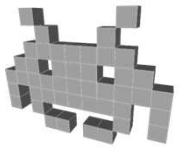
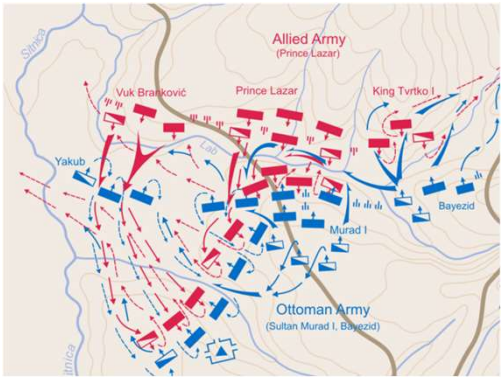
3D VideoGames
Università degli Studi di Milano



Interactive Agents for 3D Games

Marco Tarini



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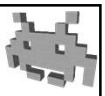
Course Plan



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 **Materials**
lec. 8: Game **Textures**
lec. 9: Game **3D Animations**
lec. 10: **3D Audio** for 3D Games
lec. 11: **Networking** for 3D Games
lec. 12: **Interactive Agents** for 3D Games
lec. 13: **Rendering Techniques** for 3D Games

For a general, deeper discussion of many of the subjects of this lecture, see the course «AI for videogames».
For ML applications, see the course «Statistical methods for ML».

★ bridge lectures

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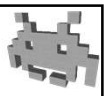
AI in games: an ongoing revolution?



- Generative AI for…
  - Meshes
  - Including UV-maps, rigs, skinning
  - Material assets
  - Including textures (all kinds)
  - Levels
  - Code, scripts, logic
  - Sound effects
  - Soundtracks, scores
  - Skeletal animations
  - Dialogs, etc

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ML in games: one particularly 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. (trivial to measure (scoring function))
      - go as fast as possible in this direction
      - stand up from prone position
      - reach the highest possible point (i.e. jump)
      - …
  - *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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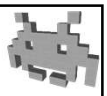
"AI" in games: examples of more traditional uses



- 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, the traditional meaning: 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
- A racing car driver
- A spaceship pilot / gunner
- A companion / buddy
- An (enemy) commander
- A zombie
- A heat seeking missile
- A WWII ace pilot
- …

"flocking" algorithms
or "crowd simulation"

the AI player
in an RTS

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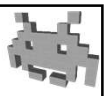
"AI" for NPC behavior: Interactive Agents (IA)



- 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

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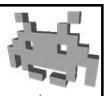
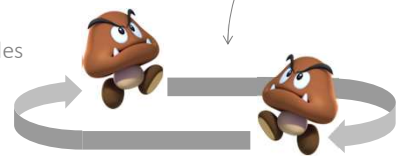
NPC behavior: designer perspective



NPC behavior is not *necessarily*
- "intelligent" / proficient ("")
- nor even complex! good at what it does

Rather, we may want NPC behavior to be (examples):
- intuitable / predictable
- learnable (by players) ← think boss battles
- understandable
- story-driven
- exploitable (interesting to exploit)
- realistic / believable ← for immersion; compare: a realistic solider (can panic), an optimal one (cannot)
- similar to human-players' behavior ← to fake players in MMO games (e.g. disconnected ones)

a common example of a very simple, but predicable / exploitable NPC behavior



Allowing game-designers to (examples):
- tune difficulty (by controlling NPC proficiency)
- elicit interesting strategies by the players
- make a given strategy rewarding
- give the illusions of competing against humans in MMO games …

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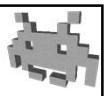
AI in Games -vs- AI to solve Games



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

Interested in AI to competently ***play*** games instead? 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
- Machine Learning applied to generation of "actions"
  - see later!

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~~Intelligent Agent~~

Interactive Agent (Believable Agent)

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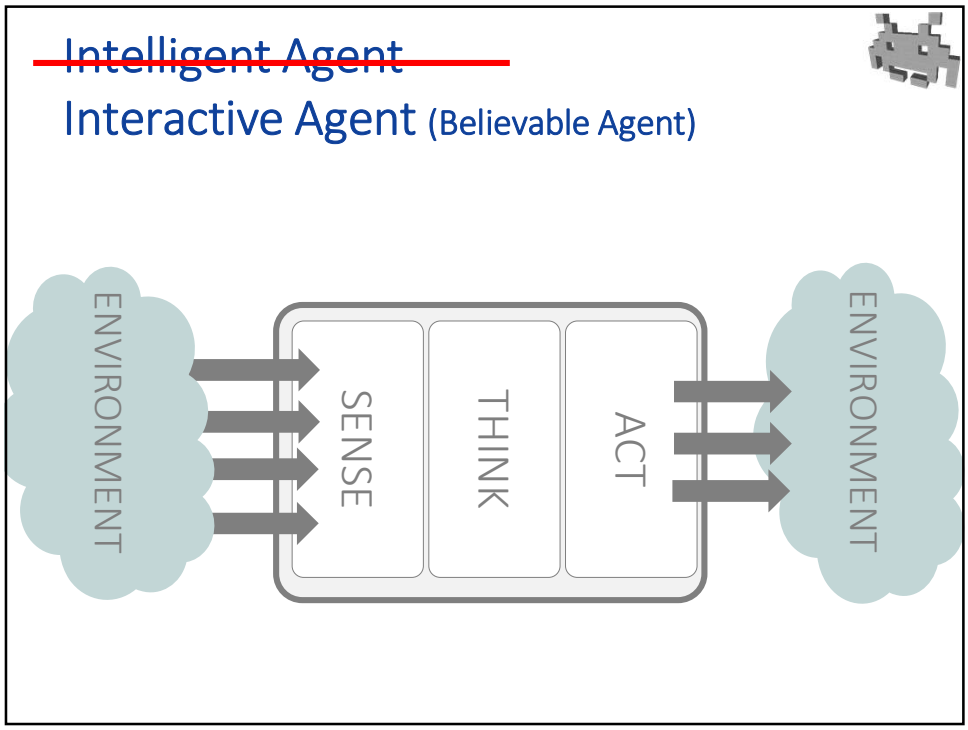
~~Intelligent Agent~~
Interactive Agent (Believable Agent)
ENVIRONMENT
SENSE
THINK
ACT
ENVIRONMENT

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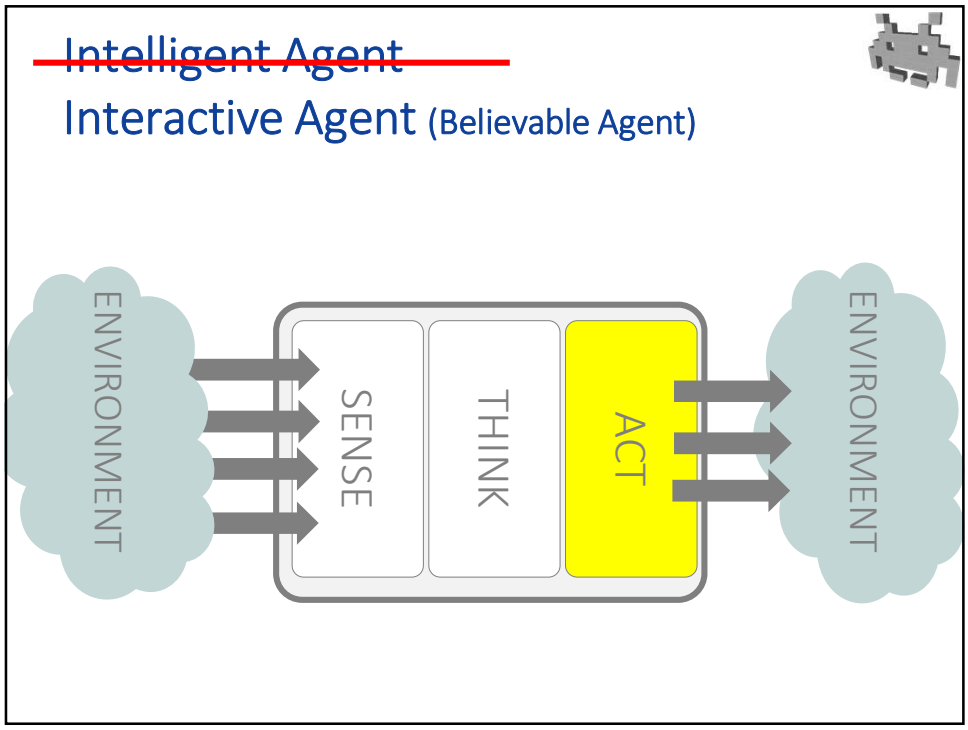
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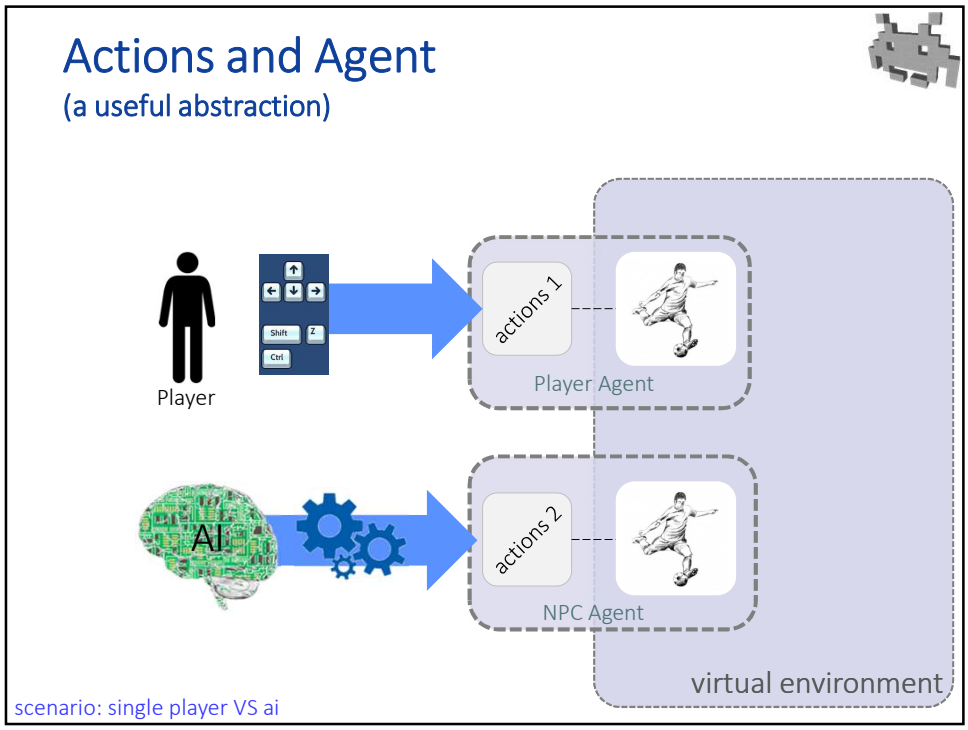
Actions and Agent
(a useful abstraction)
Player
actions 1
Player Agent
AI
actions 2
NPC Agent
virtual environment
scenario: single player VS ai

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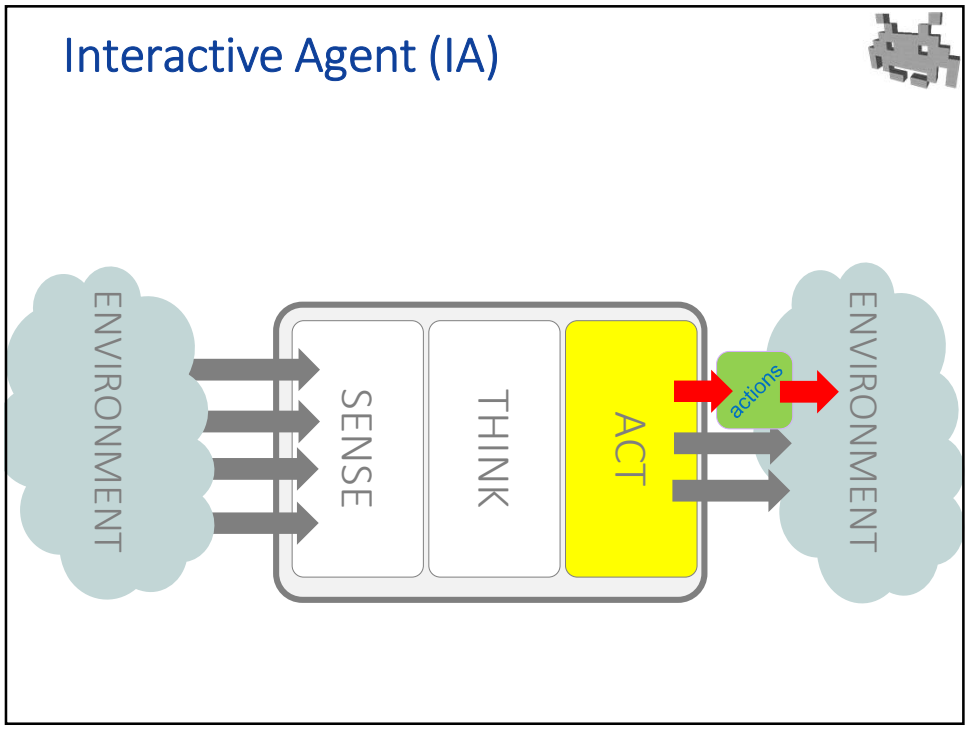
Interactive Agent (IA)
ENVIRONMENT
SENSE
THINK
ACT
actions
ENVIRONMENT

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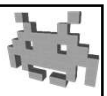
Acts: in robotics, “actuators”. In 3D games? Examples…



- Produce “actions”
  - associated to the NPC character
  - a non-cheating, symmetric NPC (simulation of a human player)
- Trigger skeletal animations / facial blend-shapes
- Cause movements / displacements of NPC 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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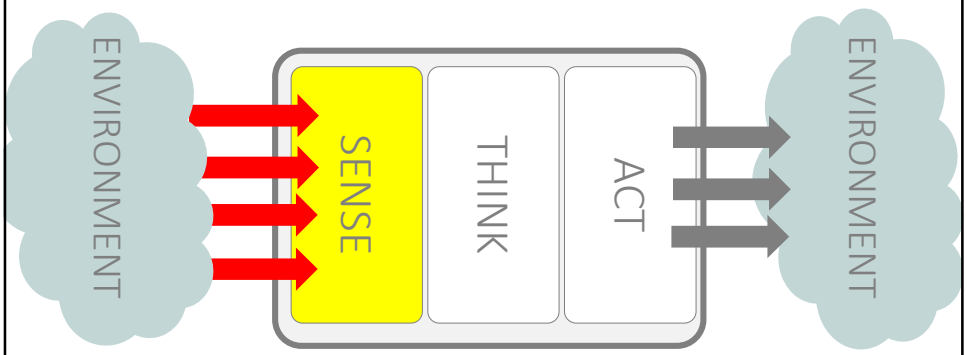
Interactive Agent (IA)



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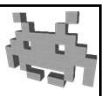
Sensing: in robotics, by “Sensors”. In 3D games?



- 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
    - ray-casting (uses colliders, specifically ray-VS-collider collision)
    - synthetize then analyze probe renderings! (accurate, expensive)
    - see math exercises: “testing if a position is in the cone of vision of NPC”
  - 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)

from the scene graph

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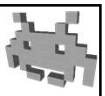
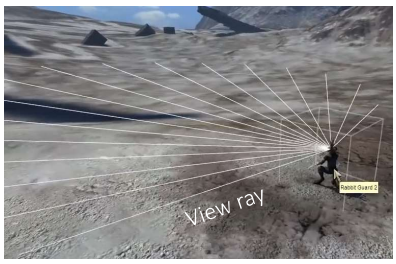
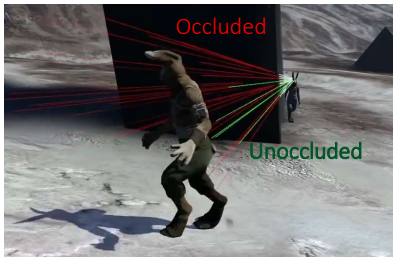
Simulating senses in a 3D environment







Sight Hearing

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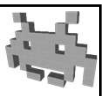
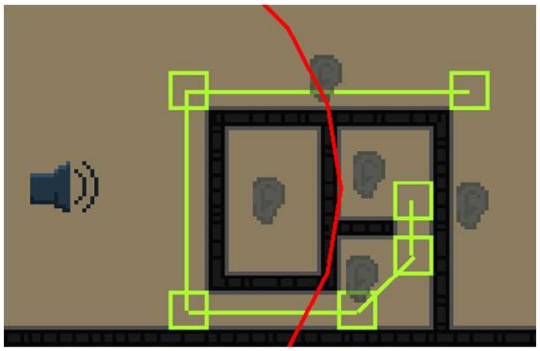
Simulating senses in a 3D env. Example: sound (with echos)



- Pathfinding for echoes simulation



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

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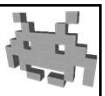
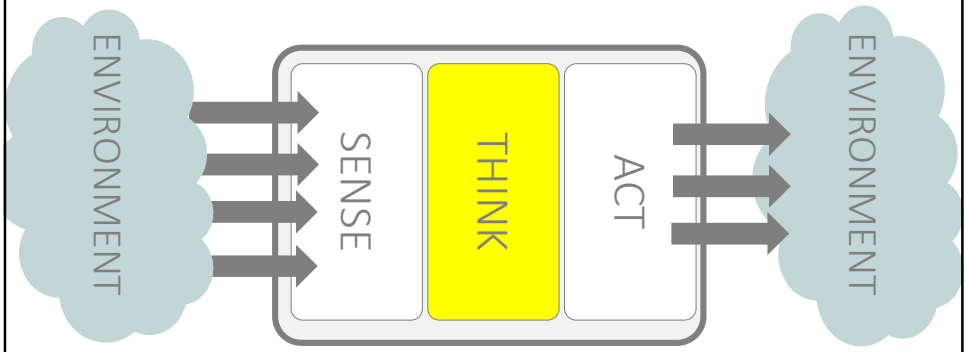
Interactive Agent (IA)





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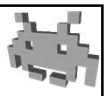
Thinking phase (aka Planning) Goals of the AI



- 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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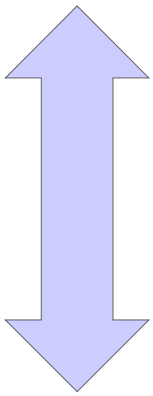
Thinking phase (aka Planning) Goals of the AI

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



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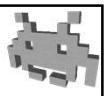
Example: terrified bystander



- 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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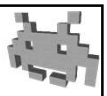
Example: guard



- 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): 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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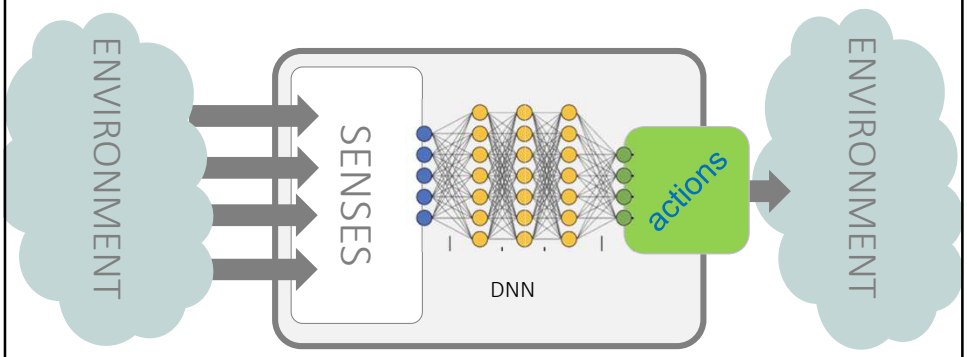
ML for the «think» phase (e.g. DNN) an emerging approach



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ML for the «think» phase (e.g. Deep Neural Networks)

- Sought Output: **actions** for the NPC
- **Supervised learning**
  - A classification task (assuming discrete actions e.g. keypresses): "given this input, should the fire/jump/left etc button be pressed?"
  - Technically a regression task (for continuous actions, e.g. mouse pos)
- **Data driven** (learn from examples):
  - Learning from detailed logs (frame-by-frame actions) captured from actual gameplay sessions by human players
  - This is the labelling in input to the learning process ("in this situation, human-players played this way")
  - Data can be easily collected in bulks (remember actions are light!)
- Objective: Convincingly **simulate human players**
  - in multiplayer games, with NP-NPC symmetry
  - Success can be measured by (simplified) "Turing test"

many successes reported in literature.

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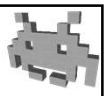
ML (e.g. Genetic Algorithms - GA) for the «think» phase



- Sought Output: **actions** for the NPC (again)
- **Genetic algorithms**
  - and other automatic optimization techniques
- Driven by a **reward function** :
  - Such as (depending on the gameplay):
    survived time, number of kills, score earned, flag captured, goals scored, (virtual) money earned, levels cleared, etc.
  - To be used as the Fitness Evaluation Function in GA
- Objective: make the NPC **competently play the game**
  - in multiplayer games, with NP-NPC symmetry
  - Success can be measured by measuring perfomances

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ML for the «think» phase: input (e.g. fed to the DNN)

Both when learning, and when employing results at game execution

more honest but more difficult (deeper DNN, longer learning, etc)

cheating but more "learnable"

- A plain RGB rendering of the screen
  - Maybe artificially low-res for practical purposes
  - Maximal honesty: same info provided to players
  - Task becomes similar to self-driving machines with cameras
  - Basically, a gimmick (not used in practice)
- A *marked* RGB rendering of the screen
  - E.g. per pixel-coding for enemies, friends, walls, etc
  - Still a gimmick…
- Simulated percepts (visual, hearing, etc)
  - E.g. N view rays with fixed pos, a label for first hit of each
- The state of the game as known by AI
  - Positions of everything *that was observed*
  - E.g.: for each relevant object:
    last observed position / orientation, time *t* of this observation
  - *It helps if it is encoded in local NPC space! (see next slide)*
- The full state of the game
  - AI "cheats" by knowing everything
  - *It helps if it is encoded in local NPC space! (see next slide)*

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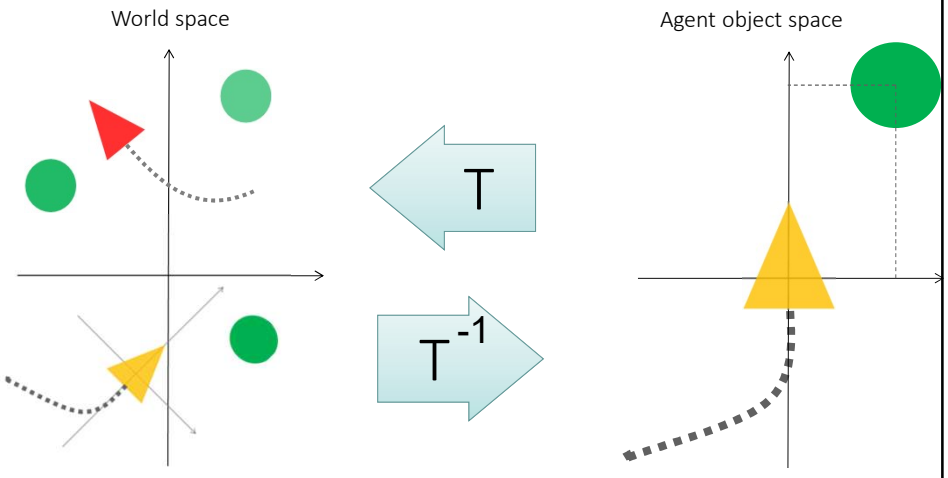
Often easier to think in local object space of the Agent (both for scripting AIs, and for ML)



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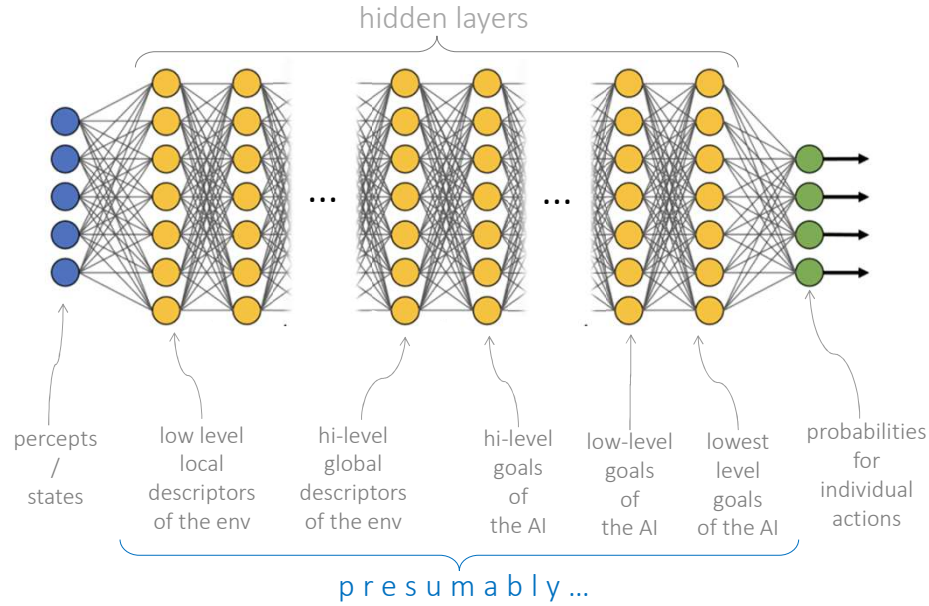
DNN at work (example)



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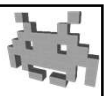
ML for the «think» phase of IA



- A fast-advancing area of research
- Promises to cover well two cases
  - learn to mimic human players (from examples)
  - learn to be proficient at the game (autonomously)
  - Benefit: automatable

"AI training against itself"

- But let's remember "AI" (NPC behavior) serves a range of other objectives
  - we need tool to allow designers to craft NPC behavior
  - as an integral part of the game design
  - controlling proficiency is just one side of it (it's more relevant for low-level goals, for which ad-hoc approaches exist – as we are about to see)

==> let's go back to discuss traditional approaches…

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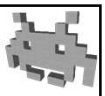
Thinking phase (aka Planning): about the lowest-level goals…



- 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…

most instances are mini-tasks
we can solve with standard solutions
(supported by the game engine?),
such as…

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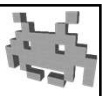
Examples of common *lowest* level tasks (1/2)



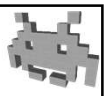
- Face towards something
  - tip: remember *atan2*
  - actions: turn left or right
- Aim a weapon
  - e.g. including ballistic
    - to predict, use *analytical* physics: pos(t) = f(t)
  - e.g. including "leading the target"
    - i.e. aim at where target *will* be at time of impact
- Avoidance / dodging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

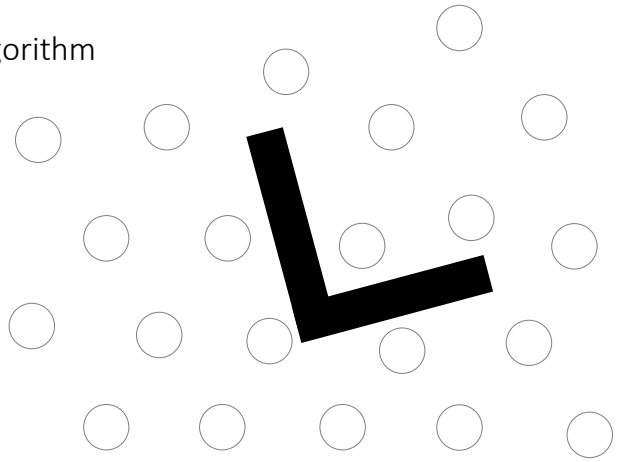
repeat a few times
(converges really fast)

44

Common lowest level tasks 2/2: Path finding



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



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Dijkstra algorithm and A* search

(part of the background, not of this course)

if you are not familiar with them,
please *do* look them up!

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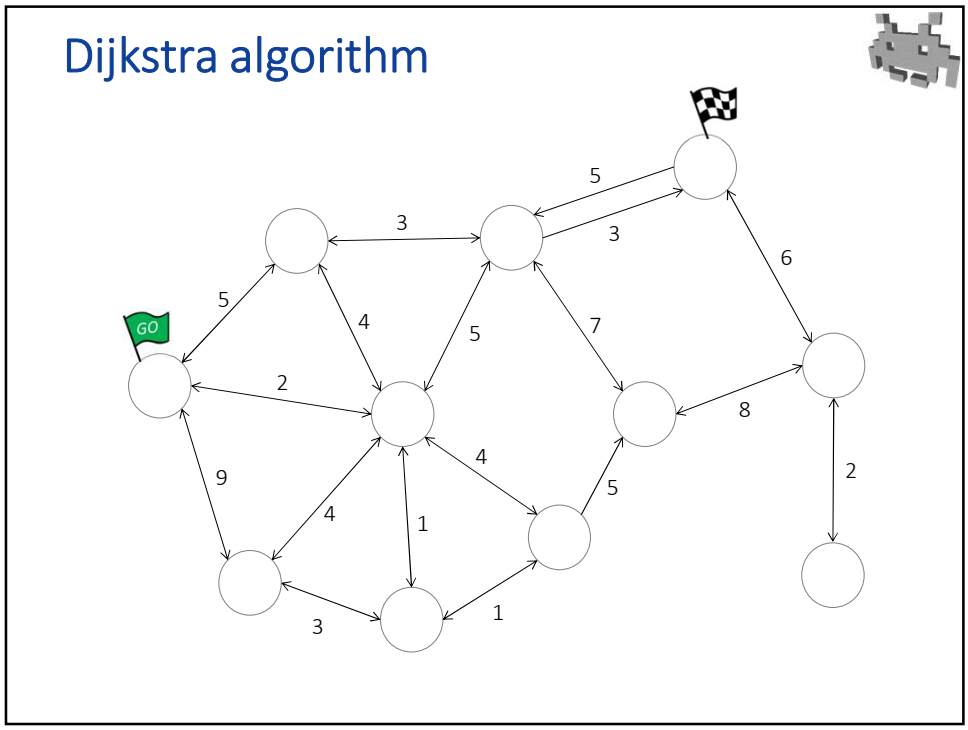
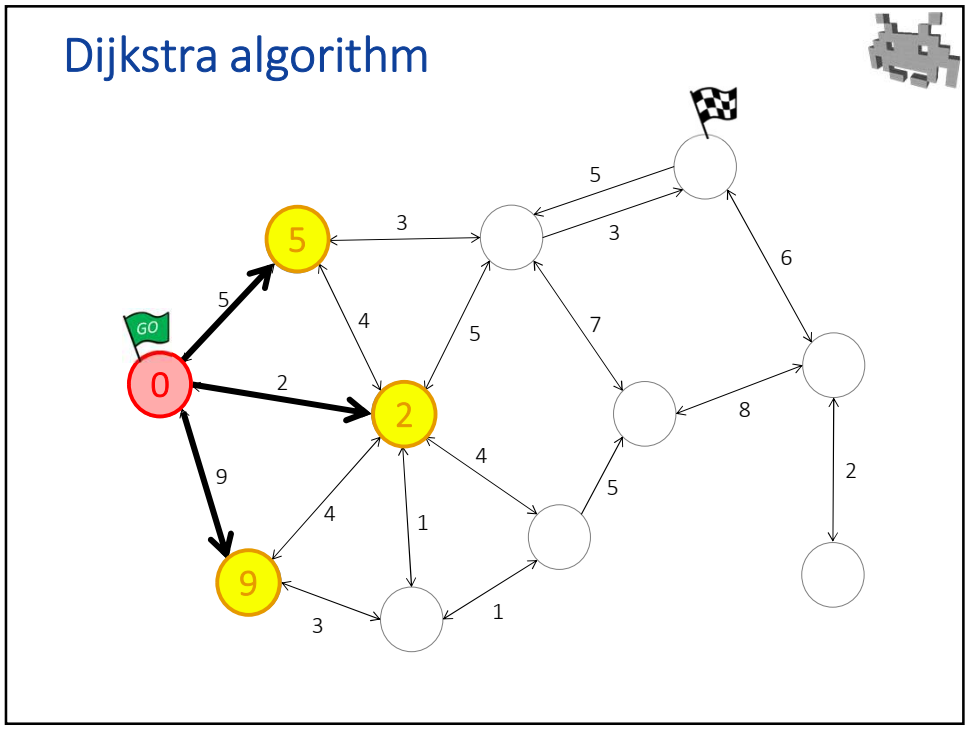
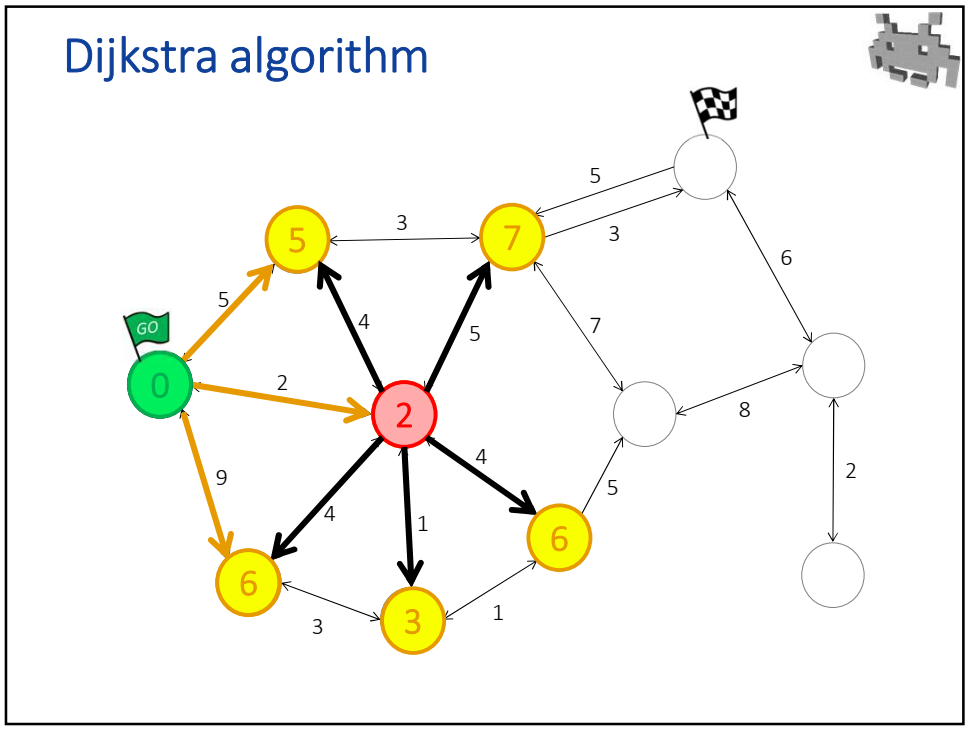

Dijkstra algorithm
GO
5
3
3
6
5
4
5
7
2
8
9
4
4
5
2
1
3
1

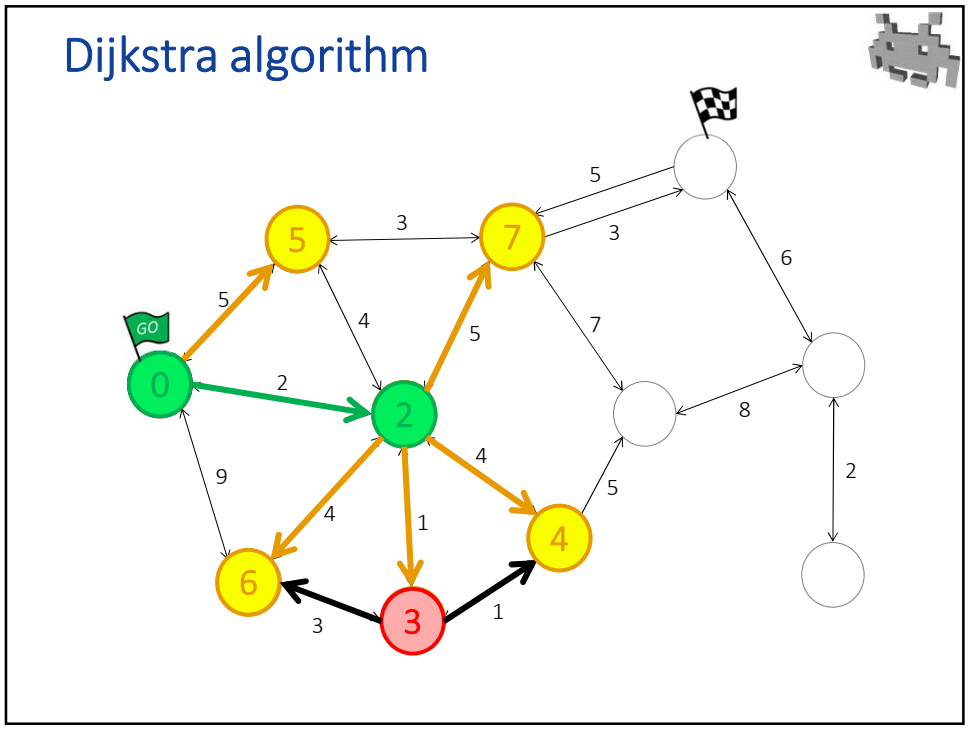
48


Dijkstra algorithm
GO
5
3
3
6
5
4
5
7
0
2
8
9
4
4
5
2
1
3
1

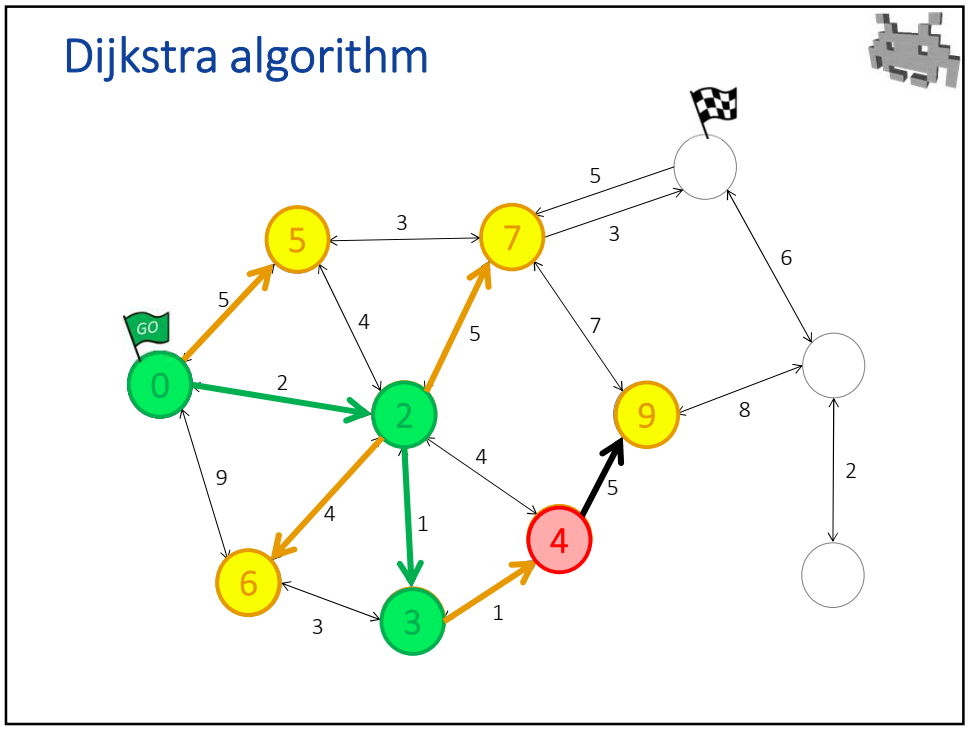
49


Dijkstra algorithm
GO
0
2
5
7
6
3
5
3
6
5
4
5
7
8
2
9
4
4
1
5
3
1

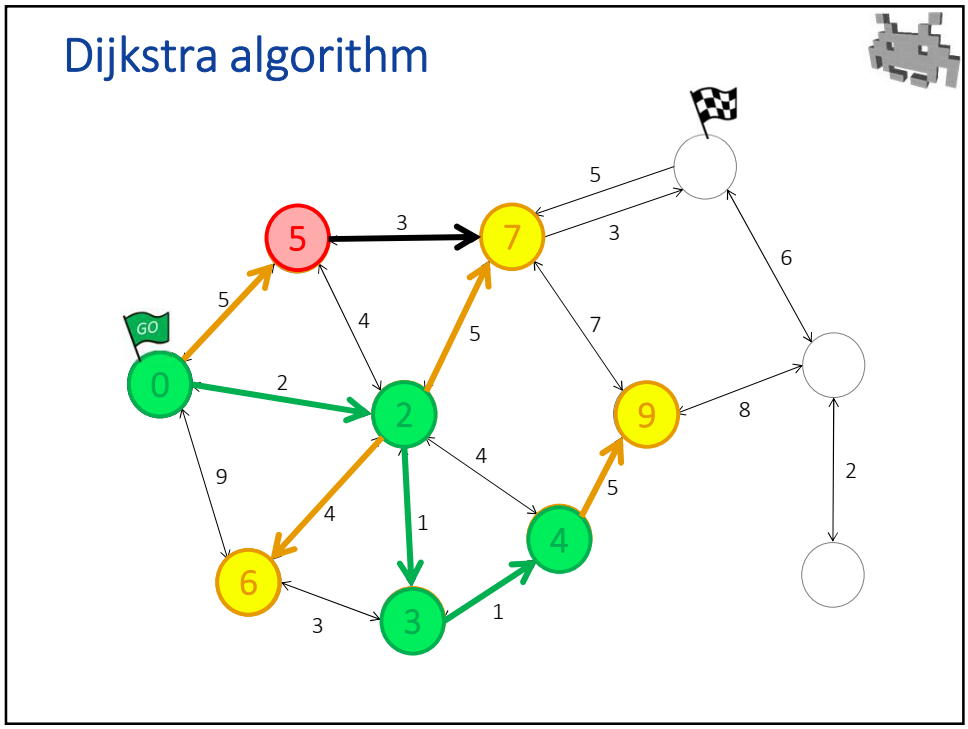
50


Dijkstra algorithm
GO
0
2
5
7
6
3
4
5
3
6
5
4
5
7
8
2
9
4
4
1
5
3
1

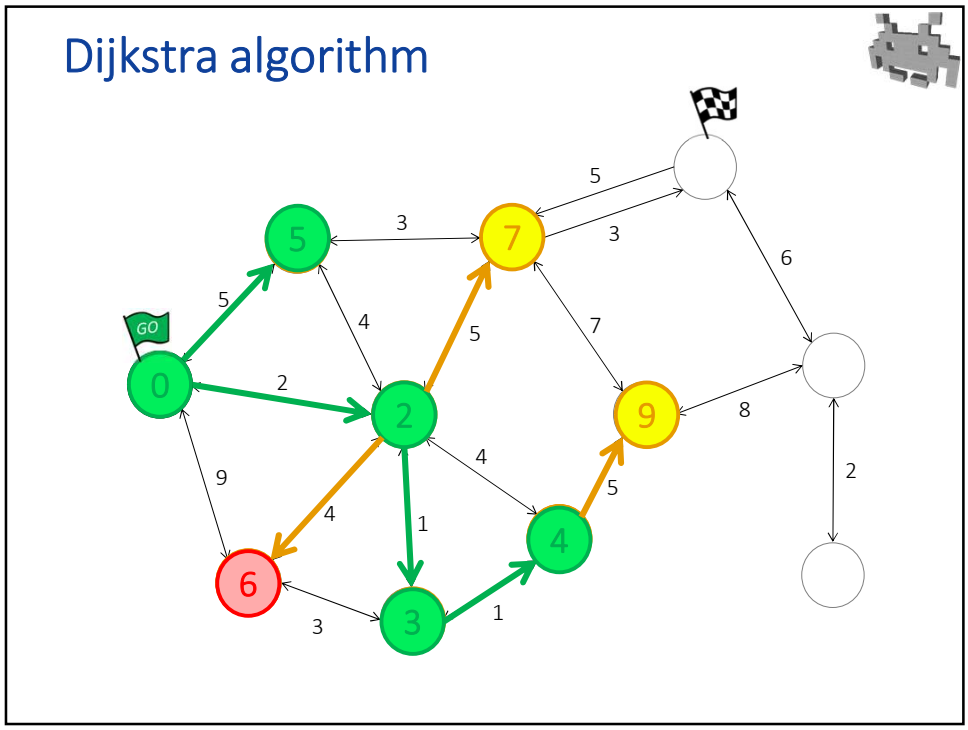
51


Dijkstra algorithm
GO
0
2
5
7
9
6
3
4
5
3
5
4
5
7
6
2
9
4
1
4
5
3
1
8
2

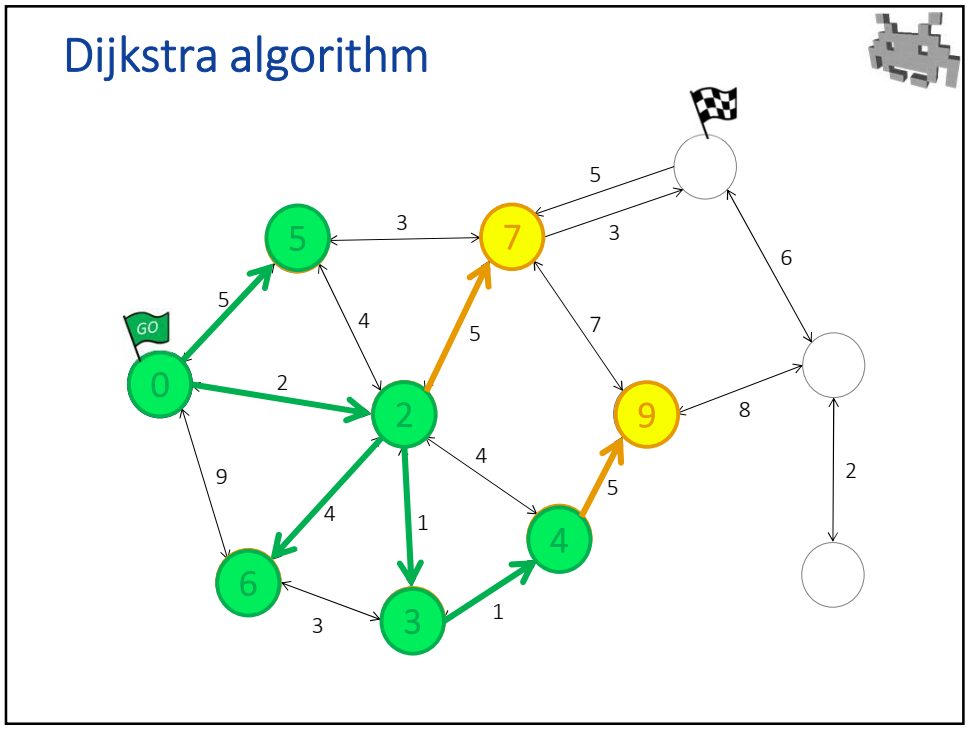
52


Dijkstra algorithm
GO
0
2
5
7
9
6
3
4
5
3
5
4
5
7
6
2
9
4
1
4
5
3
1
8
2

53

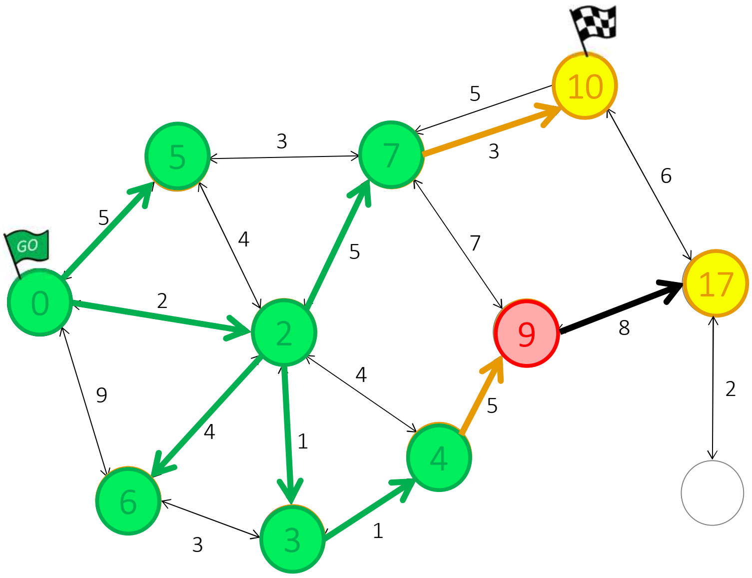

Dijkstra algorithm
GO
0
2
5
6
7
9
3
4
5
3
5
4
5
7
6
8
2
9
4
1
3
1

54


Dijkstra algorithm
GO
0
2
5
6
7
9
3
4
5
3
5
4
5
7
6
8
2
9
4
1
3
1

55

Dijkstra algorithm



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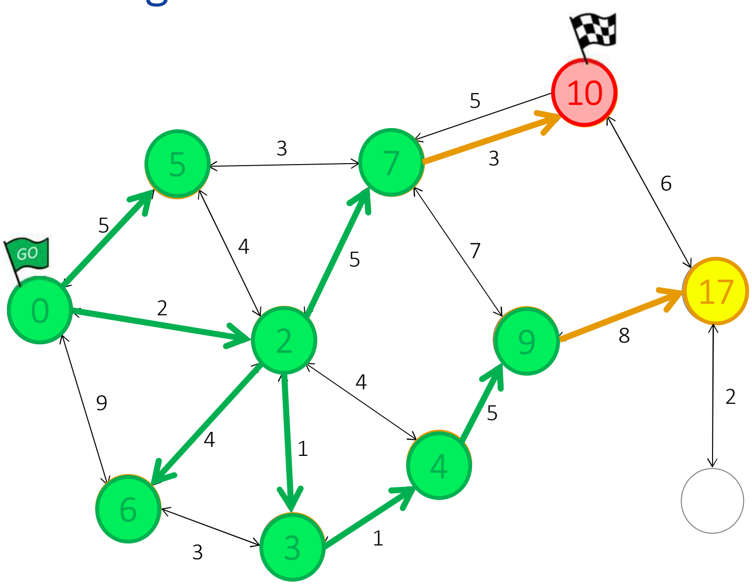
Dijkstra algorithm



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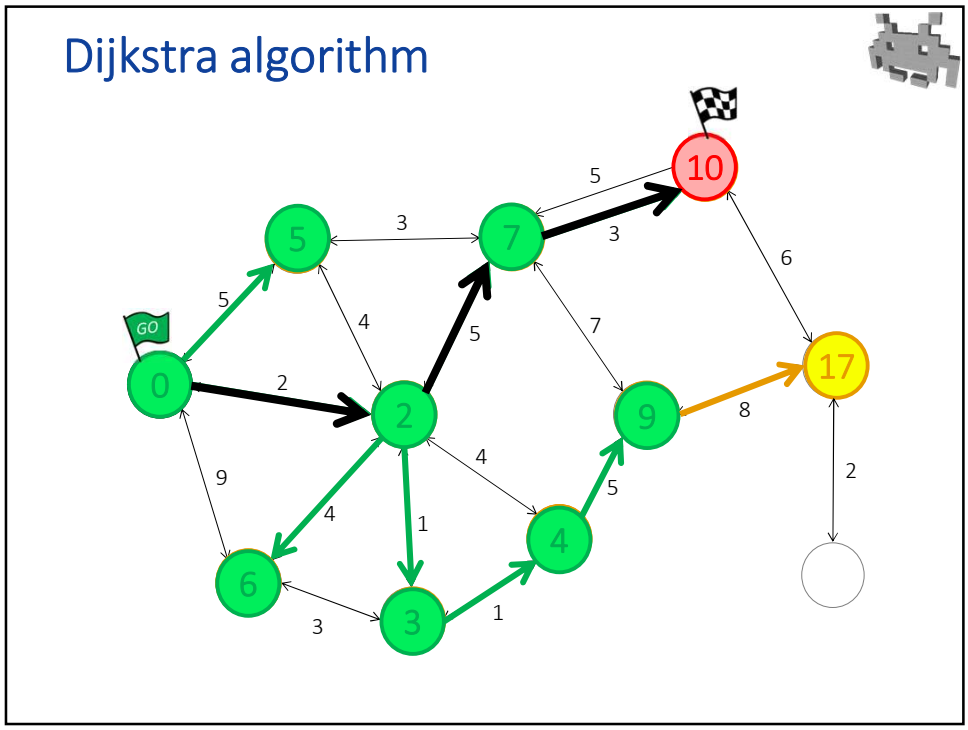
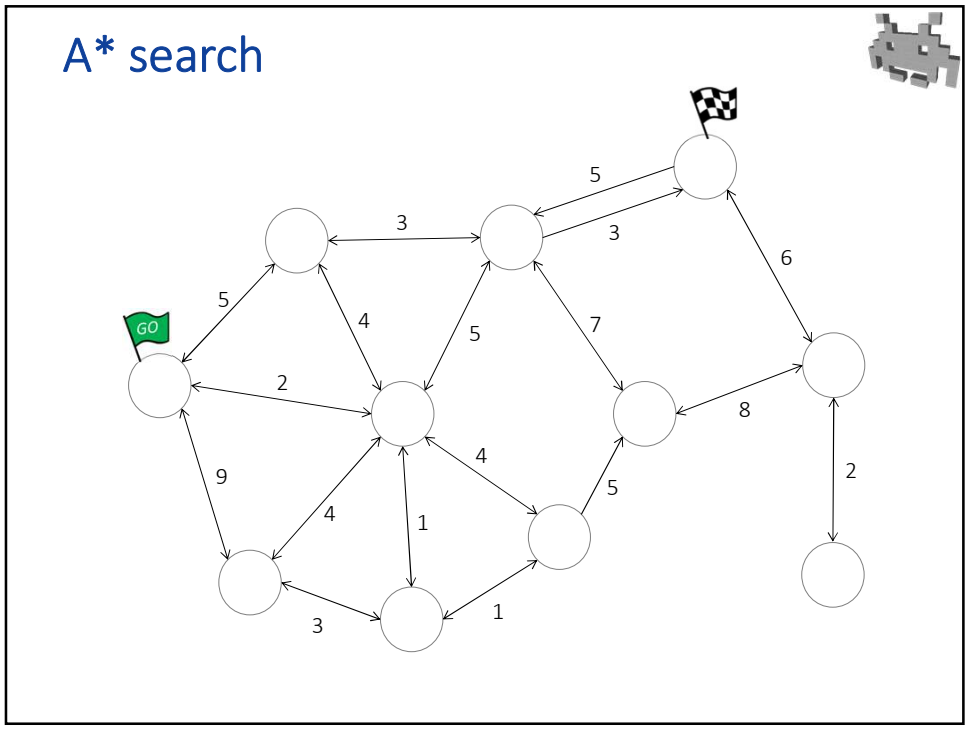
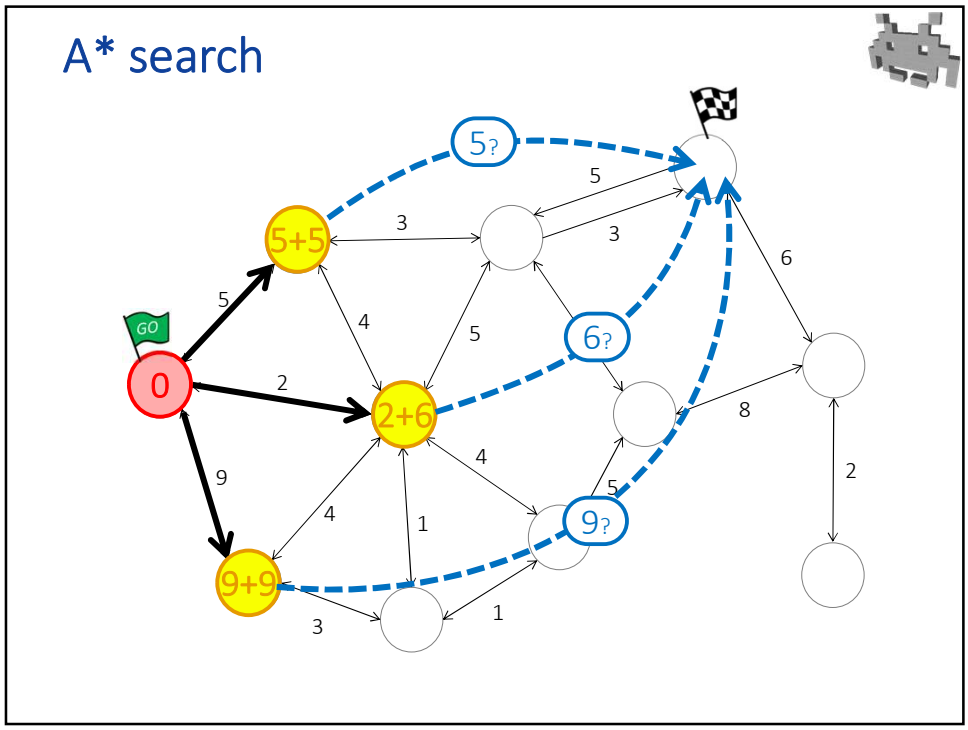

Dijkstra algorithm
GO
0
2
5
7
10
17
9
4
6
3
5
3
5
3
6
5
4
5
7
9
8
4
2
4
1
3
1

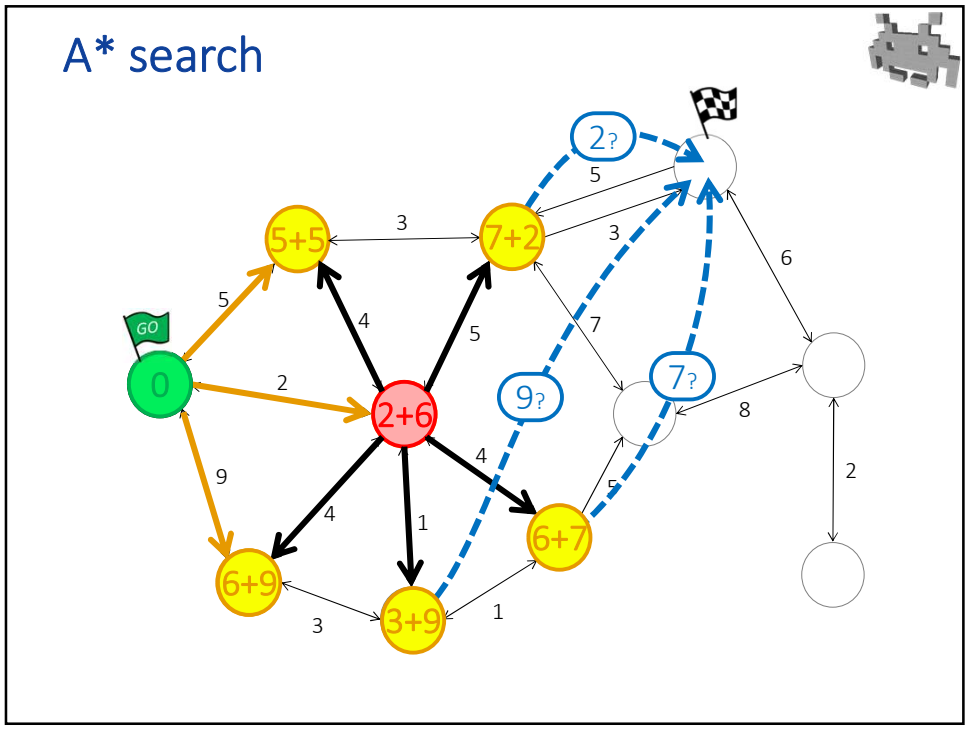
59


A* search
GO
5
3
5
3
6
5
4
5
7
2
8
9
4
5
2
4
1
3
1

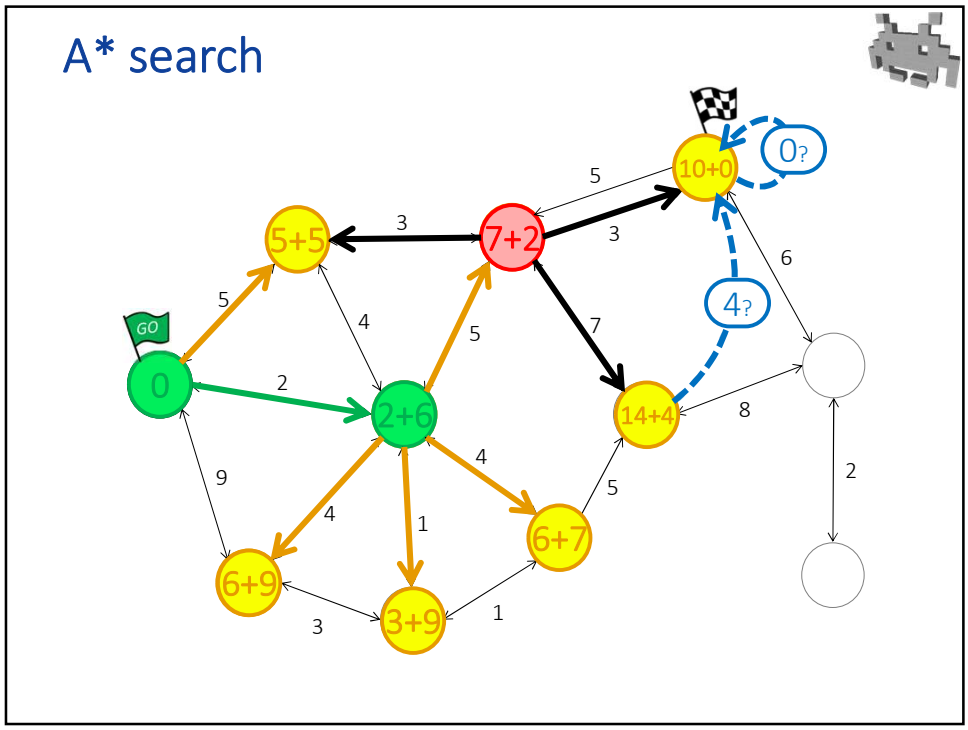
60


A* search
GO
0
5+5
2+6
9+9
5?
6?
9?
5
3
4
2
9
1
6
8

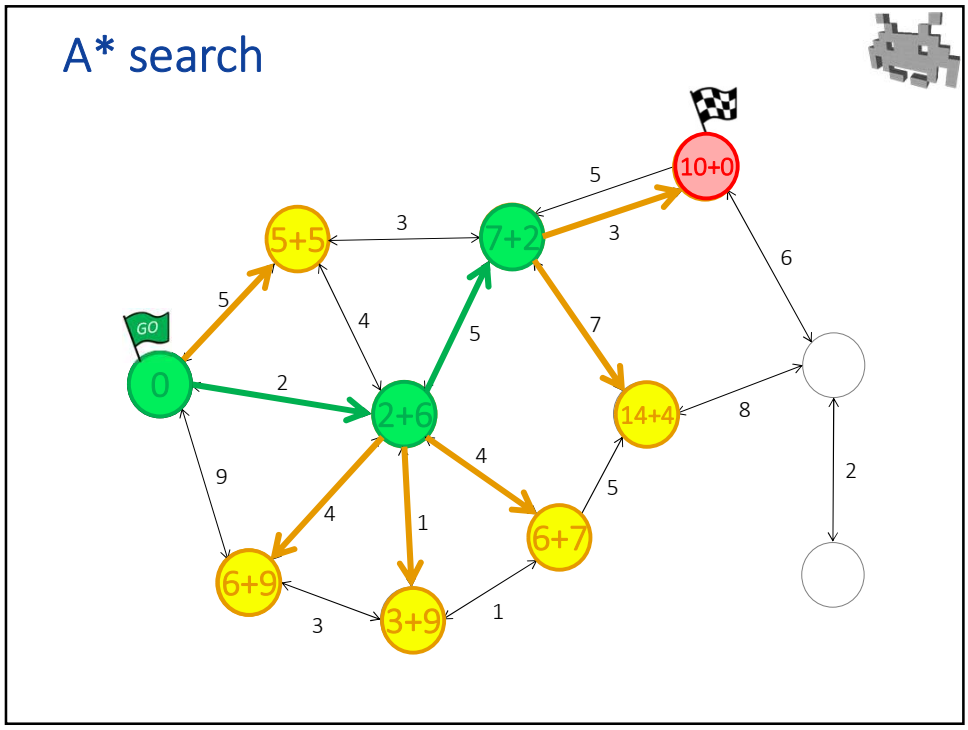
61


A* search
GO
0
5+5
7+2
2+6
6+9
3+9
6+7
2?
9?
7?
5
3
4
2
9
1
6
8
7

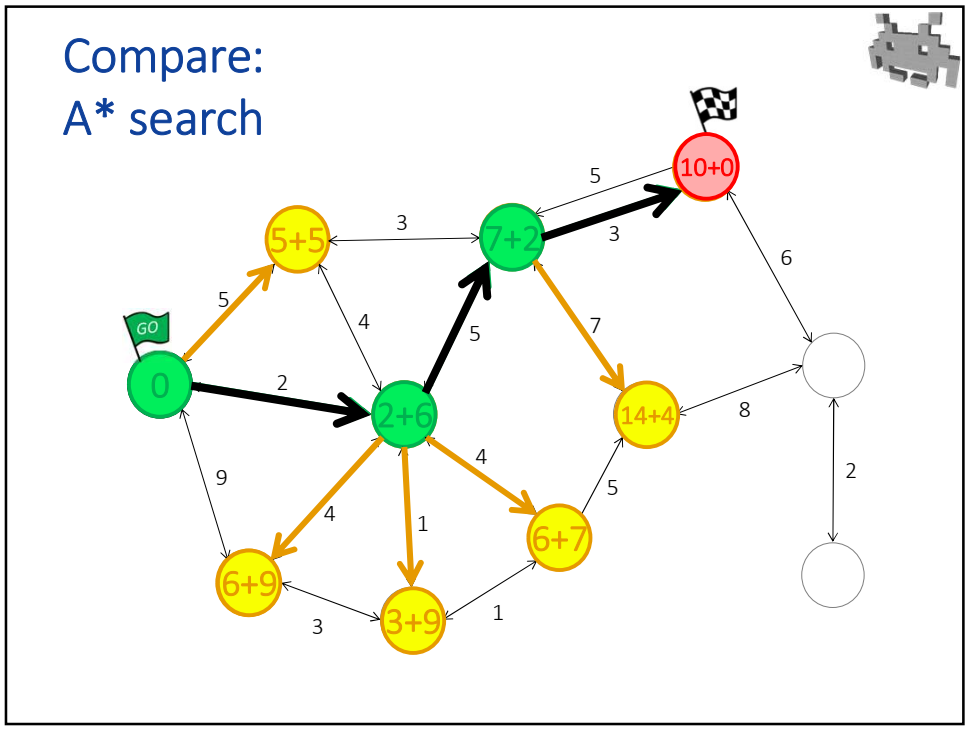
62


A* search
GO
0
5+5
7+2
10+0
0?
4?
2+6
14+4
6+7
6+9
3+9
5
3
5
4
5
7
6
2
9
4
1
4
5
8
2
3
1

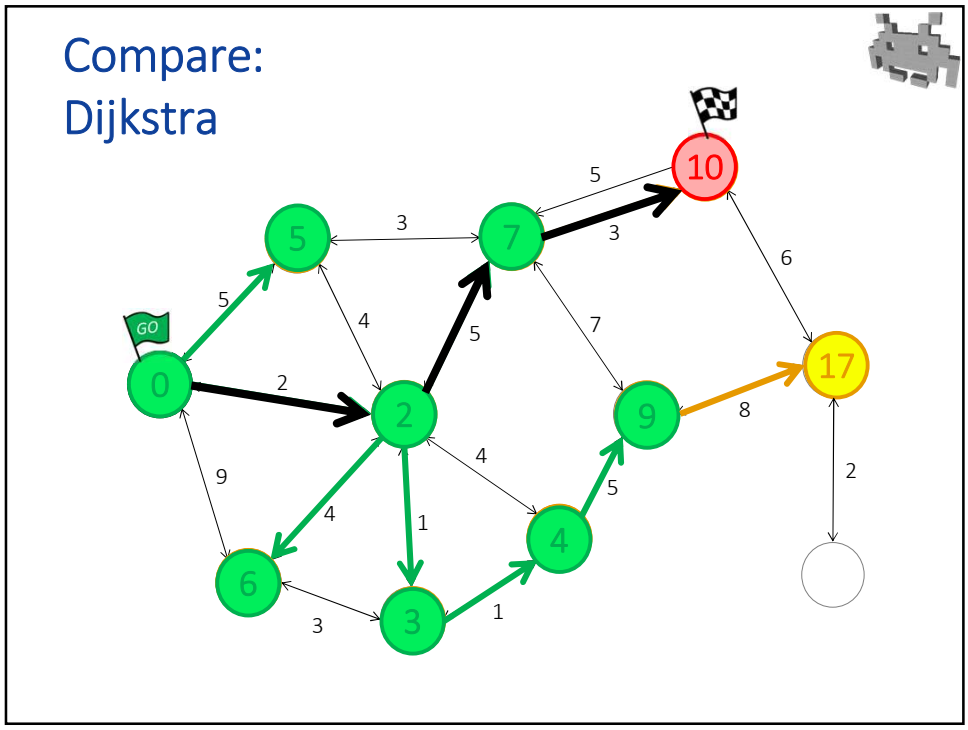
63


A* search
GO
0
5+5
7+2
10+0
2+6
14+4
6+7
6+9
3+9
5
3
5
4
5
7
6
2
9
4
1
4
5
8
2
3
1

64


Compare:
A* search
GO
0
5+5
7+2
10+0
2+6
14+4
6+7
6+9
3+9
5
3
5
4
5
7
6
2
8
9
4
4
1
5
3
1
2

66


Compare:
Dijkstra
GO
0
5
7
10
2
9
17
6
3
4
5
3
5
4
5
7
6
2
8
9
4
4
1
5
3
1
2

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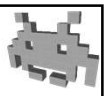
Input of Dijkstra algorithm: notes.



- 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
- Can be trivially adapted for multiple initial and target nodes
  - Returns the shortest-path between any initial and any target nodes (the smallerst!)
- The algorithm requires to keep track of a set of "active" nodes
  - (in yellow, in the graphs above)
  - 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
  - if negative costs: still terminates, only not guaranteed to find the optimum

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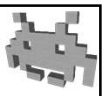
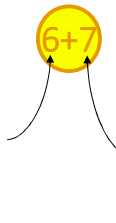
A* algorithm: ("A-star") notes





- 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 $h(X, D)$ – with X, D being nodes: returns an estimate of the *minimal* cost to go from x to Destination node D
    - Function h must be provided to the algorithm
    - 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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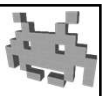
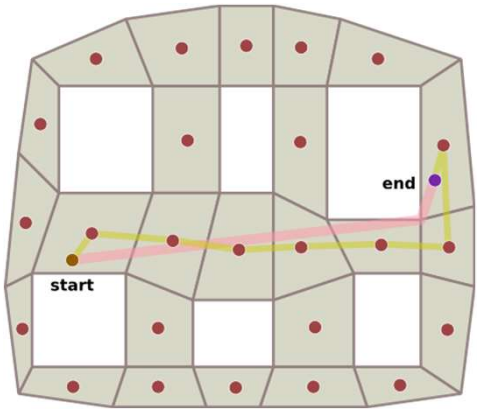
Which graph to use for A* / Dijkstra in a 3D game?



- 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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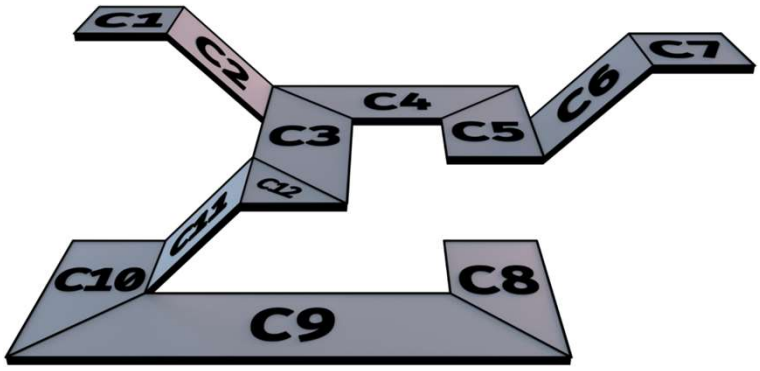
Nav Mesh (manually designed)



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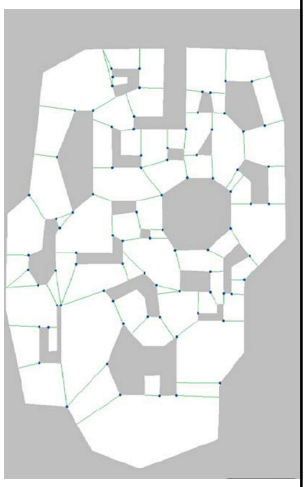
Baking a 3D Nav-Mesh



- 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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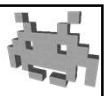
Customizing A* / Dijkstra



- 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")

find out with 3D raycasts

- Remember: A* needs underestimations
  - Decreasing costs requires care
  - E.g. add teleport doors? Be careful

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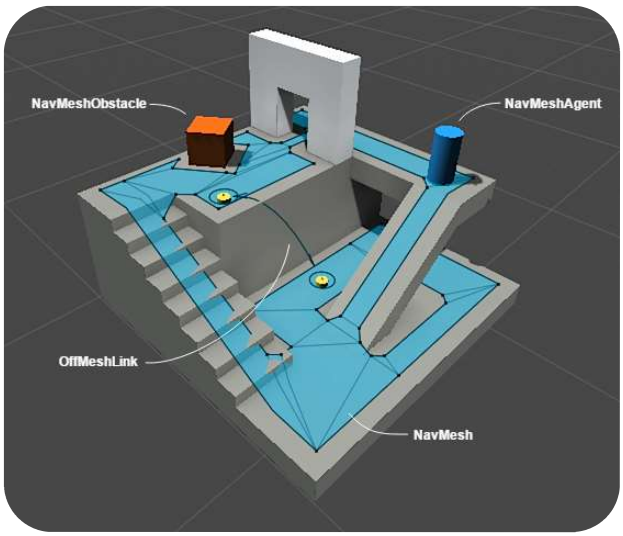
Nav Mesh: example in Unity



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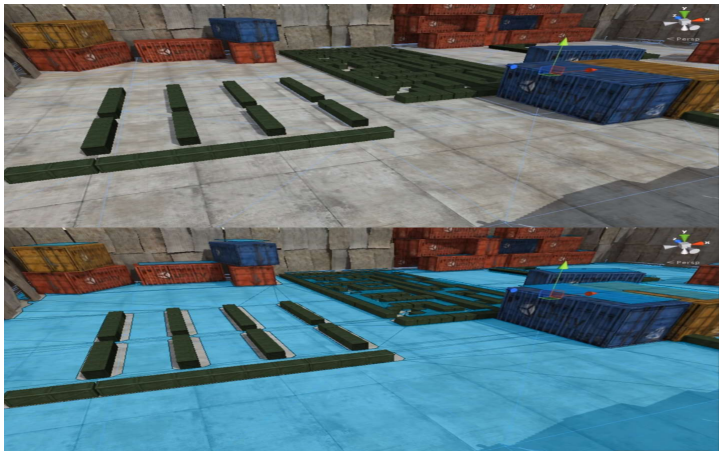
Nav-Mesh baking: example in Unity



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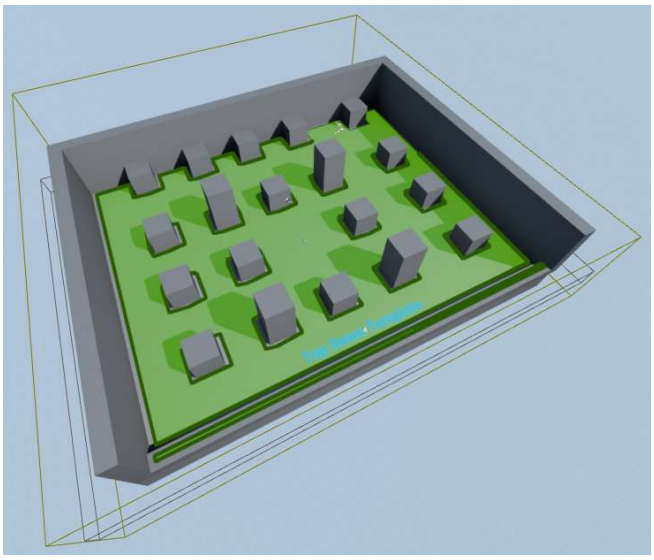
Nav-Mesh baking: example in Unreal



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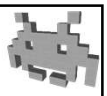
Flocking algorithms



- A mid-level objective: “stay with the group”
  - but “not too close to anyone” (avoid collisions with peers)
- 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

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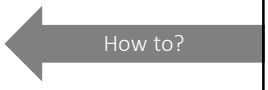
Thinking phase (aka Planning): about the mid-to-high level goals

- 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!



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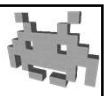
FSM
(more technically: Moore machines)



- 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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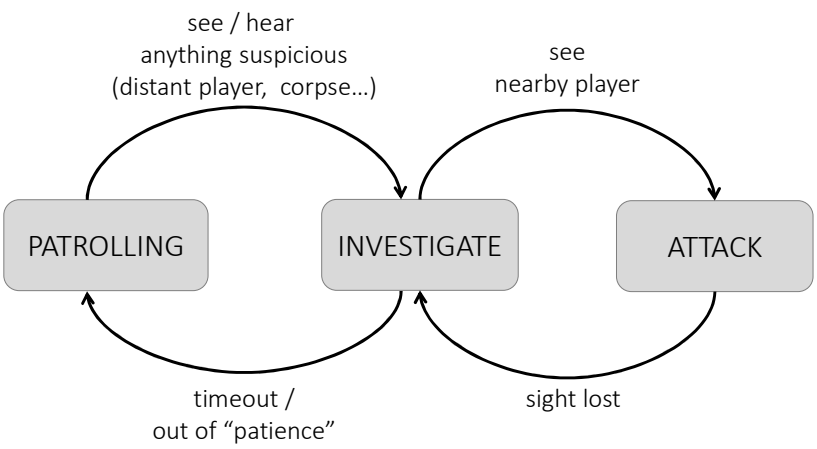
FSM example: a guard



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Implementing 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 serve as a coding guideline
  - use one “status” variable
  - transitions: manually coded in
- Or, as a behavior authoring tool
  - intended for the AI designer
  - supported by game engine
  - WYSIWYG editors possible
  - transitions: conditions (to be checked automatically)
  - statuses: linked to effects (sound, animation,…)
- Limitation: scalability (with complexity)
  - only good for simple behavior
  - quickly produces intricated nets
- Let’s see alternatives:
  - HFSM
  - Behavioral Trees

blur distinction between hi-level / low-level goals

also blur classic distinction between sensing / thinking / acting

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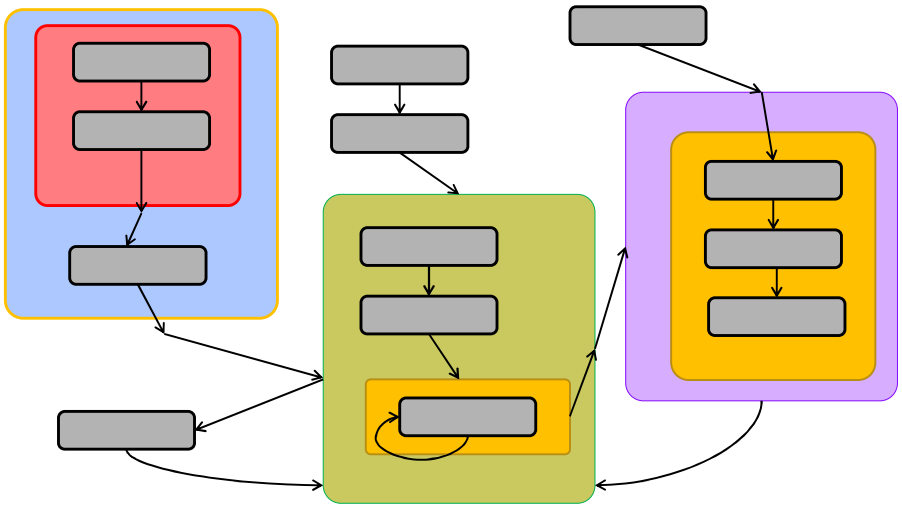
HFSM

Hierarchical Finite State Machines



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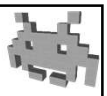
HFSM: concept



- 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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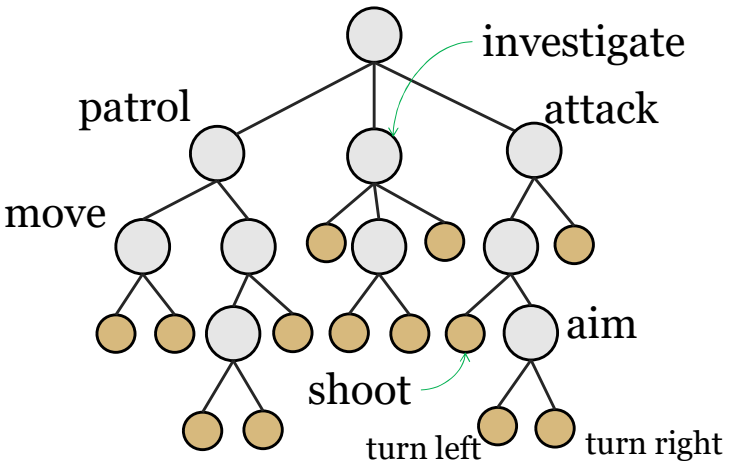
Behavioral Trees



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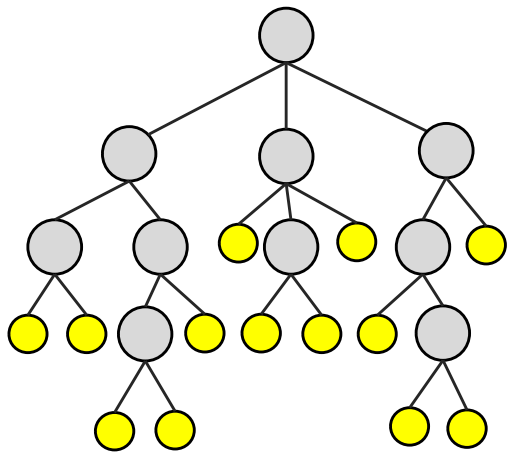
Behavioral Trees



= 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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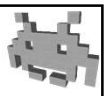
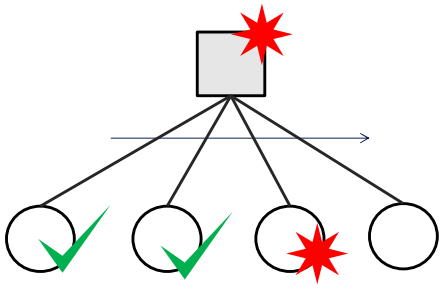
Behavioral Trees: nodes



- internal nodes: sequence



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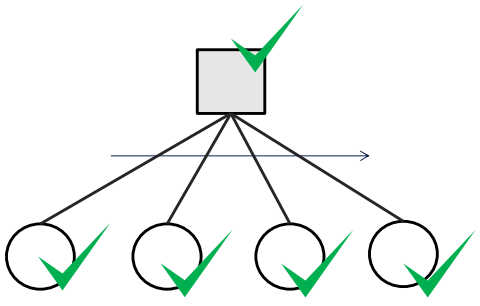
Behavioral Trees: nodes

- internal nodes: sequence



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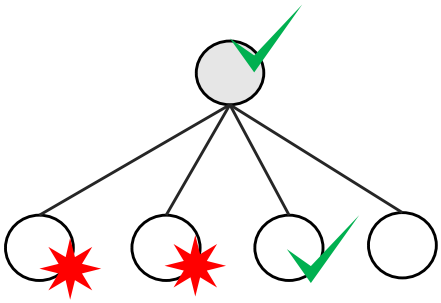
Behavioral Trees: nodes

- internal nodes: selector



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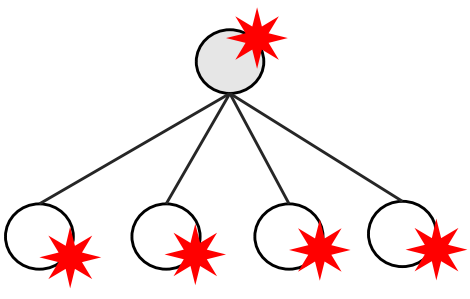
Behavioral Trees: nodes

- internal nodes: selector



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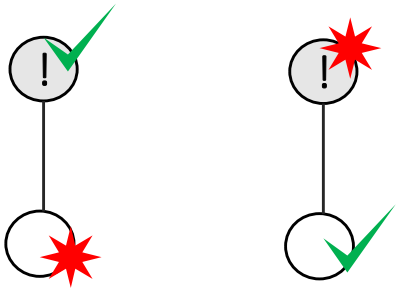
Behavioral Trees: nodes

- internal nodes: inverter



Only child

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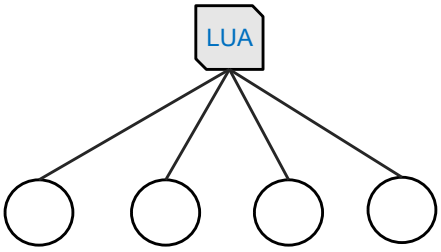
Behavioral Trees: nodes

- or, nodes can be programmed arbitrarily in scripted procedure (in , C#, JS…)
  - run children in some prescribed order
  - fail or succeed, as returned value



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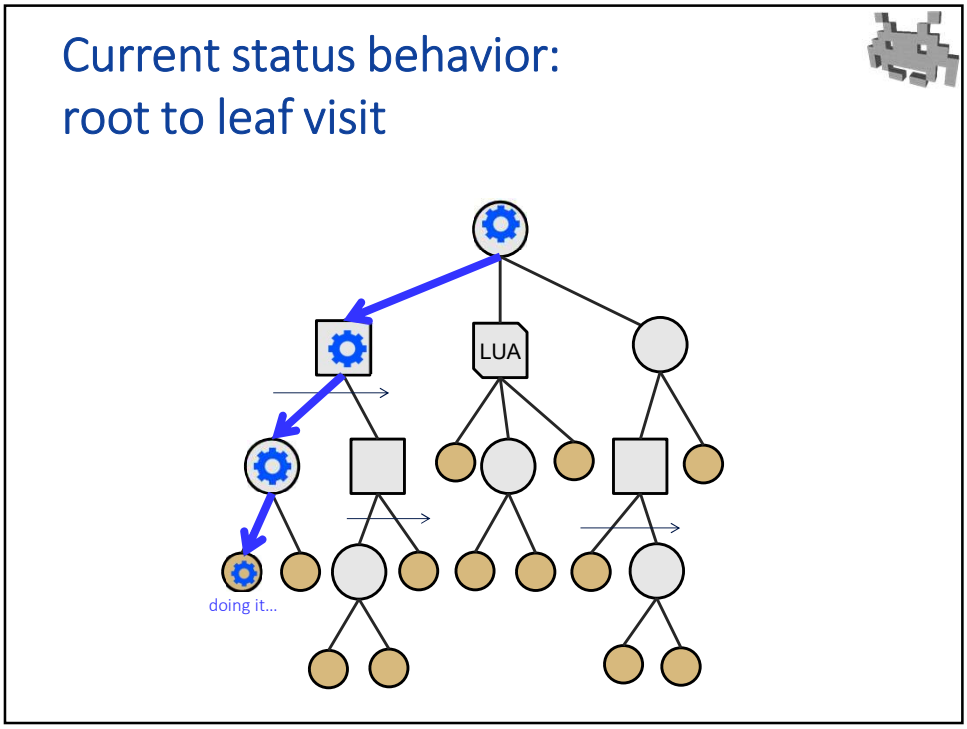
Current status behavior: root to leaf visit



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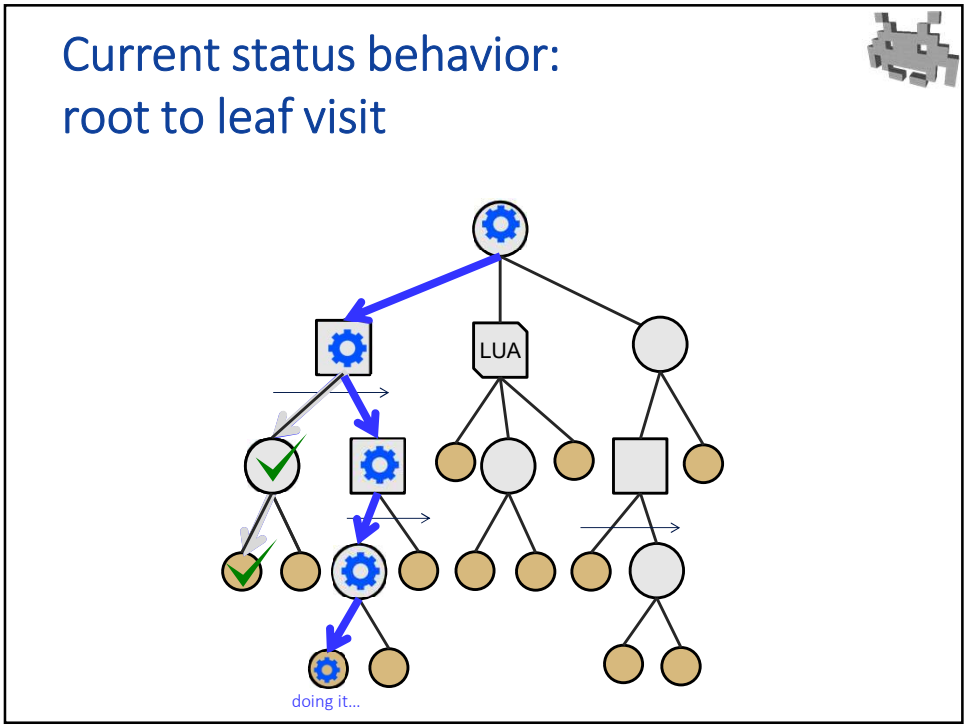
Current status behavior: root to leaf visit



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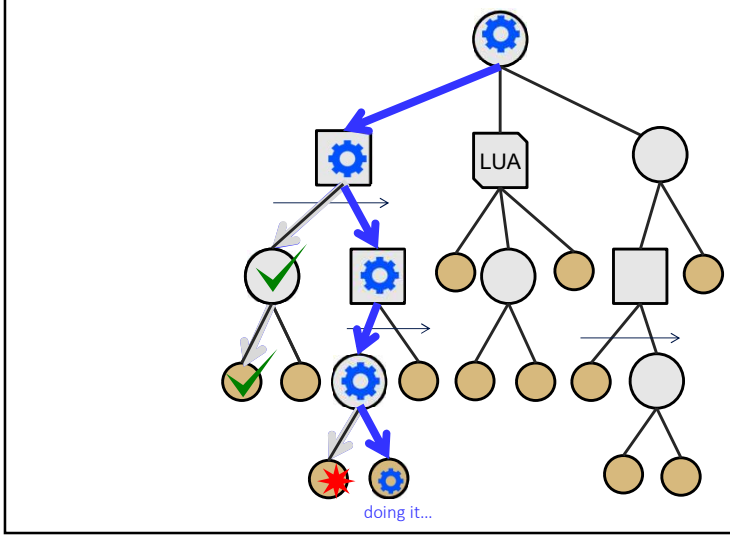
Current status behavior: root to leaf visit



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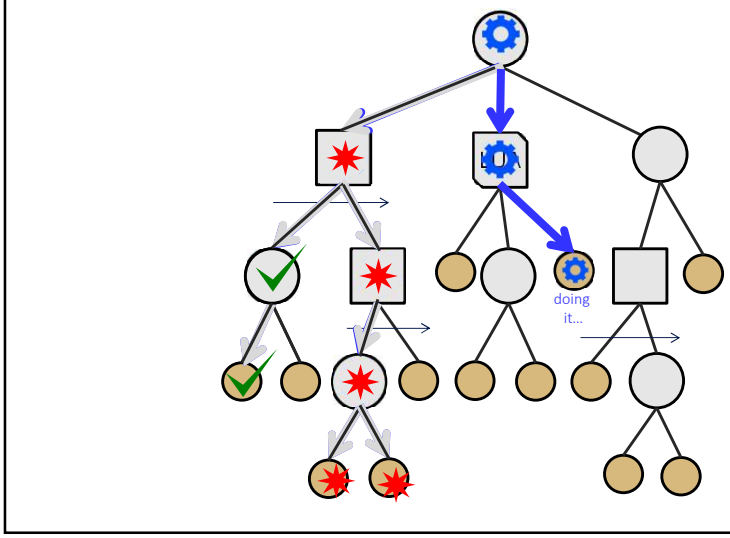
Current status behavior: root to leaf visit



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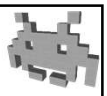
Behavior trees: notes



- 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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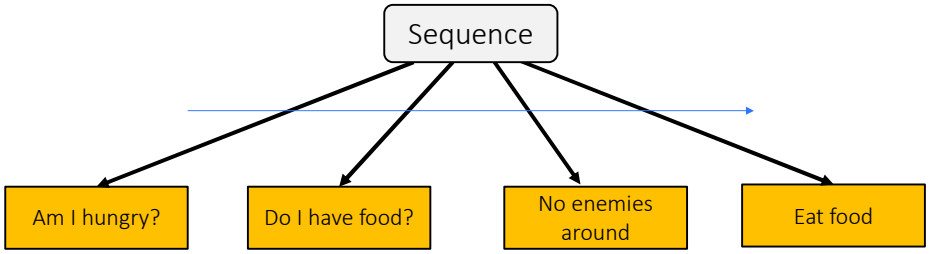
Example



Example by Chris Simpson (gamasutra)

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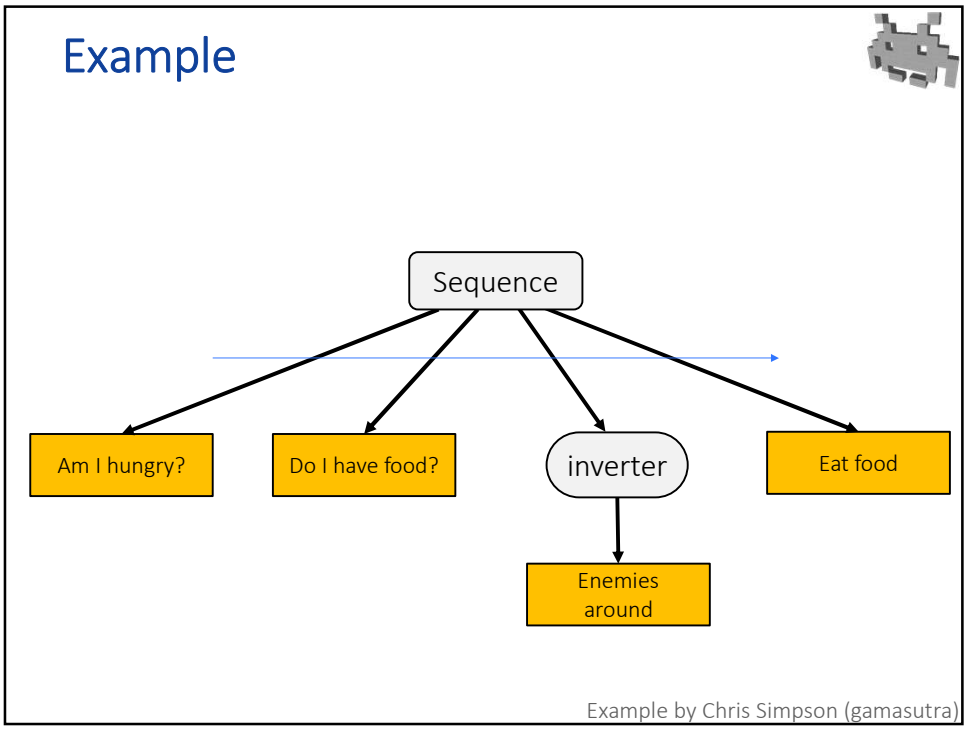
Example



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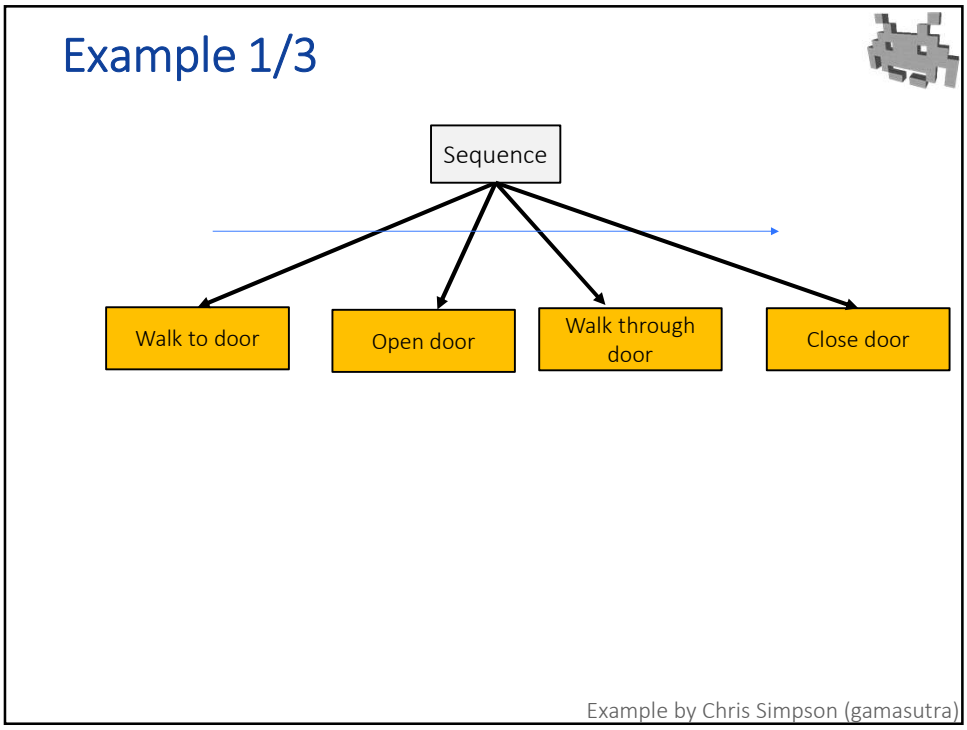
Example 1/3



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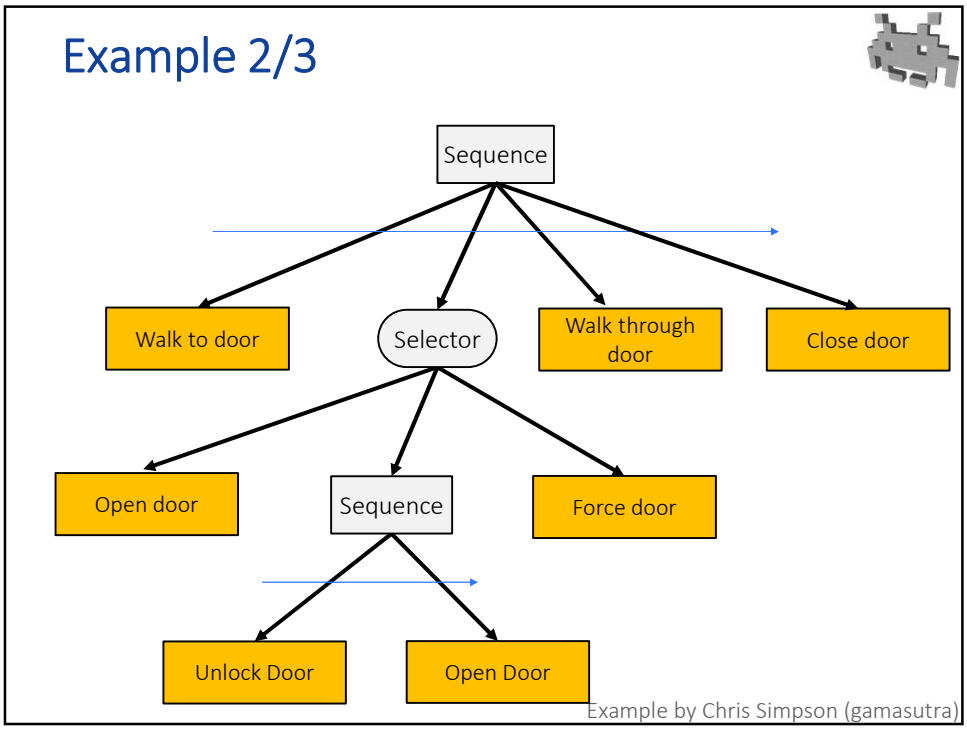
Example 2/3



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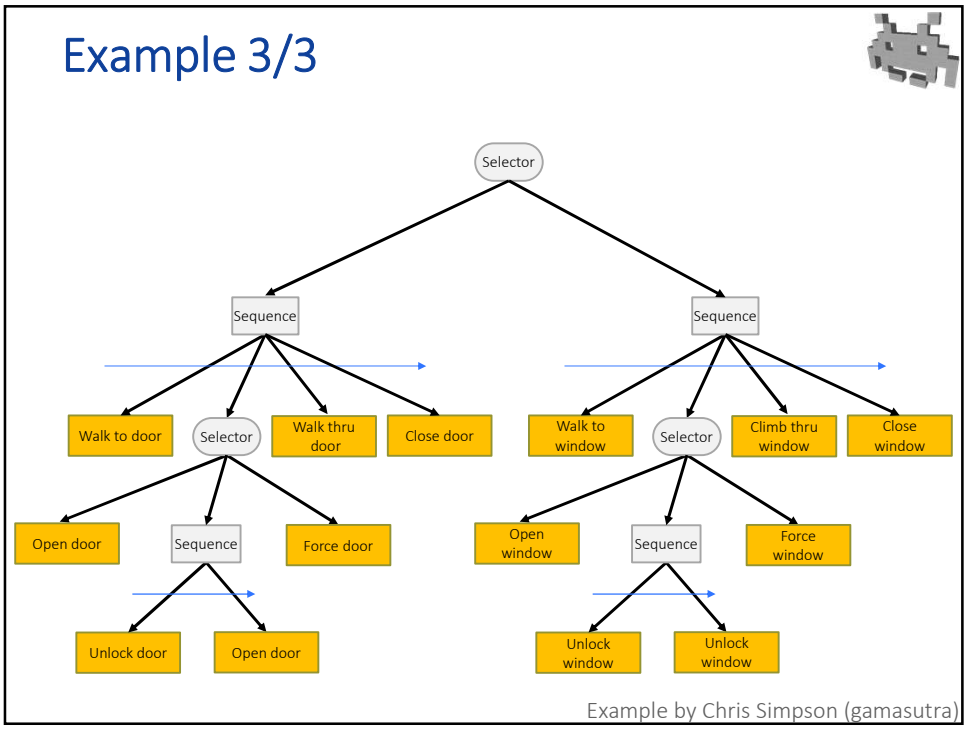
Example 3/3



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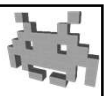
Behavioral tree: advantages



- Intuitive to model
  - even for designers without a CS background?
- Subtrees (intermediate goals) can be reused for similar situations across NPCs / games
  - E.g. anything than needs to enter the house uses the same "try to enter house" subtree
- Scripted nodes (e.g. LUA) modelling more complex decision making can also be reused
  - BT serves as a framework to organize / reuse scripts
- Simpler behaviors = building blocks of more complex behaviors
  - Top-down or bottom-up approach to NPC behavior design

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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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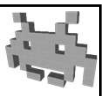
Support for NPC-behavior in a game engine: a summary



- Assets for NPC behaviors:
  - 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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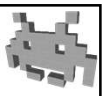
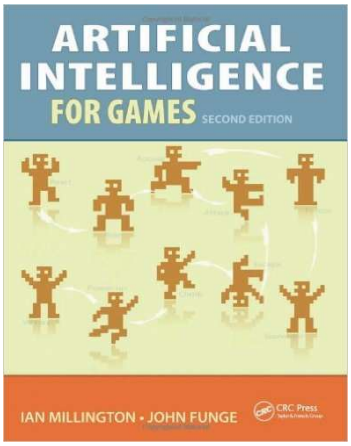
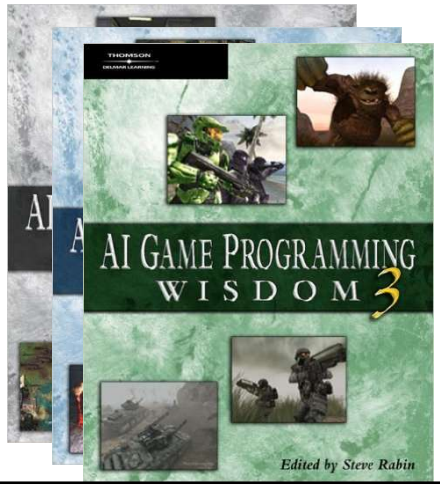
To investigate further



- AI for VideoGames course!
- Books:





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