# Principles of Computer Game Design and Implementation

**Lecture 25**

# Outline for today

- planning

# Combining Actions

- In previous lectures, behaviour of game entities was ***defined*** by the AI developer

- Behaviour trees can be seen as reactive plans
  - React to changes in the environment
  - Options are prescribed

- In traditional AI, computer is asked to ***find*** sequences of actions

# AI Planning

- Planning in AI is the problem of finding a sequence of primitive actions to achieve some goal.

- The sequence of actions is the system's plan which then can be **executed**.

- Planning requires the following:
  - representation of goal to achieve;
  - knowledge about what actions can be performed; and
  - knowledge about state of the world.

# Architecture of a Planner

goal    state of    possible actions
        environment

Planner

plan to achieve goal
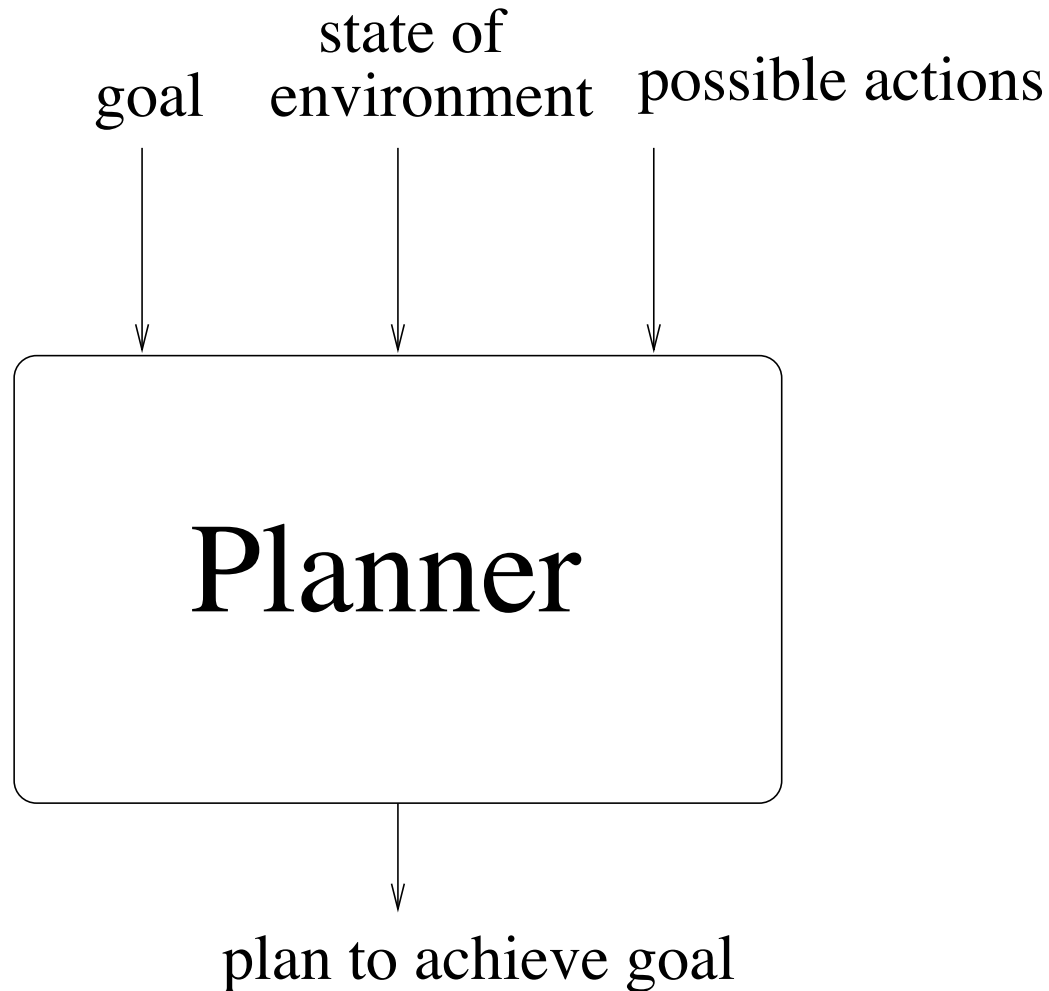
# Planning in Games

- A character may have one or more goal (motives)
- Every goal has insistence – a number
- Actions fulfil goals (to some extent)

- *Actions can be combined into a PLAN*

# GOB vs GOAP

- **Goal-oriented behaviour (GOB)**

- **Main problem: selecting an action**
  - Restricts design decisions

- **Goal-oriented action planning (GOAP)**

- **Main problem: finding a sequence of actions**
  - Often considered to be too complicated for games
    - But F.E.A.R. !
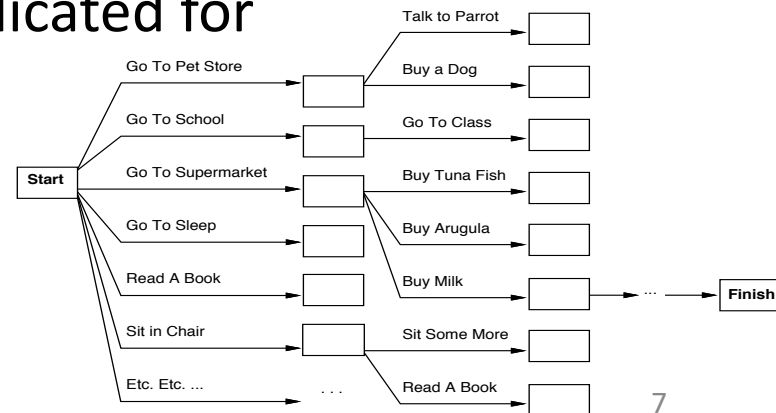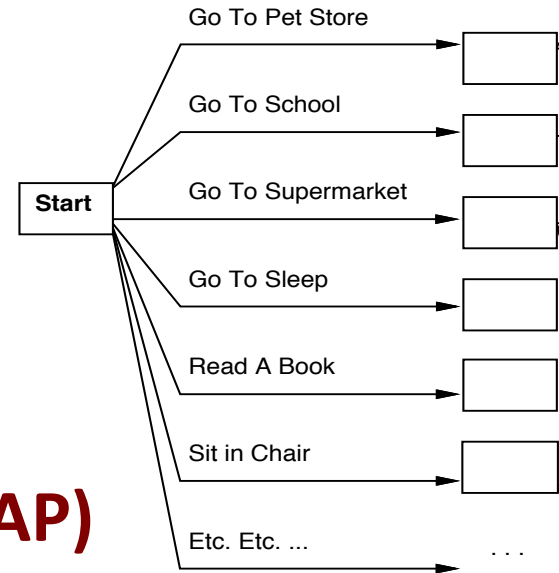
# GOB: Simple Selection

- Goals:
  - Eat = 4;        Sleep = 3
- Actions:
  - Get-Raw-Food (Eat - 3)
  - Get-Snack (Eat – 2)
  - Sleep-in-Bed (Sleep – 4)
  - Sleep-on-Sofa (Sleep – 2)

- Choose the most pressing goal;
- Find an action that most fulfils it

Works reasonably well when actions do not have side effects

# GOB: Overall Utility

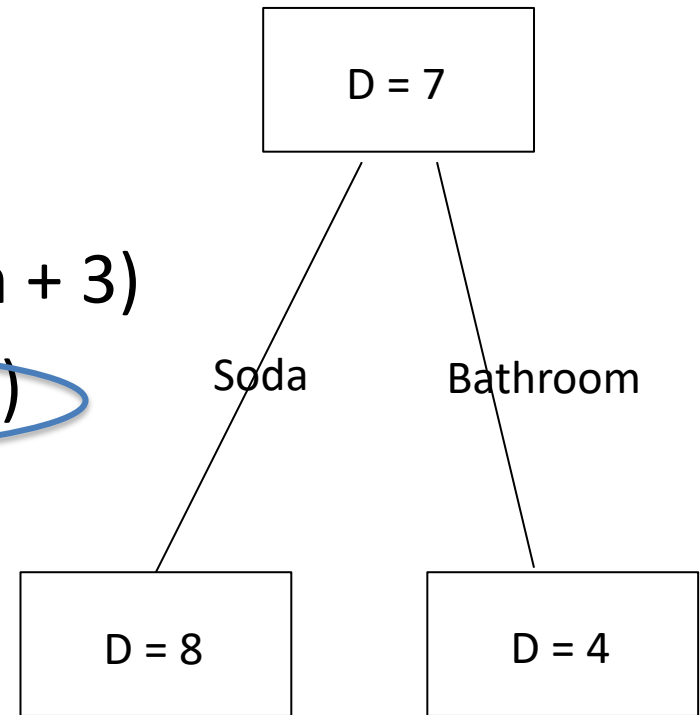$$\textbf{Discontentment} = \sum_{\text{goals}} \text{insistence}$$

- Goals:
  - Eat = 4;    Bathroom = 3

- Actions:
  - Drink-Soda (Eat − 2; Bathroom + 3)
  - Visit-Bathroom (Bathroom − 4)

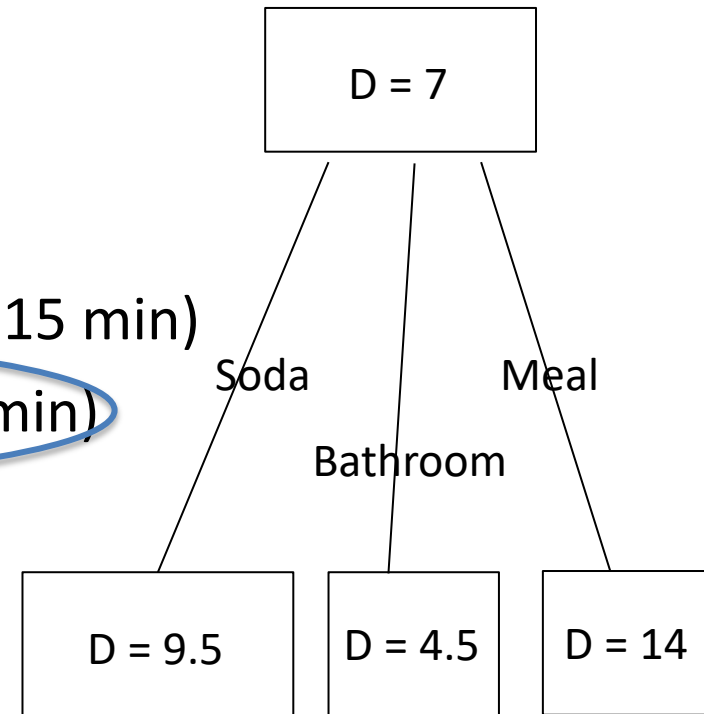D = 7

Soda          Bathroom

D = 8          D = 4

Works well when actions dependency is limited

# Overall Utility: Discontentment + Timing

$$\text{Discontentment} = \sum_{\text{goals}} \text{insistence}$$
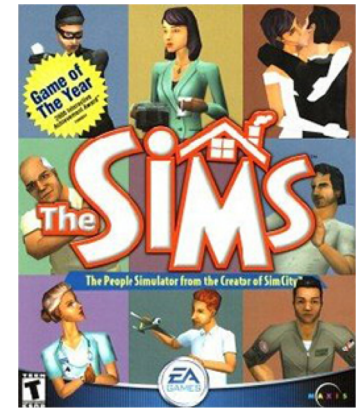
- Goals:
  - Eat = 4 + 4 per hour;
  - Bathroom = 3 + 2 per hour

- Actions:
  - Drink-Soda (Eat – 2; Bathroom + 3; 15 min)
  - Visit-Bathroom (Bathroom – 4; 15 min)
  - Cook-meal (Eat – 5; 2h)

D = 7

Soda

Bathroom

Meal

D = 9.5    D = 4.5    D = 14

Works well when actions dependency is limited

# Actions Available

- Actions defined centrally are too inflexible
- **Smart object** insert actions into AI entities
  - Oven offers a `cook` action
  - Meat offers an `eat` action
    - But how to locate such objects?

- **"Smelly GOB"**
  - Actions smell with the goal it achieves
    - `cook` smells of Eat
  - Smells spread
  - Agents follow smell towards greatest concentration

# Where GOB Fails

Energy level = 5

- Goals:
  - Heal = 4; Kill-Ogre = 3

- Actions:
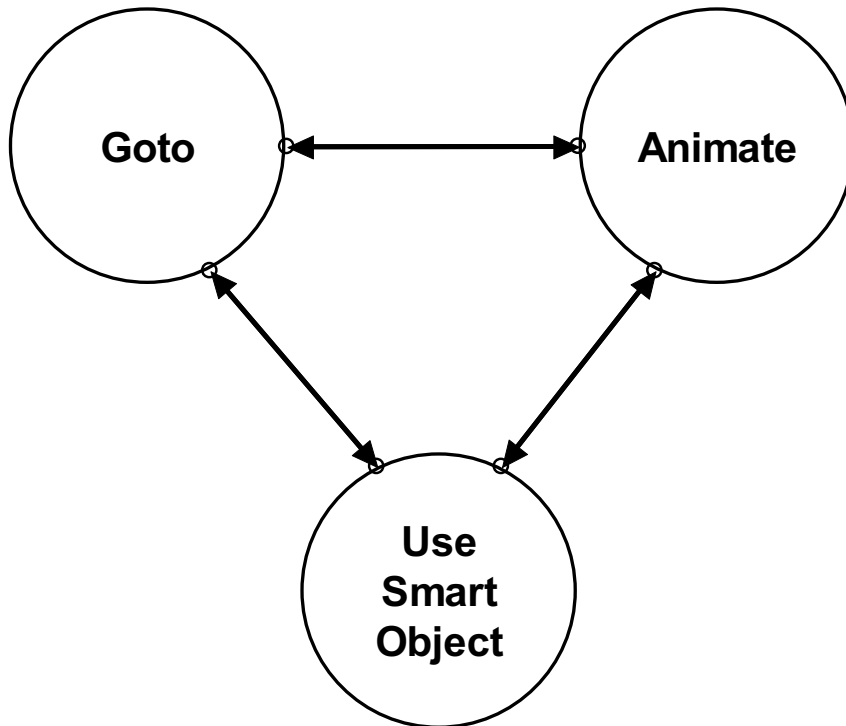  - Fireball (Kill-Ogre – 2);        3 Energy slots
  - Lesser-Healing (Heal – 2);       2 Energy slots
  - Greater-Healing (Heal – 4);      3 Energy slots

Does not work due to one action prohibiting another!

# Planning in Games

- AI Behaviour
  - FSM used in F.E.A.R.



But goto where???

Use what???

F.E.A.R. uses planning to answer these questions

Jeff Orkin. GDC'06 "Three States and a Plan: The A.I. of F.E.A.R."

# Planning in F.E.A.R.



**Design principle:**

– Create interesting spaces for combat and let the AI act

AI Agents:
- Dodge
- Take cover
- …
- Dodge roll
- Ambush

Jeff Orkin. GDC'06 "Three States and a Plan: The A.I. of F.E.A.R."

# STRIPS Planning Language

- **ST**anford **R**esearch **I**nstitute **P**roblems **S**olver

- Uses predicate logic language to represent
  - **state** of environment;
  - **goal** to be achieved;
  - **actions** available to agents.

# Example: Monkey, Box and Banana
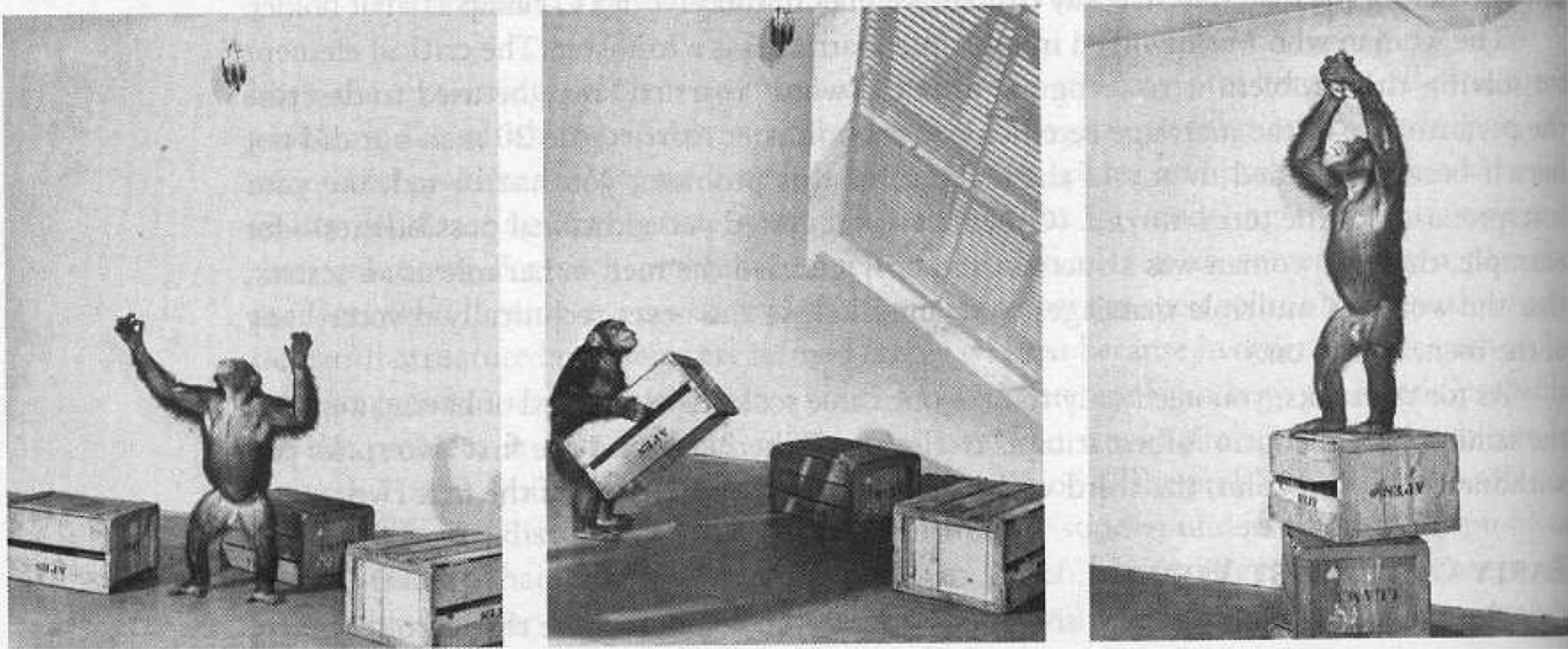


*A monkey is at the door into a room. A banana hangs from the ceiling in the middle of the room. The monkey wants the banana, but is not tall enough to get it. There is a box at the window which the monkey can climb on to get at the banana.*

# First-Order Predicates

- States can be described using:
  - MonkeyAt(x)      Monkey is at location x
  - BoxAt(x)          Box is at location x
  - BananaAt(x)      Banana is at location x
  - StandsOn(x)      Monkey stands on x
  - hasBanana        True if Monkey has Banana

0-ary predicate
(proposition)

# State Description

- State is a **conjunction** of **ground** and **function-free** atoms

- MonkeyAt(middle) ∧ BoxAt(window) ∧ BananaAt(middle) ∧ StandsOn(floor)



door            middle            window
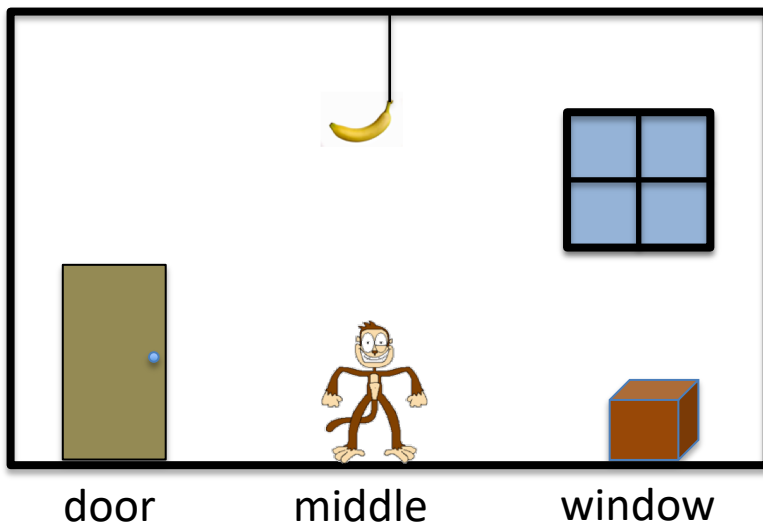
Closed world assumption:
¬hasBanana
¬MonkeyAt(window), …

*not stated – not true*

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# Initial State

- State in which planning starts
- MonkeyAt(door) ∧ BoxAt(window) ∧ BananaAt(middle) ∧ StandsOn(floor)



door          middle          window
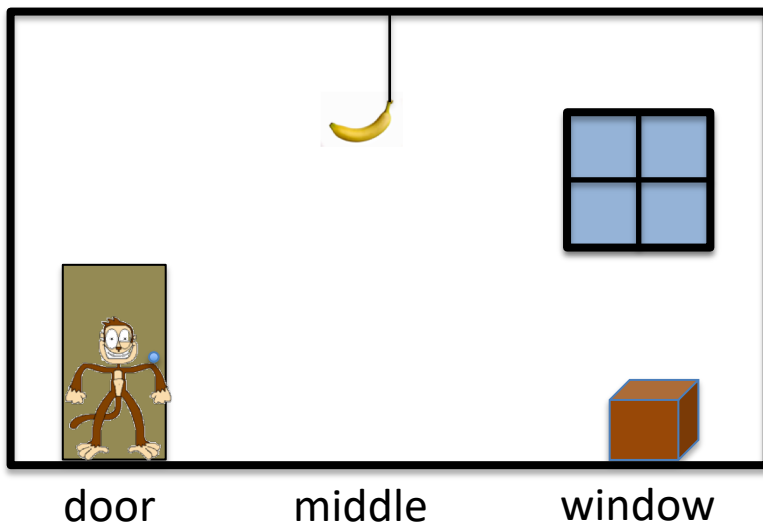
# Goal State

- Goal is a particular state:

  hasBanana

- A state S **satisfies** goal G if S contains all atoms from G (and possibly more)

**hasBanana** $\wedge$ MonkeyAt(door)

**hasBanana** $\wedge$ MonkeyAt(middle) $\wedge$ BoxAt(middle)

**hasBanana** $\wedge$ MonkeyAt(middle) $\wedge$ StandsOn(box)

- All satisfy the goal

# Actions

- Each action has
  - a *name*: which may have arguments;
  - a *pre-condition list*: list of facts which must be true for action to be executed;
  - a *delete list*: list of facts that are no longer true after action is performed;
  - an *add list*: list of facts made true by executing the action.
- Each of these may contain *variables*.

# Example: Walk



- `Walk(x,y):`
  - `pre:  MonkeyAt(x)`
  - `del:  MonkeyAt(x)`
  - `add:  MonkeyAt(y)`
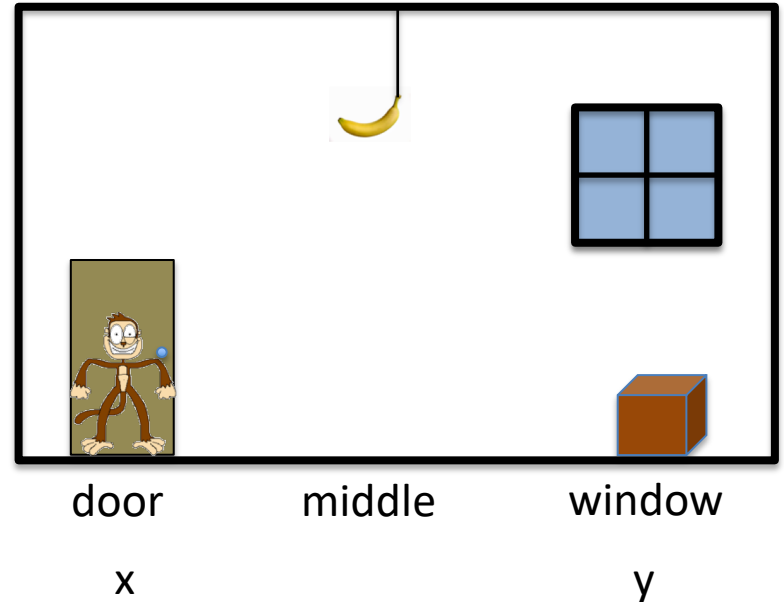
- Action instantiation:  `Walk(door,window)`
  - `x = door`
  - `y = window`

# Example: Other Actions

- `ClimbUp(x)`
  - `pre:    MonkeyAt(x), BoxAt(x), BananaAt(x),`
              `StandsOn(floor)`
  - `del:    StandsOn(floor)`
  - `add:    StandsOn(box)`
- `MoveBox(x, y)`
  - `pre:    MonkeyAt(x), BoxAt(x)`
  - `del:    MonkeyAt(x), BoxAt(x)`
  - `add:    MonkeyAt(y), BoxAt(y)`
- `TakeBanana(x)`
  - `pre: MonkeyAt(x), BoxAt(x), BananaAt(x),`
              `StandsOn(box)`
  - `del: -`
  - `add: hasBanana`
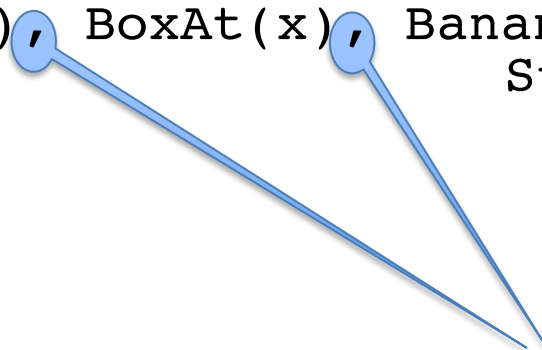
Instead of $\wedge$

# Action Effect

- The result of executing action A in state S is a state S' such that

- S' is identical to S except
  - Any atom from the *add list* of A is added to S'
  - Any atom from the *delete list* of A is deleted from S'
  - All other atoms do not change their value!

Frame condition

# STRIPS Plan

- A sequence (list) of actions with variables replaced with values
  - Move(door,window)
  - MoveBox(window, middle)
  - ClimbUp(middle)
  - TakeBanana(middles)

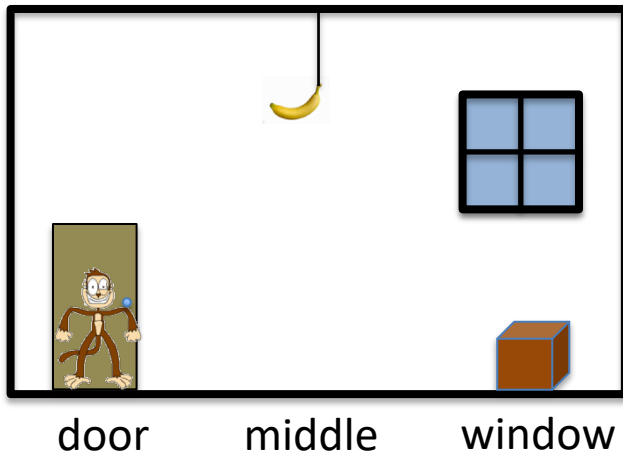door         middle         window
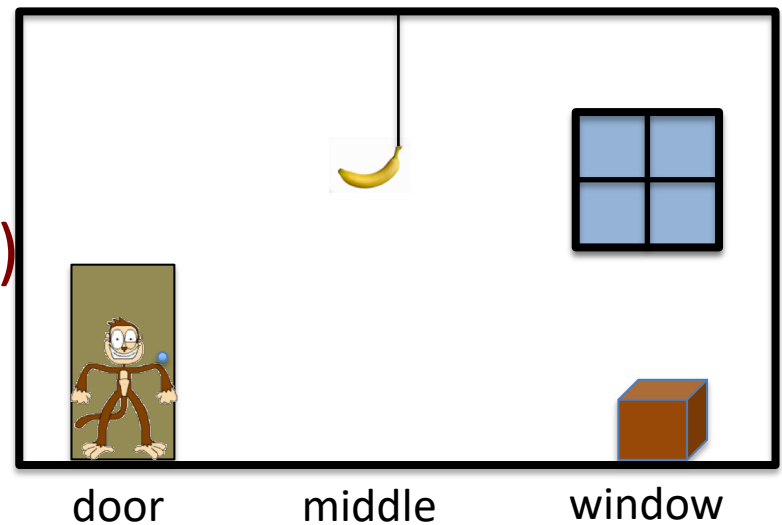
# Planning Algorithm

- There are numerous approaches to planning
  - Progressive/regressive planning
  - Partial planning
  - *Graphplan*
  - Reduction to sat
  - …
    - There is a planner competition

state of
goal    environment    possible actions

Planner

plan to achieve goal
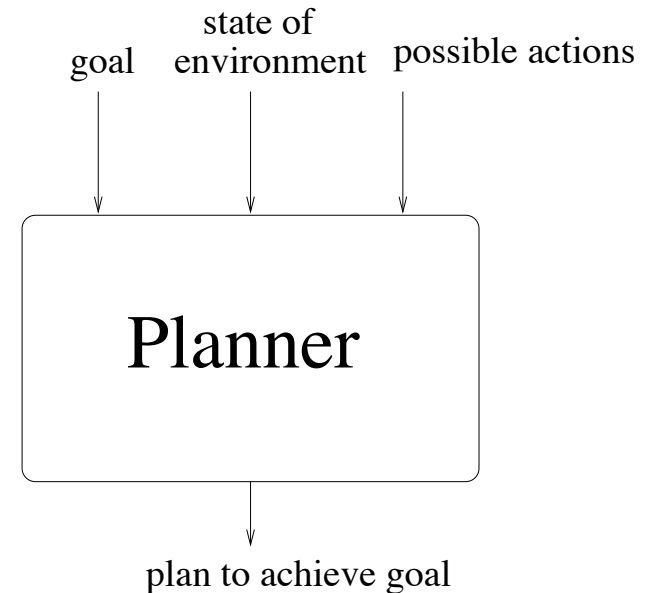
# Planning in F.E.A.R. (1)

- States represented as arrays
  - One value per predicate

[door, window, middle, floor, false]

MonkeyAt
enum

BoxAt
enum

BananaAt
enum

StandsOn
enum

hasBanana
Boolean

Goal:
   [_, _, _, _, true]

door    middle    window
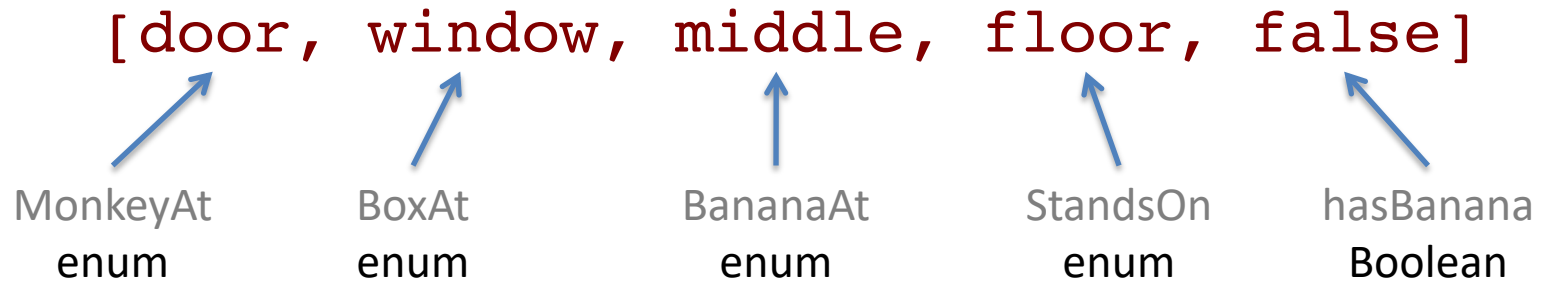
# Planning in F.E.A.R. (2)

- Procedural `pre`, `add` and `del`

- E.g.
  - `Walk(x,y):`

```
if (state[0]== x) {
    state[0] = y;
}
```
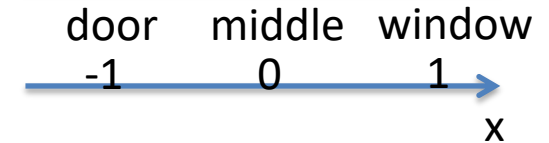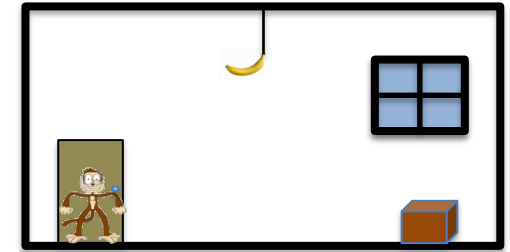
[door, window, middle, floor, false]
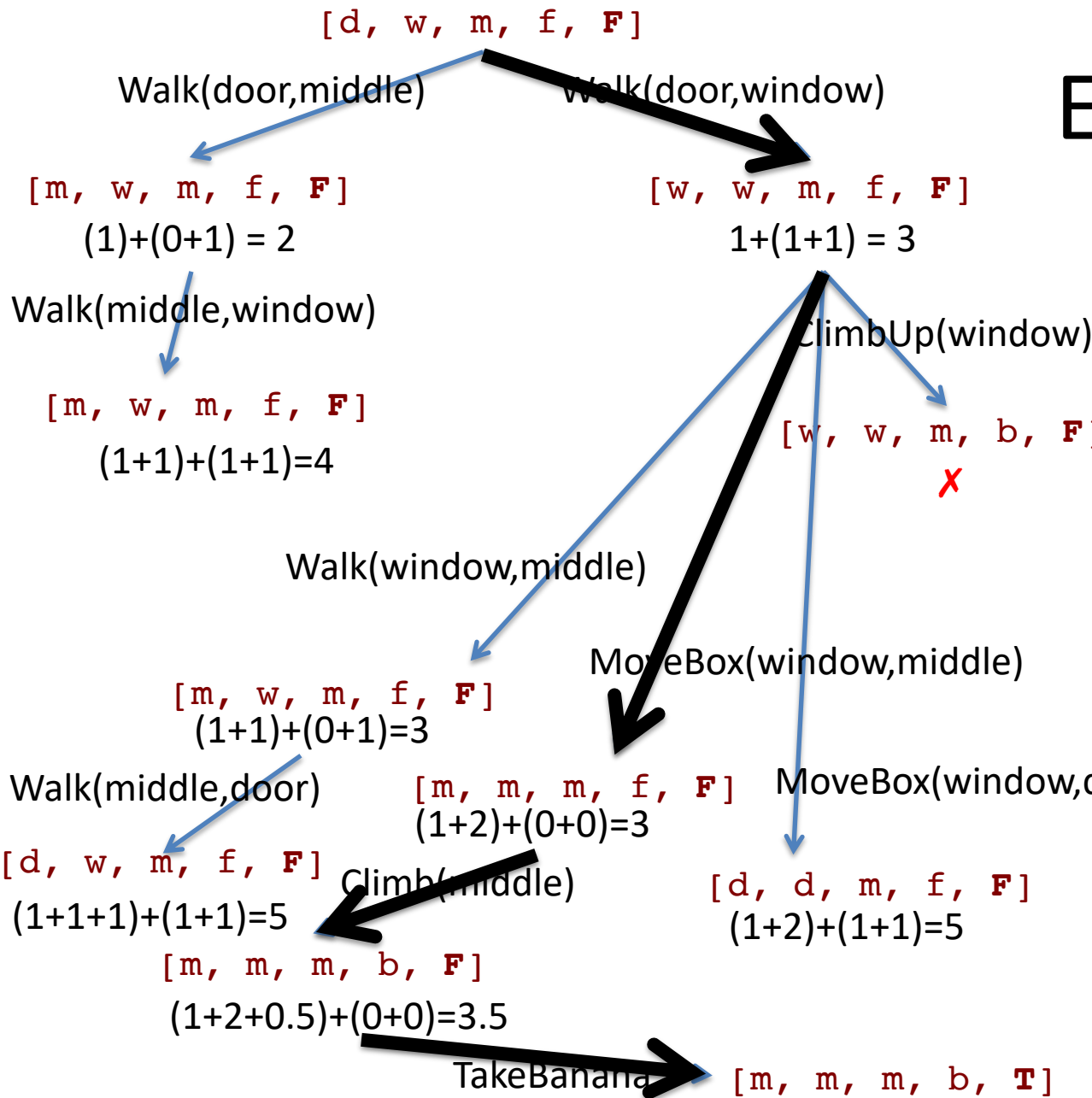
# Planning in F.E.A.R. (3)

- Assign costs to actions
  - `Walk`          costs 1
  - `MoveBox`       costs 2
  - `ClimbUp`       costs 0.5
  - `TakeBanana`    costs 0.1


- Use A* search algorithm to find a plan
  - Heuristic needed

# Example

[d, w, m, f, **F**]

Walk(door,middle)      Walk(door,window)

[m, w, m, f, **F**]                [w, w, m, f, **F**]

(1)+(0+1) = 2                    1+(1+1) = 3

Walk(middle,window)

ClimbUp(window)

[m, w, m, f, **F**]

(1+1)+(1+1)=4      [w, w, m, b, **F**]

✗

door   middle   window
-1      0      1

x

**Heuristic**:
monkey-middle distance +
box-middle distance

Walk(window,middle)

MoveBox(window,middle)

[m, w, m, f, **F**]
(1+1)+(0+1)=3

Walk(middle,door)   [m, m, m, f, **F**]  MoveBox(window,door)

(1+2)+(0+0)=3

[d, w, m, f, **F**] Climb(middle)     [d, d, m, f, **F**]

(1+1+1)+(1+1)=5                (1+2)+(1+1)=5

[m, m, m, b, **F**]

(1+2+0.5)+(0+0)=3.5

TakeBanana   [m, m, m, b, **T**]

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# Planning in Games

- Quite an effort even with A*
- Most time spent on *pathfinding*
  - *Where* to go rather than what goal to pursue
    - Will address the pathfinding problem next

- Hierarchical plans:
  - In order to carry out a higher-level plan, the planner must first refine the plan in order to produce a complete plan in terms of ground-level operations.

# Hierarchical Task Network (HTN)

- use **abstract operators** to **incrementally** decompose a planning problem from a **high-level goal** statement to a **primitive plan network**

- **Primitive operators** represent actions that are **executable**, and can appear in the final plan

- **Non-primitive operators** represent **goals** (equivalently, **abstract actions**) that require further decomposition to be executed

# HTN operator: Example

```
OPERATOR decompose
PURPOSE: Construction
CONSTRAINTS:
    Length (Frame) <= Length (Foundation),
    Strength (Foundation) > Wt(Frame) + Wt(Roof)
        + Wt(Walls) + Wt(Interior) + Wt(Contents)
PLOT: Build (Foundation)
   Build (Frame)
      PARALLEL
         Build (Roof)
            Build (Walls)
      END PARALLEL
      Build (Interior)
```
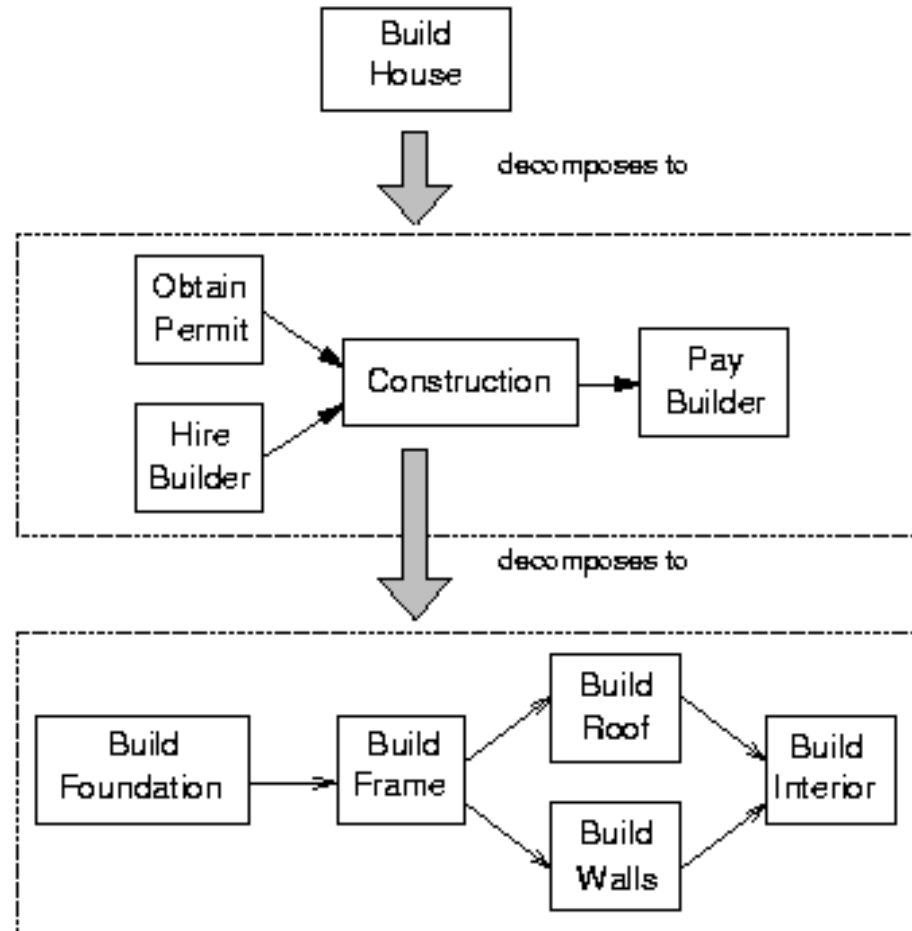
# HTN planning: Example

# Some Games Using GOAP Architectures

- F.E.A.R. 2005
- Condemned: Criminal Origins 2005
- S.T.A.L.K.E.R.: Shadow of Chernobyl 2007
- Ghostbusters 2008
- Silent Hill: Homecoming 2008
- Fallout 3 2008
- Empire: Total War 2009
- F.E.A.R. 2: Project Origin 2009
- Demigod, 2009
- Just Cause 2  2010
- Transformers: War for Cybertron  2010

http://web.media.mit.edu/~jorkin/goap.html