COMP250: Artificial Intelligence

4: Planning

Logic

Logical operations

Python	C family	Mathematics	Behaviour tree
not a	!a	$\neg A$ or $\overline{A}$	Inverter
a **and** b	a && b	$A \wedge B$	Sequence
a **or** b	a || b	$A \vee B$	Selector

The laws of thought

- Let *A* be a **proposition** (a statement about the world)
- `A` is a **boolean** value, either **true** or **false**
- The law of **identity**: `A == A` is always true
- The law of **non-contradiction**: `A && !A` is always false
  - I.e. `A` cannot be both true and false
- The law of the **excluded middle**: `A || !A` is always true;
  - I.e. `A` must be either true or false

Predicates

- **Predicates** are propositions with **parameters**
- In programming terms, a predicate is a function that returns a boolean
- E.g. `LivesIn(Bob, Falmouth)` could be a predicate for "Bob lives in Falmouth"

Quantifiers

- $P(x)$ is a predicate
- $\forall x : P(x)$ means that $P(x)$ is true **for all** values of x
- $\exists x : P(x)$ means that **there exists** at least one value of x such that $P(x)$ is true

Implication

- "A implies B" means "if A is true then B is true"
- Written as $A \implies B$
- E.g. if someone lives in Falmouth then they live in Cornwall
- $\forall x : \text{LivesIn}(x, \text{Falmouth}) \implies \text{LivesIn}(x, \text{Cornwall})$

Contrapositive

- $A \implies B$ is equivalent to $\neg B \implies \neg A$
- E.g. if someone does not live in Cornwall then we know they don't live in Falmouth
- $\forall x : \neg\,\mathrm{LivesIn}(x, \mathrm{Cornwall}) \implies \neg\,\mathrm{LivesIn}(x, \mathrm{Falmouth})$

Equivalence

- If $A \implies B$ and $B \implies A$ then A and B are **logically equivalent**
- A is true **if and only if** B is true
- Written as $A \iff B$
- E.g. "Alice lives in a city in Cornwall" if and only if "Alice lives in Truro"
- This relies on an extra piece of domain knowledge: Truro is the only city in Cornwall
  - $\forall x : \text{InCornwall}(x) \wedge \text{IsCity}(x) \implies x = \text{Truro}$

Implication is transitive

- If $A \implies B$ and $B \implies C$ then $A \implies C$
- E.g. if someone lives in Falmouth then they live in Cornwall
- And if someone lives in Cornwall then they live in England
- Therefore if someone lives in Falmouth then they live in England

Inverting quantifiers

- "Everyone who lives in Cornwall likes cider"
- $\forall x : \text{LivesIn}(x, \text{Cornwall}) \implies \text{Likes}(x, \text{Cider})$
- What is the **opposite** of this statement?
- $\neg(\forall x : \text{LivesIn}(x, \text{Cornwall}) \implies \text{Likes}(x, \text{Cider}))$
- In logical terms, the opposite is **not** "nobody who lives in Cornwall likes cider"
- It's "Not everyone who lives in Cornwall likes cider"
- I.e. "There is at least one person living in Cornwall who does not like cider"
- $\exists x : \text{LivesIn}(x, \text{Cornwall}) \land \neg \text{Likes}(x, \text{Cider})$

Planning

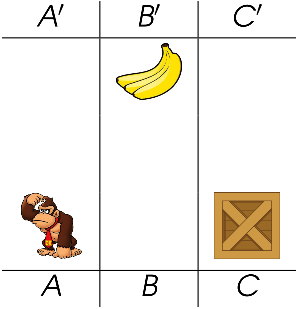
Planning

- An **agent** in an **environment**
- The environment has a **state**
- The agent can perform **actions** to change the state
- The agent wants to change the state so as to achieve a **goal**
- Problem: find a sequence of actions that leads to the goal

STRIPS planning

- **St**anford **R**esearch **I**nstitute **P**roblem **S**olver
- Describes the state of the environment by a set of **predicates** which are true
- Models a problem as:
  - The **initial state** (a set of predicates which are true)
  - The **goal state** (a set of predicates, specifying whether each should be true or false)
  - The set of **actions**, each specifying:
    - Preconditions (a set of predicates which must be satisfied for this action to be possible)
    - Postconditions (specifying what predicates are made true or false by this action)

STRIPS example



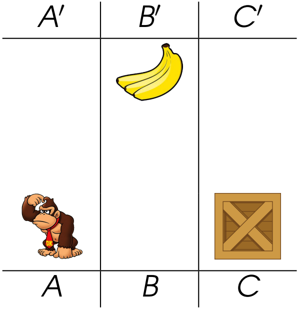
Initial state:

```
At(A),
BoxAt(C),
BananasAt(B')
```

Goal:

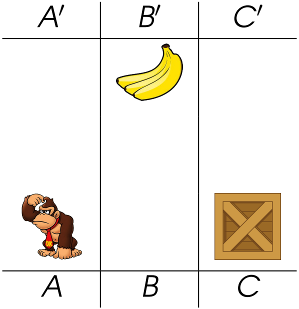
```
HasBananas
```

STRIPS example — Actions

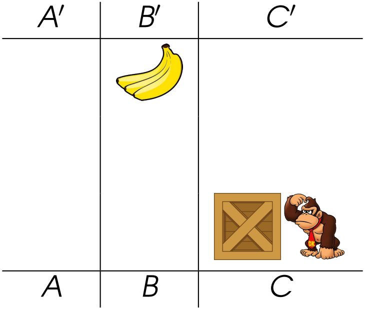



```
Move(x, y)
  Pre:  At(x)
  Post: !At(x), At(y)

ClimbUp(x)
  Pre:  At(x), BoxAt(x)
  Post: !At(x), At(x')

ClimbDown(x')
  Pre:  At(x'), BoxAt(x)
  Post: !At(x'), At(x)

PushBox(x, y)
  Pre:  At(x), BoxAt(x)
  Post: !At(x), At(y),
        !BoxAt(x), BoxAt(y)

TakeBananas(x)
  Pre:  At(x), BananasAt(x)
  Post: !BananasAt(x), HasBananas
```

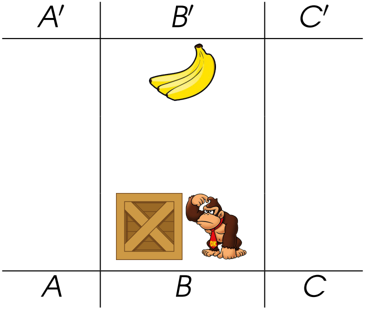
STRIPS example — Solution



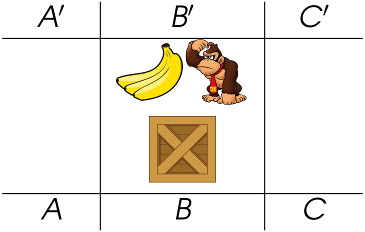
STRIPS example — Solution



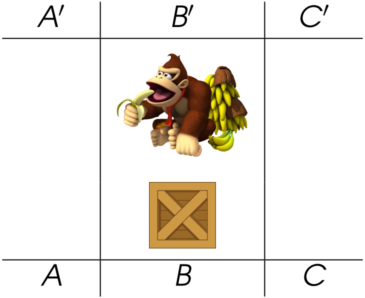
STRIPS example — Solution



STRIPS example — Solution



STRIPS example — Solution



Finding the solution

- For a given state, we can construct a list of all **valid actions** based on their **preconditions**
- We can also find the **next state** resulting from each action based on their **postconditions**
- This should sound familiar (from 2 weeks ago)...
- We can construct a **tree** of states and actions
- We can then **search** this tree to find a goal state

Tree traversal

```
procedure DepthFirstSearch
    let S be a stack
    push root node onto S
    while S is not empty do
        pop n from S
        push children of n onto S
    end while
end procedure

procedure BreadthFirstSearch
    let Q be a queue
    enqueue root node into Q
    while Q is not empty do
        dequeue n from Q
        enqueue children of n into Q
    end while
end procedure
```

Tree traversal example