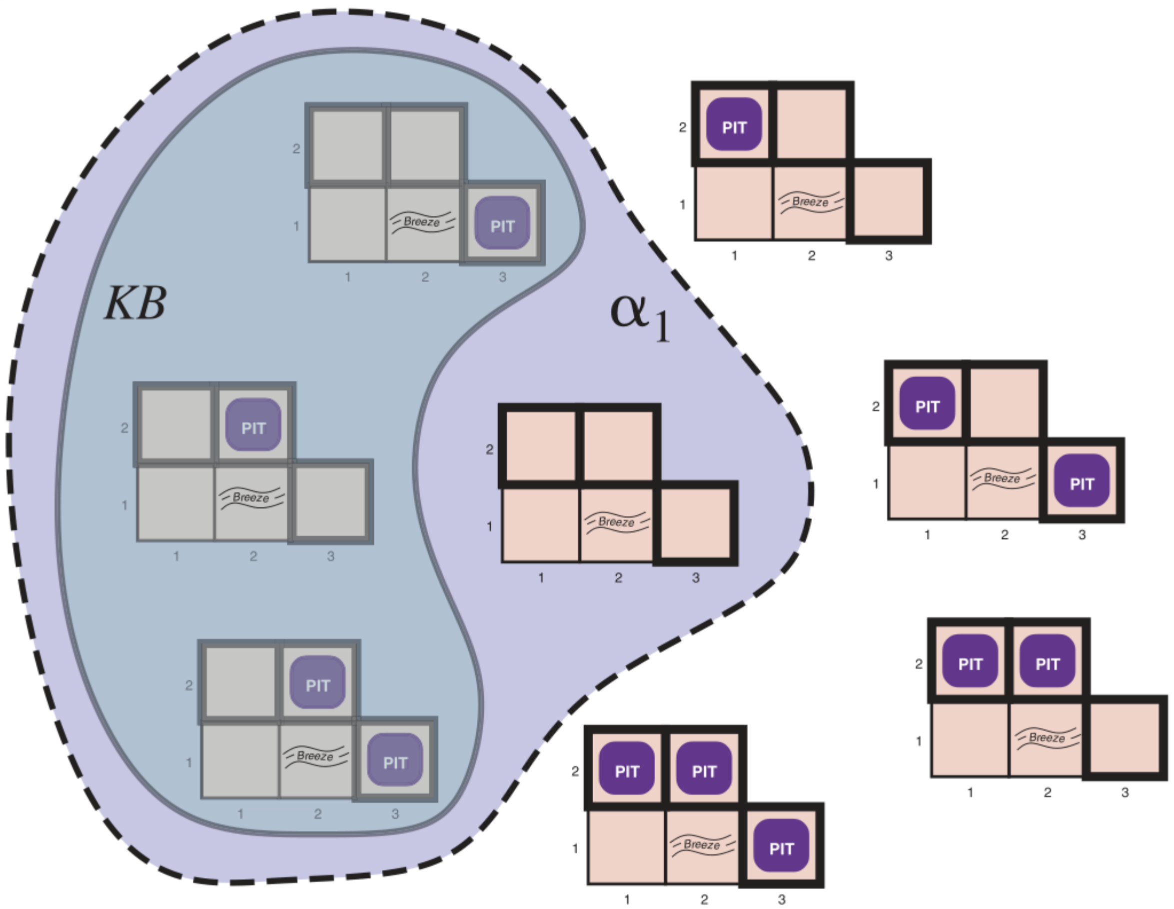

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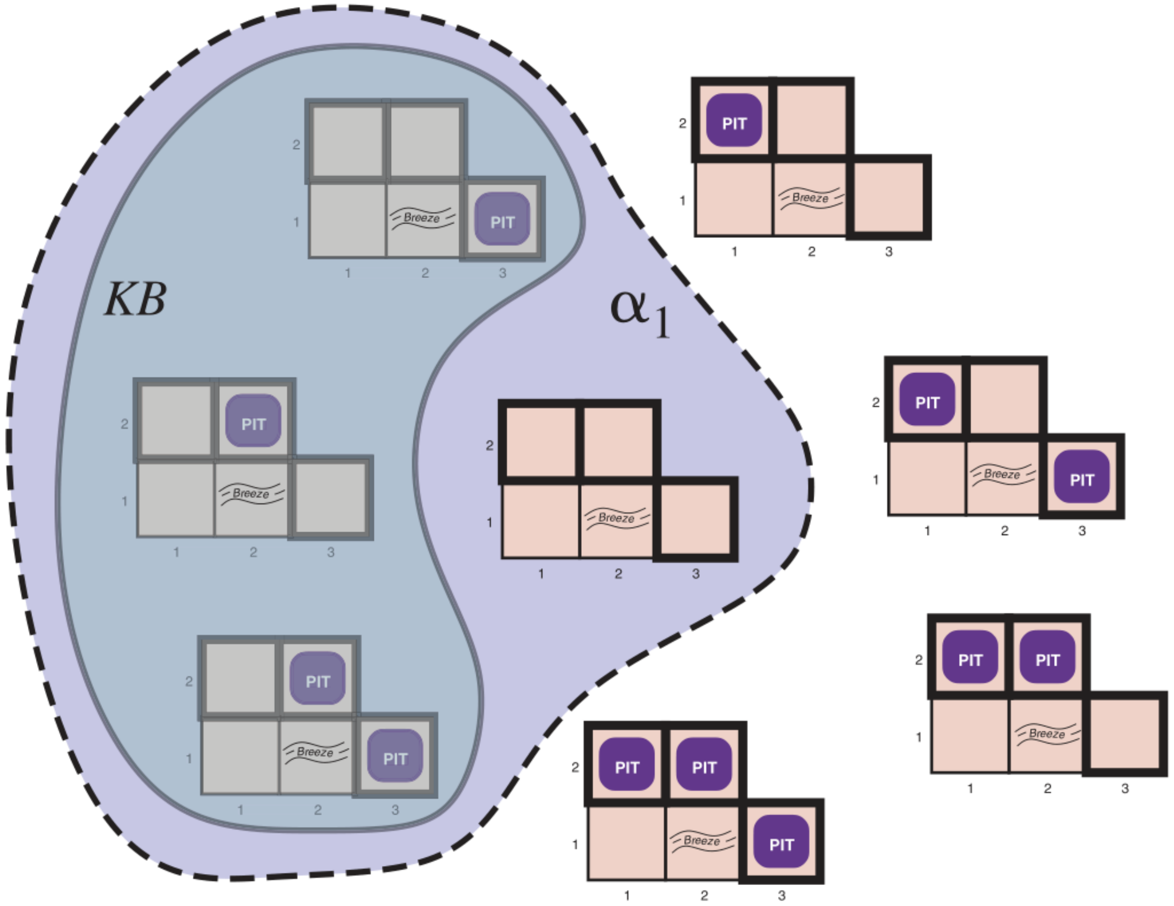

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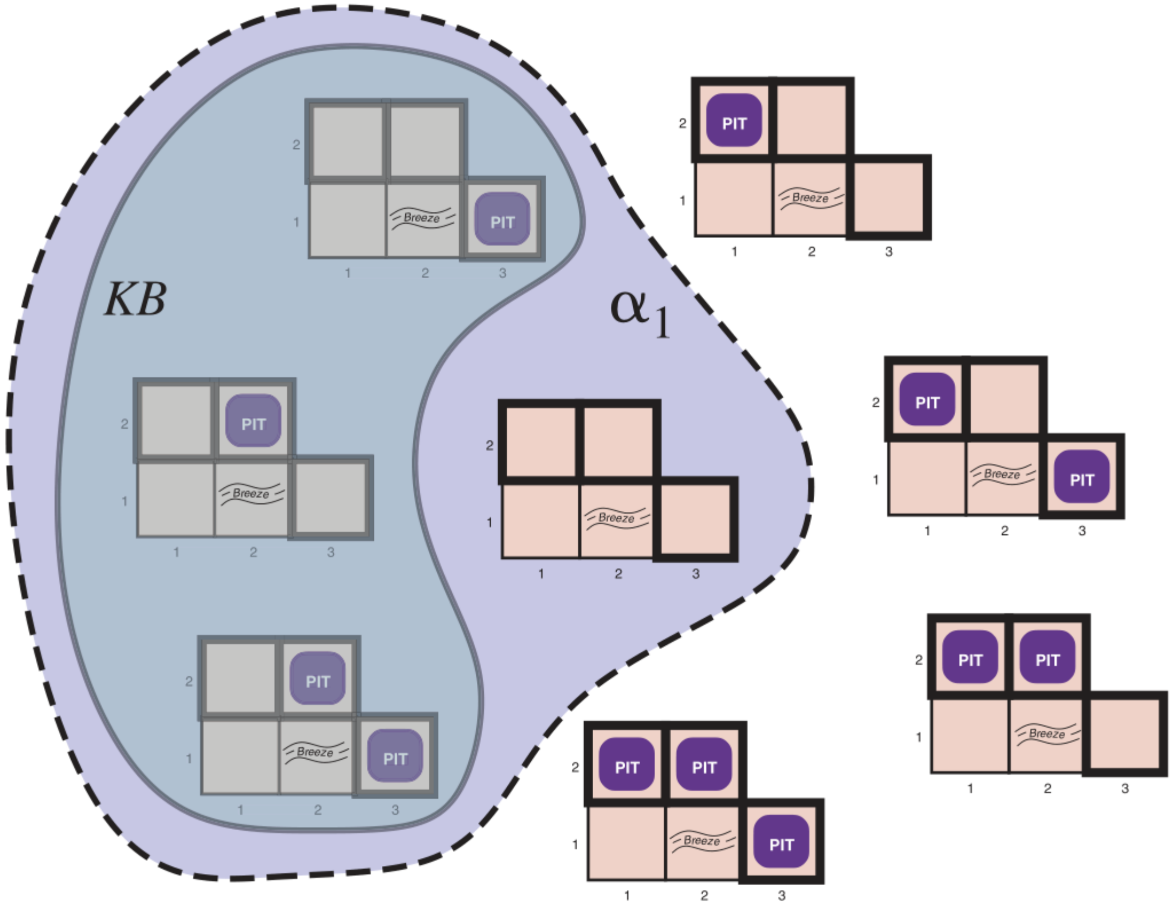

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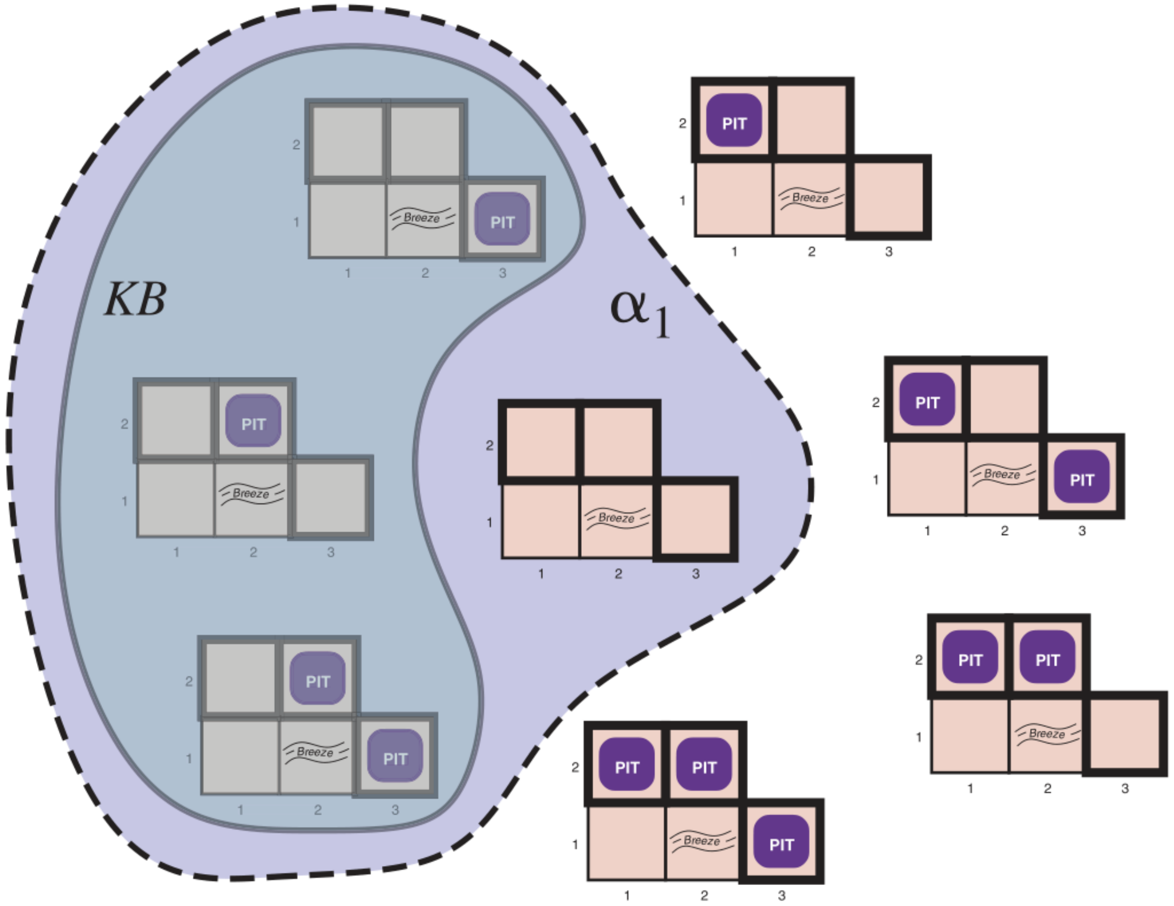

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- hence, $\mathcal{KB} \vDash \alpha_1$

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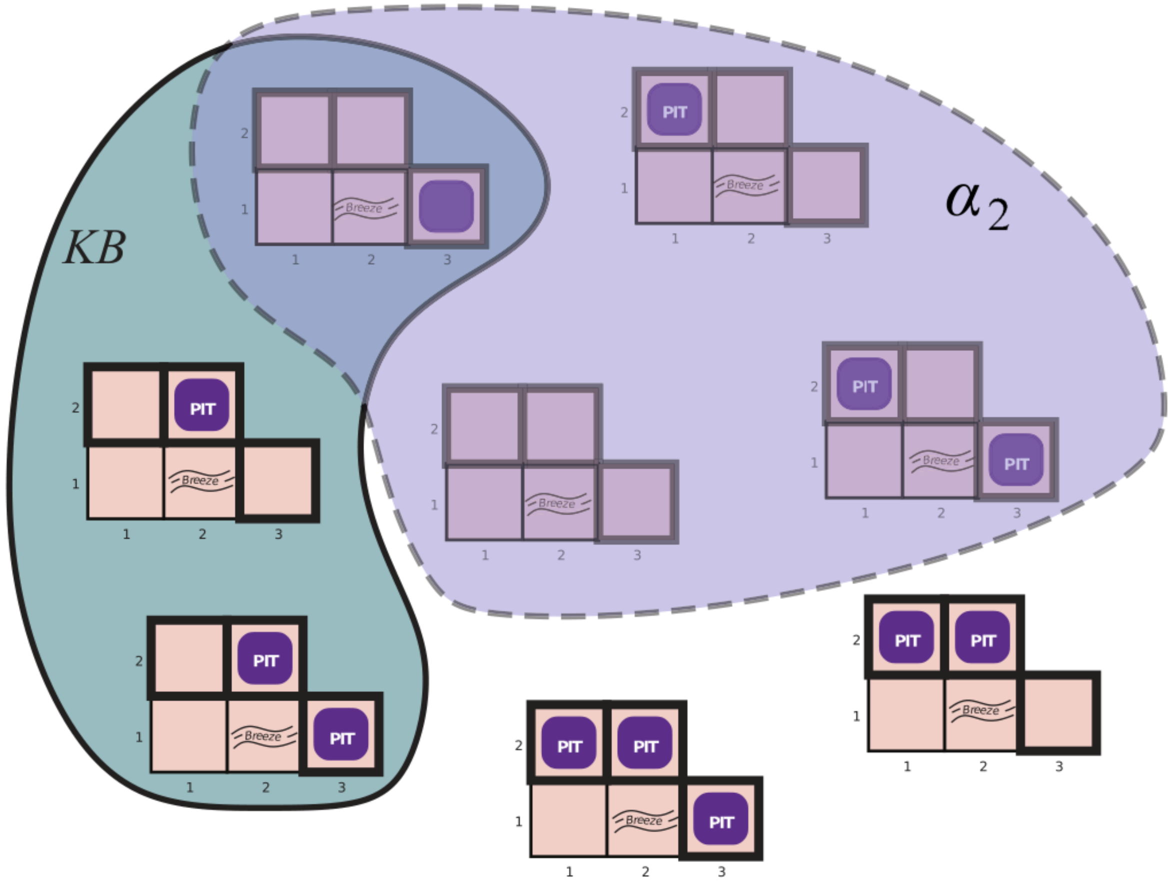

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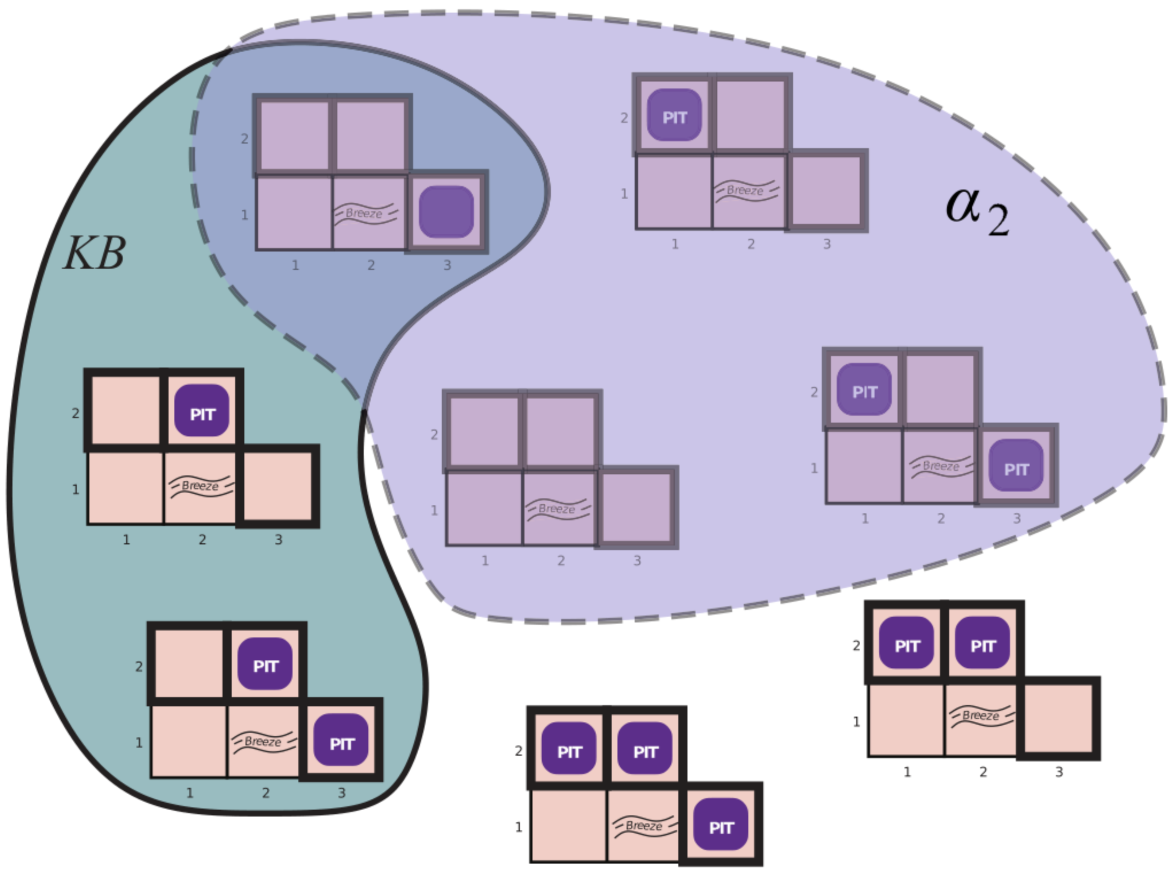

- α_2 = "There is no pit in [2,2]"

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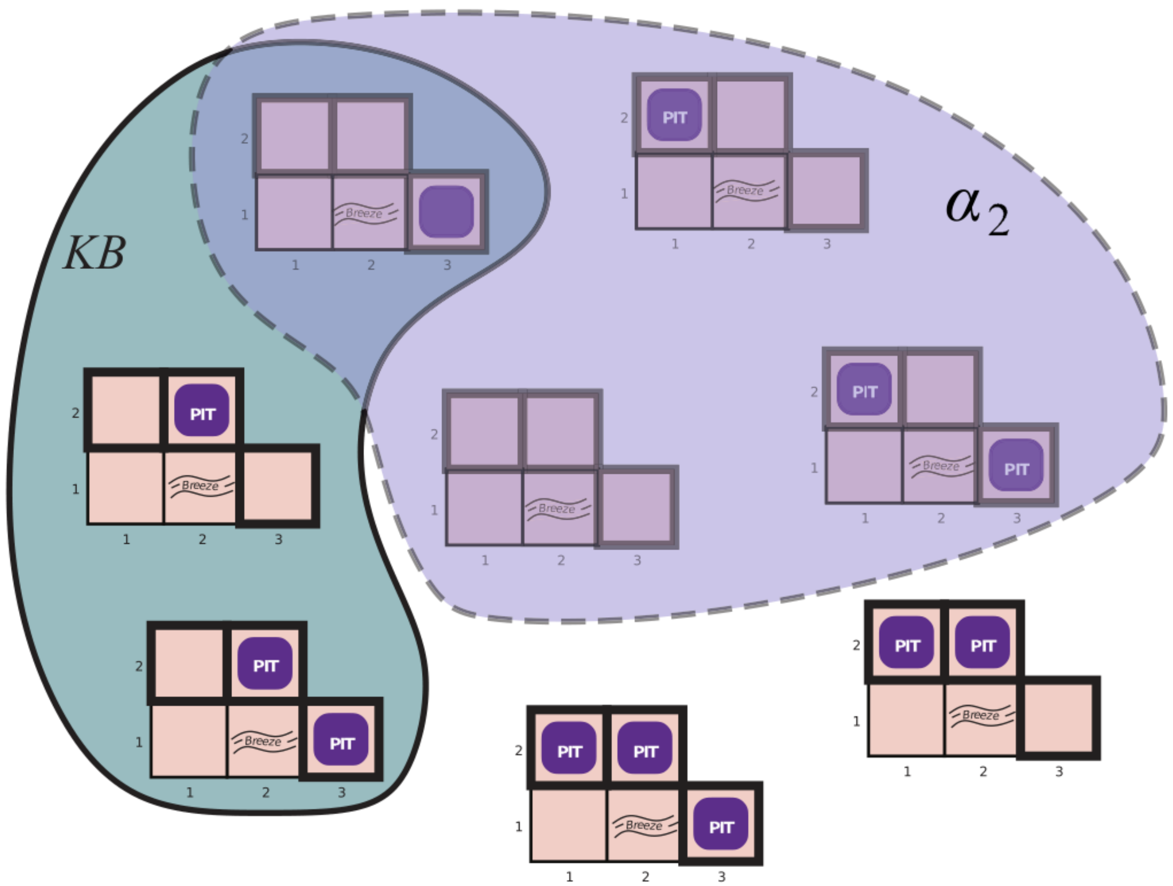

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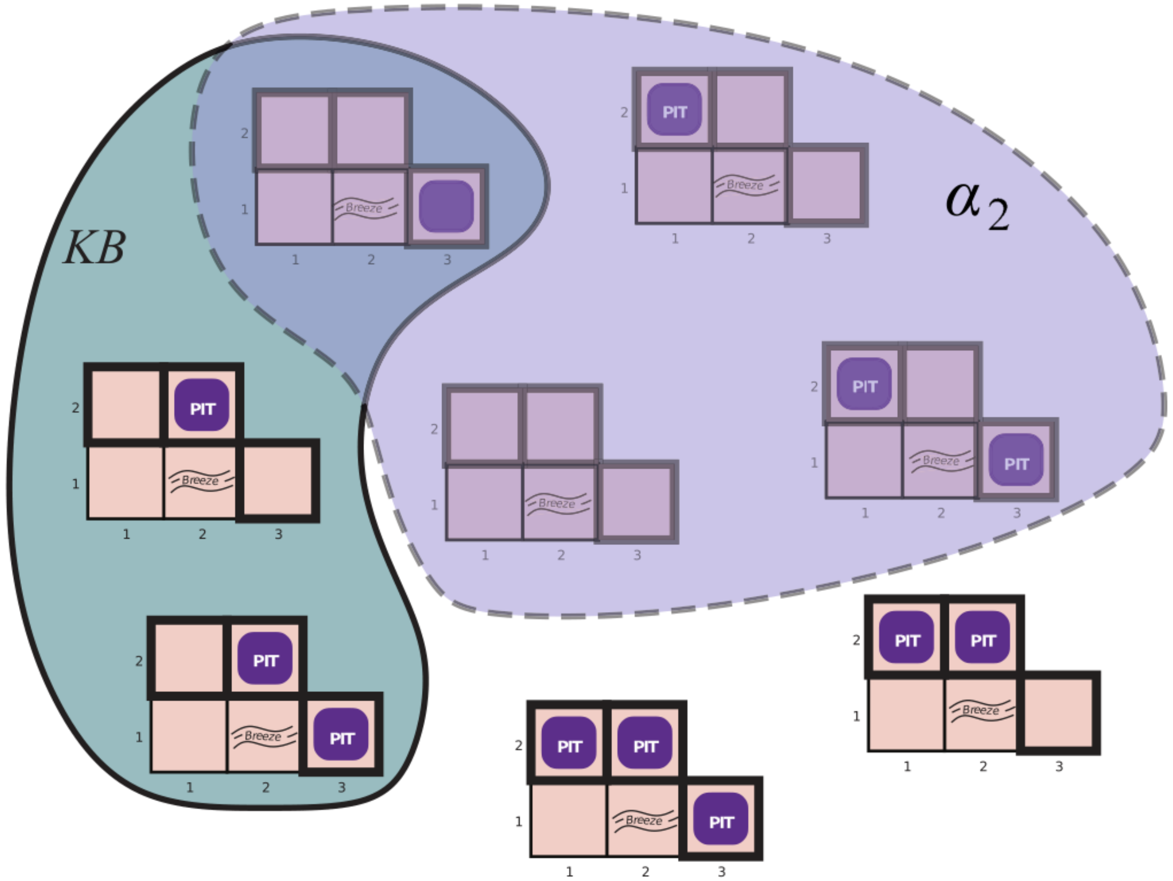

- α_2 = "There is no pit in [2,2]"
- in some model in which $\mathcal{KB}$ is true, α_2 is false
- hence, $\mathcal{KB}$ does not entail α_2

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

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A BNF (Backus-Naur 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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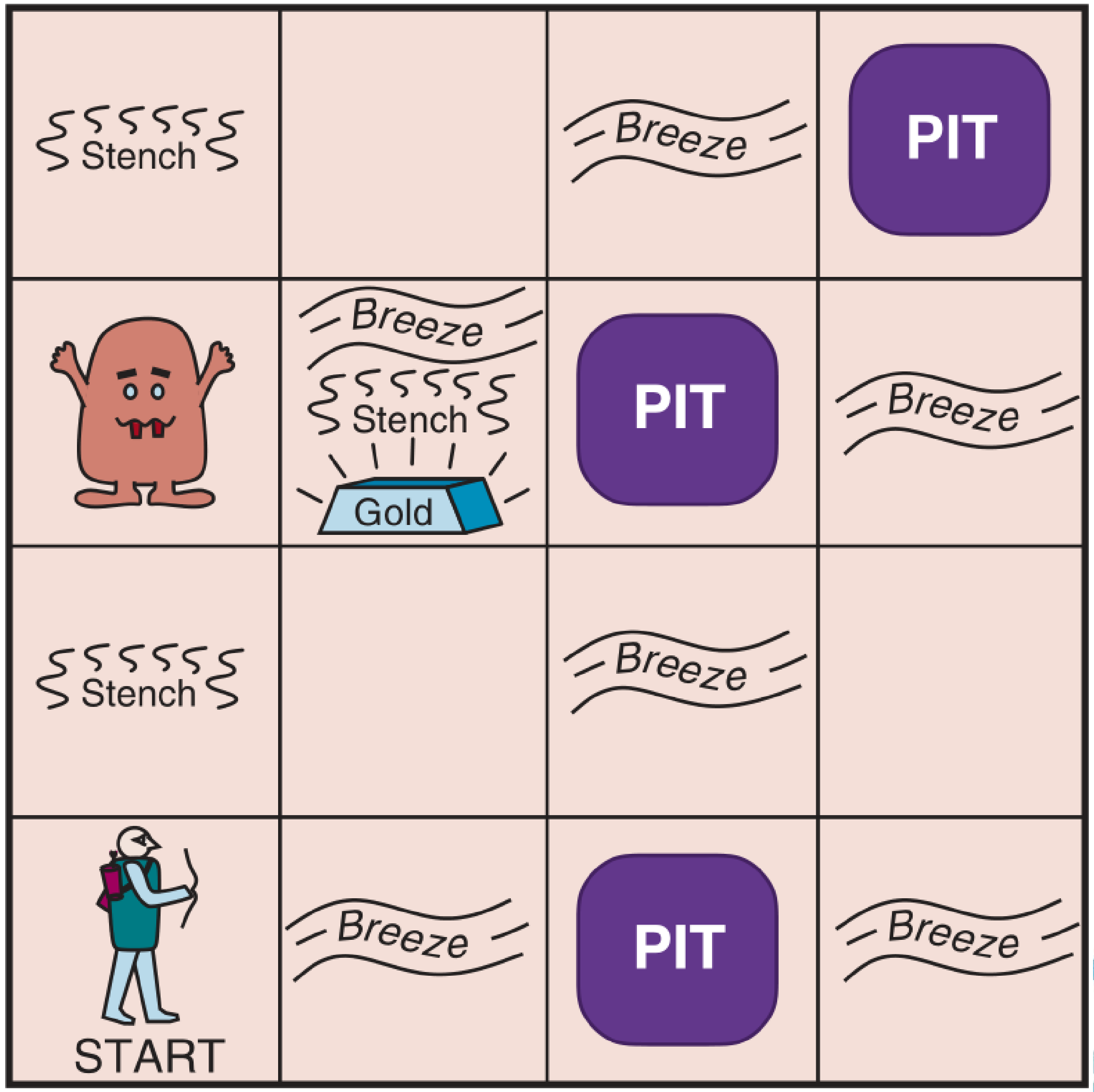

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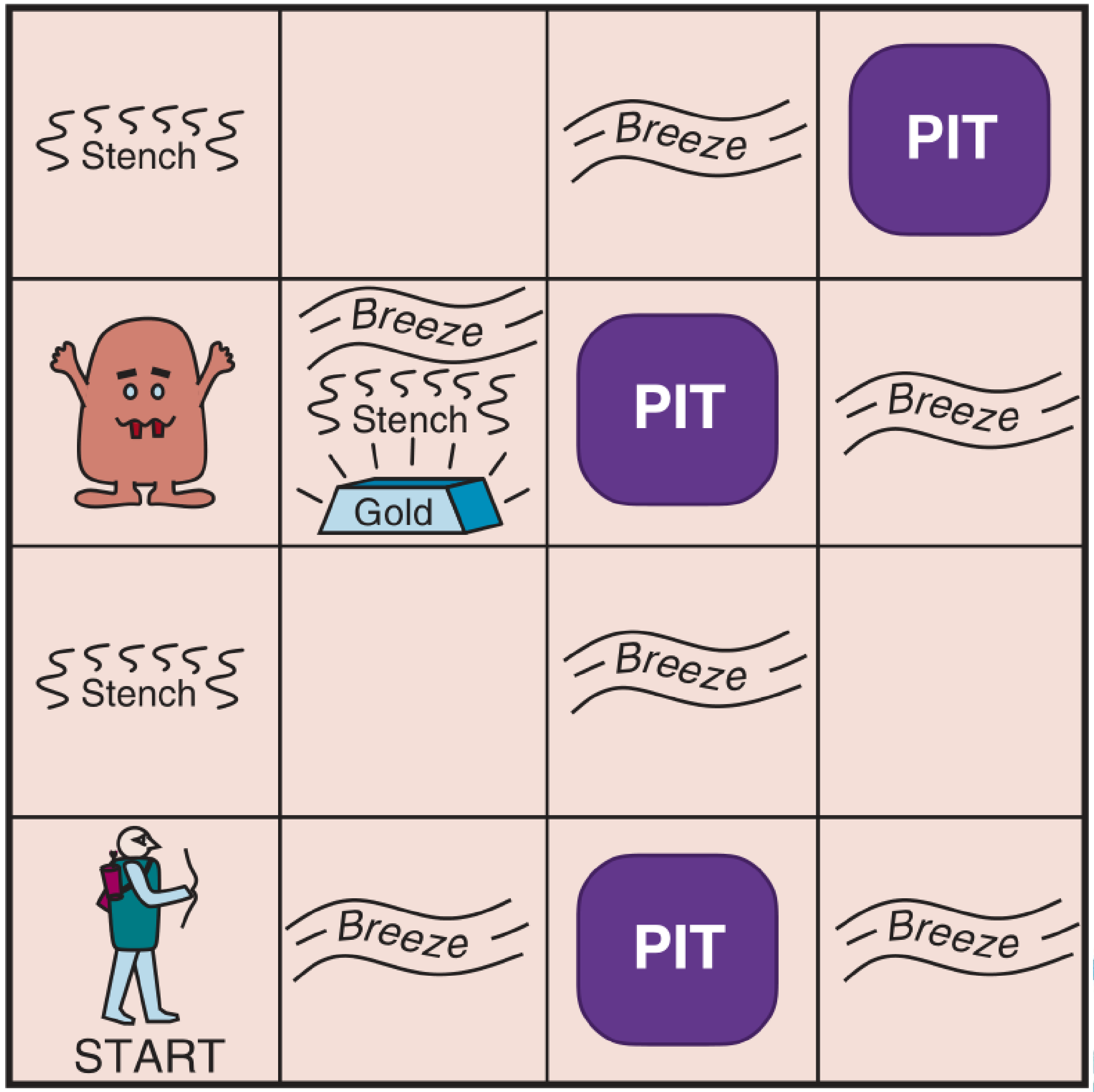

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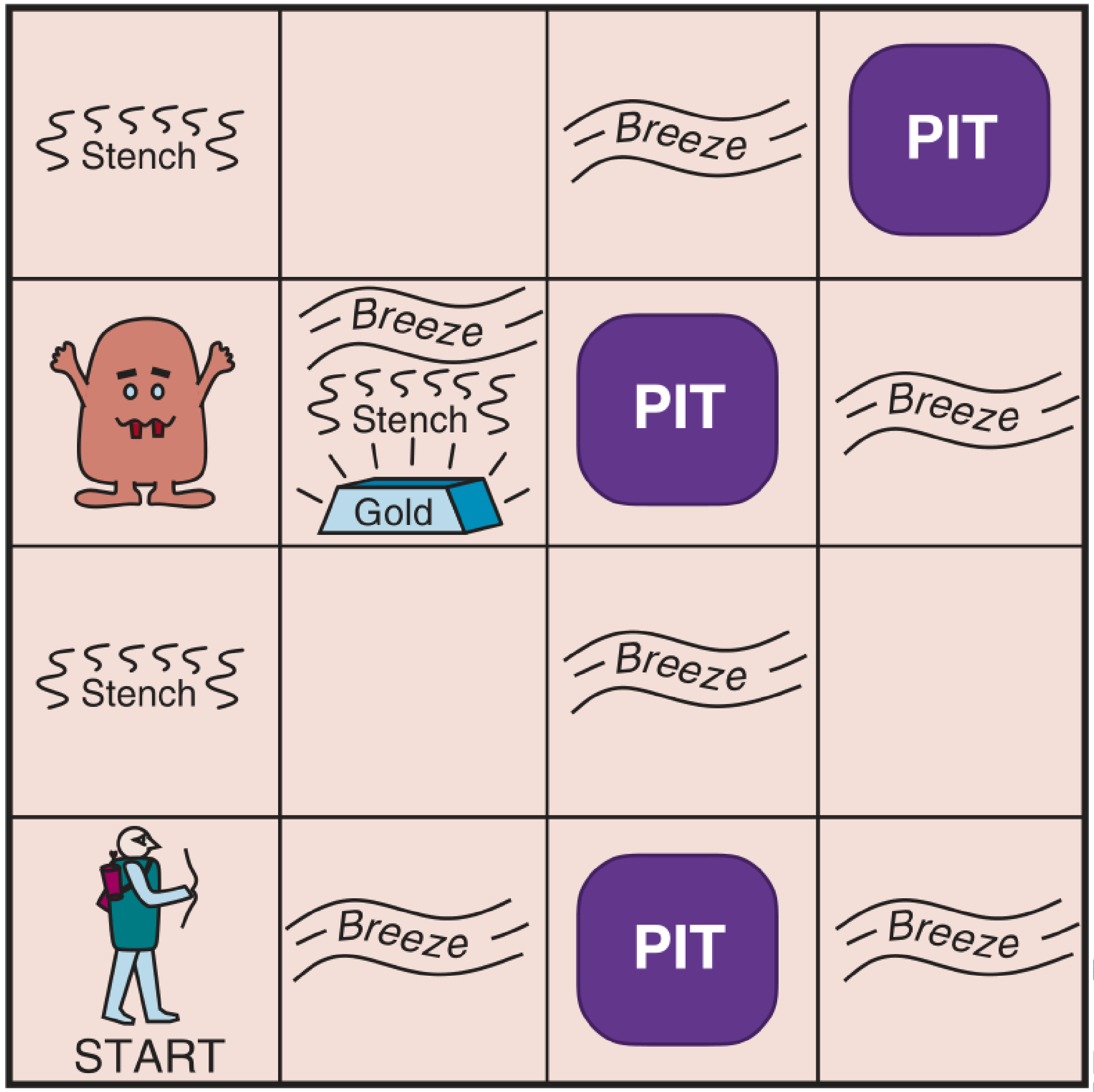

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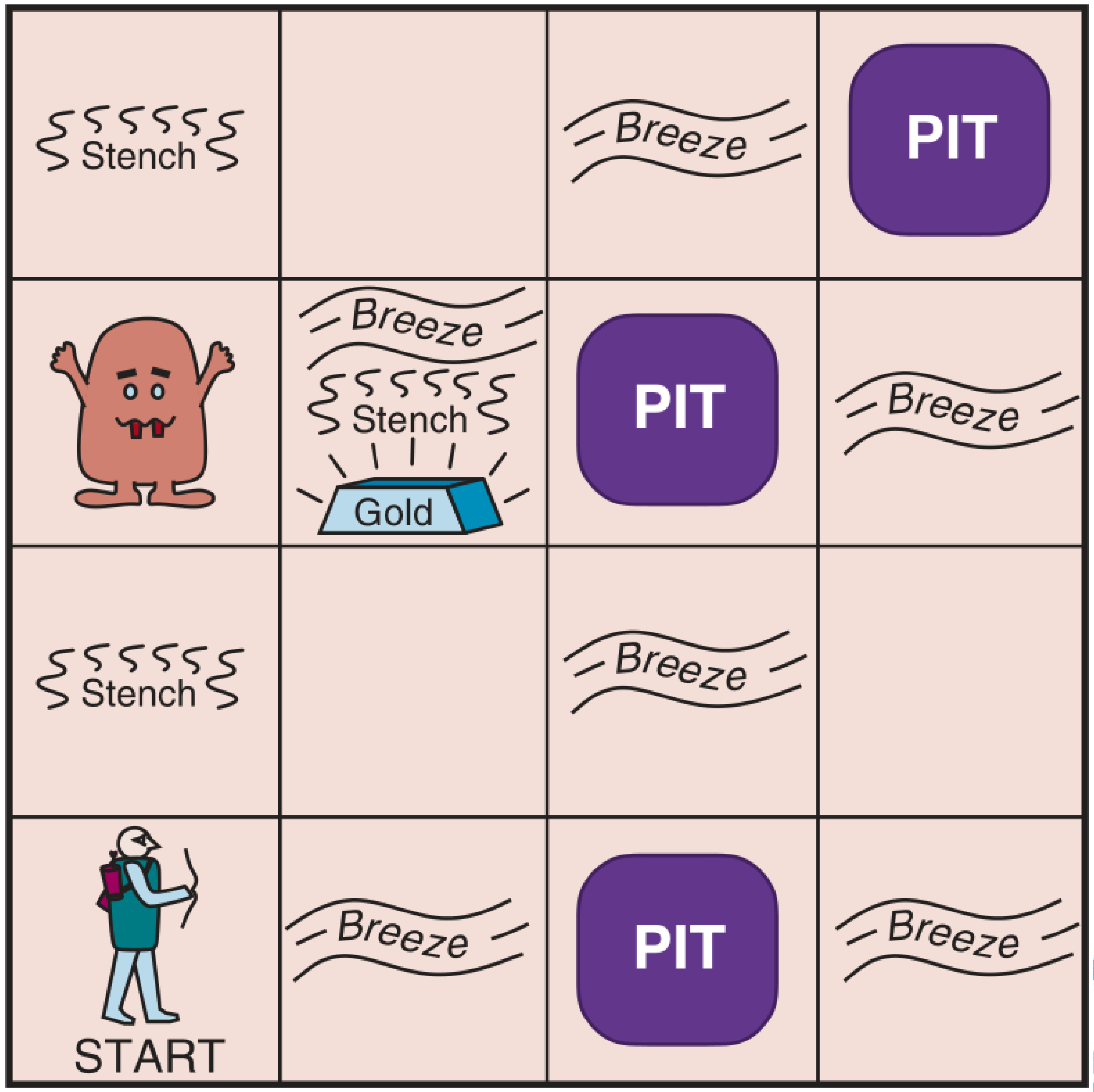

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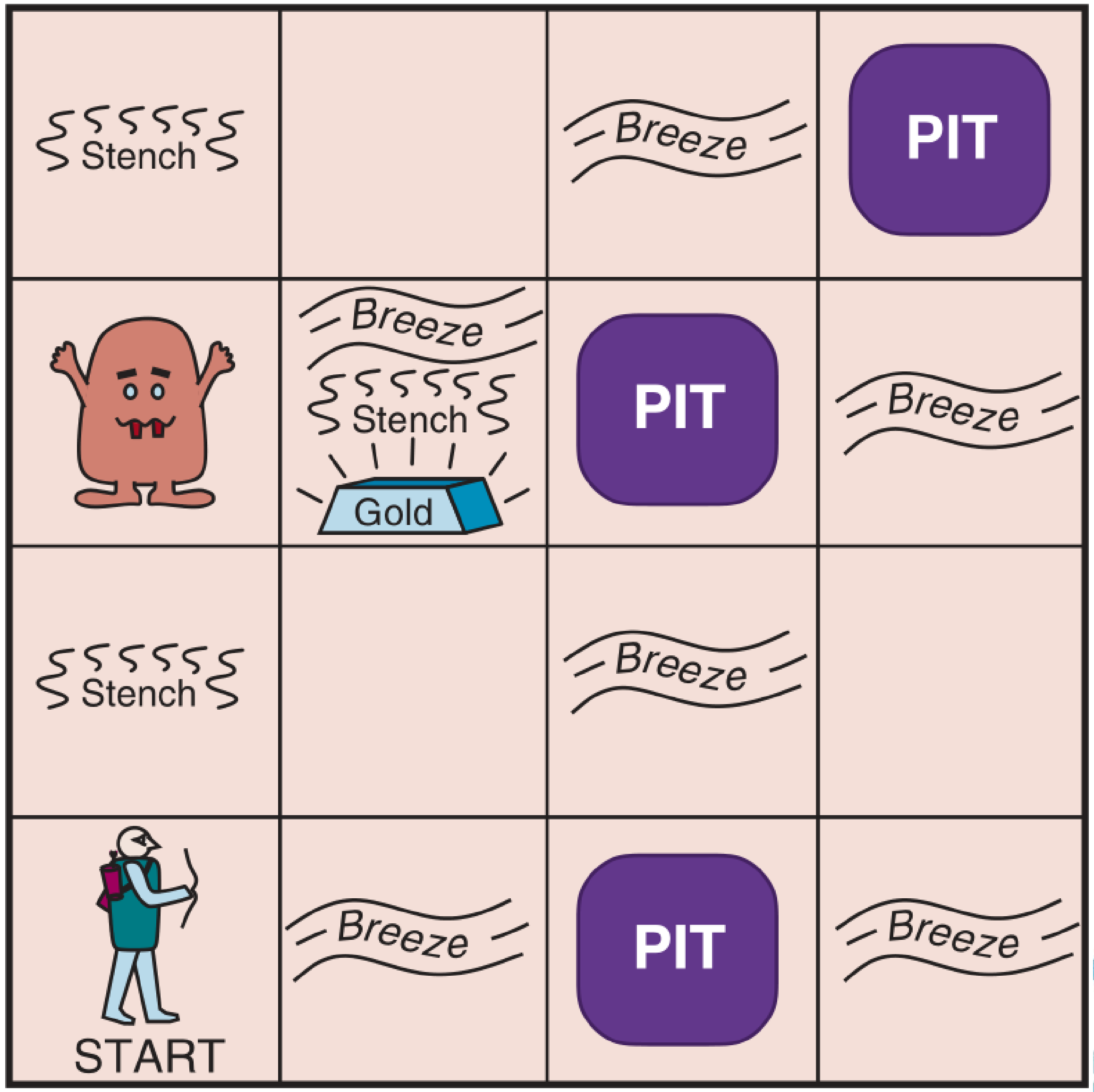

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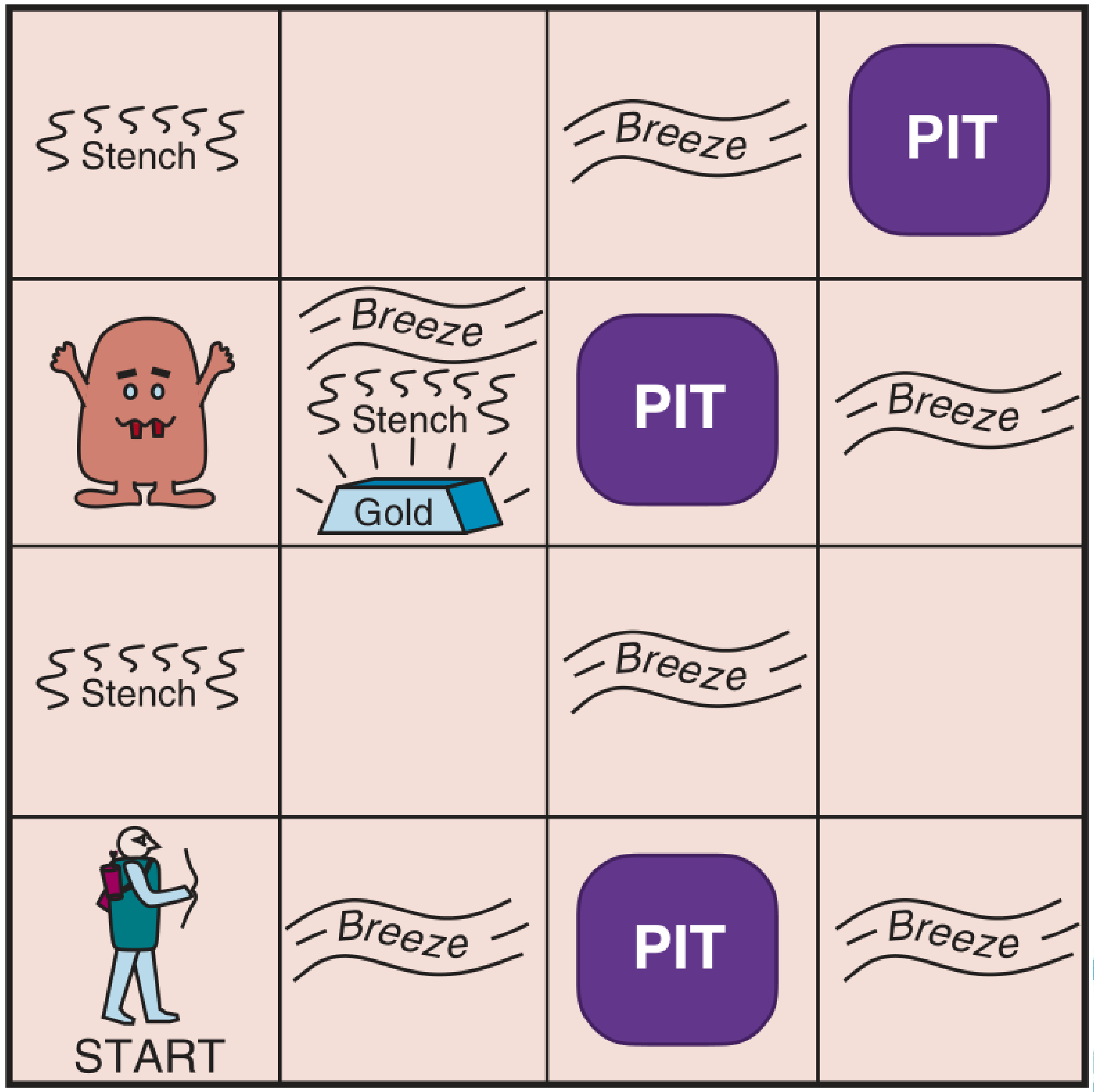

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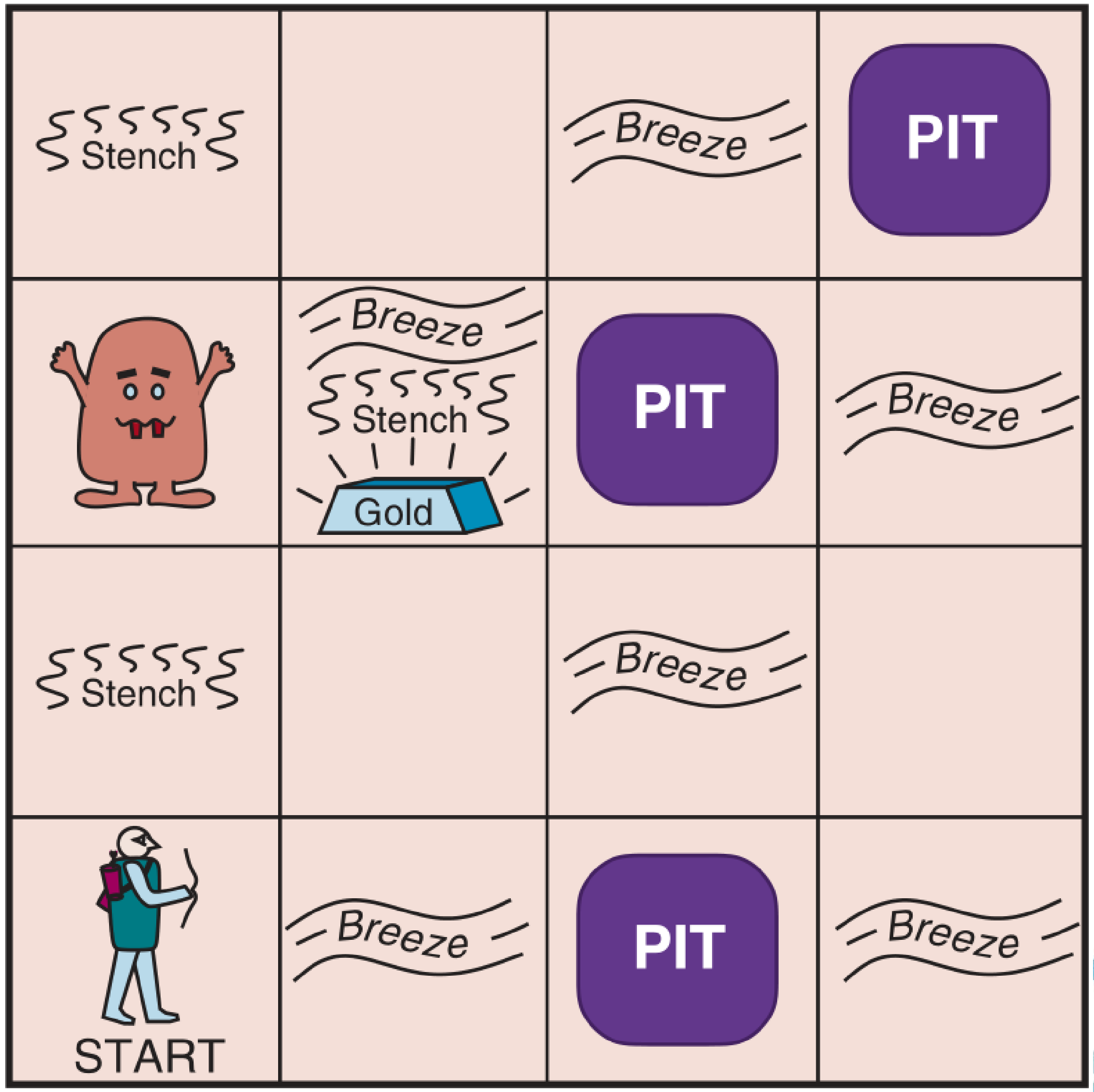

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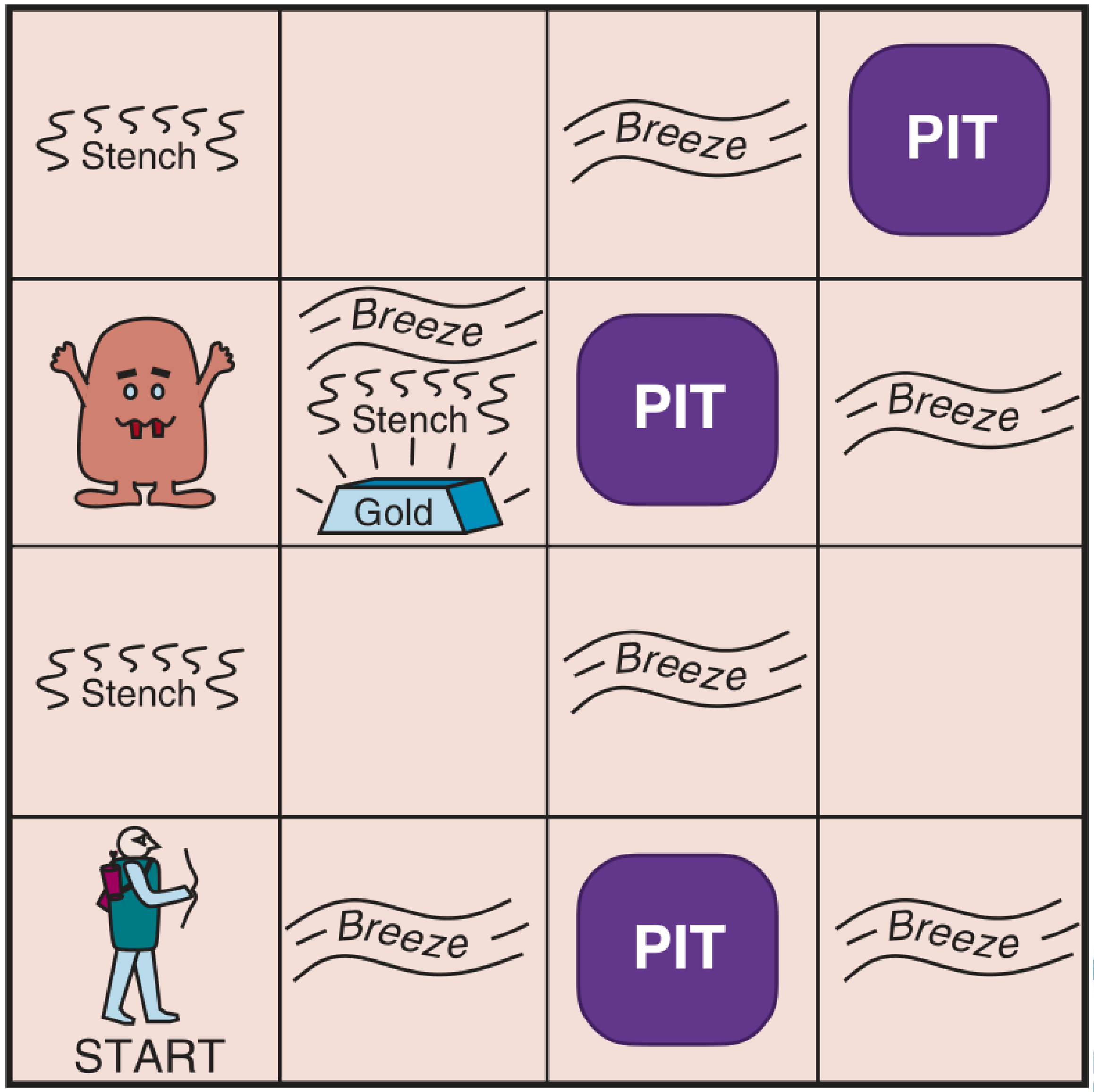

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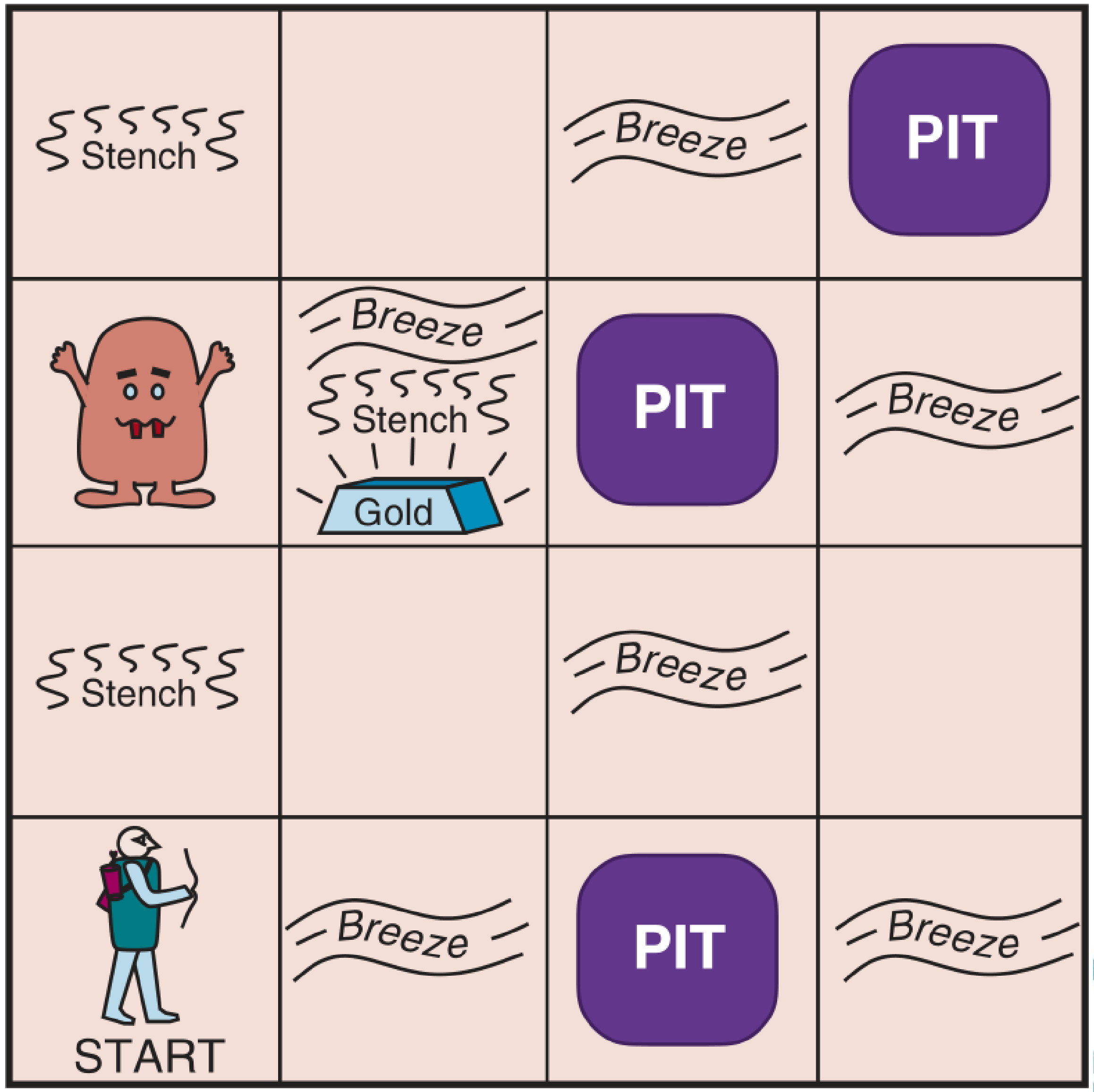

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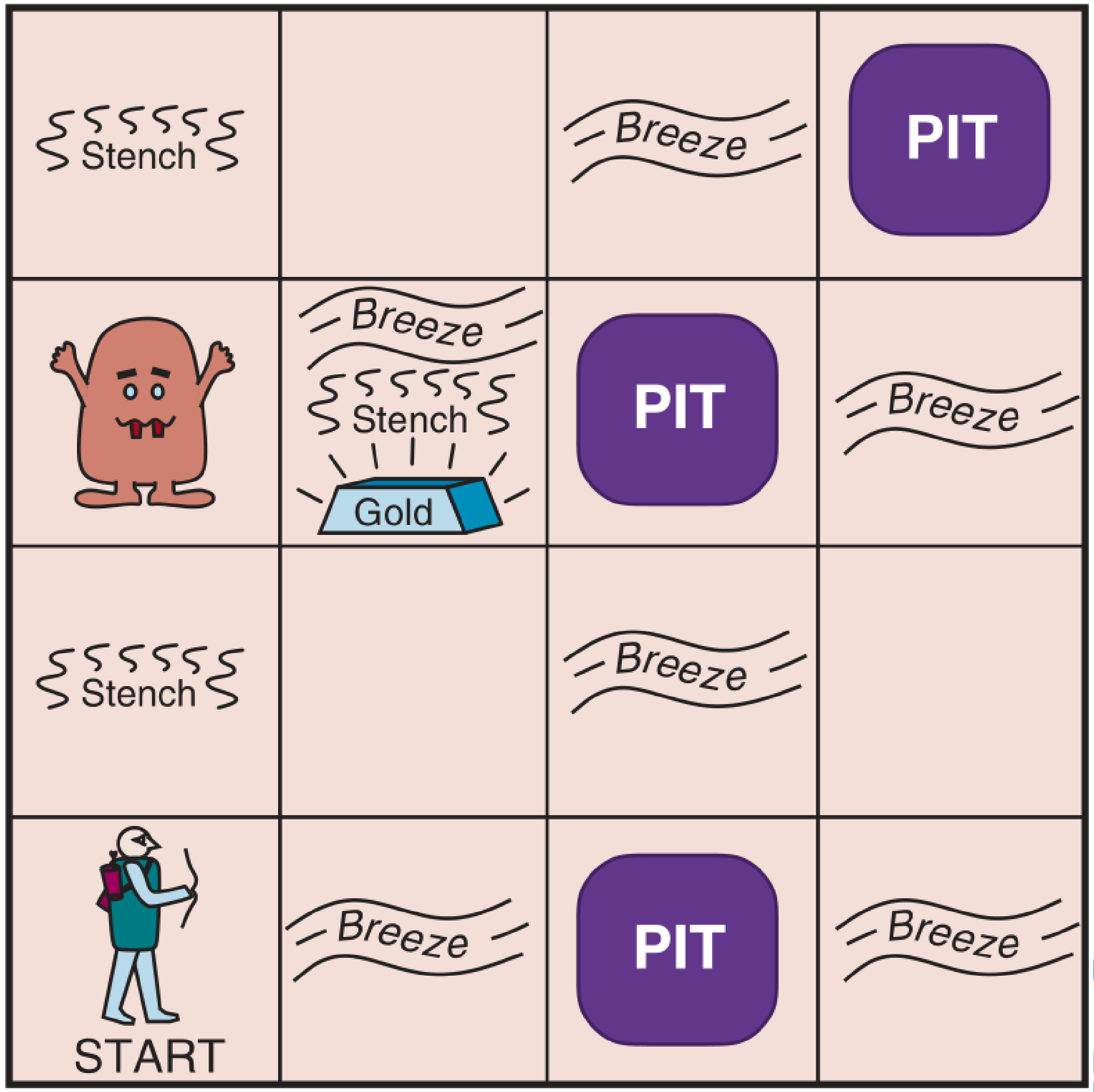

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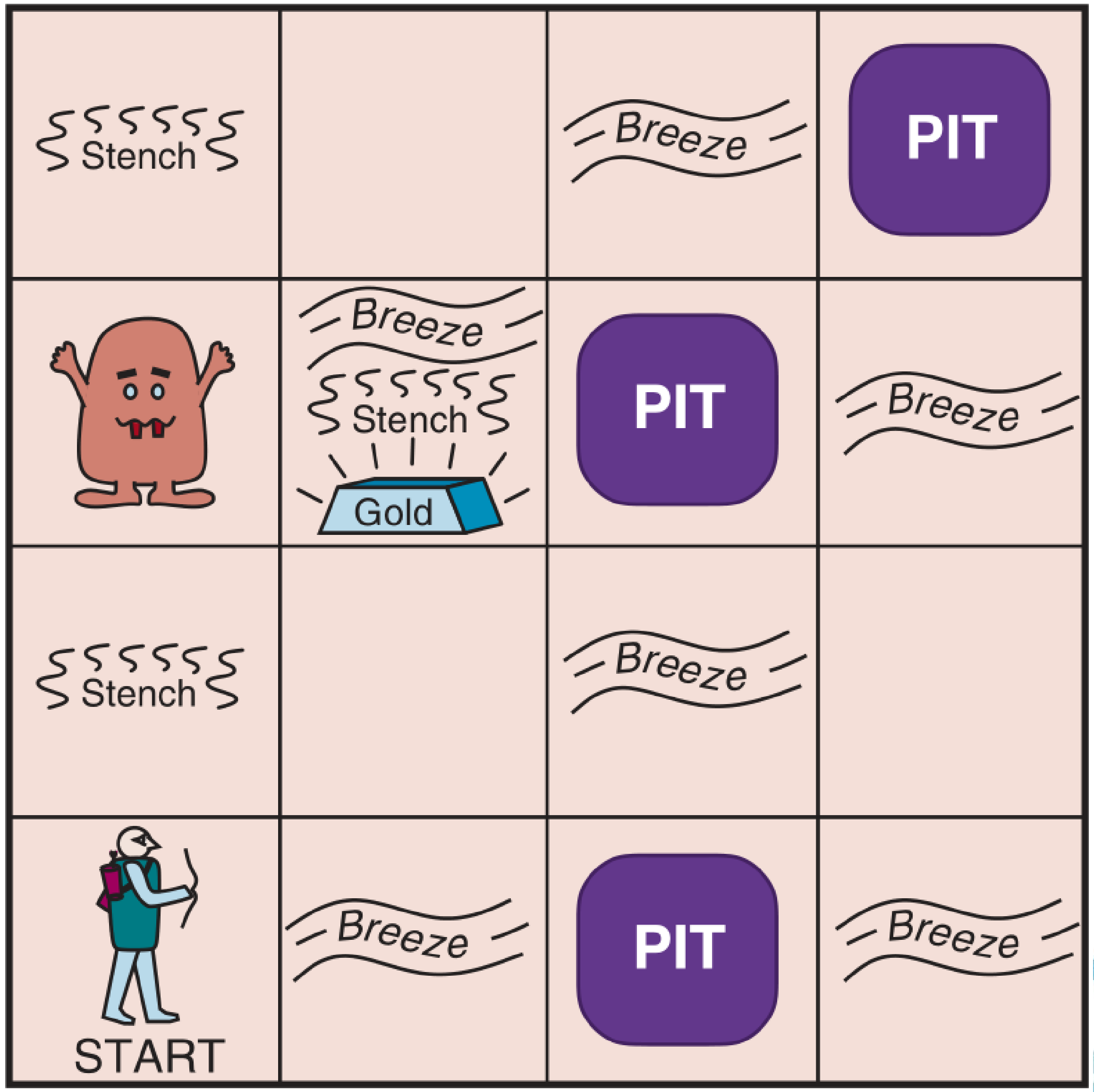

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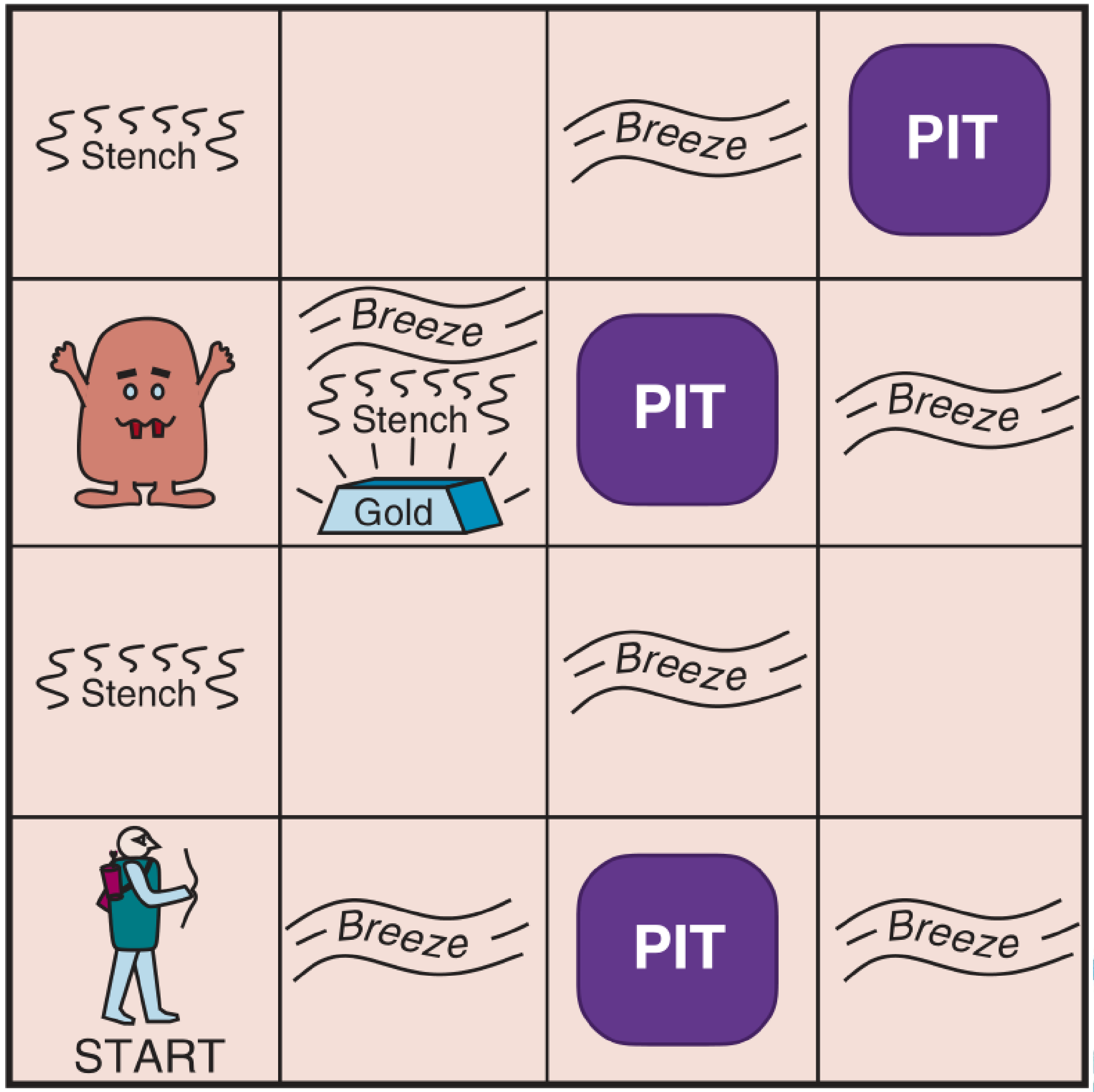

Questions (based on above $\mathcal{KB}$):

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

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Model Checking

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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*
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
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*
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
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*
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
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>
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⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
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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- *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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Wumpus: there is no breeze at [1,1], so there can be no pits in neighboring squares

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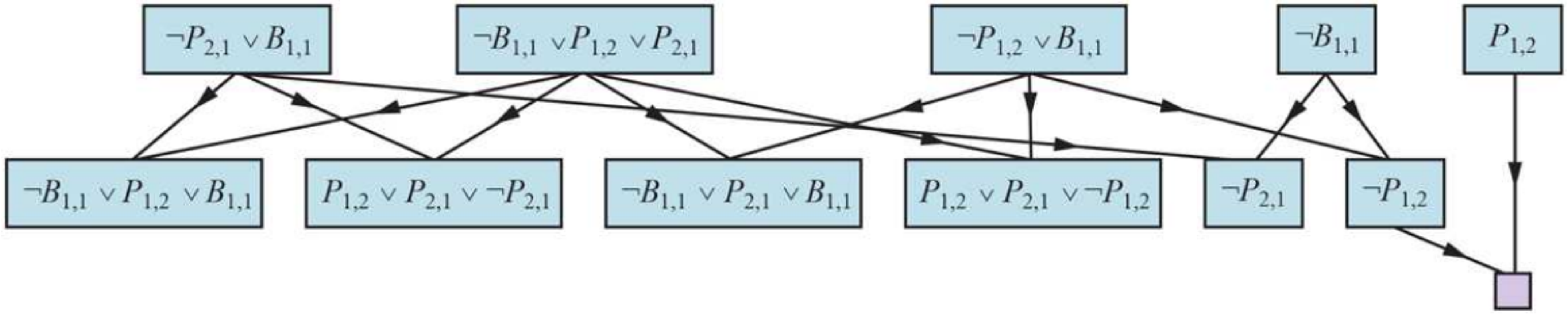

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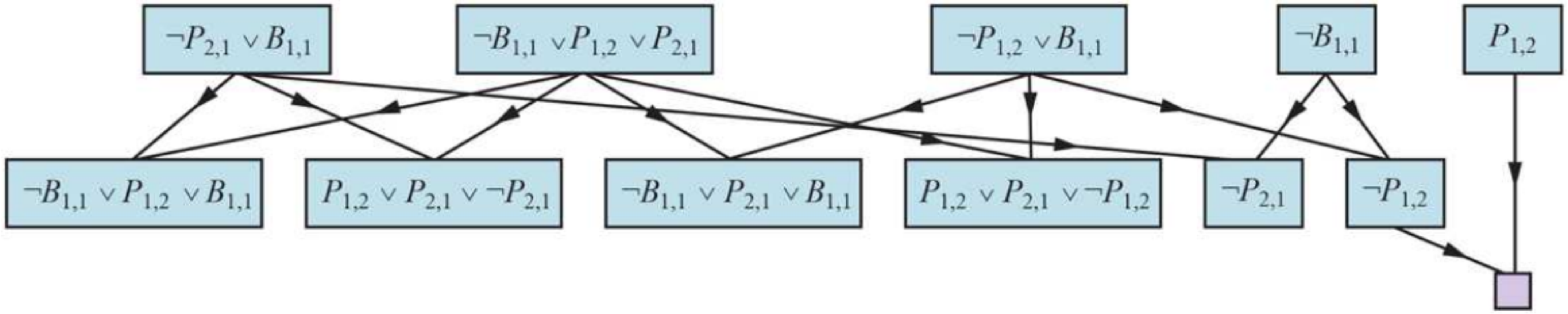

- An empty clause is yielded, meaning the query is proven

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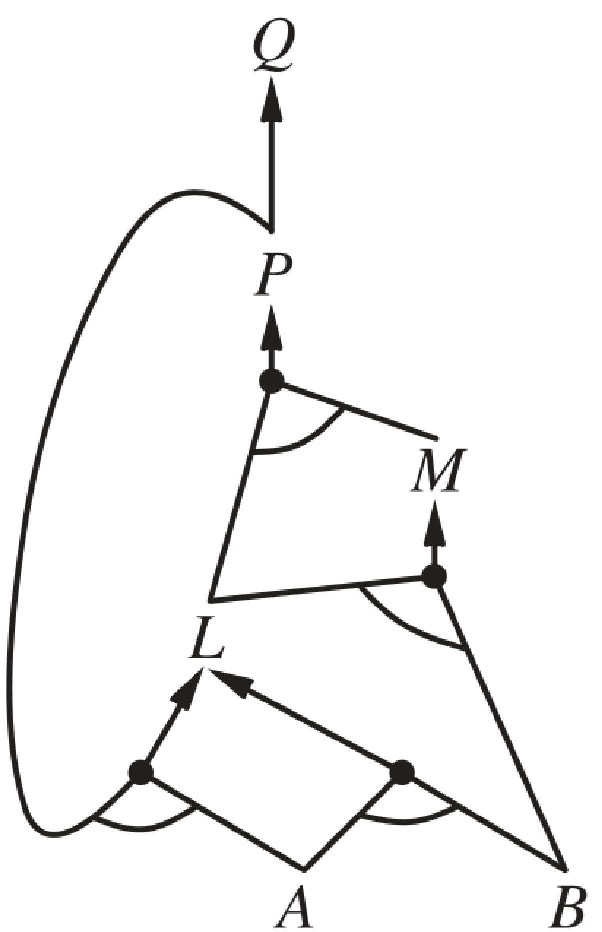
Example:

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



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First Order Logic

Declarative language that can also recognize:

- Objects: all nouns and noun phrases
- Relations: either unary or n-ary relations between objects
- Functions: relations that only have one value for a given input

Syntax of FOL:

- Terms are either: constant symbols (e.g. 13), variables, or functions (e.g. sqrt(x))
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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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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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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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