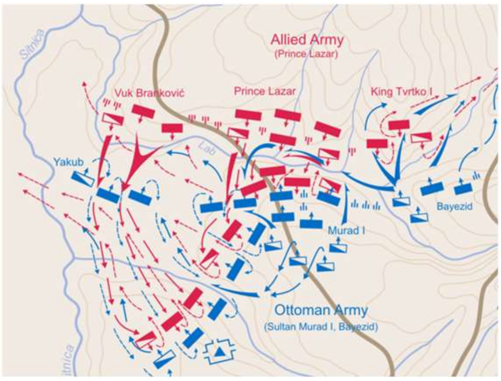


3D VideoGames
Università degli Studi di Milano

Artificial Intelligence for 3D Games

Marco Tarini



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Course Plan

- lec. 1: Introduction ●
- lec. 2: Mathematics for 3D Games ●●●●●●
- lec. 3: Scene Graph ●
- lec. 4: Game 3D Physics ●●●● + ●◖
- lec. 5: Game Particle Systems ◗
- lec. 6: Game 3D Models ●◖
- lec. 7: Game Textures ◗●
- lec. 9: Game Materials ◖
- lec. 8: Game 3D Animations ◗●●
- lec. 10: 3D Audio for 3D Games ●
- lec. 11: Networking for 3D Games ●
- lec. 12: Artificial Intelligence for 3D Games
- lec. 13: Rendering Techniques for 3D Games ●

bridge lectures

For a general, deeper discussion of many of the subjects of this lecture, see the course «AI for videogames»

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AI / ML in the real world

- Huge advancement in recent years!
  - e.g., with CNN
  - e.g., in data mining
  - e.g., in computer vision
- Main reasons:
  - computational power: tera-FLOPS by GPUs
  - huge collection of data available for training

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"AI" in games: examples of uses

- Procedural generation of...
  - levels
    - e.g., maze generation, generation of (**solvable**!) puzzles...
  - terrain
  - music, models, scenes, enemies...
- Automatic dynamic tuning of difficulty
  - learning when/how to increase/decrease difficulty
  - virtual "movie director" concept (e.g.: "time to intensify action: spawn more zombies" / "time to slow down pace: spawn less zombies")
- Ranking
  - algorithms to estimate rank of players, from game outcomes (e.g., in chess / go communities)
- An intelligent tutor / advisor
  - e.g., a non-intrusive game tutorial telling players only what they (seem to) need to get

e.g., look up "Sokoban"

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"AI" in games: one promising use (a trend in research)

- Procedural Character Animations
  - i.e., "learn how to run, walk, stand up, …"
  - *Input:*
    - a character body: skeleton structure, with "muscle" actuator → skeleton
      - muscle = springs with AI-controlled strengths
    - a given task, e.g.
      - go as fast as possible in this direction
      - stand up from prone position
      - reach the highest possible point (i.e. jump)
      - …

      → trivial to measure (scoring function)
  - *Output:*
    - how to activate muscles to do it → skeletal animations
    - (minimizing used energy)
  - *How:*
    - genetic algorithms, Evolution strategies
    - physical simulation to score candidates

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AI in games, the paradigmatic use: NPC behavior

Widely different AIs for widely different "NPC"s!

- A wild animal
- An (enemy) soldier
- A squad leader
- An (innocent) villager / bystander
- An individual in a crowd / flock / herd ← "flocking" algorithms or "crowd simulation"
- A racing car driver
- A spaceship pilot / gunner
- A companion / buddy
- An (enemy) commander ← the AI player in an RTS
- A zombie
- A heat seeking missile
- A WWII ace pilot
- …

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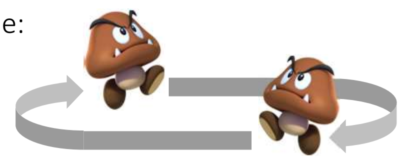
“AI” for NPC behavior: Interactive Agents (IA)

- Many differences with “problem-solving” AI:
  - “cheating” completely possible
    - e.g., info “magically” available to the Interactive Agent
  - real-time response always needed
    - very frequent decisions of the Interactive Agent (30-60 Hz!)
    - “on-line”, and “soft real time”
  - sub-optimal often *required*
- NPC behavior also determined by:
  - story telling needs
    - e.g., follow designed behavior, adhere to designed personality
  - difficulty tuning (e.g., for enemy NPCs)
  - need to interesting / fun (≠ optimal!)
  - need to be realistic / believable
    - not necessary, coherent / logical / optimal

NPC behavior: designer perspective

NPC behavior is not *necessarily*
- “intelligent”
- nor even complex

Rather, NPC behavior often needs to be:
- intuitable / predictable
- learnable
- understandable
- story driven
- exploitable (interesting to exploit)



Allowing game-designers to:
- tune difficulty
- elicit interesting strategies by the players
- make a given strategy rewarding

Marco Tarini
Università degli Studi di Milano

Game AI -vs- AI to solve Games

In a word:
entertainment, not *problem solving* !

to find more about AI to (optimally) *play* games, look for:

- min-max algorithms (with pruning)
  - algorithms to solve
    complete knowledge, turn based games
- Nash equilibrium (from Game Theory)
  - a concept to address non cooperative games

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~~Intelligent Agent~~
Interactive Agent (Believable Agent)

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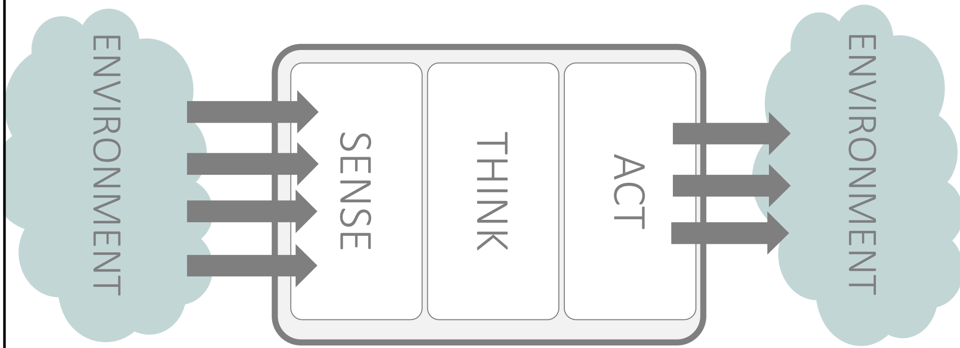
~~Intelligent Agent~~
Interactive Agent (Believable Agent)



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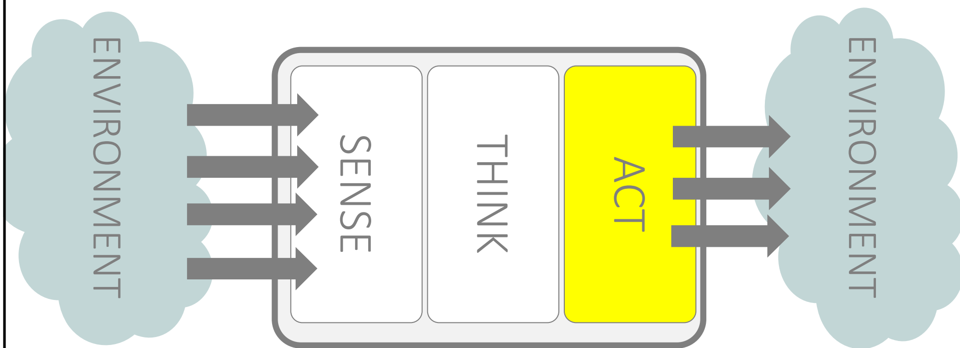
~~Intelligent Agent~~
Interactive Agent (Believable Agent)



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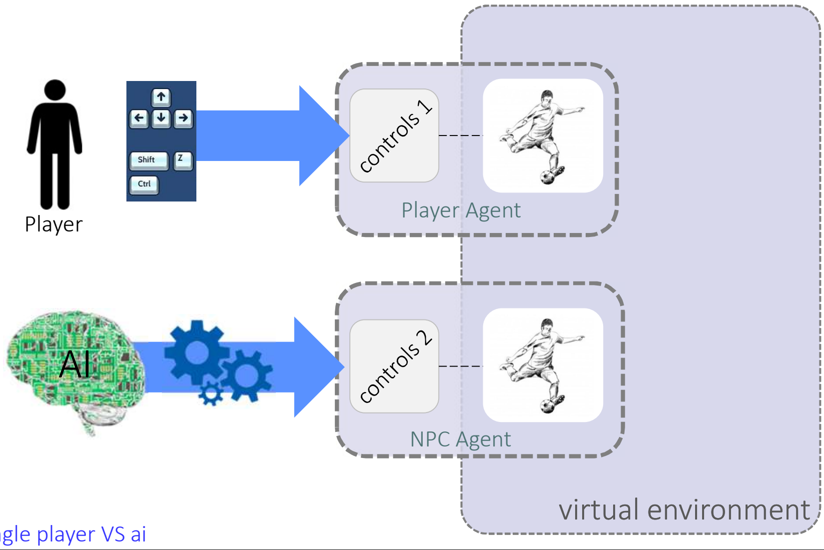
Controls and Agent

(a useful abstraction)



scenario: single player VS ai

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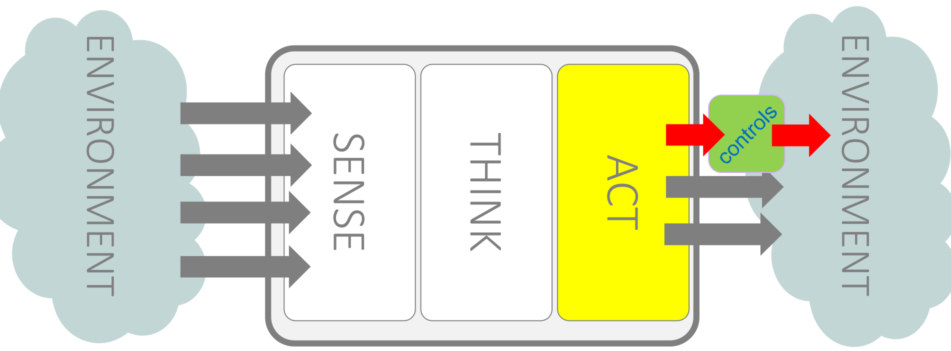
Interactive Agent



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Acts : in robotics, “actuators”. In 3D games? Examples…

- Produce “Controls”
  - associated to the NPC character
  - a non-cheating AI controlled NPC (simulates a human player)
- Trigger skeletal animations
- Cause movements / displacements of IA avatar
- Play sounds
  - voices, yells
- Issue orders (to other agents)
  - e.g., in an RTS
- Trigger effects on game-logic
  - e.g., objects appearing, doors unlocking, HP decreased / healed, money spent / gain, etc

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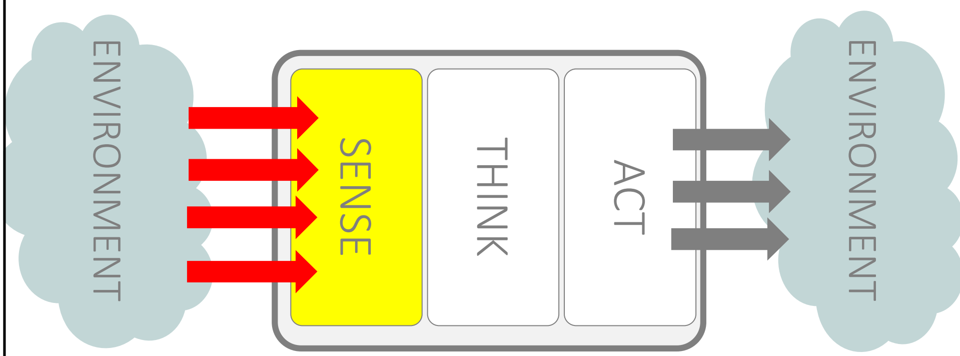
Interactive Agent



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Sensing

In robotics, by “Sensors”. In games?

- Gather info (“percepts”)
  - which will be used for the “think” phase
  - NB: this info must often persist in the “mind” of the agent!
    - more abut this in the next phase
- Performed at regular intervals, or “on demand” (by the AI)
- Simulating senses in a 3D world…
  - Sight
    - way1: ray-casting
      - (uses ray-VS-hitbox collision)
    - way2: synthetize then analyze probe renderings! (accurate, expensive)
  - Hearing, Smell
    - simple testing against influence sphere
  - Touch / Proximity sensing:
    - collision detection / spatial queries
- …or “cheating” (common)
  - “magically” sensing data straight from the game status
  - (simple, and often ok – when plausibility not compromised too much)

e.g. the scene graph

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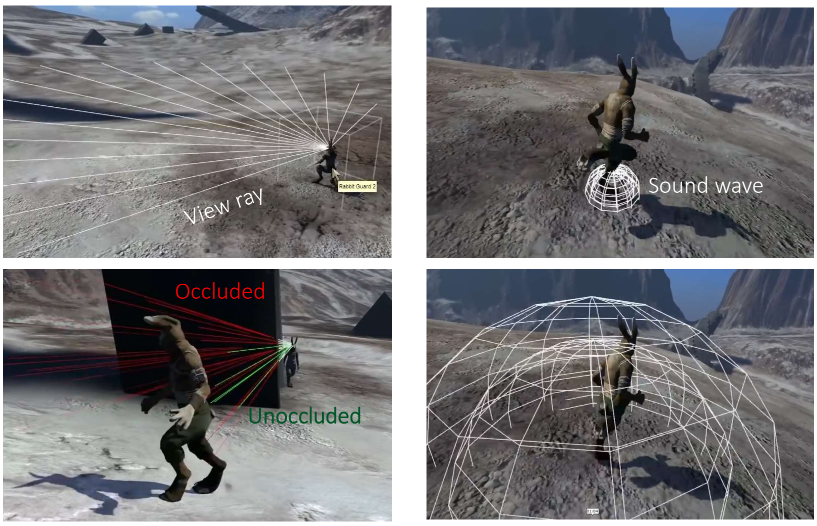
Simulating senses in a 3D environment



Sight Hearing

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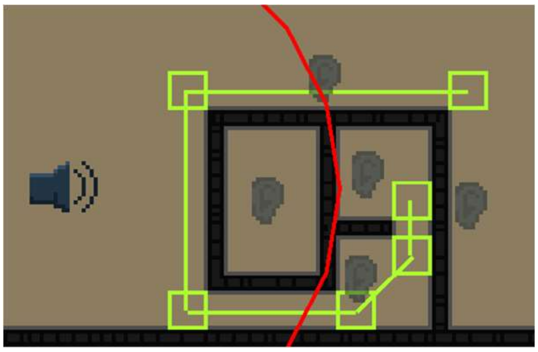
Simulating senses in a 3D env. Example: sound (with echos)

- Pathfinding for echoes simulation



example from **Tendril: Echo Received** by **cepnox** https://forums.tigsource.com/index.php?topic=60709.0

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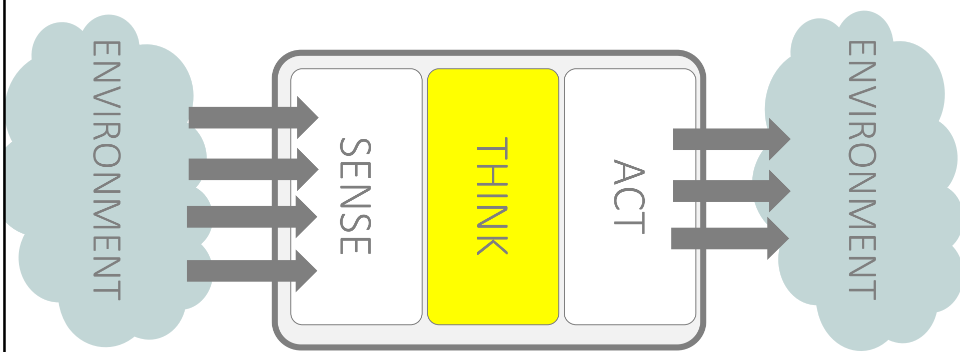
Interactive Agent (IA)



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Thinking phase (aka Planning): includes status / memory of the AI

- Status of the AI: modeling the “mind” of the AI
  - current goals
    - hi-level, low-level… (more about this later)
  - internal model of the environment (as perceived by IA)
    - accumulates info gathered by senses
    - occasionally, also obtained
      from (simulated) communication with other NPCs
    - can be arbitrarily complicated, or very simplistic
  - moods/mindsets/dispositions (e.g., toward player)
    - internal values modelling the varying lvl of:
      fear, patience, rage, distress, confidence,
      hunger/thirst, fondness toward player, etc
- persistence of these mind elements
  can be made more or less prolonged
  - e.g., deleted, to model agent forgetfulness
  - e.g., deleted, to reflect awareness that data went stale

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Thinking phase (aka Planning) Goals of the AI

- Typically, Hierarchical Logic
  - Hi-level Decisions => Hi-Level Goals
    - update: not very often
  - …
  - Lower-level Goals
    - update: more often
  - …
  - Lowest-level Goals
    - solving low level tasks
  - Acts!

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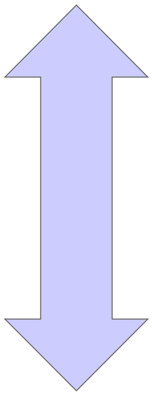
Authoring an AI for an NPC

- Cascading goals
  - Hi-Level Goals
  - Mid-Level Goals
  - Low-level Goals
  - Lower-level Goals
  - …
  - …
  - Acts



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Authoring an AI for an NPC: *classic approach*

- Cascading goals
  - Hi-Level Goal ← FSM
  - Mid-Level Goal ← Scripts
  - Low-level Goal ← Scripts / Hard-Wired Subroutines (by the AI engine)
  - Acts

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Example: terrified bystander

- Cascading goals
  - Hi-Level Goal — I'm "*Escaping*"
  - Mid-Level Goal — I'm going for *that* hiding spot
  - Low-level Goal — I'm passing through here (find route to it -- navigation)
  - Acts — (actual movements + "panicked-run" animation)

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Example: WWII soldier

- Cascading goals
  - Hi-Level Goal — I'm "*Sniping*"
  - Low-Level Goal — I'm going for *that* enemy soldier
  - Lowest-level Goal — I'm aiming at *this (x,y,z)* (the center of his exposed head)
  - Acts — crouched-aim animation + turn left by 2.5 deg + IK to re-orient rifle vertically

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Example: guard

- Cascading goals
  - Hi-Level Goal — I'm *"Patrolling"*
  - Low-Level Goal — I'm going to my 3rd *nav-point*
  - Lowest-level Goal — I'm passing through *here* (find route to it – navigation)
  - Acts — actual movements + "alerted-walk" animation

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Thinking phase (aka Planning): about the lowest-level goals…

- Typically, Hierarchical Logic
  - Hi-level Decisions => Hi-Level Goals
    - update: not very often
  - …
  - Lower-level Goals
    - update: more often
  - …
  - Lowest-level Goals
    - solving low level tasks
  - Acts!

such as…
each instance is a mini problem-solving task

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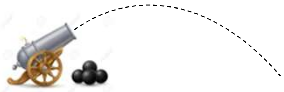
Examples of common *lowest* level tasks (1/2)

- Face towards something
  - tip: remember *atan2*
  - actions: turn left or right
- Aim a weapon
  - e.g. including ballistic
    - to predict, use *analytical* physics: pos(t) = f(t)
  - e.g. including "leading the target"
    - i.e. aim at where target *will* be at time of impact
- Avoidance / dodging
  - of an incoming bullet
- …



```
vec3 target_pos = target.pos;

float target_dist = dist( me.pos , target_pos );
float eta = target_dist / bullet_speed;
target_pos = target.pos + target.vel * eta;

face_towards( target_pos );
```

repeat a few times
(converges really fast)

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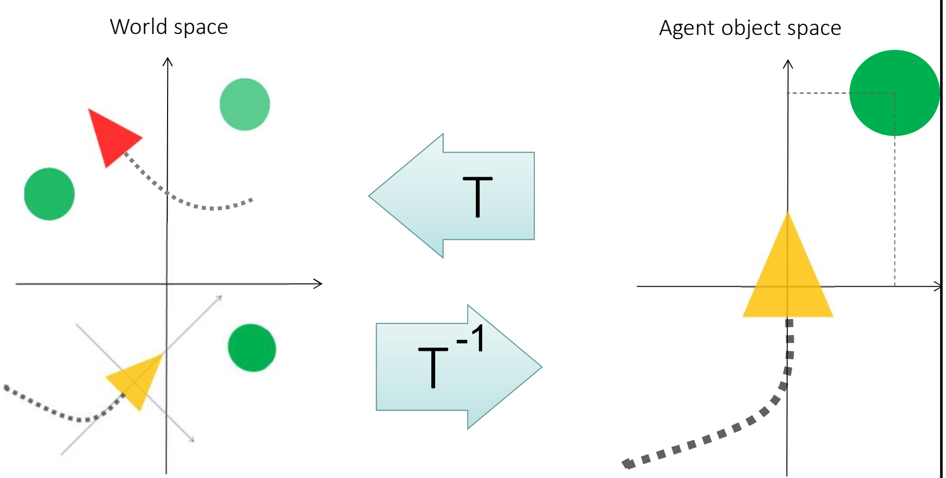
Often easier to think in local object space of the IA



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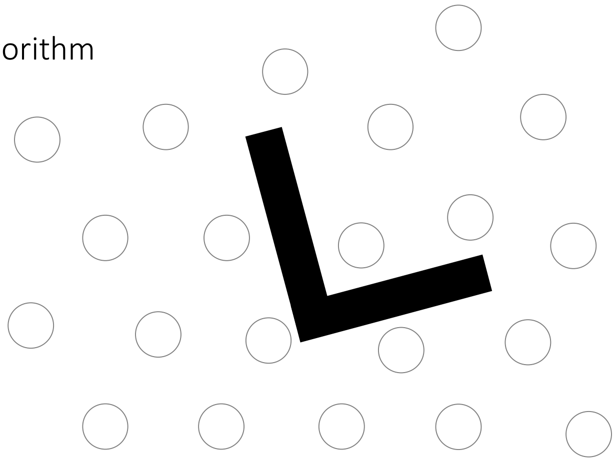
Common lowest level tasks 2/2: Path finding

- Path finding
  - Dijkstra's algorithm
  - A* search



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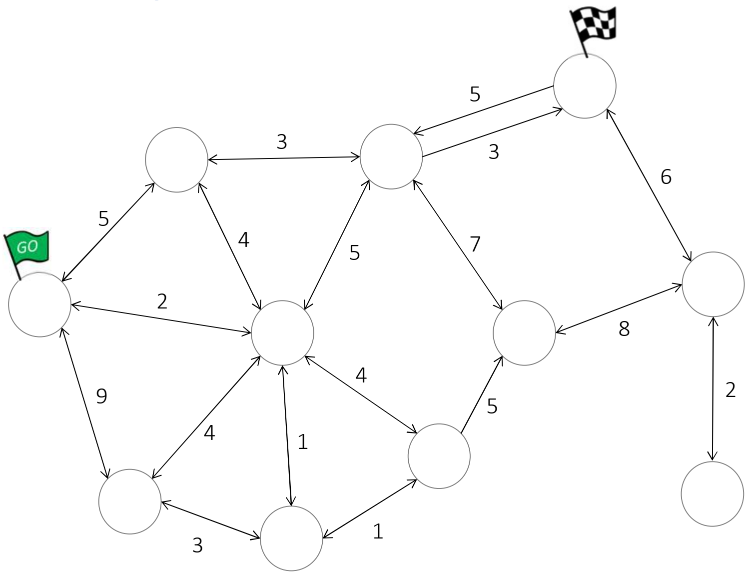
Dijkstra algorithm



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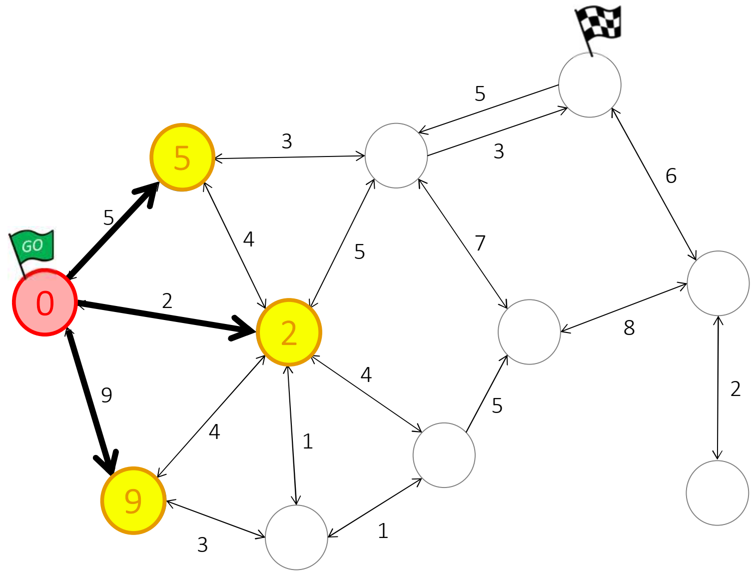
Dijkstra algorithm



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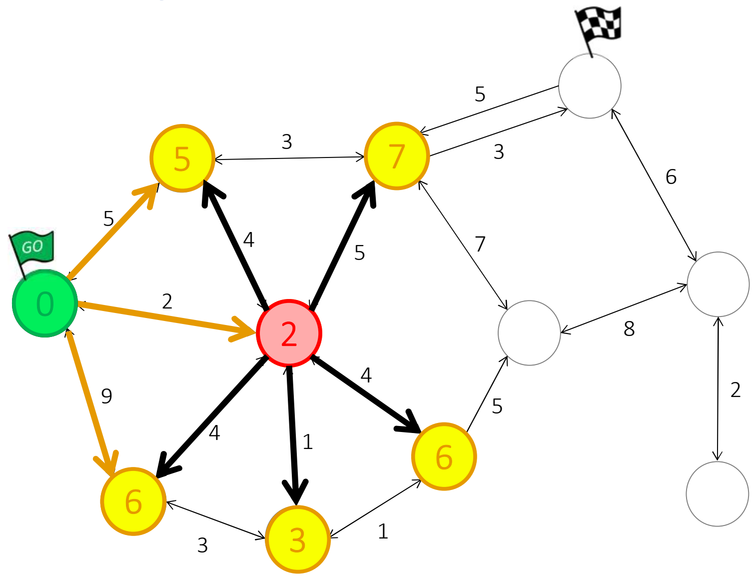
Dijkstra algorithm



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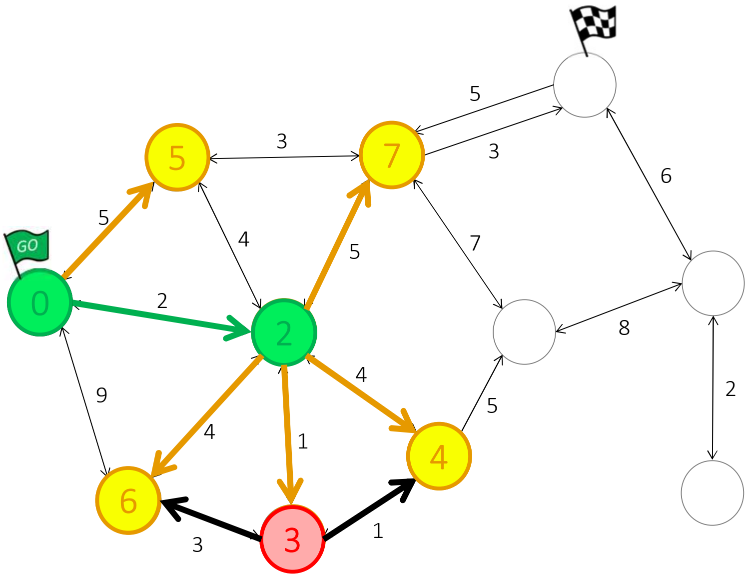
Dijkstra algorithm



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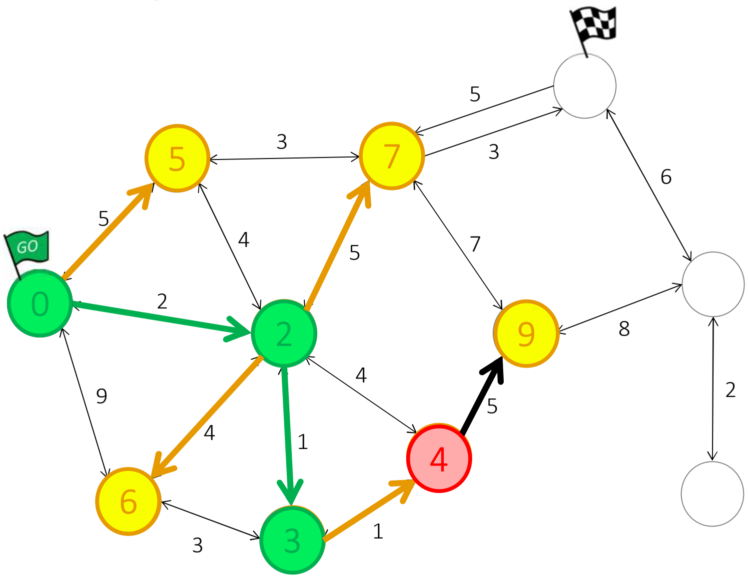
Dijkstra algorithm



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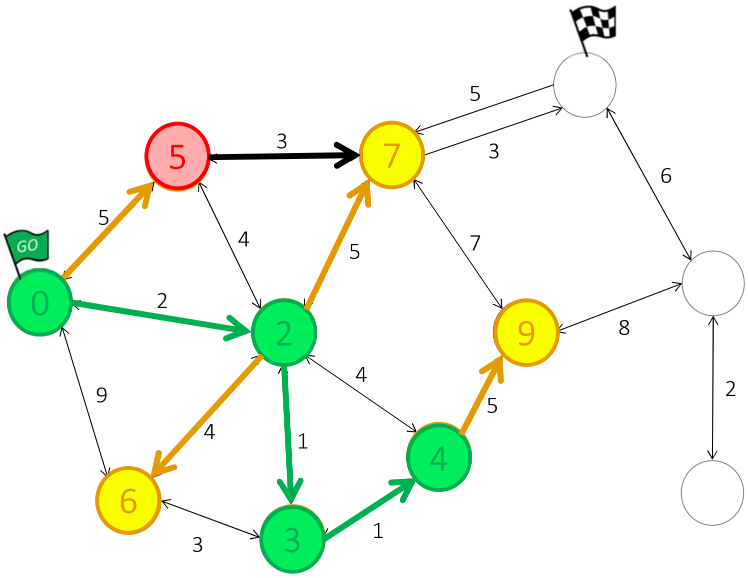
Dijkstra algorithm



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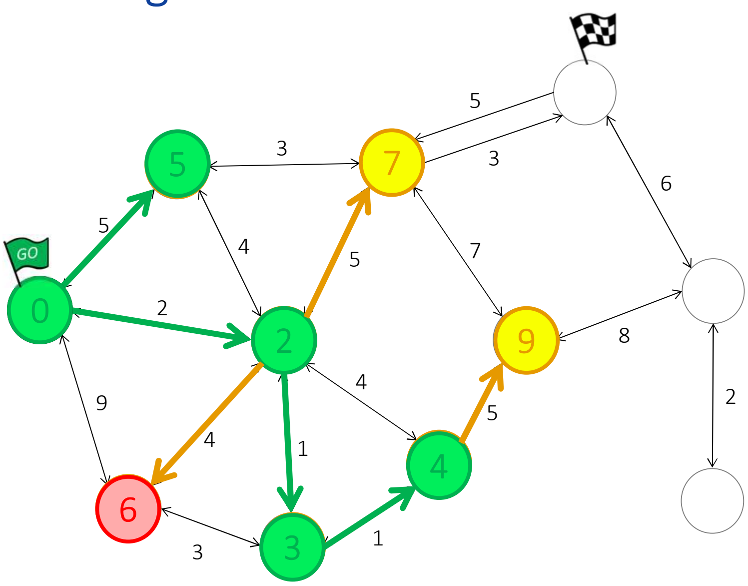
Dijkstra algorithm



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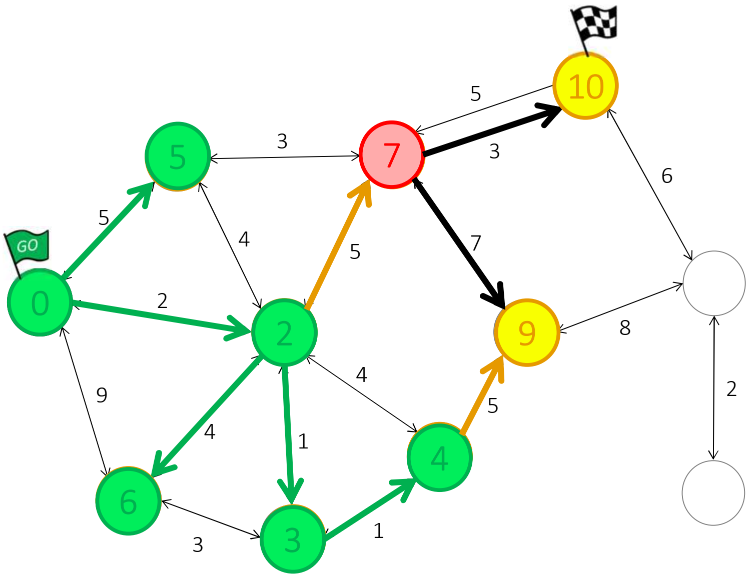
Dijkstra algorithm



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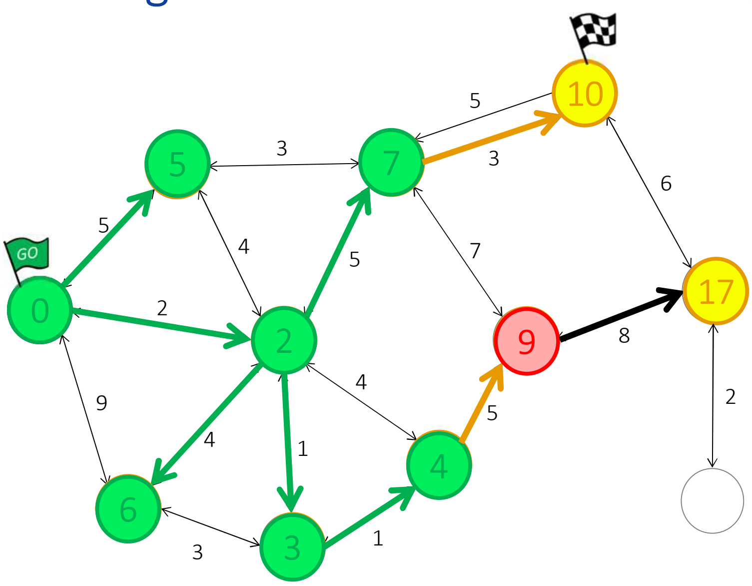
Dijkstra algorithm



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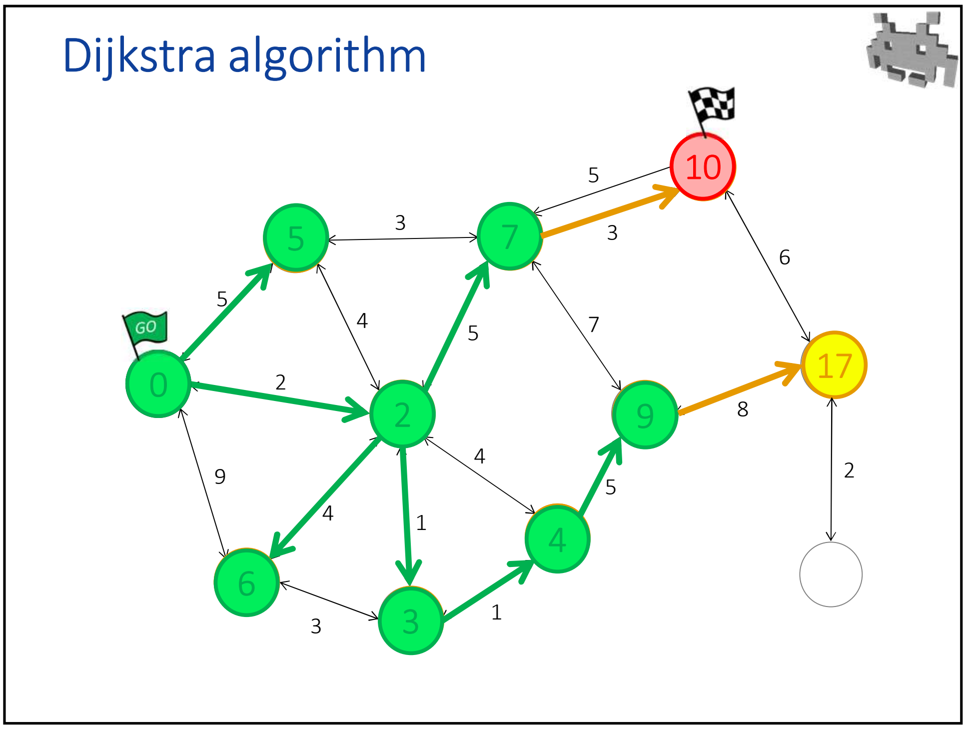
Dijkstra algorithm
10
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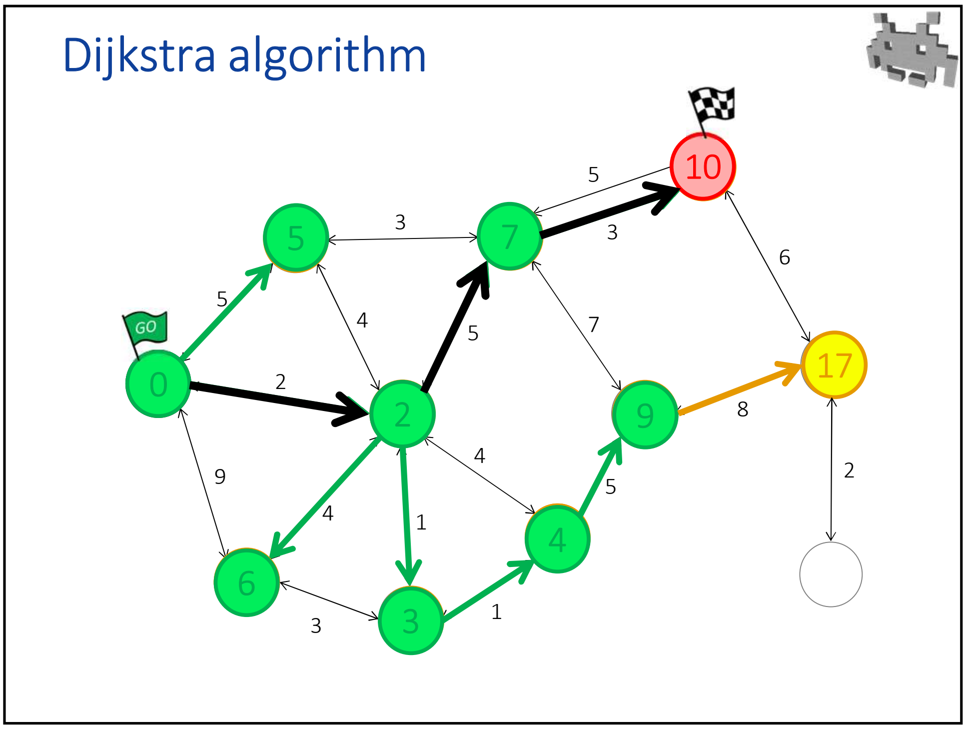
Dijkstra algorithm
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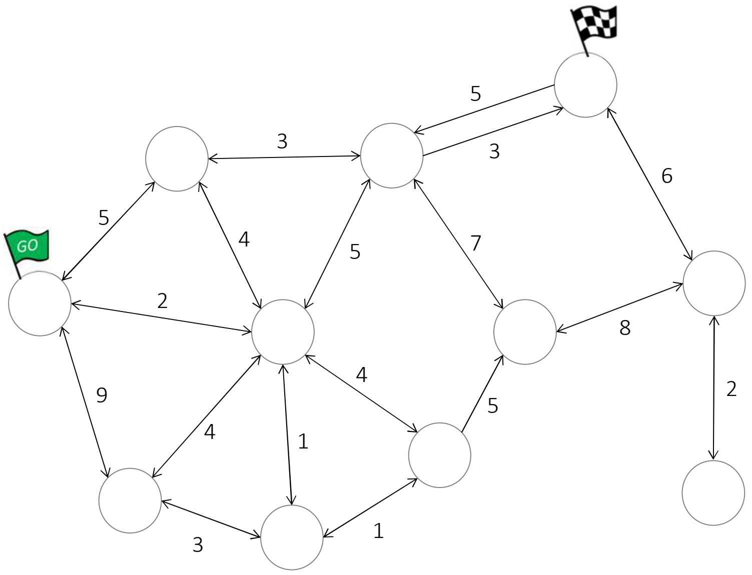
A* search



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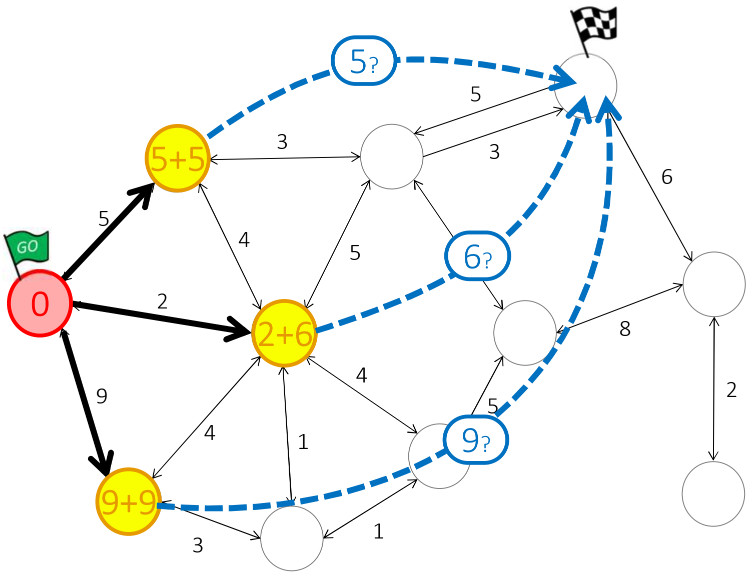
A* search



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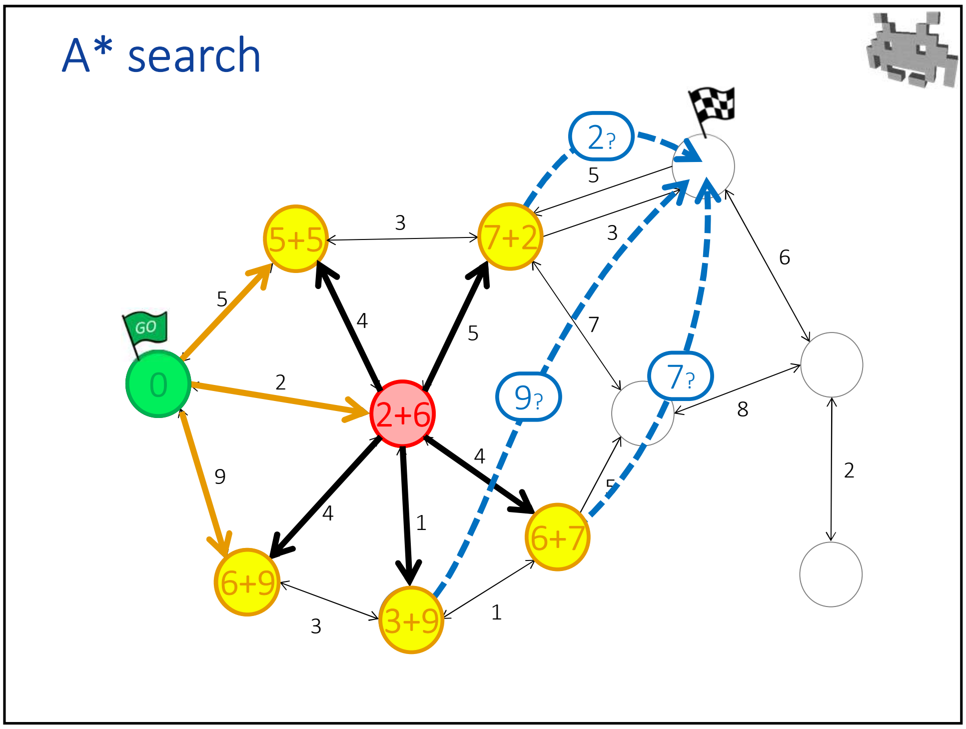
A* search
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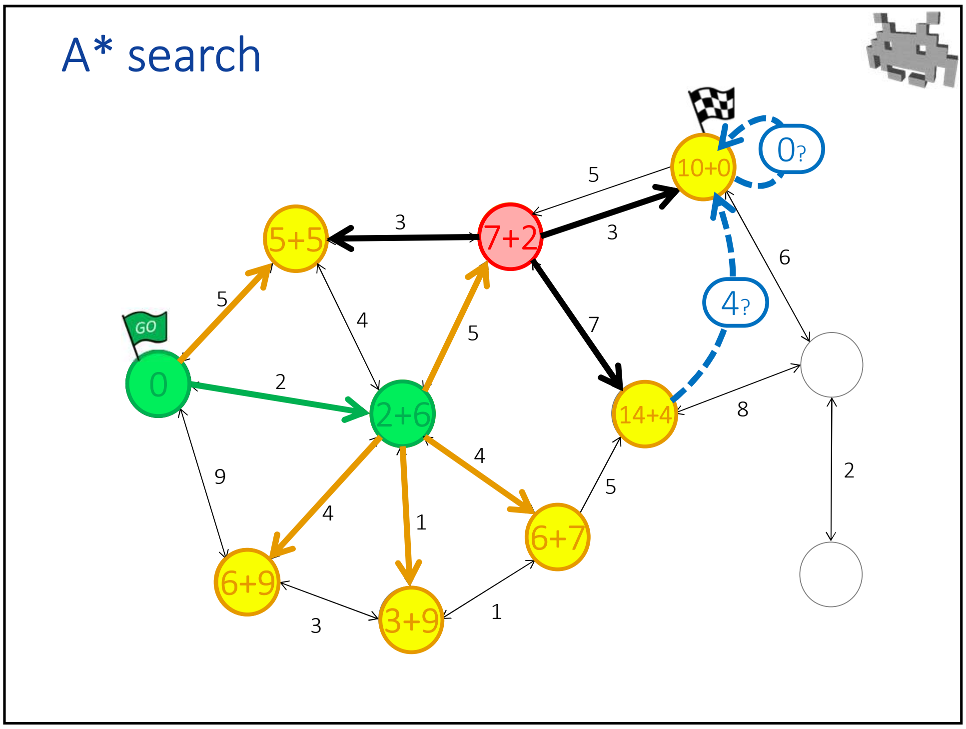
A* search
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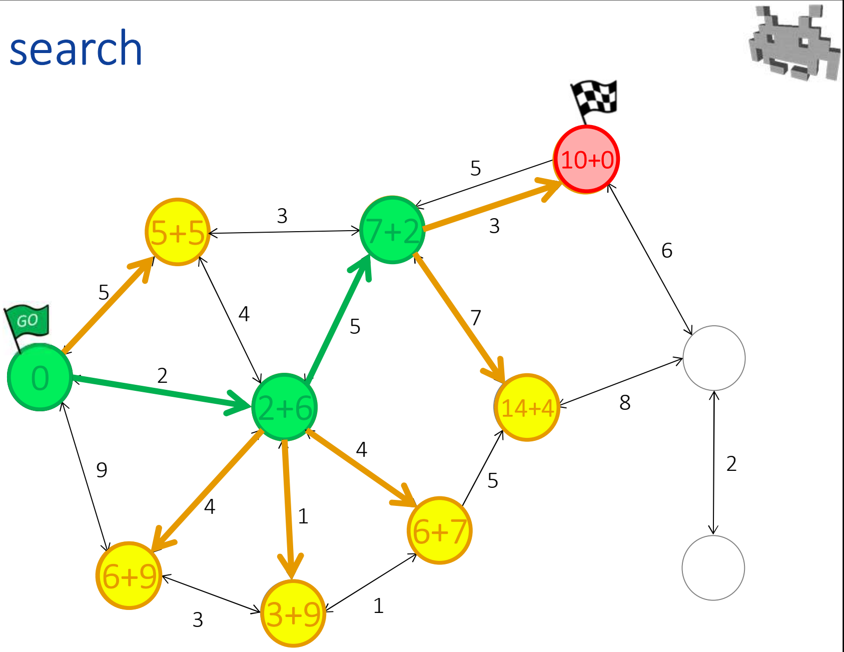
A* search



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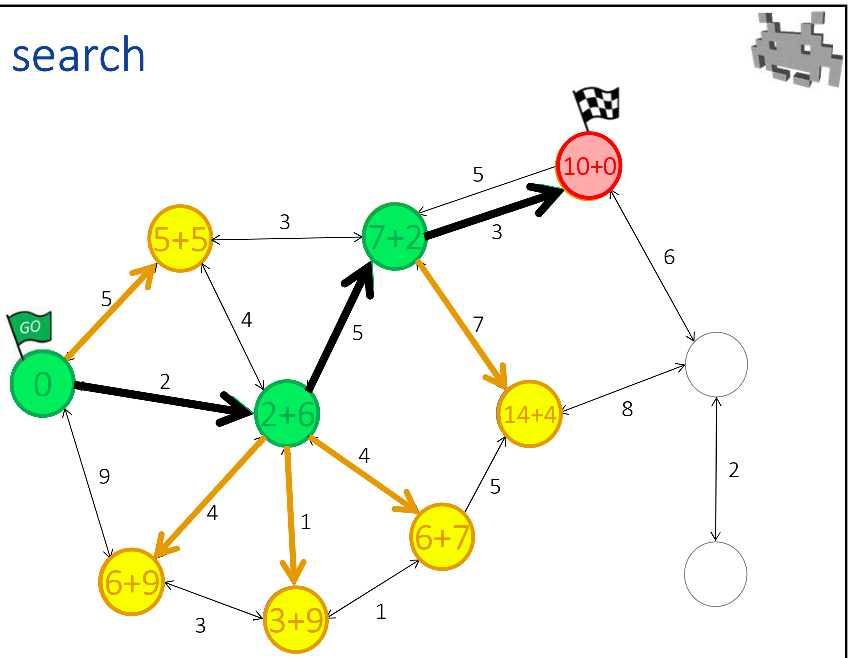
A* search



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Input of Dijkstra algorithm: notes.

- graph (nodes, arches)
  - nodes = locations where the Interactive Agent can be
  - arches = paths to go from node A to node B, for example…
    - …a straight path from A to B (to be run / walked)
    - …a potential jump reaching B from A
    - …a drop down from A to B (note: arches are not necessarily bidirectional!)
- a (non-negative!) cost, associated to each arch
  - e.g., estimated time needed to go from A to B
  - in general, this reflets the willingness of the IA to pass through there
  - flexible! easy to adapt costs to reflect specific scenarios, e.g.:
    - “that path is vulnerable to enemy shooting”: higher cost
    - “that path is across lava. It hurts! (costs HP)”: higher cost
    - “that path occludes friendly fire lines”: higher cost
    - “I risk being spotted on that path (I don’t want to be seen)”: higher cost
- Start node and Destination node(s)
  - Destination nodes can be multiple

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Dijkstra algorithm: notes.

- Any nodes is visited / processed only once
  - Or zero times! Not all nodes are visited
- The algorithm requires to keep track of a set of “active” nodes
  - (in yellow, in the graph)
  - nodes are removed and added to this set
  - it is necessary to find the minimal element in this set
  - → ideal data structure for this : heap (priority queue)
- Output: path from Start node to Dest node
  - it’s guaranteed to be the minimal-cost path
  - the path with the minimum associate cost
  - also, the cost of this path
  - also, a minimum span tree of all visited nodes (results can be reused for all visited nodes)

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A* algorithm: (“A-star”) notes

6+7

Minimal cost to go from Start to here

Estimated (minimal!) cost to go from here to Dest

- Dijkstra not efficient enough
  - visits too many nodes
  - explores paths which are obviously wrong
  - it’s greedy, only guided only by distance from Start)
- “A* search” is a variation. Main idea:
  smarten up! with an estimate of the remaining distance to Dest
  - function $h(X)$ – with X being a node:
    returns an estimate of the *minimal* cost to go from x to Dest
    - h is provided by the user
    - it must be: fast (constant time, possibly)
    - it must be: strictly optimistic!
      produced estimations AT MOST the real cost (never more)
      – underestimation ok, overestimation NOT OK
    - good example: simple Euclidean distance (disregarding obstacles!)
- Output: *still* the optimal path
  - as long as the estimator never overestimates costs
  - the better the estimations, the quickest the algorithm
    - e.g.: if $h(X)$ is always 0 (technically, still correct): A* does the same as Dijkstra
    - e.g.: perfect estimation (hypothetical case): A* only explores nodes in optimal path

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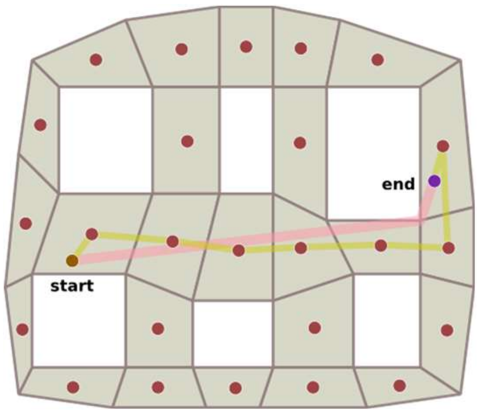
Which graph to use for A* / Dijkstra in a 3D game?

- Answer: Nav-meshes (“Navigation meshes”) or AI meshes
  - a polygonal mesh
  - faces: graph nodes (places where the NPC can stand)
  - edges between faces: graph arches (passage the NPC can traverse)



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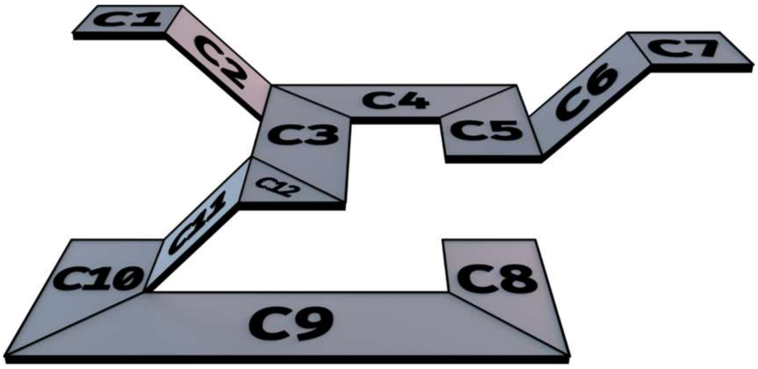
Nav Mesh (manually designed)



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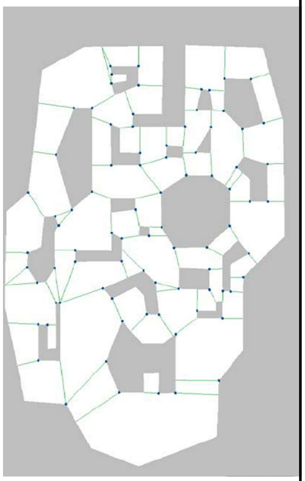
Baking a 3D Nav-Mesh

- Input:
  - the scene graph
  - static 3D collision proxies in its nodes
  - a proxy for the NPC (e.g. a capsule)
- Baking
  - Find nodes
    - places where an NPC can stand. How: collisions tests
  - Find arches, for each type of movement
    - Walk: dynamic collision test to determine if it is possible to go from A to B
    - Jump up: heuristics about height differences
    - Jump down: other 3D spatial heuristics
  - Add costs (e.g. time estimations)
- Add ad-hoc or dynamic behavior
  - E.g. add/remove arches when a door gets unlocked/locked,
  - Add/remove arches when a magic teleport portal is activated/deactivated,
  - etc



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Customizing A* / Dijkstra

- Cost function ≠ time or distance
- Customize the costs freely
  - E.g. doors: add cost to open them
  - E.g. in a shooter:
    - Increase cost of nodes currently "under friendly fire" ("don't get in the line of fire of your friends")
    - Increase cost of exposed nodes ("don't get caught in the open")
- Remember: A* needs underestimations
  - Decreasing costs requires care
  - E.g. add teleport doors? Be careful

find out with 3D raycasts

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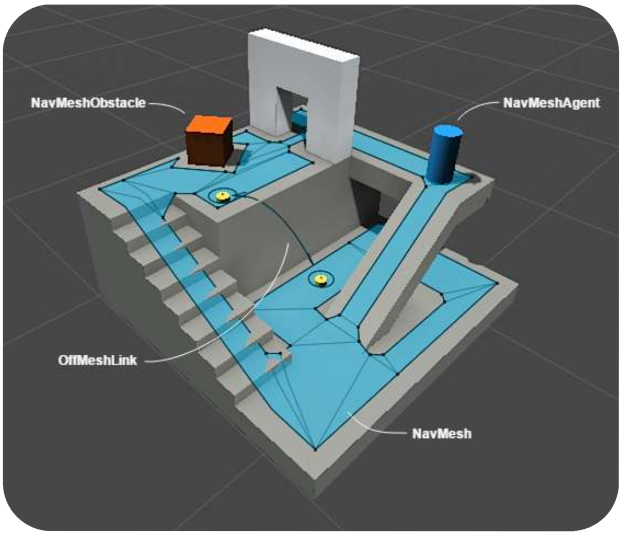
Nav Mesh: example in Unity



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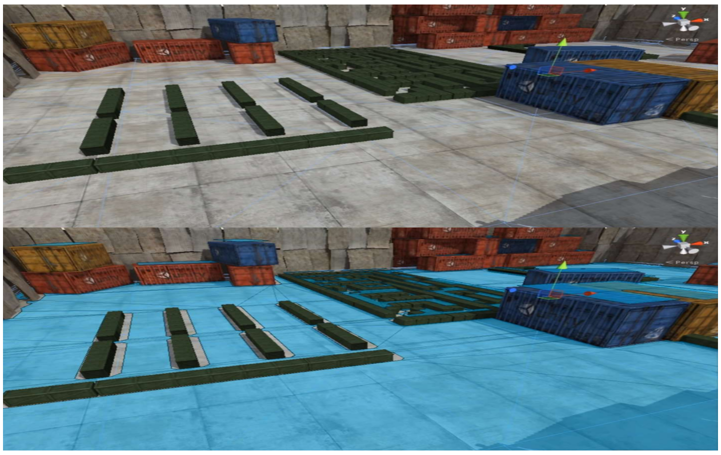
Nav-Mesh baking: example in Unity



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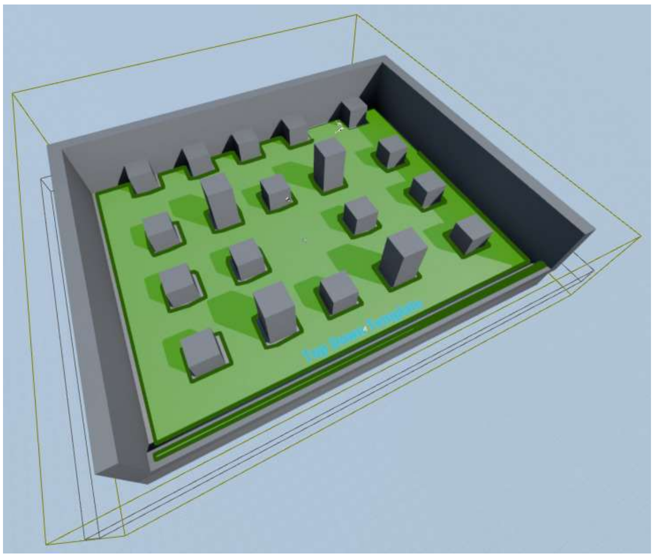
Nav-Mesh baking: example in Unreal



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Flocking algorithms

- A mid-level objective: “stay with the group”
  - but “not too close to anyone”
- Each element of the swarm is attracted to the position of the 3D barycenter of the swarm
  - but avoids collision with closer members
- ==> decent flocking behavior emerges
  - E.g. flock of birds, school of fishes
  - This is just the A-B-C of flocking algorithms
  - Many subtilities can be added

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Thinking phase (aka Planning): about the mid-to-high level goals

- Hierarchical Logic
  - Hi-level Decisions => Hi-Level Goals
    - update: not very often
  - …
  - Lower-level Goals
    - update: more often
  - …
  - Lowest-level Goals
    - solving low level tasks
  - Acts!

How to?

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FSM
(more technically: Moore machines)

- Nodes = states
  - Associated to actions / behavior routines
  - Current node: current state of the IA mind
- Arches = transitions
  - associated to senses / external events (including time-has-passed event)

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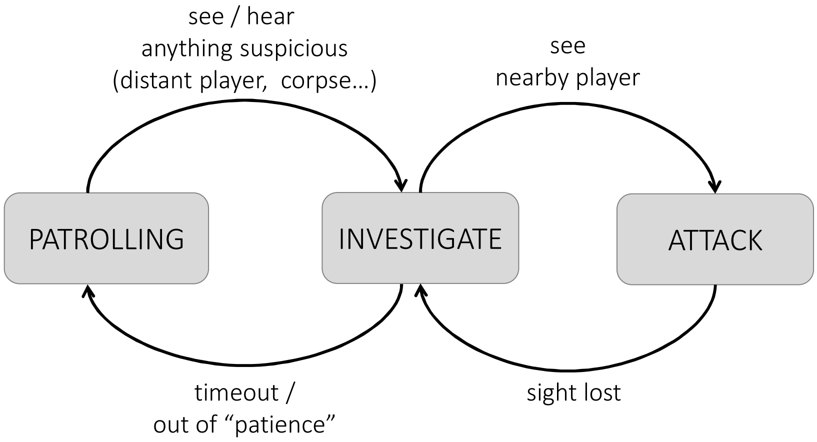
FSM example: a guard



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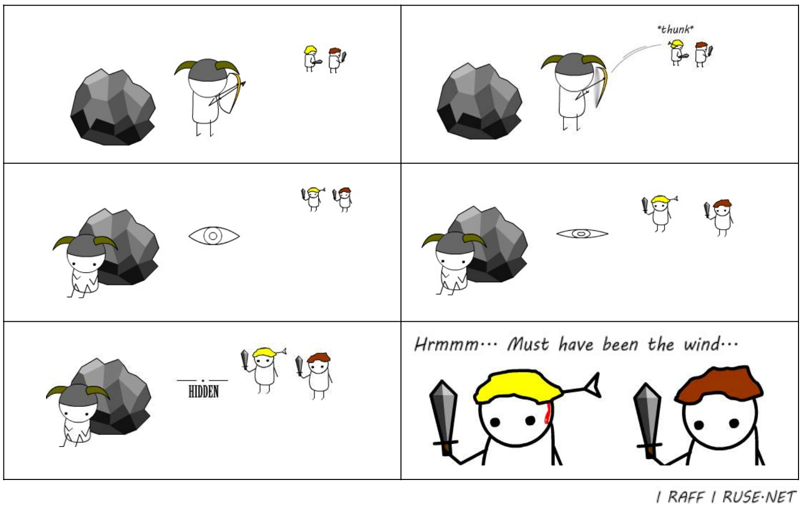

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Coding FSM

```
if (status==PATROLING)
  then doPatroling();
if (status==ATTACK)
  then doAttack();

procedure doPatroling(){
   //  …
   if next_nav_point reached …

   // state transitions
   if (target_in_sight)
     then status = ATTACK;
}
```

- FSM can be a coding guideline
  - use one "status" variable
  - transitions: manually coded in
- Or, a behavior authoring tool
  - intended for the AI designer
  - hardwired support, by game AI engine
  - maybe edited with WYSIWYG editor
  - transitions: conditions (to be checked automatically)
  - statuses: linked to effects (sound, animation,…)

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Authoring an AI for an NPC: more tools

- Problem with the FSM approach :
  - does not scale well
    with world / behavior complexity
    - quickly produces very complex nets
    - (it's ok, for simple behavior)
- Alternatives:
  - HFSM
  - Behavioral Trees

unified handling of all levels; blurs classic distinction between hi-level / low-level goals

also blur classic distinction between sensing / thinking / acting

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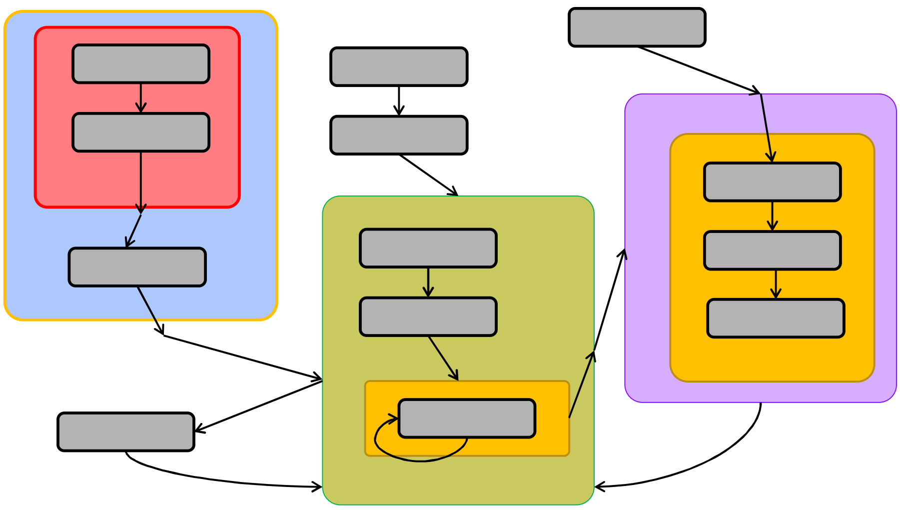
HFSM
Hierarchical Finite State Machines



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HFSM: concept

- An FSM where a state can be a sub-FSM
  - meta-state = sub-FSM
  - meta-transitions =
    checked from any state of the current sub-FSM
  - recursive (multiple levels)
- Advantages:
  - easier design
  - aids reusing chunks of behavior
    (from a designed AI to another)

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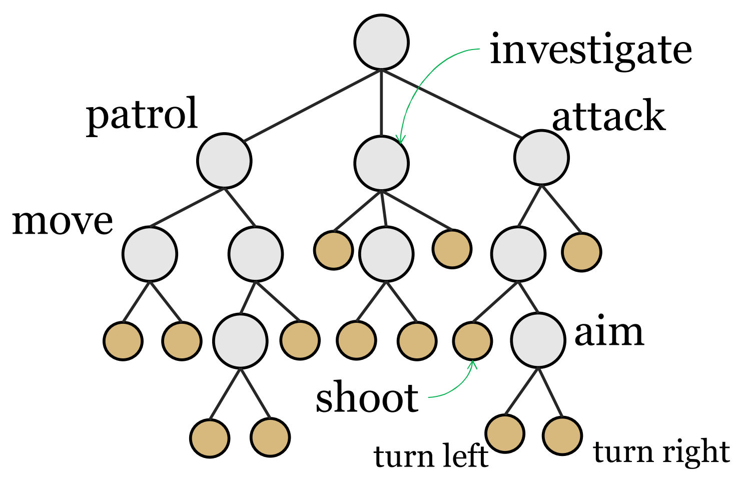
Behavioral Trees



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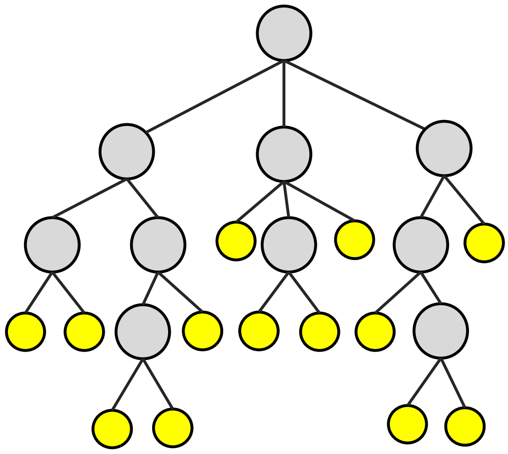
Behavioral Trees



= interface between IA and environment: acts, sensing (queries)

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Behavioral Trees: nodes

- every node, when it has done *running*, can either have:
  - failed
  - succeeded
- leaves are interaction with environment
  - action leaf:
    - animations, movements, sound, game logic…
    - Success: finished it.
      Failure: could not do it
      - (e.g. movement negated by obstacle, object not in inventory…)
  - sense leaf :
    - queries on senses, on game status, …
    - Success / Failure: query result
      (e.g see / not see an obstacle in front of IA)
  - the distinction is not necessarily strict

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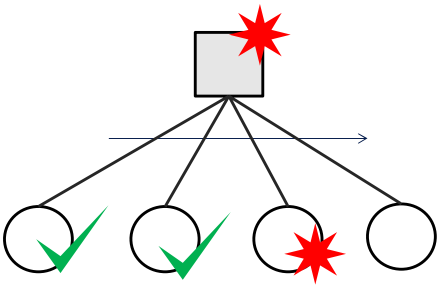
Behavioral Trees: nodes

- internal nodes: sequence



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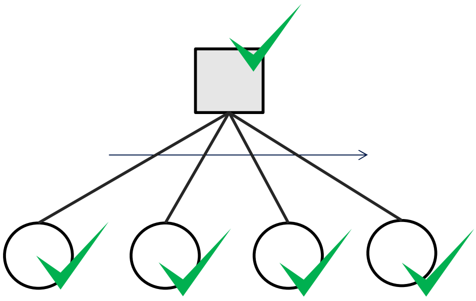
Behavioral Trees: nodes

- internal nodes: sequence



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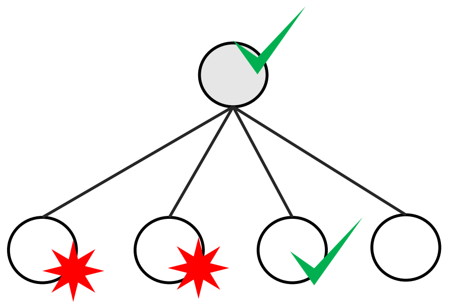
Behavioral Trees: nodes

- internal nodes: selector



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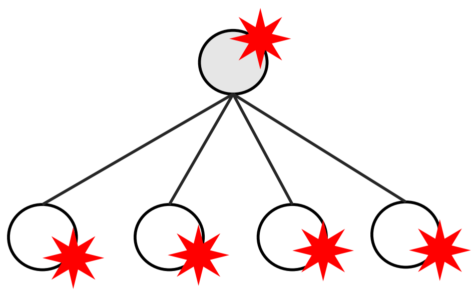
Behavioral Trees: nodes

- internal nodes: selector



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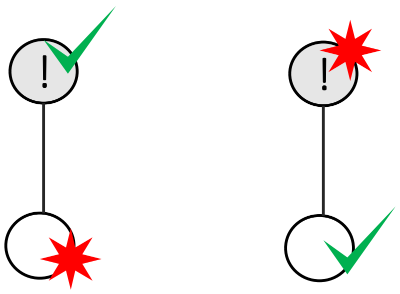
Behavioral Trees: nodes

- internal nodes: inverter



Only child

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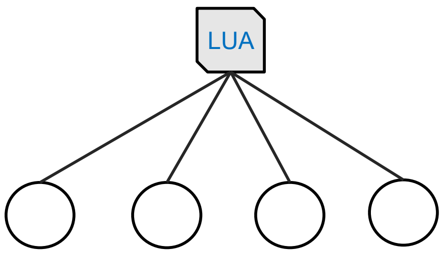
Behavioral Trees: nodes

- or, nodes can be programmed arbitrarily in scripted procedure) (in Lua, C#, JS...)
  - run children, as calls
  - fail or succeed, as returned value



BT as a framework to organize / reuse scripts

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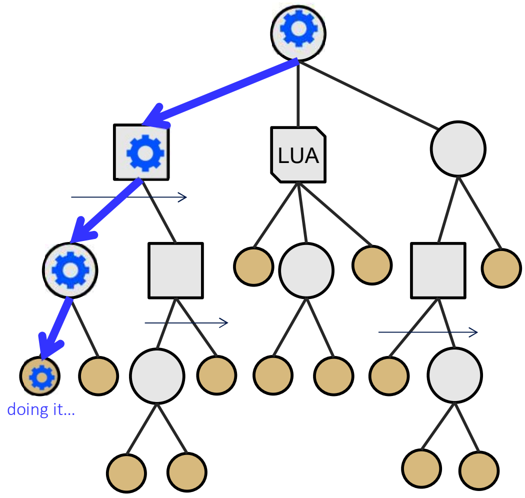
Current status behavior: root to leaf visit



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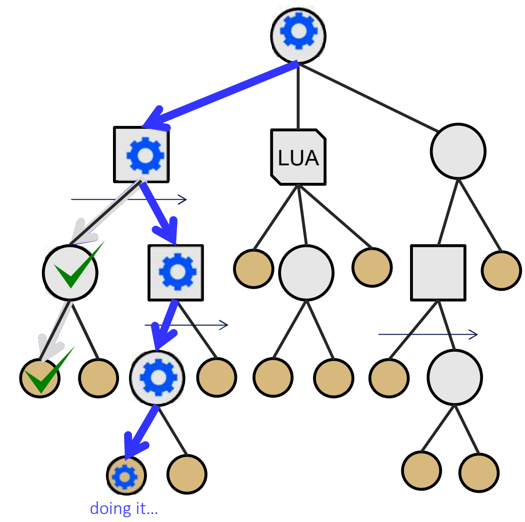
Current status behavior: root to leaf visit



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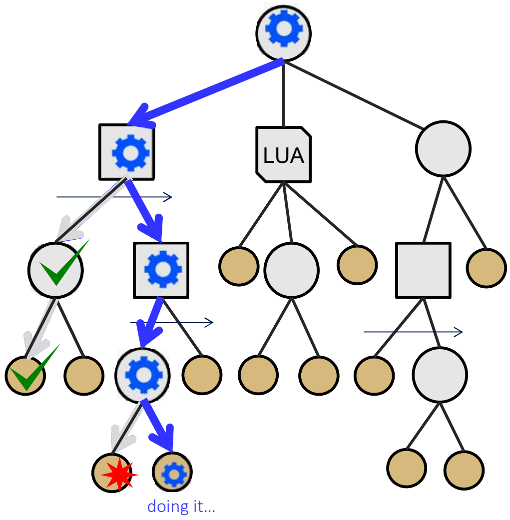
Current status behavior: root to leaf visit



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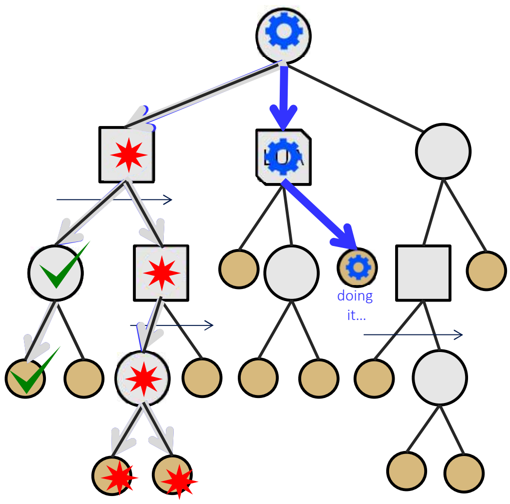
Current status behavior: root to leaf visit



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Behavior trees: notes

- Each node can be:
  - failed
  - success
  - in progress
  - (or, still unvisited)
- Current IA-mind status:
  root-to-leaf path of ⚙ nodes
  - Shallow nodes: current high-level objectives
  - Deeper nodes: current low-level objectives
  - Leaf at the end of the path: current action/sensing action

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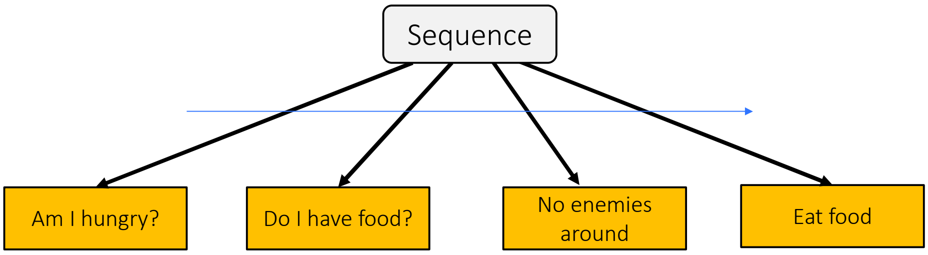
Example



Example by Chris Simpson (gamasutra)

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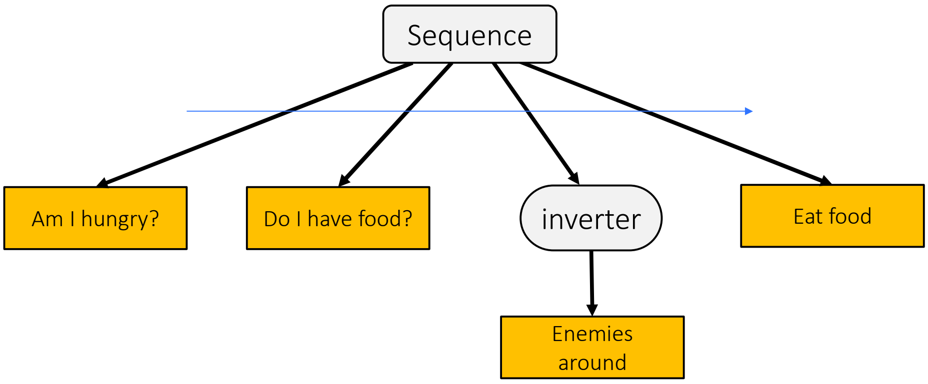
Example



Example by Chris Simpson (gamasutra)

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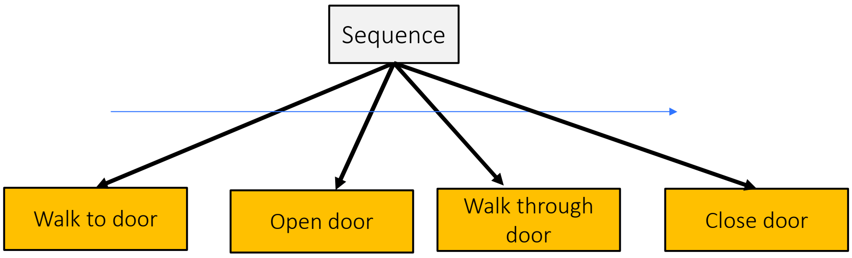
Example 1/3



Example by Chris Simpson (gamasutra)

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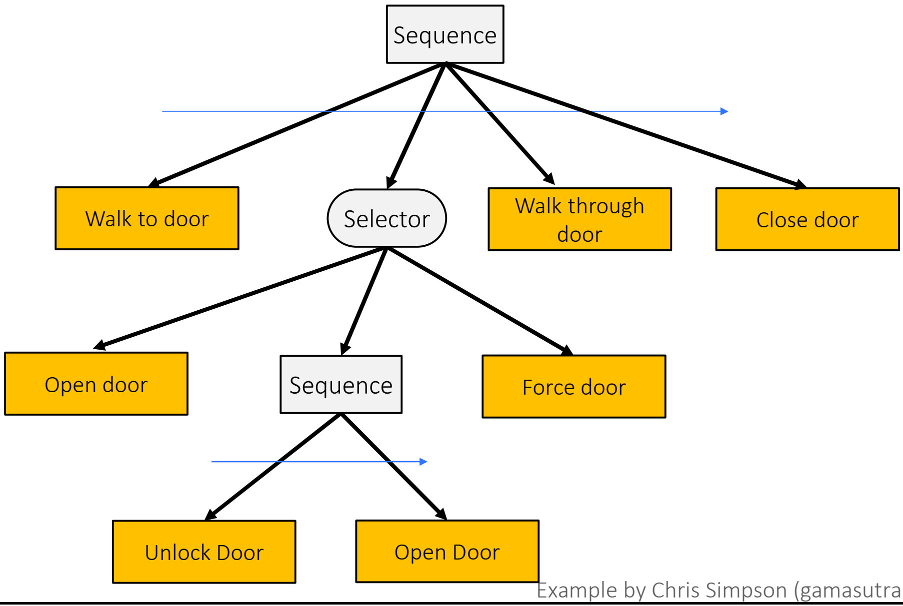
Example 2/3



Example by Chris Simpson (gamasutra)

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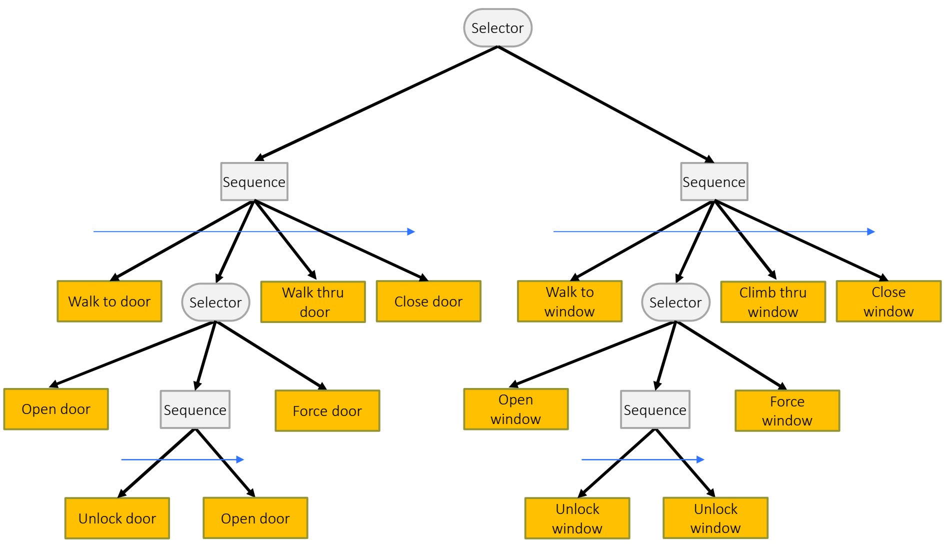
Example 3/3



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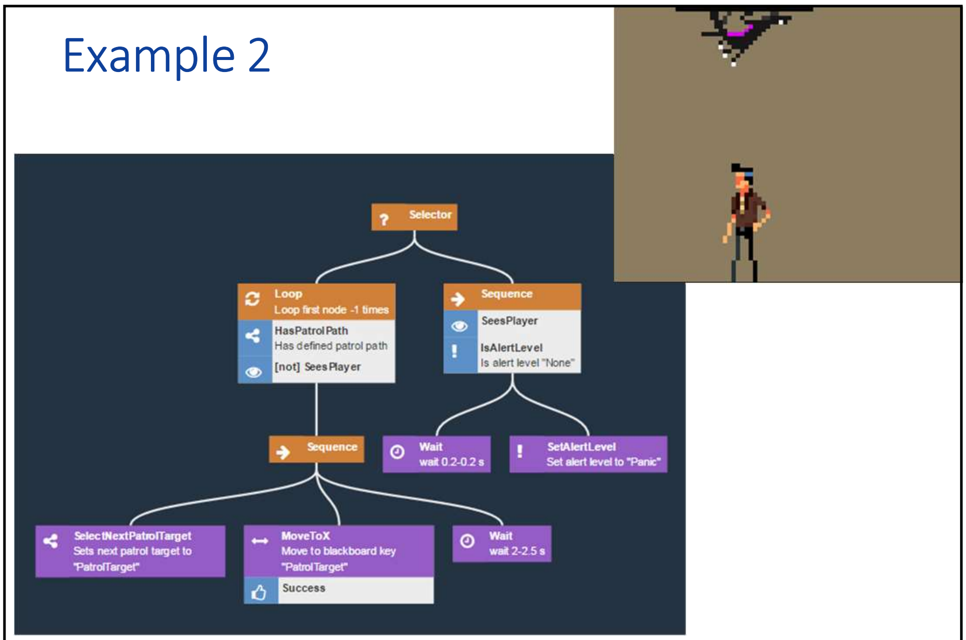
Example 2



example from **Tendril: Echo Received** by **cepnox** https://forums.tigsource.com/index.php?topic=60709.0

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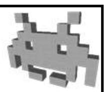
Other mid-level goals for AI in 3D games



- Often, completely ad-hoc strategies:
  - E.g., in a car-driving racing game:
    - compute-and-bake (or, manually edit) the *optimal* path for each racing circuit e.g., as a b-spline curve or as a segmented curve
    - make NPC cars target the path position ahead of them (mid level), but avoid collisions (low level)
    - result: decently competent car-racer behavior

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AI support in a game engine: a summary

- Assets for (NPC) AI:
  - for *behavior modelling*:
    - Scripts (can well be the only one)
    - FSM
    - HFSM
    - BT
  - for *navigation*:
    - nav-meshes (aka AI-meshes)
  - for *sensing / queries*:
    - hit-boxes, bounding volumes, spatial indexing
    - the same ones used by physic engine for collision detection
- Game tools
  - to assist their construction (by AI designer)
- Support for a few hard-wired functions
  - to solve lowest level tasks om a 3D environment

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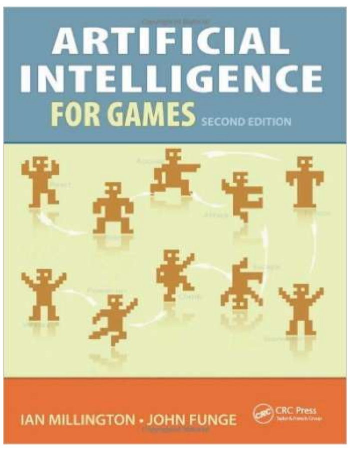
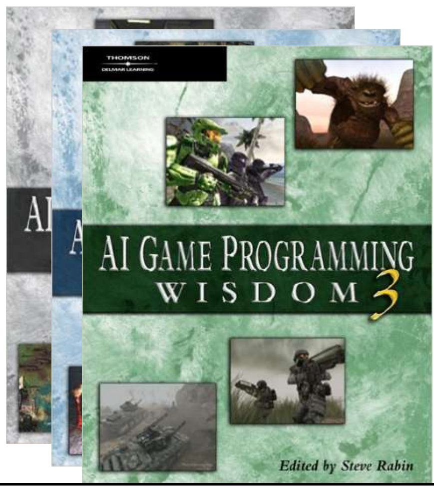
To investigate further

- AI for VideoGames course!
- Books:





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