Artificial Intelligence and Computer Games

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Also based on talks by Doug Church and Lars Lidén

What is AI?

- The term AI is broadly used in computer games
  - Behave rationally: Use available knowledge to maximize goal achievement.
    - Often leads to optimization techniques.
  - A set of capabilities: Problem solving, learning, planning, ...
- Different game genre employs different techniques

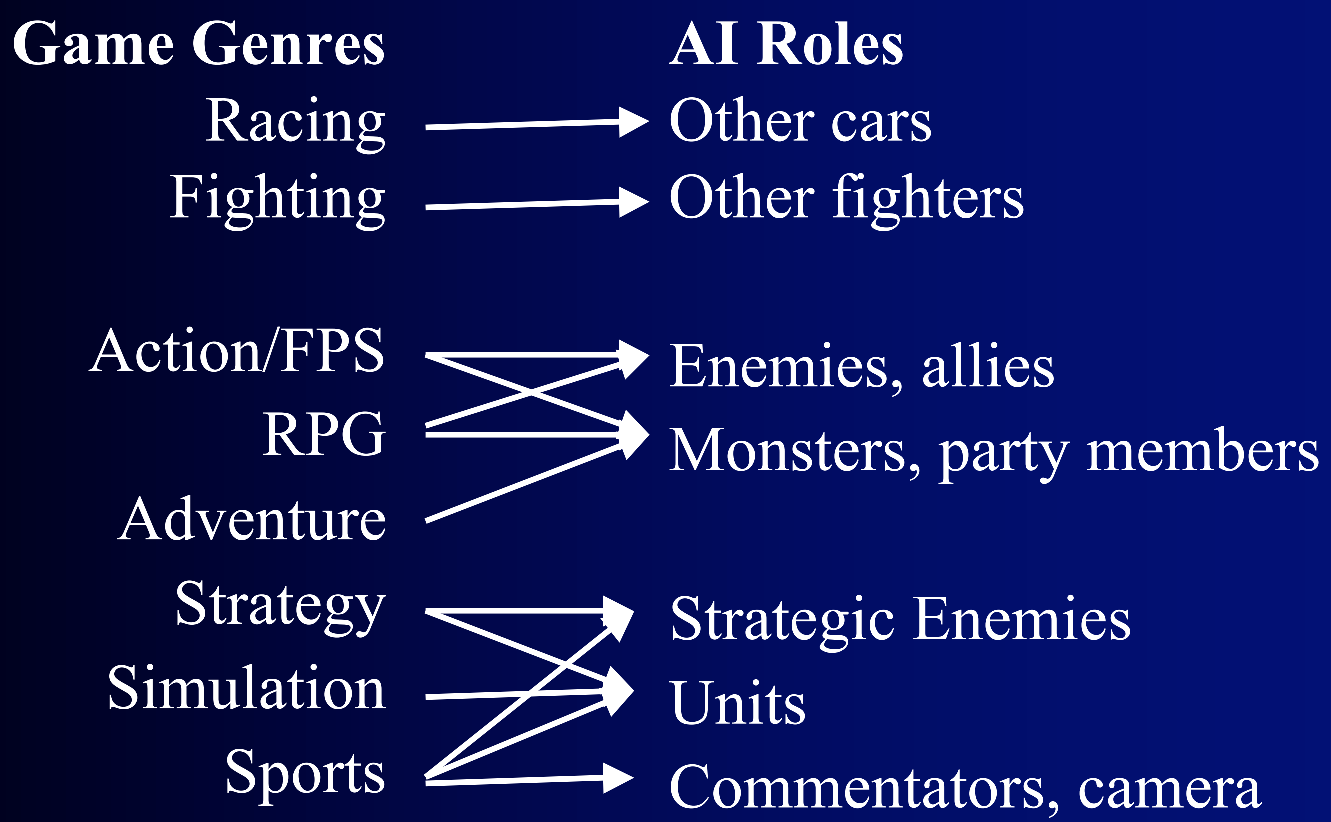
Roles of AI in Games

- Opponents
- Teammates
- Strategic Opponents
- Support Characters
- Autonomous Characters
- Commentators
- Camera Control
- Plot and Story Guides/Directors

AI Provides

- Character, Emotion
- Understanding Environments
- Solving Logic, Resolving Rules
- Decision making, w/Attitude Bias
- Not yet “virtual people”, as such

AI Roles in Games



Obvious Examples

Situations where “AI” might be, could be, should be, and is used in Games

- Car Game – write a virtual driver
- Shooter – write a virtual player
- Sports Games – write a virtual coach
- RTS – write a virtual general

Racing Opponents

- Originally follow course “on rails”
- Next allow different speeds in curves, hills, …
- Finally, control vehicle using game physics
  - Use human play traces
  - Provide variety and skill levels with different humans
  - Transition between trace following and respond to dynamics
    - Powerups, human player, …
- Rubber banding near player make it challenging
- Attempt to have driver “personality”

Somewhat Real Examples

- Car Game – write AI to keep races close
- Shooter – enemies die lots, win little
- Sports – commentators, help player
- RTS – generals who work on pacing
- It is A Question of Design Purpose

Commentator Examples

- Excitement, plus reason for play result
- Finite range of possible utterances
  - “decision quality” is often less important than the “media asset quality”
- Better to be silent than stupid
- Correct isn’t good enough
  - [take a knee != loss of 2]

Requirements for Game AI

- What is the goal of the game?
  - Focus on the Player Experience
- How is the AI going to further that goal?
  - Needs to achieve design aim (and be fun)
  - Foil for the player, creates opportunity
- Dynamic challenge
- Assists in Driving the action
- Allow player to understand AI actions
- Configurable, Override-able, Testable
  - Reproducibility is vital, for test and design
- Satisfies data and speed constraints

The “Thief” AI

Design Goals

- Player is going to be a Thief
- I.e. Sneak Around, Ambush, Hide, Steal
  - AI must allow players to make plans
  - And react to player actions, provide challenge
- Game will feature a loose overall story
  - Ability to script/override behavior
  - In game actions fed back out to story control

“Watch-able” by the player

- Has to “go about its business” with intent
- Actions must make sense to player
  - “interestingly predictable”
  - present play opportunities for player
- Overemphasize thoughts
  - Telegraph all actions
  - Goals must be very explicit

Artificial Stupidity

- Intelligence != Fun
  - What makes a game entertaining and fun does not necessarily correspond to making characters smarter
  - Must be fun, not correct
- The player is, after all, supposed to win
- Lars Liden’s 11 Ways to be stupid

1. Don't cheat

- AI should not be omniscient:
  - Knows where enemies are without seeing them
  - Know where to find resources, weapons, ammo
- Players can detect cheating and will find the game unfair

2. Don’t kill on first attempt

- It’s not fun to suddenly and unexpectedly take damage
- Player may feel cheated, particularly if attacked with a weapon that kills the player or does a lot of damage
- By missing the player the first time, it gives the player a second to react and still keeps the tension high

3. Have horrible aim

- Having abundant gun fire in the air keeps the player on the move and the tension high
- However, the player is supposed to win
- By giving NPC bad aim, one can have abundant gun fire without being too hard on the player
- “Half-Life” used a wide spread on NPC weapons (as much at 40 degrees)

4. Never shoot when first see the player

- When a player first walks into an area and is spotted by an enemy, the enemy should never attack right away
- A secondary activity, such as running for cover or finding a good shooting location is more desirable
- Gives player time to react

5. Warn the Player

- Before attacking the player, warn the player that you are about to do so
  - Make a sound (beep/click)
  - Play a quick animation
  - Say “Gotcha!”, “Take this”
- This is particularly important when attacking from behind

6. Attack “kung-fu” style

- Player is usually playing the role of “Rambo” (i.e. one man taking on an army)
- Although many NPCs may be in a position to attack the player, only a couple should do so at a time
- The remaining NPCs should look busy, reloading, changing positions, etc.

7. Tell the player what you are doing

- Interpreting the actions of AIs can often be subtle
- Complex behaviors are often missed by the player. (Lot’s of work for nothing)
- AIs should tell the player what they are doing
  - “flanking!” “cover me!” “retreat!”
- Players will often intuit intelligence behavior that isn’t really there

8. Intentionally be vulnerable

- Players learn to capitalize on opponent's weaknesses
- Rather than allowing the player to discover unintentional weaknesses in the AI, vulnerability should be designed into an AI's behavior
  - Stop moving before attacking
  - Pause and prepare weapon before attacking
  - Act surprised and slow to react when attacked from behind
- Planned vulnerability makes the characters seem more realistic
- Unintentional mistakes break the realism (seems like fighting a computer program)

9. Don’t be perfect

- Human players make mistakes
- When AIs behave perfectly they seem unnatural
- If an AI knows how to avoid trip mines, run into then occasionally
- When reloading, sometimes fumble with the gun

10. Pull back last minute

Trick:

- Push the player to the limit
- Attack vigorously until the player is near death
- Then pull back. Enemy becomes easier to kill
- Makes player feel like they really accomplished something

11. React To Mistakes

- Mistakes in AI are inevitable
- Unhandled, they make make the AI look dumb
- By recognizing mistakes and reacting to them intelligently they can be turned into features

11. React To Mistakes

- Example 1:
  - Occasionally when an NPC throws a grenade, it bounces off of another object and lands back at the NPCs feet
    - (Note that the player occasionally makes this mistake too!)
  - Looks dumb as the NPC blows himself up
  - If the NPC reacts, however, the mistake turns into a feature:
    - NPC body and facial expression can show surprise, fear
    - NPC can say "Oh Shoot!" or "Doh!"

11. React To Mistakes

- Example 2:
  - Player throws a grenade at a group of NPCs. As they are crowded together not all of them are able to find a path to get away
  - Looks dumb if the NPCs that can't get away, shuffle around trying to get out
  - If we detect that the problem has arisen, can have the trapped NPC's react
    - Crouch down and put hands over head

Themes

- Player Player Player Player Player Player
- How can AI enhance player experience
- AI is facilitator of the “fun”
- Enable creative expression for player
  - Allow player to impact the world
  - Put player in interesting situations
- Entertaining game != “smarter” opponents
  - Machine opponents are babysitters, not ruthless opponents
  - Players aren’t pro players, or pro strategists
  - Give player ways to make the big play
- The illusion of intelligence is far more important than actual intelligence
  - Predictable often more important than smart
  - Clever AI decisions are no better than secret special knowledge if player can’t tell

Observations

- AI has three basic game roles
  - Replacement for human opponents and players
  - Support characters for interesting player interaction
  - Units for player management

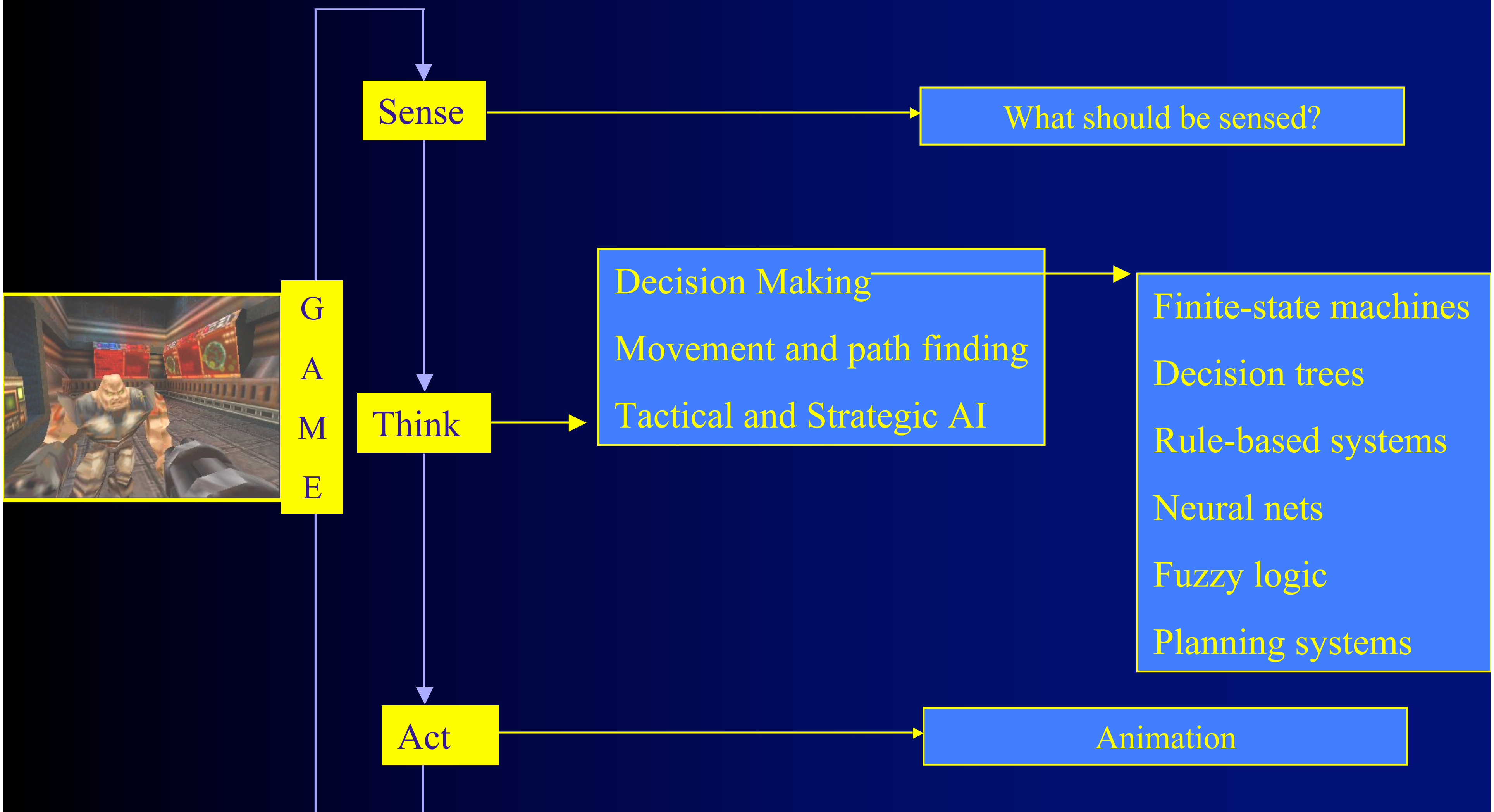
- Entertainment is much more important than realism
  - Cheating is ok if user can’t detect it
  - Play to lose or at least make it challenging
  - Must include variable levels of skills

- No single type of AI is right for all games or all AI roles

AI Agent in a Game

- Each time through control loop, “tick” each agent
  - Sometimes only 1/N times through loop
  - More frequently if in view of player
- Define an API for agents: sensing and acting
- Encapsulate all agent data structures
  - And so agents can’t trash each other or the game
  - Share global data structures on maps, etc.

Execution Flow of an AI Engine

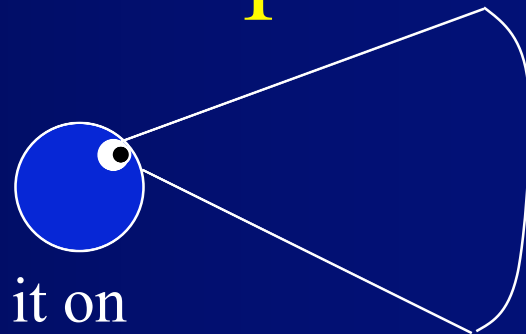


Structure of an Intelligent Agent

- Sensing: perceive features of the environment
- Thinking: decide what action to take to achieve its goals, given the current situation and its knowledge
- Acting: doing things in the world

- Thinking has to make up for limitations in sensing and acting
- The more accurate the models of sensing and acting, the more realistic the behavior

Sensing Limitations & Complexities

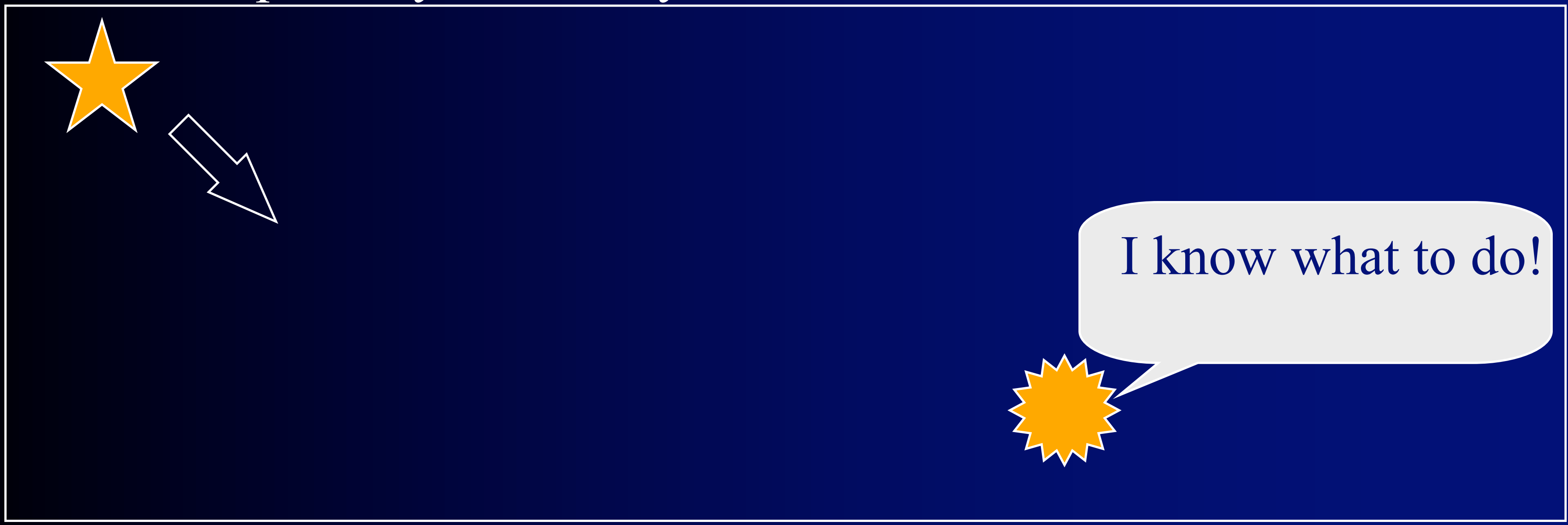


- Limited sensor distance
- Limited field of view:
  - Must point sensor at location and keep it on
- Obstacles
- Complex room structures
  - Detecting and computing paths to doors
- Different sensors give different information and have different limitations
  - Sound: omni-directional, gives direction, distances, speech, ...
  - Vision: limited field of view, 2 1/2D, color, texture, motion, ...
  - Smell: omni-directional, chemical makeup

  ⇨ Need to integrate different sources to build complete picture.

Perfect Agent: Unrealistic

- Sensing: Have perfect information of opponent
- Thinking: Have enough time to do any calculation
  - Know everything relevant about the world
- Action: Flawless, limitless action
  - Teleport anywhere, anytime



Conflicting Goals for AI in Games

- Goal Driven
- Reactive
- Knowledge Intensive
- Human Characteristics
- Low CPU & Memory Usage
- Fast & Easy Development

Complexity

- Complexity of Execution
  - How fast does it run as more knowledge is added?
  - How much memory is required as more knowledge is added?
- Complexity of Specification
  - How hard is it to write the code?
  - As more “knowledge” is added, how much more code needs to be added?
- Memory of prior events
  - Can it remember prior events?
  - For how long?
  - How does it forget?

Execution Flow of an AI Engine

G
A
M
E

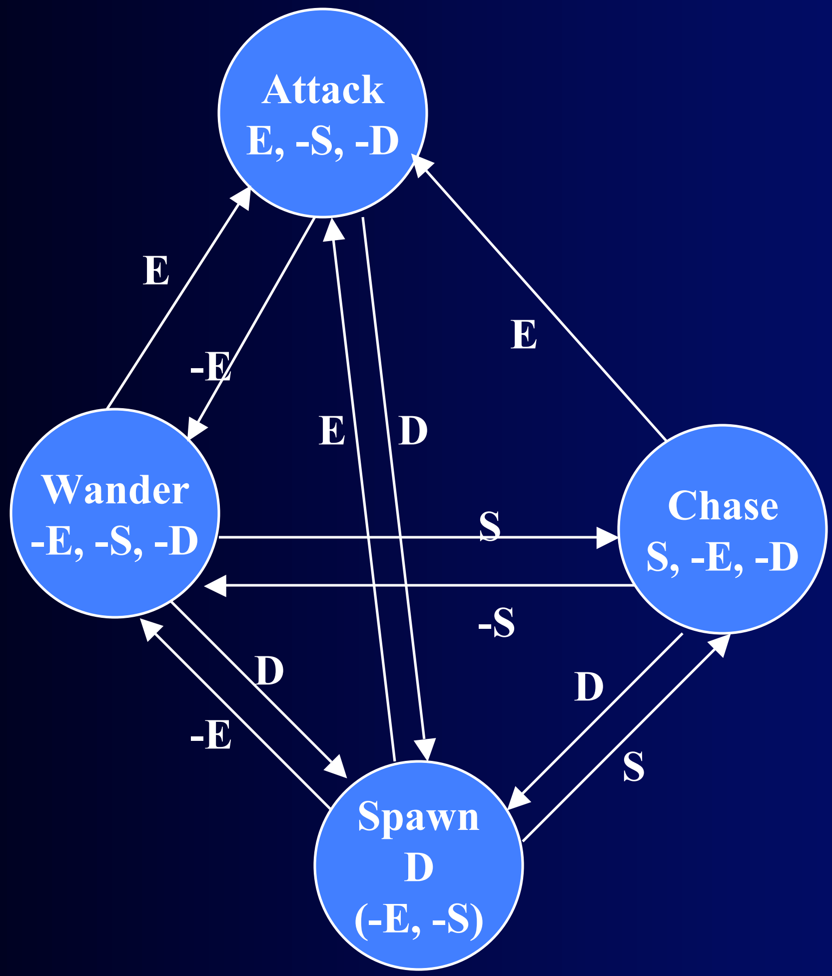
Sense → What should be sensed?

Think →
- Decision Making
- Movement and path finding
- Tactical and Strategic AI

Decision Making →
- Finite-state machines
- Decision trees
- Rule-based systems
- Neural nets
- Fuzzy logic
- Planning systems

Act → Animation

Finite State Machine



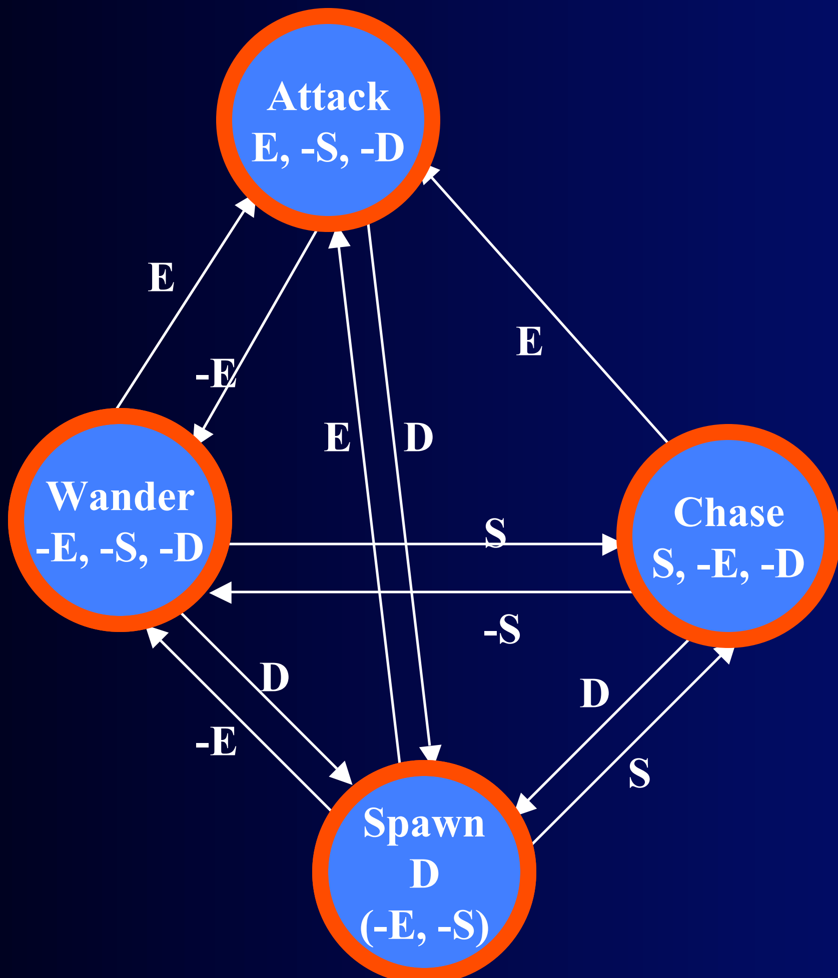
Events:

E=Enemy Seen

S=Sound Heard

D=Die

Example FSM



Events:

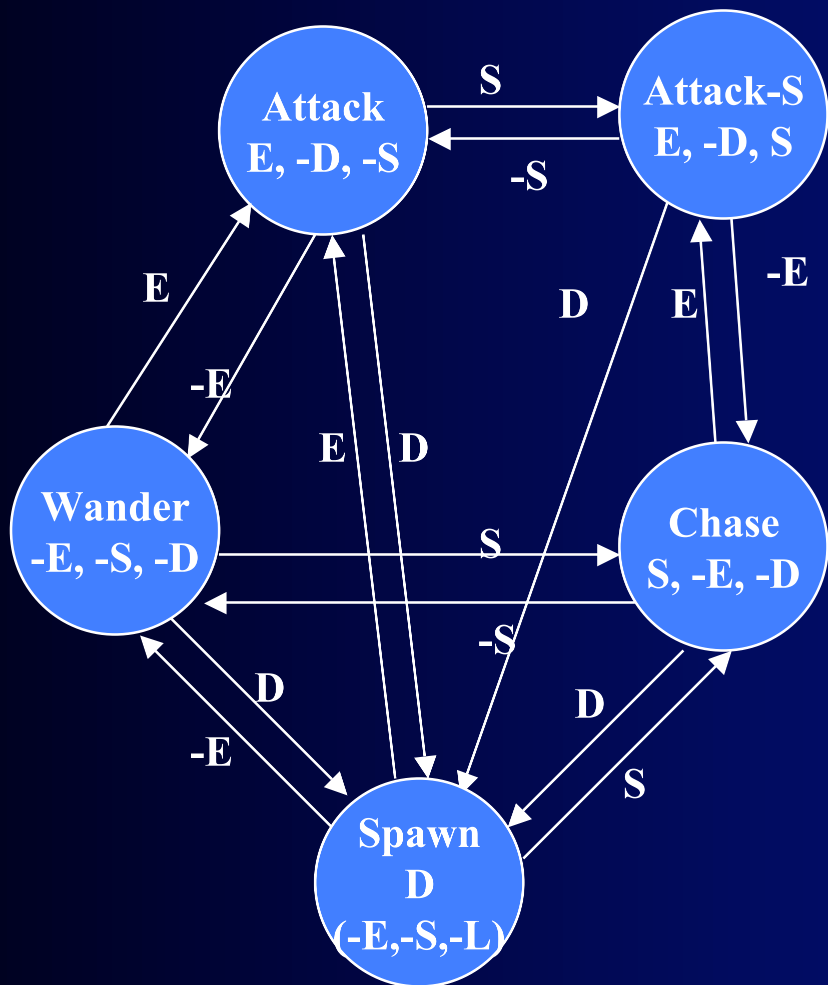
E=Enemy Seen

S=Sound Heard

D=Die

Problem: No transition from attack to chase

Example FSM - Better



Events:

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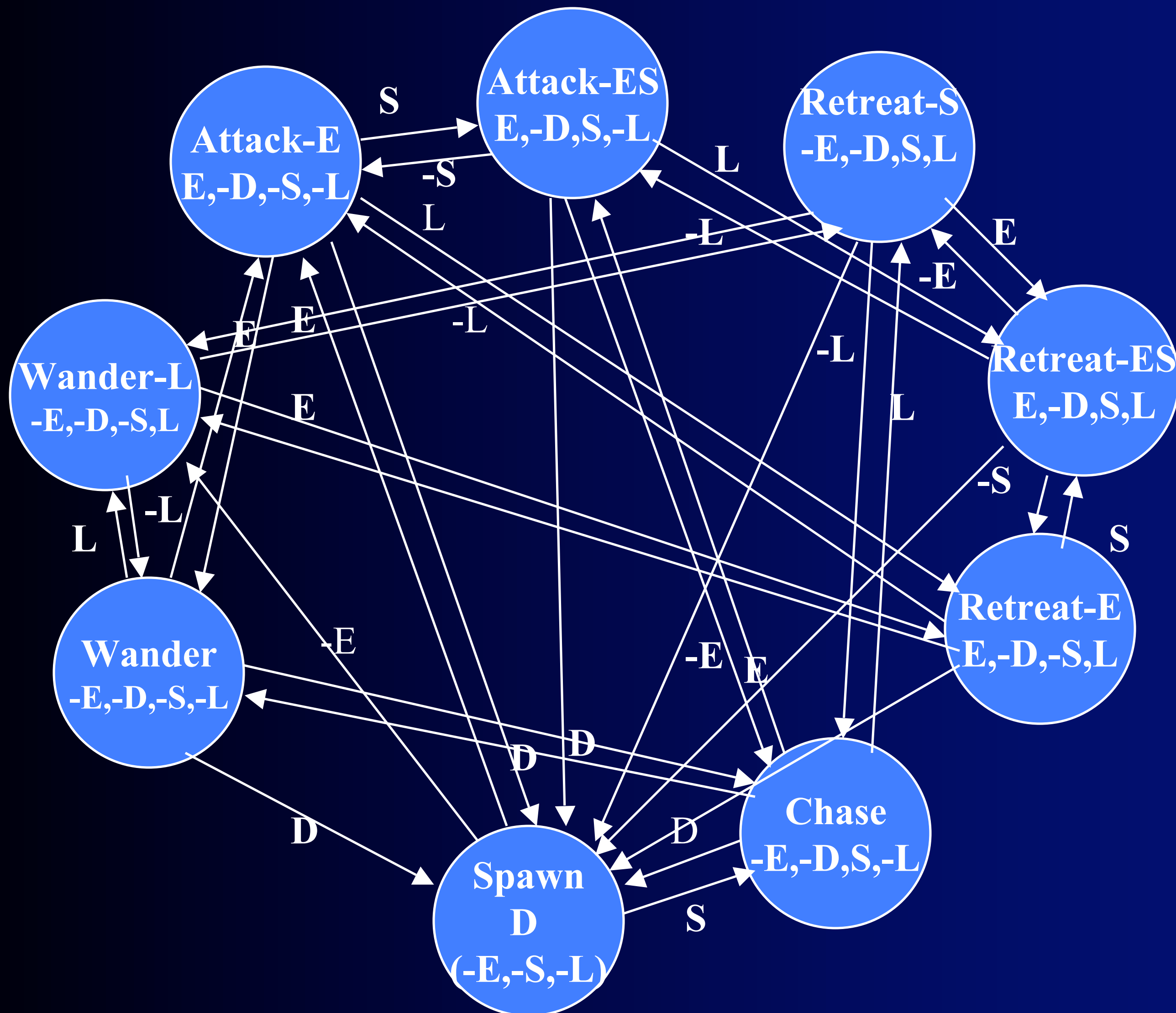
Example FSM with Retreat

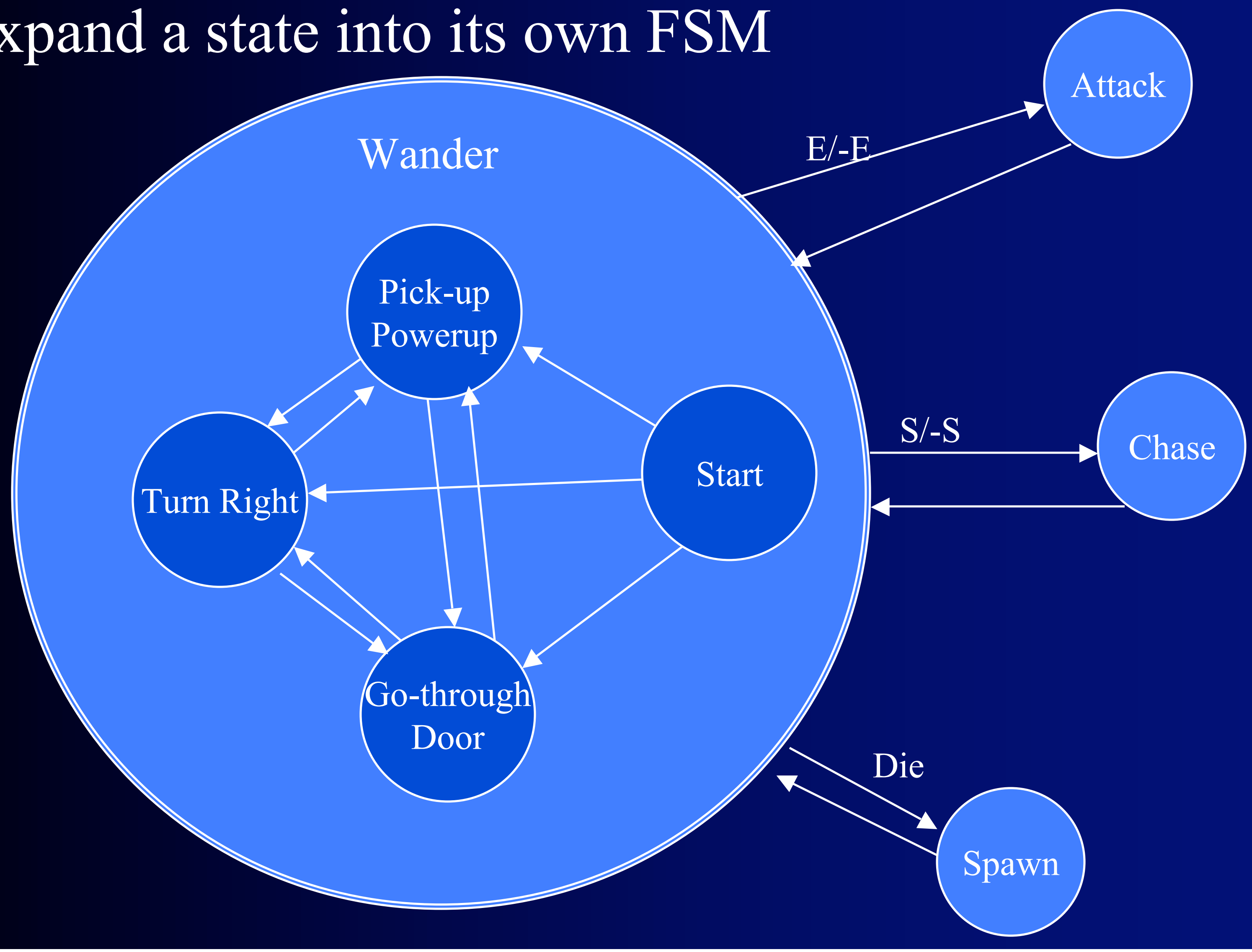


Events:
E=Enemy Seen
S=Sound Heard
D=Die
L=Low Health

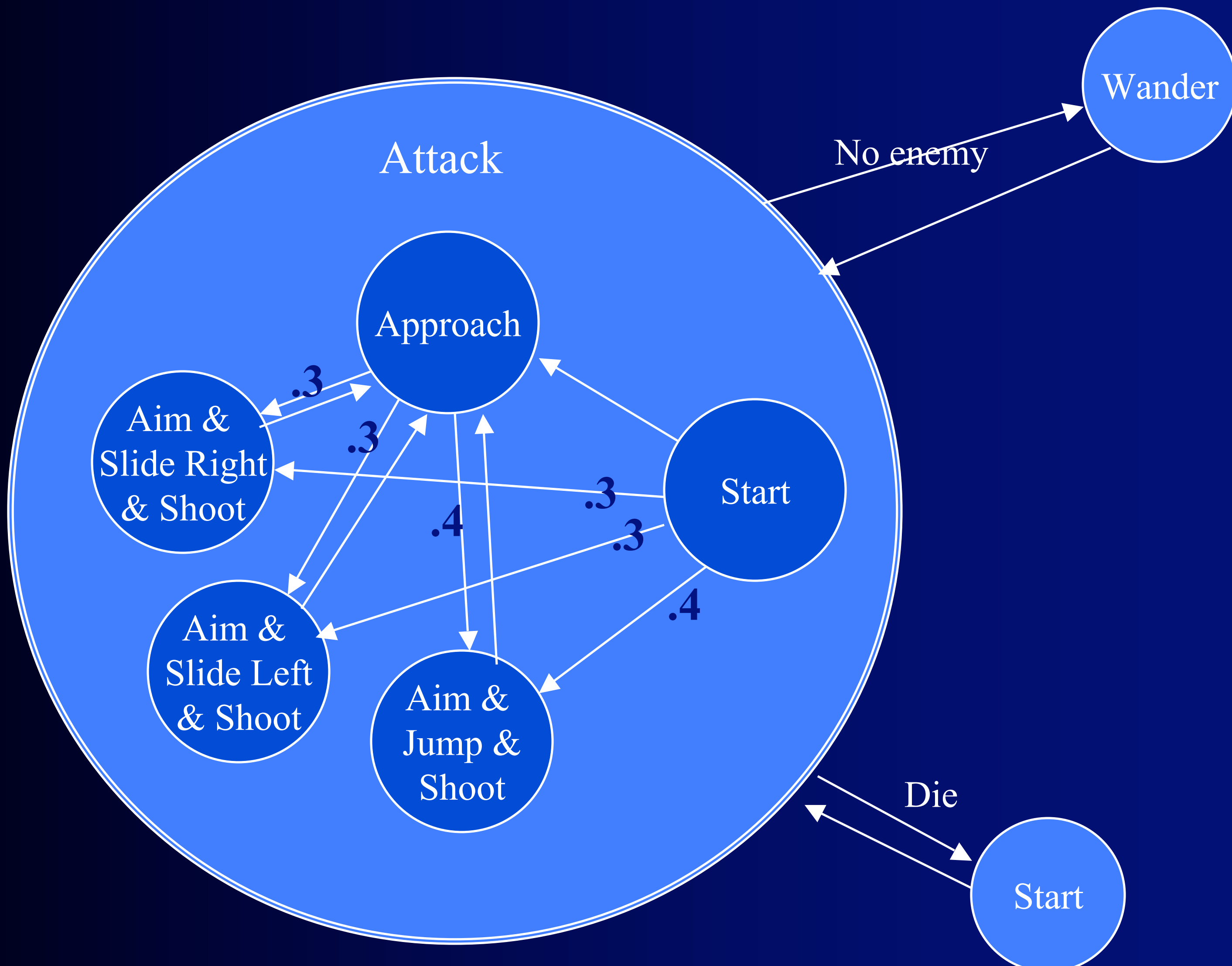
Each feature with N values can require N times as many states

Hierarchical FSM

- Expand a state into its own FSM



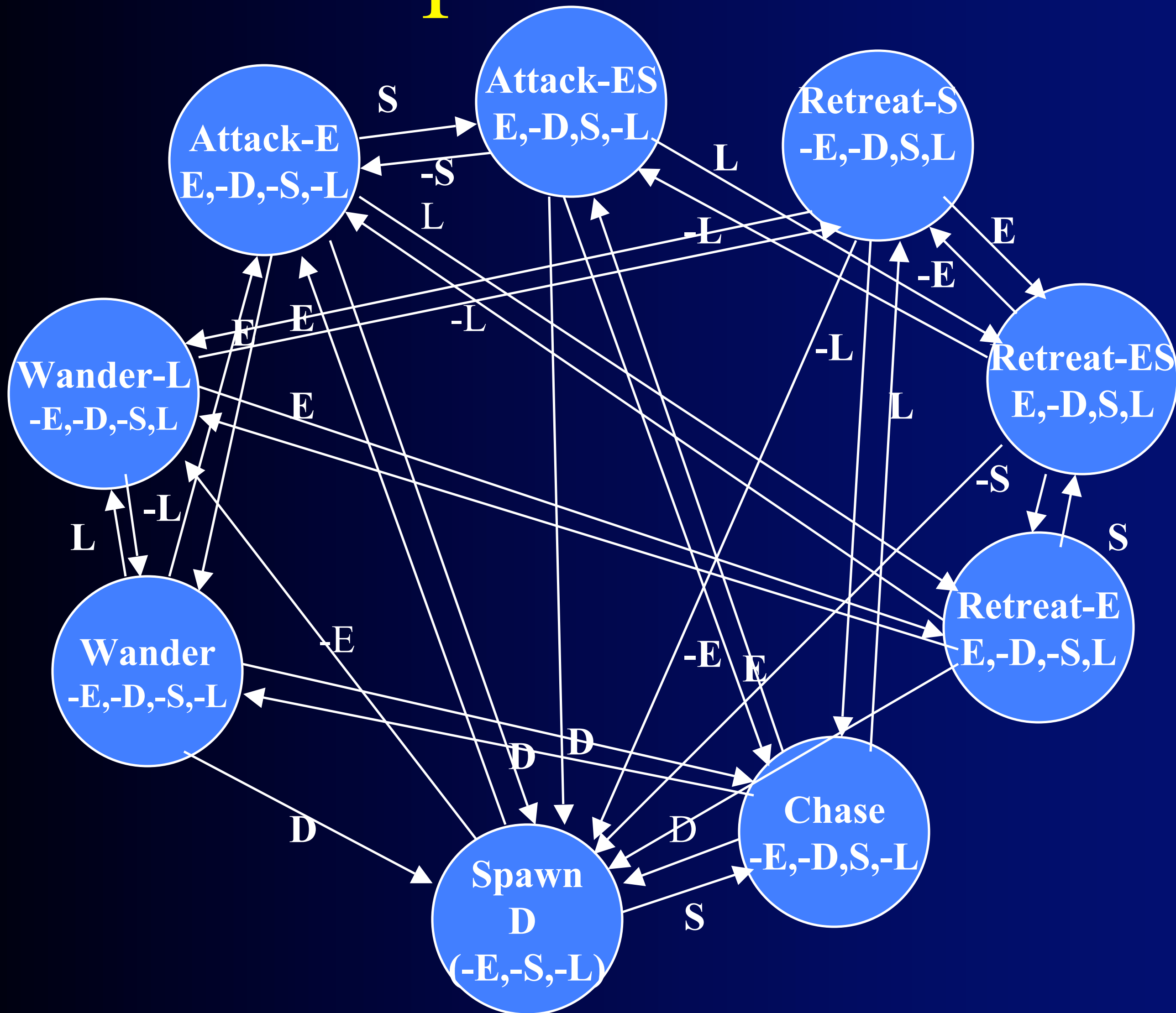
Non-Deterministic Hierarchical FSM (Markov Model)



Decision Trees

- Tree nodes represent attribute tests
  - One child for each possible value of the attribute
- Leaves represent classifications
- Classify by descending from root to a leaf
  - At root test attribute associated with root attribute test
  - Descend the branch corresponding to the instance’s value
  - Repeat for subtree rooted at the new node
  - When a leaf is reached return the classification of that leaf

Example FSM with Retreat



Events:

E=Enemy

S=Sound

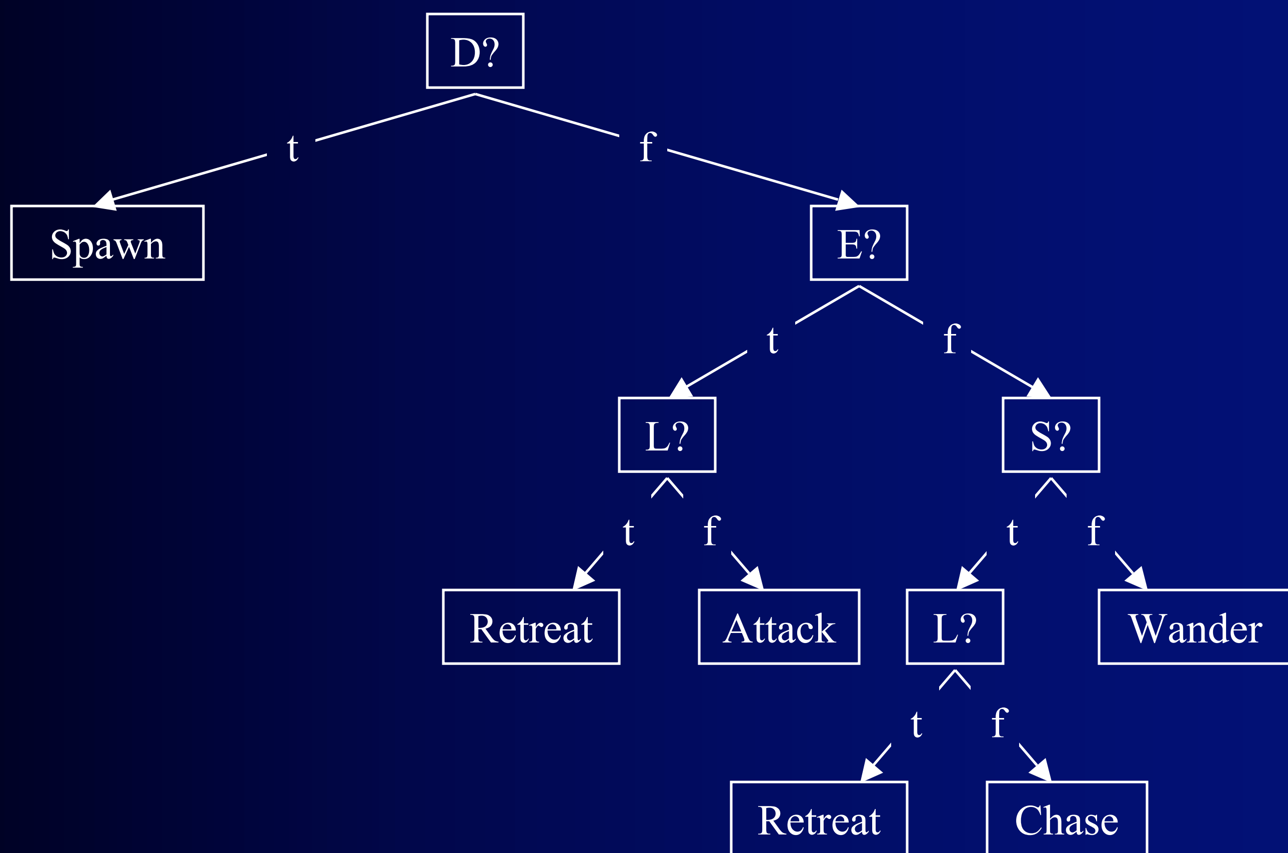
D=Die

L=Low Health

Each new feature can double number of states

Decision Tree for Quake

- Input Sensors: E=<t,f> L=<t,f> S=<t,f> D=<t,f>
- Categories (actions): Attack, Retreat, Chase, Spawn, Wander



Learning Decision Trees

- Decision trees are usually learned by induction
  - Generalize from examples
  - Induction doesn’t guarantee correct decision trees
- Learning is non-incremental
  - Need to store all the examples
- If X is true in every example X must always be true
  - More examples are better
  - Errors in examples cause difficulty
  - Note that induction can result in errors

Entropy

- Entropy: how “mixed” is a set of examples
  - All one category: Entropy = 0
  - Evenly divided: Entropy = $\log_2$(# of examples)
- Given S examples Entropy(S) = $\Sigma -p_i \log_2 p_i$ where p_i is the proportion of S belonging to class i
  - 14 days with 9 in play-tennis and 5 in no-tennis
    - Entropy([9,5]) = 0.940
  - 14 examples with 14 in play-tennis and 0 in no-tennis
    - Entropy ([14,0]) = 0

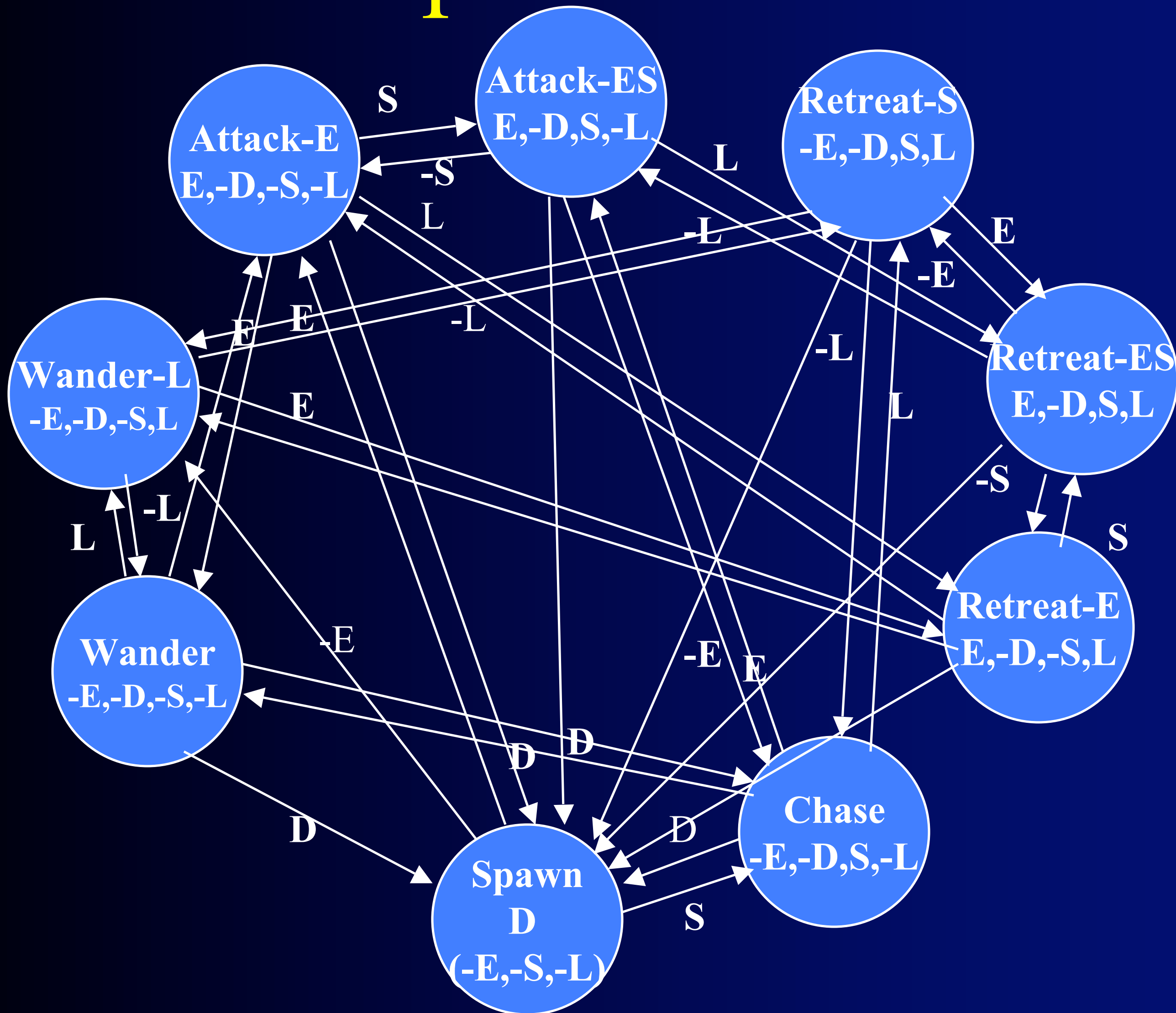
Information Gain

- Information Gain measures the reduction in Entropy
  - Gain(S, A) = Entropy(S) – Σ A/S Entropy(A)
- Example: 14 days: Entropy([9,5]) = 0.940
  - Measure information gain of Wind=<weak,strong>
    - Wind=weak for 8 days: [6,2] out of [9,5]
    - Wind=strong for 6 days: [3,3] out of [9,5]
    - Gain(S,Wind) = 0.048
  - Measure information gain of Humidity=<high,normal>
    - 7 days with high humidity: [3,4] out of [9,5]
    - 7 days with normal humidity: [6,1] out of [9,5]
    - Gain(S,Humidity) = 0.151
  - Humidity has a higher information gain than Wind
    - So choose humidity as the next attribute to be tested

Learning Example

- Learn a decision tree to replace the FSM
- Four attributes: Enemy, Die, Sound, Low Health
  - Each with two values: true, false
- Five categories: Attack, Retreat, Chase, Wander, Spawn
- Use all 16 possible states as examples
  - Attack(2), Retreat(3), Chase(1) Wander(2), Spawn(8)
- Entropy of first 16 examples (max entropy = 4)
  - Entropy([2,3,1,2,8]) = 1.953

Example FSM with Retreat



Events:

E=Enemy

S=Sound

D=Die

L=Low Health

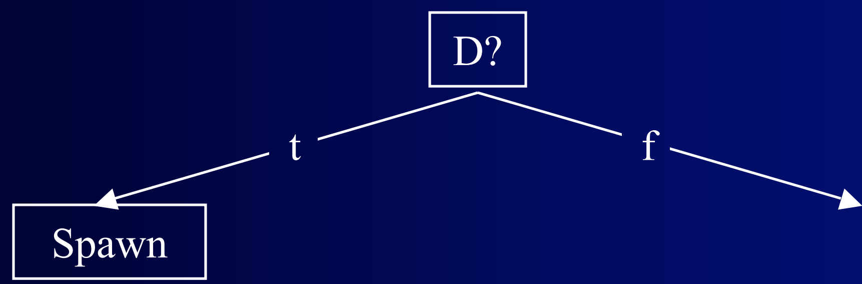
Each new feature can double number of states

Learning Example (2)

- Information gain of Enemy
  - 0.328
- Information gain of Die
  - 1.0
- Information gain of Sound
  - 0.203
- Information gain of Low Health
  - 0.375

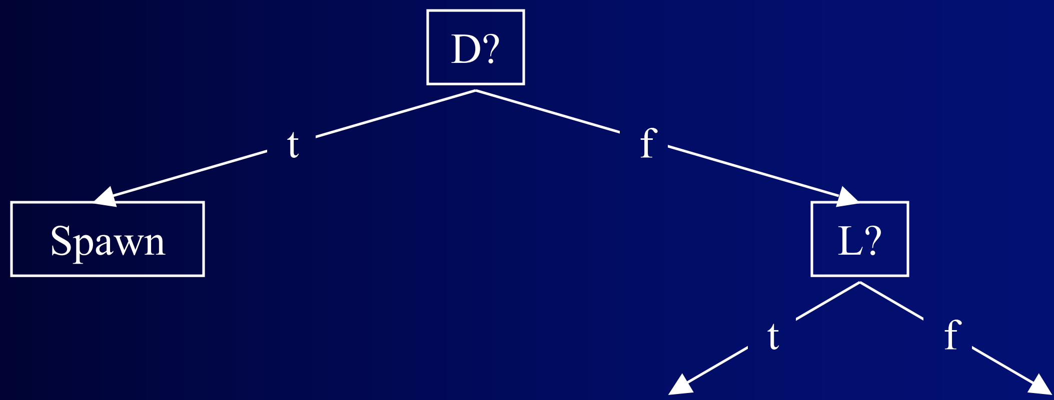
- So Die should be the root test

Learned Decision Tree



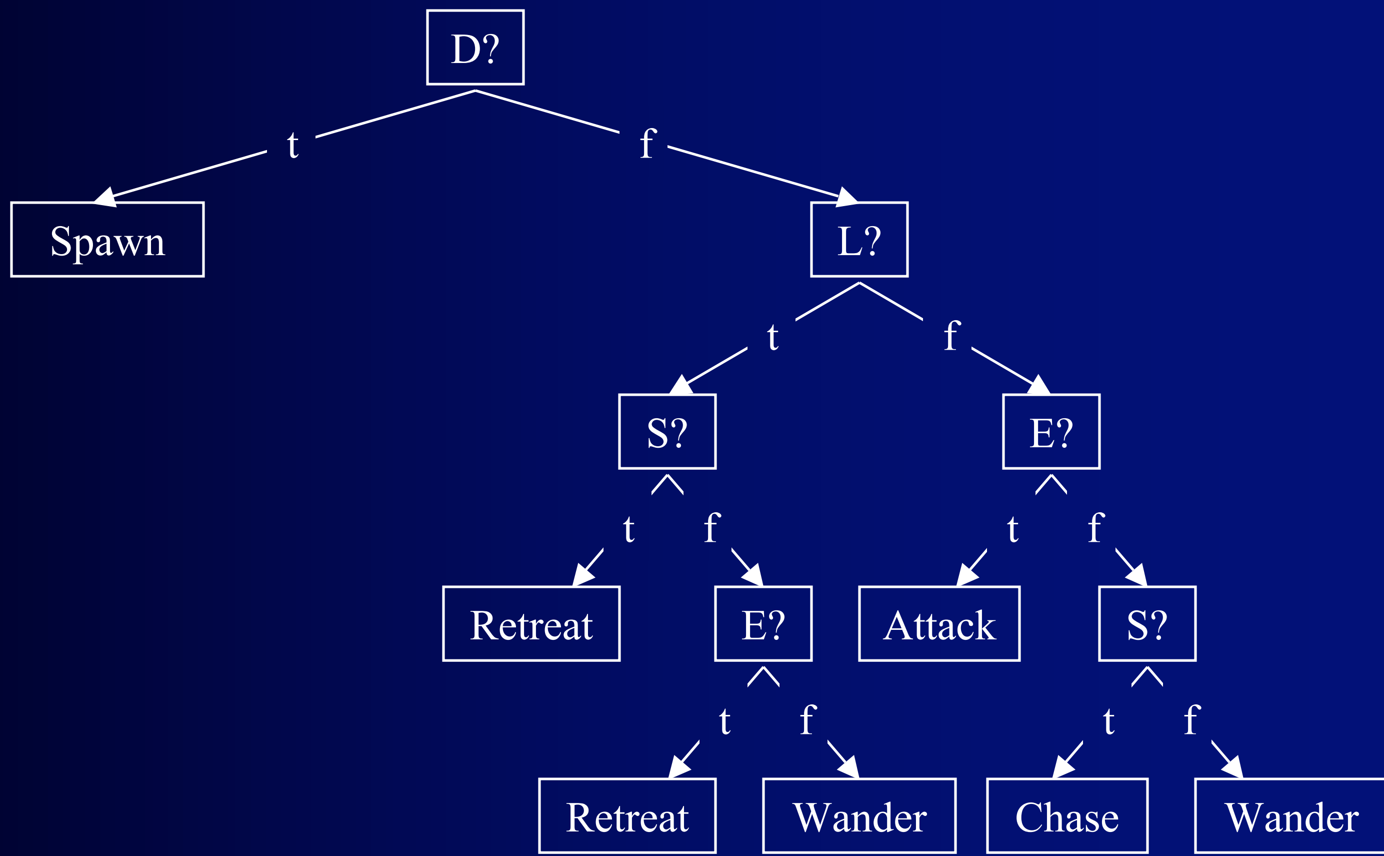
- 8 examples left [2,3,1,2] = 1.906
- 3 attributes remaining: Enemy, Sound, Low Health
- Information gain of Enemy
  - 0.656
- Information gain of Sound
  - 0.406
- Information gain of Low Health
  - 0.75

Learned Decision Tree (2)



- 4 examples on each side: t = 0.811; f = 1.50
- 2 attributes remaining: Enemy, Sound
- Information gain of Enemy (L = f)
  - 1.406
- Information gain of Sound (L = t)
  - .906

Learned Decision Tree (3)



Decision Tree Evaluation

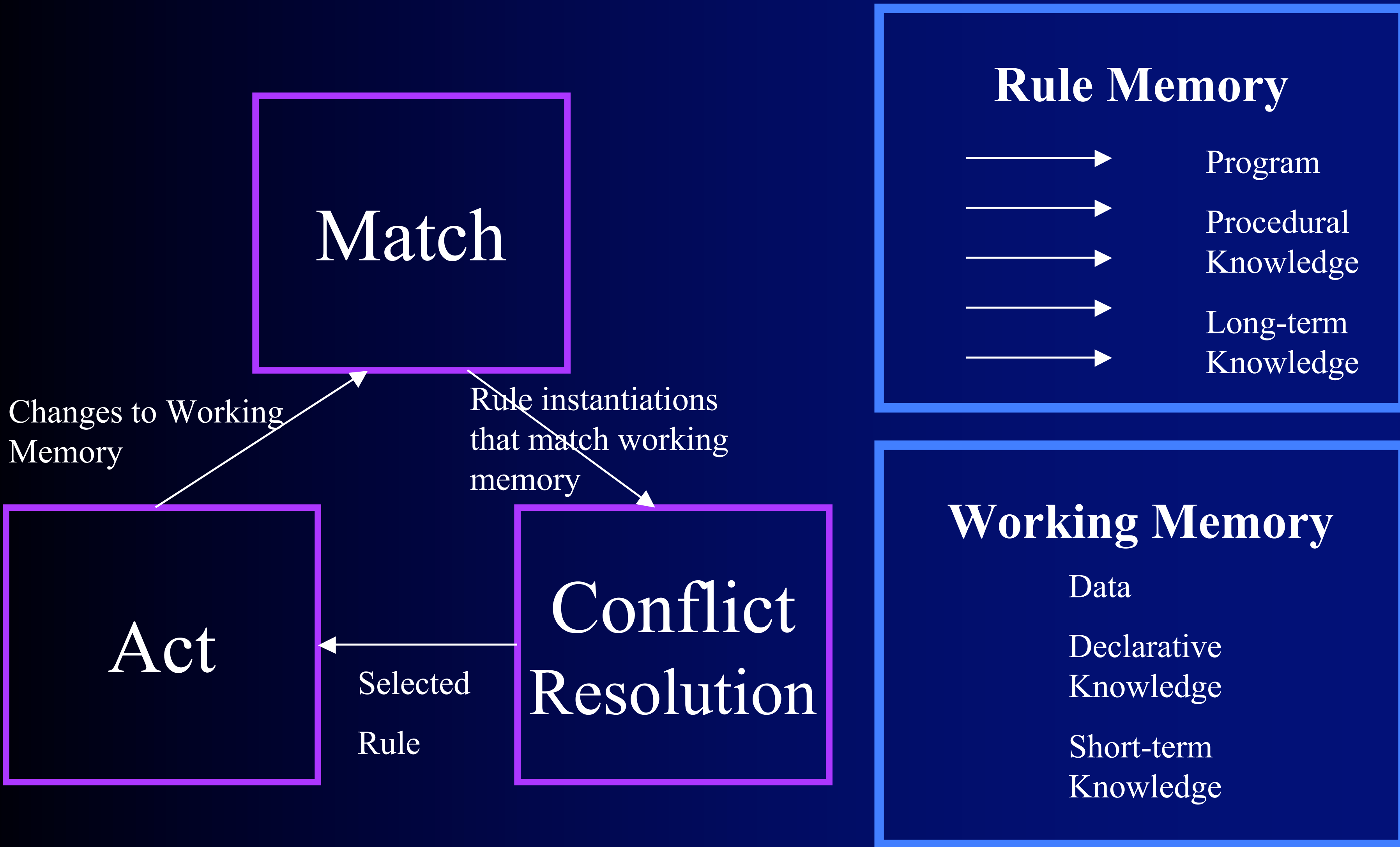
- Advantages
  - Simpler, more compact representation
  - State = Memory
    - Create “internal sensors” – Enemy-Recently-Sensed
  - Easy to create and understand
    - Can also be represented as rules
  - Decision trees can be learned
- Disadvantages
  - Decision tree engine requires more coding than FSM
  - Need as many examples as possible
  - Higher CPU cost
  - Learned decision trees may contain errors

Rule-based System

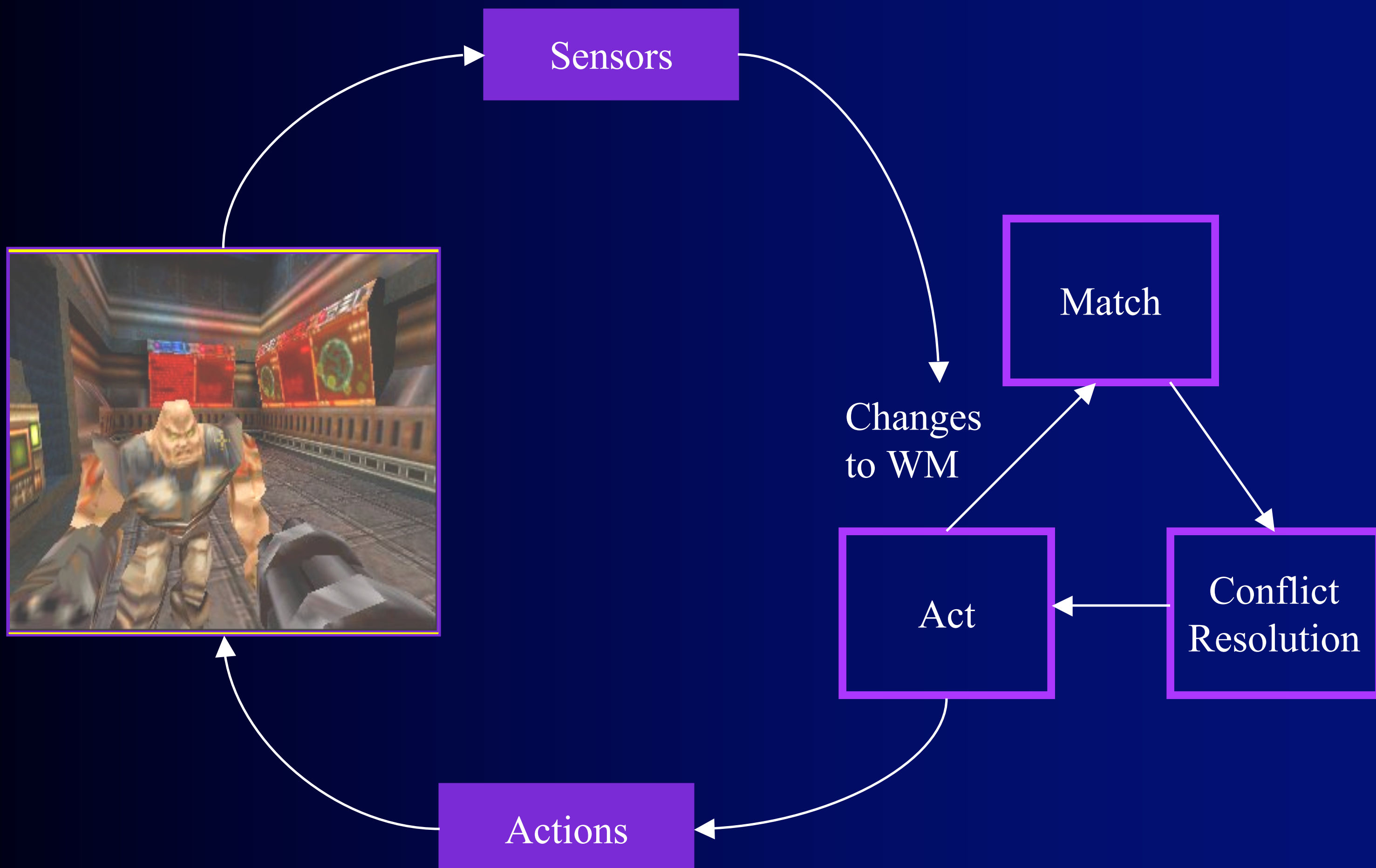
```
; The AI will attack once at 1100 seconds and then again
; every 1400 sec, provided it has enough defense soldiers.

(defrule
      (game-time > 1100)
=>
      (attack-now)
      (enable-timer 7 1100))

(defrule
      (timer-triggered 7)
      (defend-soldier-count >= 12)
=>
      (attack-now)
      (disable-timer 7)
      (enable-timer 7 1400))
```

Age of
Kings
Microsoft

Rule-Based Systems Structure



Complete Picture



Simple Approach

- No rules with same variable in multiple conditions
- Restricts what you can write, but might be ok for simple systems

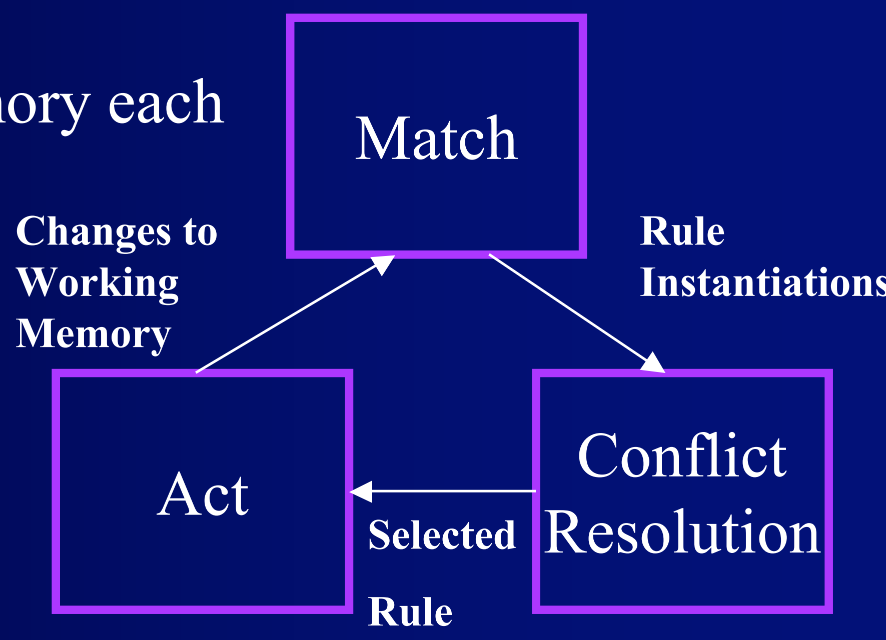
Picking the rule to fire

Simple approach

- Run through rules one at a time and test conditions
- Pick the first one that matches
- Time complexity depends on:
  1. Number of rules
  2. Complexity of conditions
  3. Number of rules that don’t match

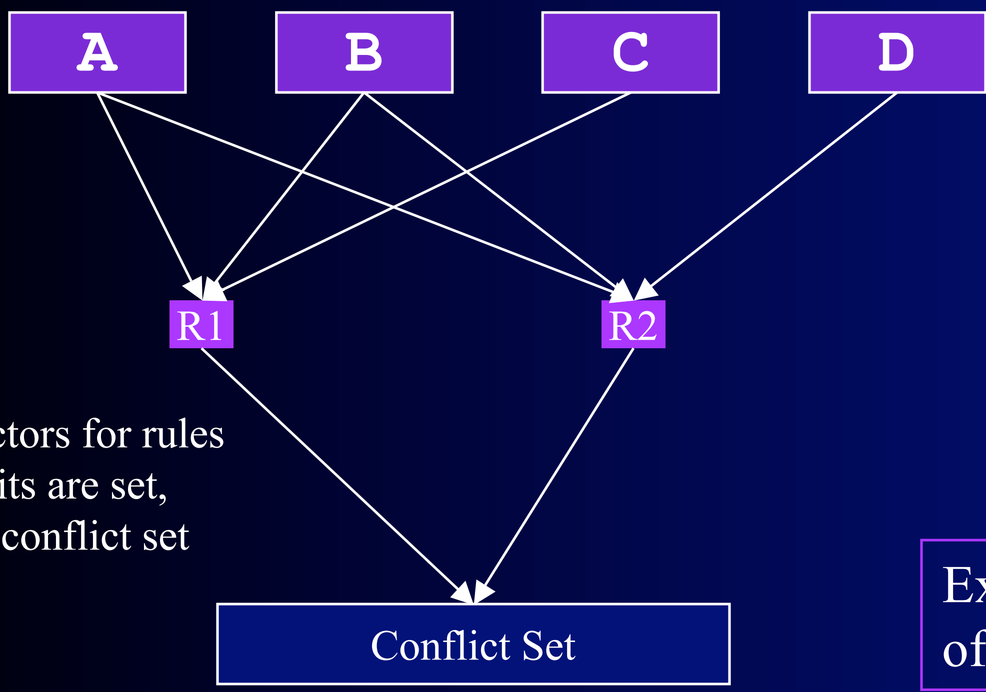
Creating Efficient Rule-based Systems

- Where does the time go?
  - 90-95% goes to Match
- Matching all rules against all of working memory each cycle is way too slow
- Key observation
  - # of changes to working memory each cycle is small



Picking the next rule to fire

- If only simple tests in conditions, compile rules into a match net
- Process *changes* to working memory: hash into tests



`R1: If A, B, C, then …`

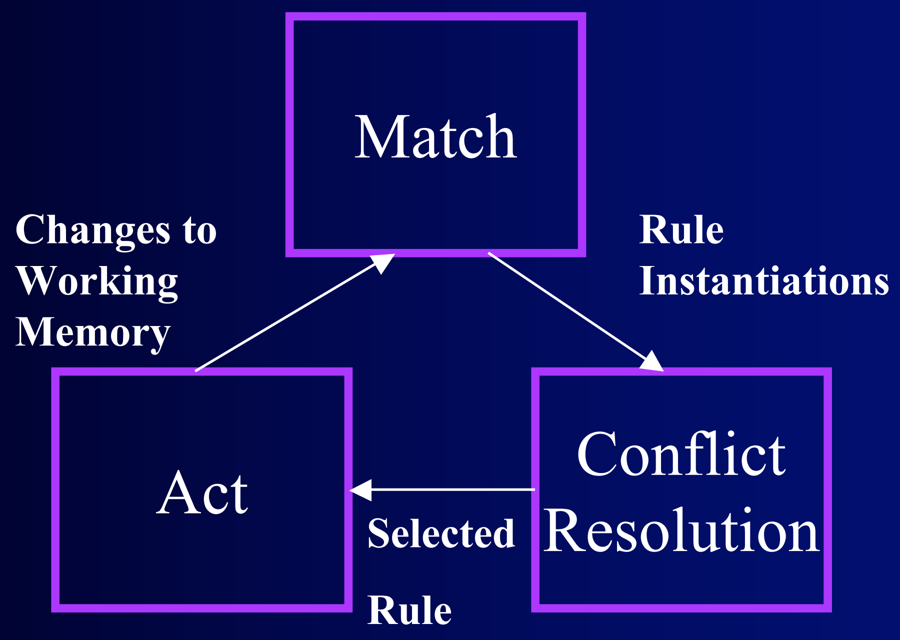
`R2: If A, B, D, then …`

Bit vectors for rules
if all bits are set,
add to conflict set

Expected cost: Linear in the number of changes to working memory

Conflict Resolution

- Which matched rule should fire?
- Which *instantiation* of a rule should fire?
  - Separate instantiation for every match of variables in rules



Conflict Resolution Filters

Select between instantiations based on filters:

1. Refractory Inhibition:
   - Don’t fire *same instantiation* that has already fired
2. Data Recency:
   - Select instantiations that match most recent data
3. Specificity:
   - Select instantiations that match more working memory elements
4. Random
   - Select randomly between the remaining instantiations

Other Conflict Resolution Strategies

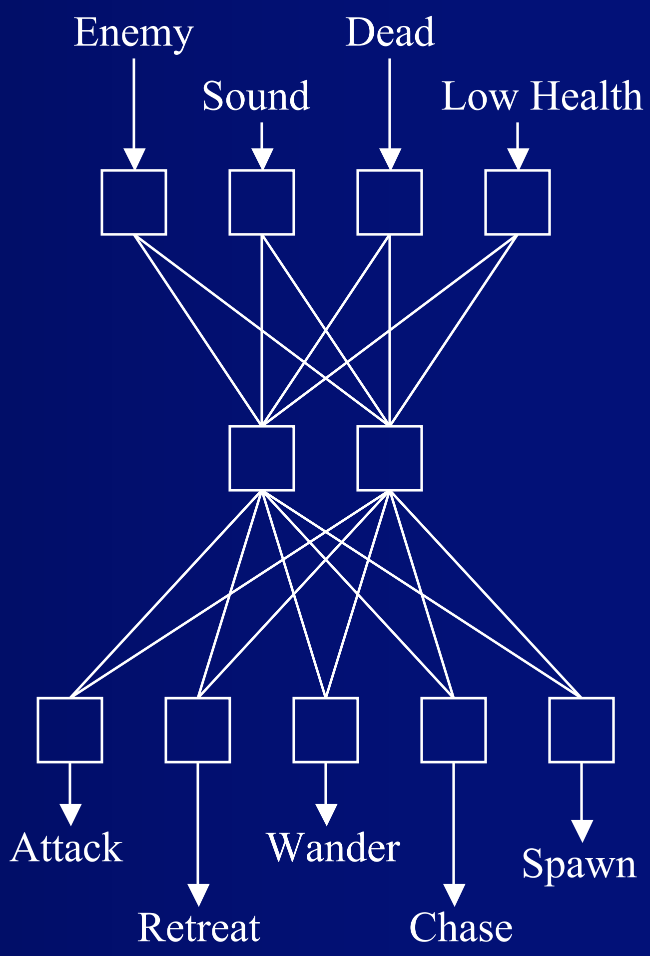
- Rule order – pick the first rule that matches
  - Makes order of loading important – not good for big systems
- Rule importance – pick rule with highest priority
  - When a rule is defined, give it a priority number
  - Forces a total order on the rules – is right 80% of the time
  - Decide Rule 4 [80] is better than Rule 7 [70]
  - Decide Rule 6 [85] is better than Rule 5 [75]
  - Now have ordering between all of them – even if wrong

Rule-based System Evaluation

- Advantages
  - Corresponds to way people often think of knowledge
  - Very expressive
  - Modular knowledge
    - Easy to write and debug compared to decision trees
    - More concise than FSM
- Disadvantages
  - Can be memory intensive
  - Can be computationally intensive
  - Sometimes difficult to debug

Neural Network for Quake

- Four input neuron
  - One input for each condition
- Two neuron hidden layer
  - Fully connected
  - Forces generalization
- Five output neuron
  - One output for each action
  - Choose action with highest output
  - Probabilistic action selection



Back Propagation

- Learning from examples
  - Examples consist of input and correct output
- Learn if network's output doesn't match correct output
  - Adjust weights to reduce difference
  - Only change weights a small amount (η)
- Basic neuron learning
  - $W_{i,j} = W_{i,j} + \Delta W_{i,j}$
  - $W_{i,j} = W_{i,j} + \eta(t-o)a_j$
  - If output is too high (t-o) is negative so $W_{i,j}$ will be reduced
  - If output is too low (t-o) is positive so $W_{i,j}$ will be increased
  - If a_j is negative the opposite happens

Neural Networks Evaluation

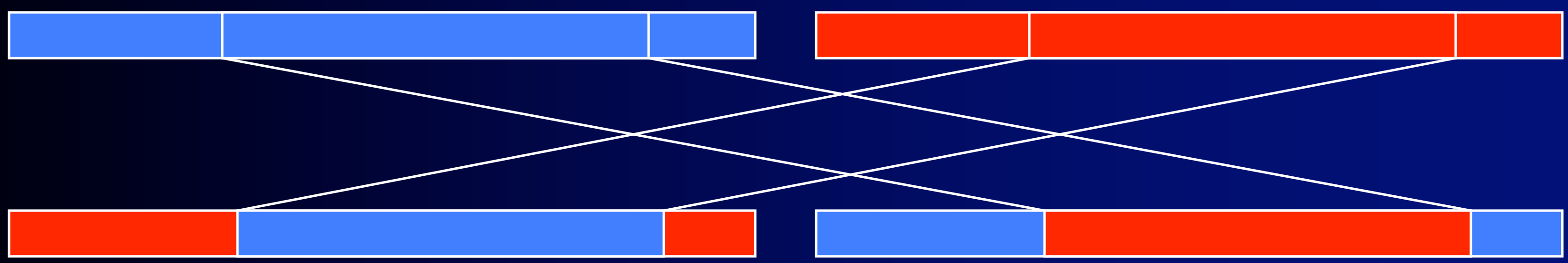
- Advantages
  - Handle errors well
  - Graceful degradation
  - Can learn novel solutions
- Disadvantages
  - Can’t understand how or why the learned network works
  - Examples must match real problems
  - Need as many examples as possible
  - Learning takes lots of processing
    - Incremental so learning during play might be possible

Genetic Algorithm: Inspiration

- Evolution creates individuals with higher fitness
  - Population of individuals
    - Each individual has a genetic code
  - Successful individuals (higher fitness) more likely to breed
    - Certain codes result in higher fitness
    - Very hard to know ahead which combination of genes = high fitness
  - Children combine traits of parents
    - Crossover
    - Mutation
- Optimize through artificial evolution
  - Define fitness according to the function to be optimized
  - Encode possible solutions as individual genetic codes
  - Evolve better solutions through simulated evolution

Genetic Operators

- Crossover
  - Select two points at random
  - Swap genes between two points

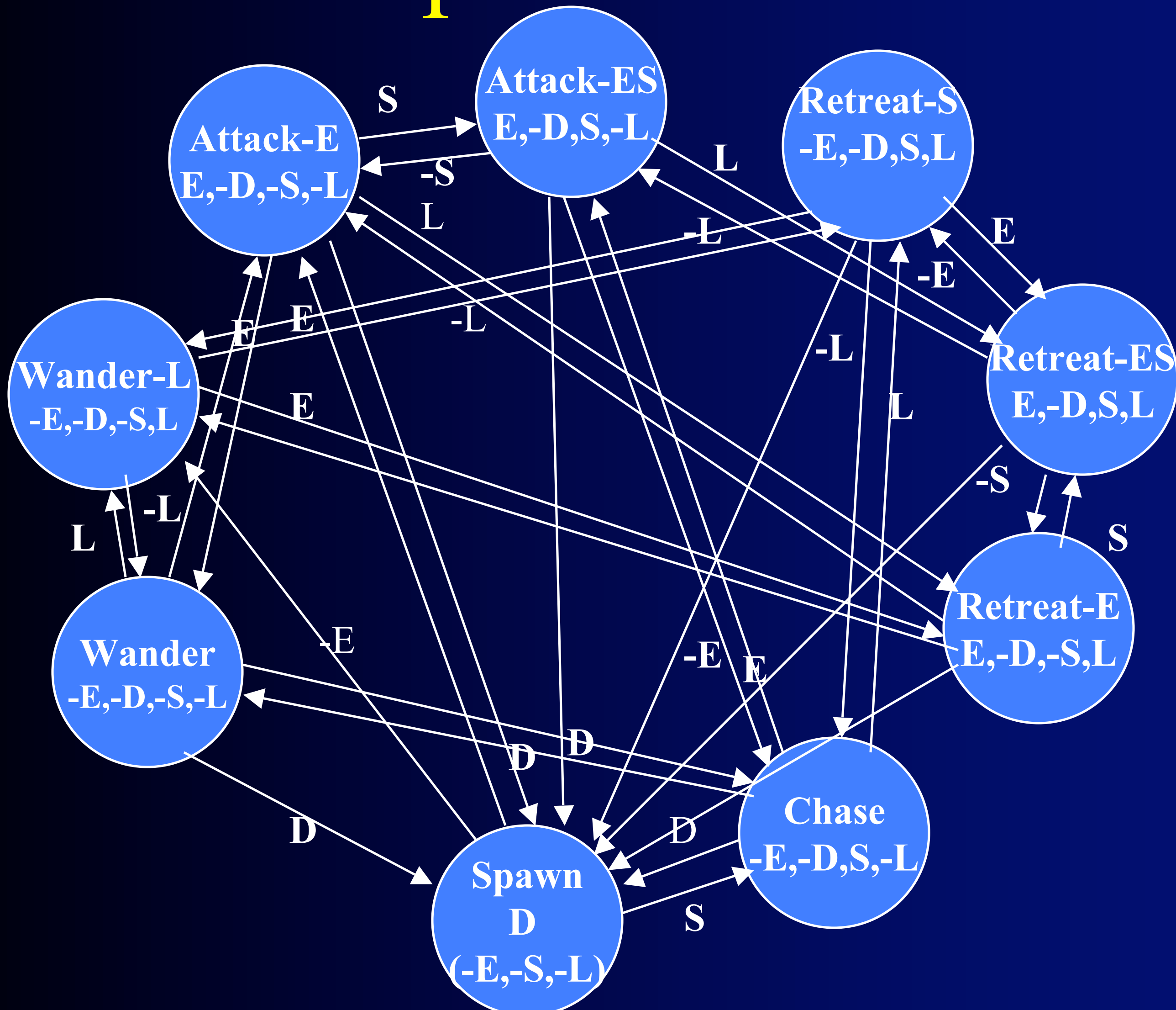


- Mutate
  - Small probably of randomly changing each part of a gene

Representation

- Gene is typically a string of symbols
  - Frequently a bit string
  - Gene can be a simple function or program
    - Evolutionary programming
- Every possible gene must encode a valid solution
  - Crossover should result in valid genes
  - Mutation should result in valid genes

Example FSM with Retreat



Events:

E=Enemy

S=Sound

D=Die

L=Low Health

Each new feature can double number of states

Representing rules as bit strings

- Conditions
  - Enemy = <t,f>: bits 1 and 2
    - 10: Enemy = t; 01: Enemy = f; 11: Enemy = t or f; 00: Enemy has no value
  - Sound = <t,f>: bits 3 and 4
  - Die = <t,f>: bits 5 and 6
  - Low Health = <t,f>: bits 7 and 8
- Classification
  - Action = <attack,retreat,chase,wander,spawn>
  - Bits 9-13: 10000: Action = attack
- 111101100001: If dead=t then action=spawn
- Encode 1 rule per gene or many rules per gene
- Fitness function: % of examples classified correctly

Genetic Algorithm Example

- Initial Population

```
10 11 11 11 11010: E => Attack or Retreat or Wander
11 10 10 11 10100: S D => Attack or Chase
01 00 01 10 01100: -E -D L => Retreat or Chase
10 10 10 11 00010: E S D => Wander
...
```

- Parent Selection

```
10 11 11 11 11010: Sometimes correct
11 10 10 11 10100: Never correct
01 00 01 10 01100: Sometimes correct
10 10 10 11 00010: Never correct
...
```

Genetic Algorithm Example

- Crossover

```
 10 11 11 11 11010: Sometimes correct
 01 00 01 10 01100: Sometimes correct

 10 10 01 10 01010: E S -D L => Retreat or Wander
 01 01 11 11 11100: -E -S => Attack or Retreat or Chase
```

- Mutate

```
 10 10 01 10 01010: E S -D L => Retreat or Wander
 10 10 01 10 01000: E S -D L => Retreat
```

- Add to next generation

```
 10 10 01 10 01000: Always correct
 01 01 11 11 11100: Never correct
 ...
```

Genetic Algorithm Evaluation

- Advantages
  - Powerful optimization technique
  - Can learn novel solutions
- Disadvantages
  - Finding correct representation can be tricky
    - The richer the representation, the bigger the search space
  - Fitness function must be carefully chosen
  - Evolution takes lots of processing
    - Can’t really run a GA during game play
  - Solutions may or may not be understandable

Fuzzy Logic

- Philosophical approach
  - Ontological commitment based on "degree of truth"
  - Is ***not*** a method for reasoning under uncertainty
    - See probability theory and Bayesian inference
- Crisp Facts – distinct boundaries
- Fuzzy Facts– imprecise boundaries
- Example – Scout reporting an enemy
  - "Two to three tanks at grid NV 123456" (Crisp)
  - "A few tanks at grid NV 123456" (Fuzzy)
  - "The water is warm." (Fuzzy)
  - "There might be 2 tanks at grid NV 54 (Probabilistic)

Fuzzy Rules

- If the water temperature is cold and water flow is low then make a positive bold adjustment to the hot water valve.
- If position is unobservable, threat is somewhat low, and visibility is high then risk is low.

Fuzzy Variable

Fuzzy Value represented as a fuzzy set

Fuzzy Modifier or Hedge

Fuzzy Sets

- Classical set theory
  - An object is either in or not in the set
- Sets with smooth boundary
  - Not completely in or out – somebody 6” is 80% tall
- Fuzzy set theory
  - An object is in a set by matter of degree
  - 1.0 => in the set
  - 0.0 => not in the set
  - 0.0 < object < 1.0 => partially in the set
- Provides a way to write symbolic rules but “add numbers” in a principled way

Apply to Computer Game

- Can have different characteristics of entities
  - Strength: strong, medium, weak
  - Aggressiveness: meek, medium, nasty
  - If *meek* and attacked, run away fast.
  - If *medium* and attacked, run away slowly.
  - If *nasty* and *strong* and attacked, attack back.
- Control of a vehicle
  - Should slow down when *close* to car in front
  - Should speed up when *far* behind car in front
- Provides smoother transitions – not a sharp boundary

Evaluation of Fuzzy Logic

- Does not necessarily lead to non-determinism
- Advantages
  - Allows use of numbers while still writing “crisp” rules
  - Allows use of “fuzzy” concepts such as medium
  - Biggest impact is for control problems
    - Help avoid discontinuities in behavior
- Disadvantages
  - Sometimes results are unexpected and hard to debug
  - Additional computational overhead
  - Change in behavior may or may not be significant

Fighting Opponents

- Must select between different attacks, blocks, etc.
- Could easily overwhelm human
  - Reaction-time
- Rely heavily on motion-capture for animation
- Varying amounts of AI
- State machines
- Some learning/adaptation

Tactical Enemies

- Early days
  - Run and shoot: no navigation
  - Sometimes see through walls
- Next step
  - “Invisible” nodes for navigation
  - Pick up powerups on the fly
  - Still little or no obstacle avoidance
  - Variability in skill
- Key issues
  - Challenging but not overwhelming opponents
- Example games
  - Deus Ex, Return to Wolfenstein, Max Payne, Metal Gear Solid, Halo
- Standard technology
  - Scripting languages, hierarchical finite-state machines

Action/FPS Game Opponent

- Provide a challenging opponent
  - Not always as challenging as a human -- Quake monsters
  - What ways should it be subhuman?
- Not too challenging
  - Should not be superhuman in accuracy, precision, sensing, ...
- Should not be too predictable
  - Through randomness
  - Through multiple, fine-grained responses
  - Through adaptation and learning

Tactical Opponent

Strategic Enemies

- Decide on overall strategy
  - Aggressive, defensive
  - Throw a lot, run a lot, dump and chase, …
- Resource Allocation
  - Decide what to build, mine, grow, … with available resources
- Control Units
  - To build, mine, grow, attack, defend, …
  - Use special abilities of units
- Sometimes cheat to overcome weaknesses
- Play to lose?
- Example games
  - Football, Age of Kings, Starcraft, Warcraft, …
- Standard technology
  - Predefined scripts/plans
  - Simple rule-based systems

Units

- Military units, team sport players, …
- Path planning and route following are very important!
  - Efficient, flexible A*
- Formations, collision detection, motion capture
- Standard technology:
  - Scripting languages
  - Finite-state machines
  - Simple rule-based systems

Support Characters

- Scripted behavior
  - Small set of behavior routines
  - Small set of responses to predefined set of questions
  - Navigate via nodes
- Example Games
  - Blade Runner, Diablo II, Monkey Island series, …