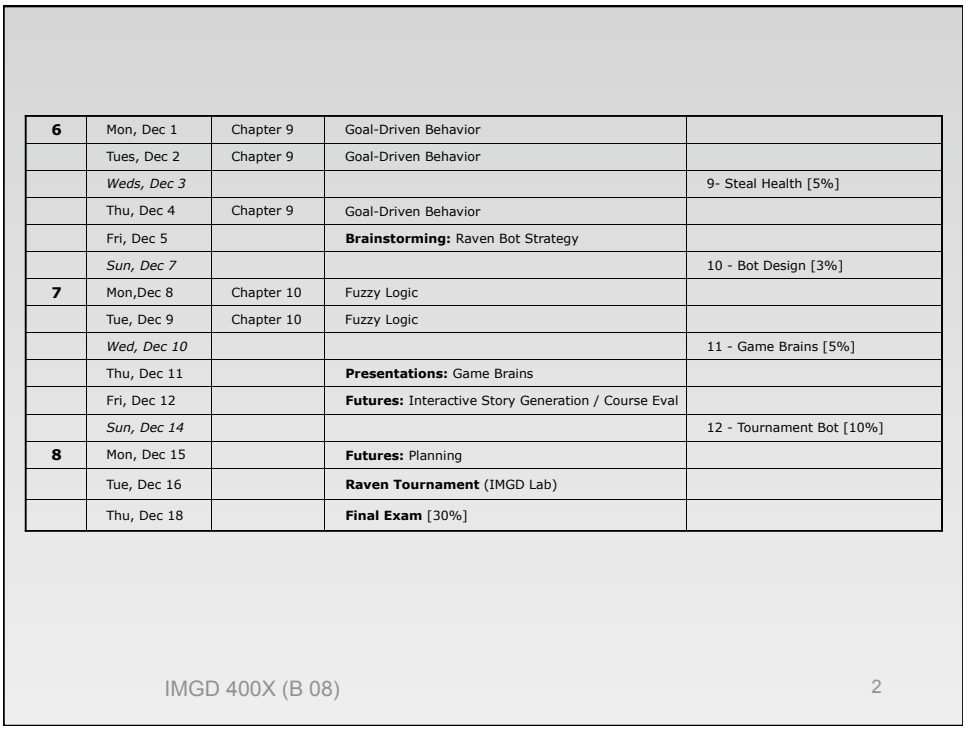
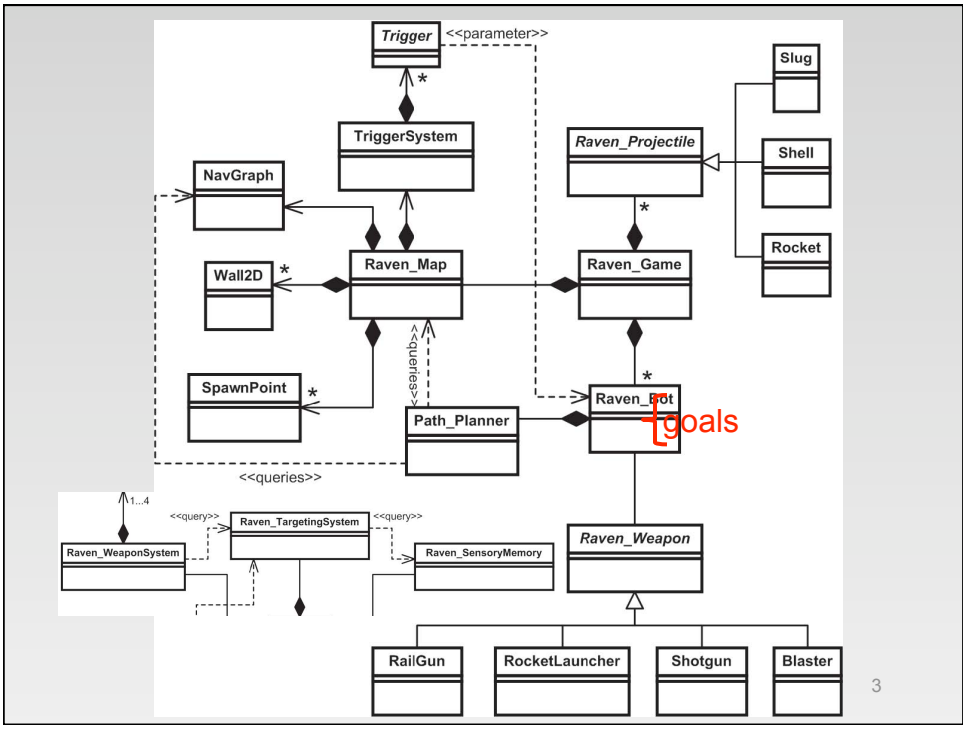


6	Mon, Dec 1	Chapter 9	Goal-Driven Behavior	
	Tues, Dec 2	Chapter 9	Goal-Driven Behavior	
	Weds, Dec 3			9- Steal Health [5%]
	Thu, Dec 4	Chapter 9	Goal-Driven Behavior	
	Fri, Dec 5		**Brainstorming:** Raven Bot Strategy	
	Sun, Dec 7			10 - Bot Design [3%]
7	Mon,Dec 8	Chapter 10	Fuzzy Logic	
	Tue, Dec 9	Chapter 10	Fuzzy Logic	
	Wed, Dec 10			11 - Game Brains [5%]
	Thu, Dec 11		**Presentations:** Game Brains	
	Fri, Dec 12		**Futures:** Interactive Story Generation / Course Eval	
	Sun, Dec 14			12 - Tournament Bot [10%]
8	Mon, Dec 15		**Futures:** Planning	
	Tue, Dec 16		**Raven Tournament** (IMGD Lab)	
	Thu, Dec 18		**Final Exam** [30%]	



Outline

- Goals and planning in AI
  - for more, see Russell & Norvig, AI textbook
- Goal tree execution
  - decomposing and monitoring goals
- Goal arbitration
  - choosing a toplevel goal
- Achitecture Extensions / Applications
  - player possession
  - interruptions
  - special path obstacles
  - command queuing
  - scripting

Goals and Planning in AI

- Goals
  - intuitive and cognitively motivated concept
  - an abstraction that guides behavior
  - often formalized as a partial description of a desired state of the world

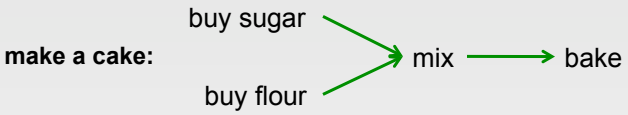
Goal	Desired World State
go to the cinema	I am at the cinema
attack (given bot)	I am firing on the bot

Goals and Planning in AI

- Desired world state
  - is this the same notion of "state" as in state machines?
    - no, states in FSM are part of mental states of agent
    - states in FSM more analogous to (can be used like) goals
    - some similar implementation features (see later)
  - degrees of formalization
    1. just the *name* of the goal, e.g., GoToCinema
    2. code/*procedure* to test if world is in desired state (goal succeeded) or not (goal failed), e.g., test location
    3. *declarative*/logical representation (very difficult in general)

Goals and Planning in AI

- What is a *plan* ?
  1. a *sequence* of *actions* to achieve a *goal*, e.g.,
     leave the house: [walk to closet, open closet door, remove coat from coat hook, ...]
     – *sequence:* totally ordered
     – *action:* directly executable by agent (changes world state)
     – *goal:* desired world state
  2. a *partially ordered set* of actions, e.g.,



Goals and Planning in AI

- What is *planning* ?
  - given a goal
  - construct a plan to change current (or given) world state into desired world state
  - usually involves search (in space of possible plans)
  - multiple solutions possible
  - plan may fail, especially if world changes due to other factors than own actions (e.g., other agents)
  - **example:** path planning
    – given current and desired location
    – find sequence of movements from here to there
  - *will talk about non-path applications of planning in games in final futures lectures*

Goals and Planning in AI

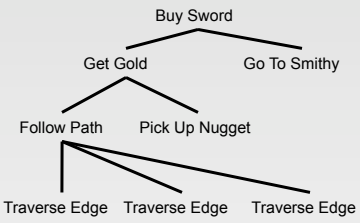
- What is *re-planning* ?
  - when the current plan for a goal fails
    - – you executed all the actions in the plan
    - – but the world is not in the desired state
      - > assumes you have some test for failure
    - – or some planned action is not executable
      - > e.g., cannot open door (because locked)
      - > assumes actions have some test for block/failure
      - > could be a faulty plan or world changed unexpectedly
  - need to construct another plan for same goal
    - – starting with current world state
    - – and maybe other constraints based on current failure

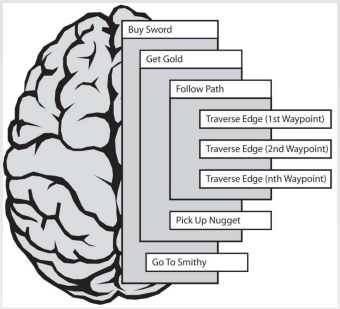
Goals and Planning in AI

- Alternative to searching for plans ?
  - search can be expensive and error-prone
  - predefine specific plans for particular goals
  - quickly look up plan for goal
  - may be more than one choice (need to decide)
  - can be “manual” or cached from previous (e.g., offline) searches
  - already “knowing” a lot of plans for commonly occurring goals in a domain makes you an “expert”

Goals and Planning in AI

- *Hierarchical plans*
  - tree of goals and actions (aka “atomic” or “primitive” goals)
  - child/parent relationship called “subgoal” or “step”
  - actions appear only at leaves
  - all internal nodes are (“composite” / “abstract” / “nonprimitive”) goals
  - subgoals at each level may be totally or partially ordered
  - decomposition can be via planning (search) or predefined

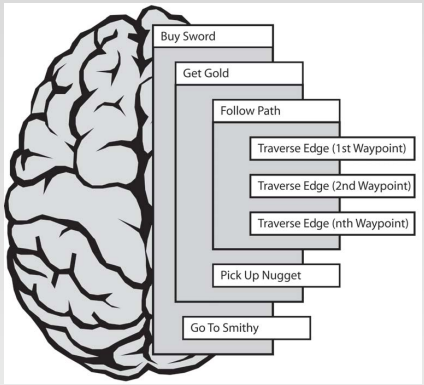




Goals and Planning in AI

- Hierarchical plans
  - when fully expanded (“decomposed”)
    - – all leaves are actions
    - – leaves constitute a sequential or partially ordered plan
  - often expanded (“decomposed”) incrementally
    - – some leaf nodes are not actions
    - – not “directly executable” by agent
    - – what is directly executable depends on level of modeling
    - – not efficient or effective to expand goal nodes before they are “live”, because
      - > will have more information later
      - > e.g., to choose between alternative decompositions

Goals and Planning in AI



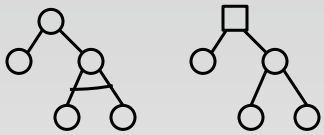
Goals and Planning in AI

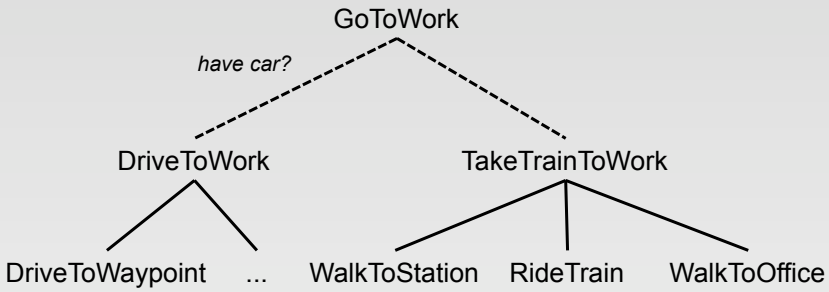
- Hierarchical Task Networks (HTN's)
  - AI term for predefined library of hierarchical plans
  - the library usually implemented using a declarative representation
    - e.g., ANSI/CEA-2018 (http://ce.org/cea-2018)

```
<task name="Buy Sword>
   <subtask task="Get Gold" .../>
   ...
</task>
```

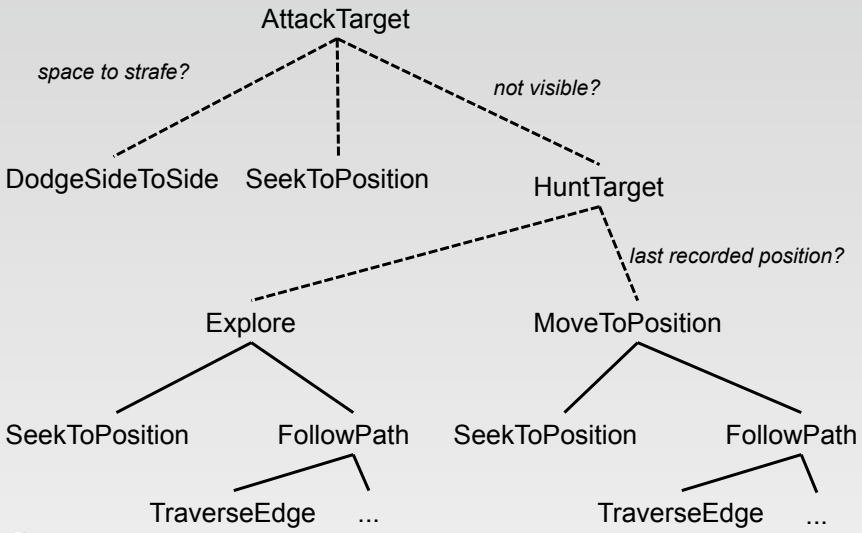
Goals and Planning in AI

- "And/Or Tree"





HTN in Raven



Goal/Behavior Trees

- What Buckland describes in Chapter 9 is essentially a
  - procedural implementation of
  - hierarchical task networks (and/or trees)
  - with totally order subgoals
- This technique is becoming popular in AI game dev community under the title of "behavior trees"
  - see http://aigamedev.com/videos/behavior-trees-part1

Goal/Behavior Tree Execution Issues

- choosing among alternative decompositions of a goal (into subgoals and actions)
- sequencing of subgoals/actions
- monitoring of goal completion/failure
- re-planning after failure

Goals

- Same base class used both for composite and atomic goals (actions)
- Atomic goals (4) currently in Raven
  - Wander, SeekToPosition, TraverseEdge, DodgeSideToSide
- Composite goals (7) currently in Raven
  - *Think*: special root node (discuss later)
  - *Toplevel goals:* GetItem(*), AttackTarget, Explore
  - *Intermediate goals:* MoveToPosition, FollowPath, HuntTarget

Key Properties of a Goal

- **Status** (enum)
  - ***inactive*** – waiting (e.g., due to predecessors not completed); default initial status
  - ***active*** – can be processed on next update
  - ***completed*** – will be removed on next update
  - ***failed*** – will be re-planned or removed on next update
- **Subgoals** (std::list<Goal>)
  - for composite goals only
  - in order of required execution

Key Methods of a Goal

- Activate
- Process
- Terminate
- HandleMessage

Goal::Activate

- Analogous to State::Enter
- contains initialization code (see Terminate)
- for atomic steering goals (e.g,. Wander), turns on steering behavior
- for composite goals, chooses subgoals (decomposition method)
- may be called multiple times for re-planning
- set status to 'active'
  - unless cannot decompose (e.g., target no longer exists)
  - then status set to 'completed', so goal removed

Goal::Process

- analogous to State::Execute
- always starts with ActivateIfInactive()
  - gives Activate method a chance to re-plan
- for composite goals calls ProcessSubgoals
- returns goal status

Goal::Terminate

- analogous to State::Exit
- cleanup code before goal destroyed
- for atomic steering goals, turns off steering behavior

Goal::HandleMessage

- analogous to State::HandleMessage
- for composite goals, if message not handled by self, dispatch to first subgoal
- messages only used in goal code for asynchronous (cf. time slicing) notification from path finder
  - Msg_PathReady
  - Msg_NoPathAvailable

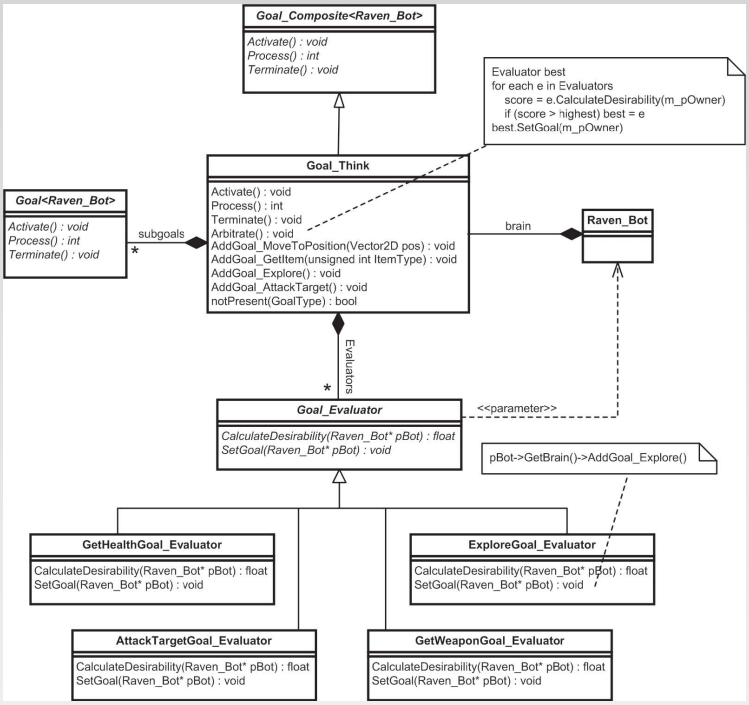
  handled by MoveToPosition and Explore

Code Walk

- Start at AbstRaven_Bot "brain"
- Goal_Composite::ProcessSubgoals
- Atomic Goals
  - Wander
  - TraverseEdge
- Composite Goals
  - FollowPath (TraverseEdge subgoals)
  - MoveToPosition (FollowPath subgoal)
  - AttackTarget
- *Run demo with goal tree display on*

Goal Arbitration

- Six toplevel ("strategy") goals
  - Explore
  - AttackTarget
  - GetItem
    - health
    - rocket launcher
    - shotgun
    - railgun
- How does bot decide which to pursue at any given moment? (Only one at a time)



Goal Evaluators

- List of evaluators stored in “brain” (Goal_Think)
  - One for each toplevel goal
- **CalculateDesirability** method
  - returns value between 0 and 1 (inclusive)
  - evaluated on every update for each goal
    - allows “opportunistic” behavior
  - highest value becomes current goal
    - replaces current goal if different, even if not completed!
  - uses “helper functions”
    - static methods in Raven_Feature
    - each “extracts” useful features from game state
    - features combined with weights to compute desirability

Feature Extractors (0,1)

- Health(pBot)
  - normalize health range to (0,1)
- DistanceToItem(pBot, int ItemType)
  - to nearest item of given type
  - if none, return 1
- IndividualWeaponStrength(pBot, int WeaponType)
  - how much ammo bot has for given weapon type
  - relative to max amount it can carry (return 1)
- TotalWeaponStrength(pBot)
  - combination of three individual weapon strengths

GetHealthGoal_Evaluator

$$Desirability_{health} = k \times \left(\frac{1 - Health}{DistToHealth} \right)$$

- the *farther away* health pack is, the *less* desirable
  - cannot divide by zero, since triggered if inside bounding radius (and thus doesn't exist any more)
- the *less* healthy, the *more* desirable
  - if at max health, desirability is zero
- k is source-level "tweak factor"

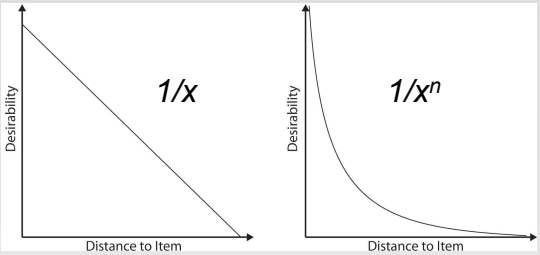
GetWeaponGoal_Evaluator

$$Desirability_{weapon} = k \times \left(\frac{Health \times (1 - WeaponStrength)}{DistToWeapon} \right)$$

- the *farther away* weapon is, the *less* desirable
- the *less* healthy, the *less* desirable to get weapon
- the *more* ammo it has, the *less* desirable
- k is source-level "tweak factor"

Non-Linear Functions

$$Desirability_{weapon} = k \times \left(\frac{Health \times (1 - WeaponStrength)}{DistToWeapon^{2}} \right)$$



- relative "pull" of weapon becomes much stronger as you get closer

AttackTargetGoal_Evaluator

$$Desirability_{attack} = k \times TotalWeaponStrength \times Health$$

- the *stronger* you feel, the *more* desirable to attack
  - health
  - total weapon strength
- k is source-level "tweak factor"

ExploreGoal_Evaluator

- returns fixed value of 0.05
- last resort

"Personalities"

- e.g., cautious versus aggressive
- Per-bot parameter file contains additional tweak ("bias") factor for each toplevel goal
- Easy to multiply in at end of desirability calculation

```
Bot_HealthGoalTweaker     = 1.2
Bot_ShotgunGoalTweaker  = 0.6
Bot_RailgunGoalTweaker    = 0.5
Bot_RocketLauncherTweaker = 0.6
Bot_ExploreTweaker          = 0.2
Bot_AggroGoalTweaker        = 0.8
```

(Note inconsistent naming in Burke code ☹)

Code Walk

- Goal_Think
- GetWeaponGoal_Evaluator
- *Run demo with evaluator values displayed.*

Homework #9 – Due Weds Midnight

- Adding a new goal, StealHealth, with associated evaluator
- Your bot should collect a health pack even if it doesn't need it, when there is a nearby opponent who does need it
- Detailed instructions online
- Familiarize you with goal code for tournament

Architecture Extensions / Applications

- Player Possession
- Interruptions
- Special Path Obstacles
- Command Queuing
- Scripting

Player Possession

- Player “possesses” bot
  - right click once to select
  - right click again to possess
  - sets isPossessed() flag
- Right click on map to indicate destination
  - adds MoveToPosition goal to brain
  - invokes path planner in Activate method
  - other goal arbitration turned off

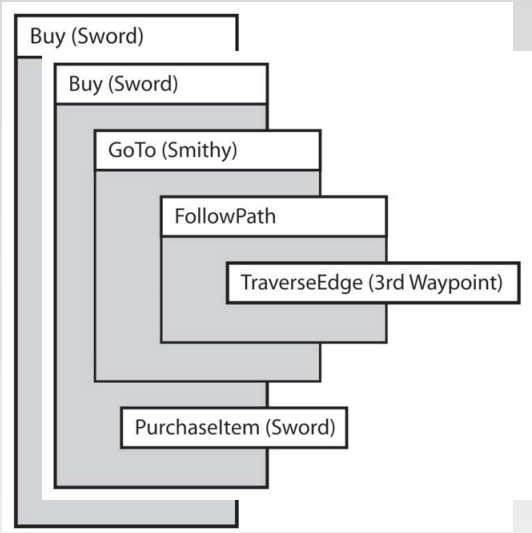
Interruptions

- Toplevel goal arbitration (desirability evaluation) "throws away" the current goal when a "better" (higher scoring) goal is detected
  - a "one-track mind"
  - you might return to the first goal when the new goal is done (or before)---it all depends on the desirability evaluation at each tick
  - but there is no memory of previous goal (or its state information)
  - e.g., AttackTarget, GetHealth, AttackTarget
  - is this good or bad?
  - depends on what?

Interruptions

- an alternative approach/mechanism
  - which can co-exist with toplevel arbitration
  - when a new goal becomes appropriate
    - as determined by some event or evaluation function
    - e.g., "incoming!", or "gas tank low"
  - push it onto the front of the lowest level current subgoal list
  - when the this new goal completes, the original subgoals (and parents) will continue as before
  - the new goal will function as an interruption

Interruptions

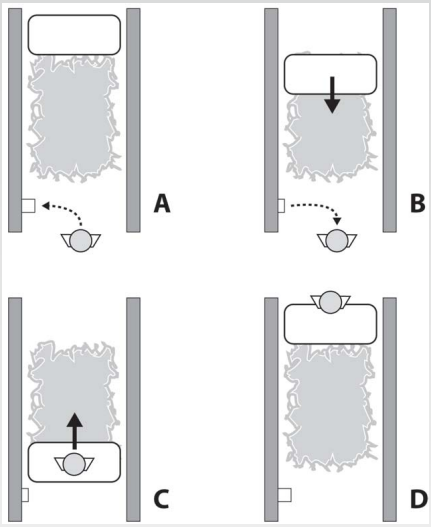


Interruptions

- But what if interruption has changed the world state enough to "break" the plan of the interrupted goal?
  - e.g., defending attacker has taken bot far from planned waypoint path
- Plans already need to have code to check for failure and trigger re-planning (recursively up the goal tree)
- **Conclusion:** Our bots are pretty simple and don't need interruptions, but a more "cognitively oriented" game might benefit

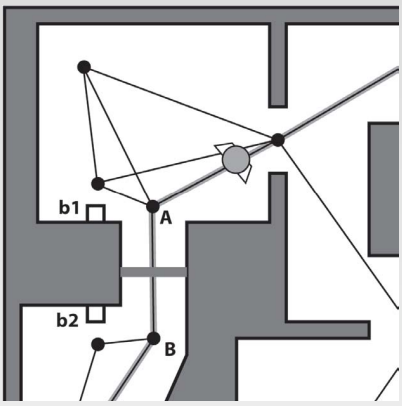
Special Path Obstacles

- bot calls the moving platform and rides it across the pit of fire...
- underlying path edge is specially marked
- FollowPath adds special subgoal instead of usual TraverseEdge



Special Path Obstacles

- Sliding door example in Raven
  - code walk
  - demo



Command Queuing

- How about letting the player put subgoals directly into the tree?
  - gives the player a way to “instruct and forget” an NPC
  - e.g., “attack this house, then take down the flag, then retreat to meeting area”
  - need some kind of user interface design
- Navigation waypoint example in Raven
  - holding down ‘Q’ key while clicking right
  - adds MovePosition goal to back of subgoal list (queue)
  - code walk
  - demo

Scripting

- How about exposing the subgoal lists to Lua scripting?

```
function AddGenie (...)
  genie = CreateGenie(...)
  genie:SayPhrase(“Welcome...”)
  genie:SayPhrase(“Follow me...three wishes...)
  genie:LeadPlayerToPosition(...)
  genie:VanishInPuffOfSmoke
end
```

Scripting

- What do you need to do?
  - expose C methods in Lua to add subgoals to current goal
  - call appropriate Lua method from C Activate (planning) method of goal
  - optionally expose additional methods to create objects, etc.

The Road to Tournament

- *Fri, Dec 5:* Brainstorming Raven bot strategy
- *Sun, Dec. 7:* Bot Design (HW #10) due
- *Sun, Dec. 14:* Tournament bot (HW #11) due
- *Tue, Dec. 16:* Raven Tournament (IMGD Lab)