Lecture 19

Character Behavior
Classical AI vs. Game AI

**Classical:** Design of *intelligent agents*
- Perceives environment, maximizes its success
- Established area of computer science
- Subtopics: planning, machine learning

**Game:** Design of *rational behavior*
- Does not need to optimize (and often will not)
- Often about “scripting” a personality
- More akin to cognitive science
Take Away for This Lecture

• Review the **sense-think-act** cycle
  • How do we separate actions and thinking?
  • Delay the sensing problem to next time

• What is **rule-based** character AI?
  • How does it relate to sense-think-act?
  • What are its advantages and disadvantages?

• What **alternatives** are there to rule-based AI?
  • What is our motivation for using them?
  • How do they affect the game architecture?
Role of AI in Games

• **Autonomous Characters** (NPCs)
  • Mimics the “personality” of the character
  • May be opponent or support character

• **Strategic Opponents**
  • AI at the “player level”
  • Closest to classical AI

• **Character Dialog**
  • Intelligent commentary
  • Narrative management (e.g. Façade)
Role of AI in Games

- **Autonomous Characters** (NPCs)
  - Mimics the “personality” of the character
  - May be opponent or support character

- **Strategic Opponents**
  - AI at the “player level”
  - Closest to classical AI

- **Character Dialog**
  - Intelligent commentary
  - Narrative management (e.g. Façade)
Review: Sense-Think-Act

- **Sense:**
  - Perceive the world
  - Reading the game state
  - **Example:** enemy near?

- **Think:**
  - Choose an action
  - Often merged with sense
  - **Example:** fight or flee

- **Act:**
  - Update the state
  - Simple and fast
  - **Example:** reduce health
**S-T-A: Separation of Logic**

- **Loops** = sensing
  - Read other objects
  - *Aggregate* for thinking
  - **Example**: nearest enemy

- **Conditionals** = thinking
  - Use results of sensing
  - Switch between possibilities
  - **Example**: attack or flee

- **Assignments** = actions
  - Rarely need loops
  - Avoid conditionals

```java
move(int direction) {
    switch (direction) {
        case NORTH:
            y -= 1;
            break;
        case EAST:
            x += 1;
            break;
        case SOUTH:
            y += 1;
            break;
        case WEST:
            x -= 1;
            break;
    }
}
```
S-T-A: Separation of Logic

- **Loops** = sensing
  - Read other objects
  - *Aggregate* for thinking
  - **Example**: nearest enemy

- **Conditionals** = thinking
  - Use results of sensing
  - Switch between possibilities
  - **Example**: attack or flee

- **Assignments** = actions
  - Rarely need loops
  - Avoid conditionals

```java
move(int direction) {
    switch (direction) {
    case NORTH:
        y -= 1;
        break;
    case EAST:
        x += 1;
        break;
    case SOUTH:
        y += 1;
        break;
    case WEST:
        x = 1;
        break;
    }
}
```
S-T-A: Separation of Logic

- **Loops** = sensing
  - Read other objects
  - *Aggregate* for thinking
  - **Example**: nearest enemy

- **Conditionals** = thinking
  - Use results of sensing
  - Switch between possibilities
  - **Example**: attack or flee

- **Assignments** = actions
  - Rarely need loops
  - Avoid conditionals

```java
move(int direction) {
    switch (direction) {
    case NORTH:
        y -= 1;
        break;
    case EAST:
        x += 1;
        break;
    case SOUTH:
        y += 1;
        break;
    case WEST:
        x -= 1;
        break;
    }
}
```

```java
move(int dx, int dy) {
    x += dx;
    y += dy;
}
```
S-T-A: Reducing Dependencies

Actor1
Controller

GameState

Actor2
Controller

Actor1

Actor2
S-T-A: Reducing Dependencies

Actor1 Controller

GameState

Actor2 Controller

Actor1

Actor2

Compute Sensing
S-T-A: Reducing Dependencies

- **Actor1 Controller**
  - **Actor1**
  - **GameState**
  - **Actor2**
  - **Actor2 Controller**

- **Compute Thinking**
S-T-A: Reducing Dependencies

Actor1
Controller

Compute
Actions

Actor2
Controller

GameState

Actor1

Actor2
Review: Sense-Think-Act

- **Sense:**
  - Perceive the world
  - Reading the game state
  - **Example:** enemy near?

- **Think:**
  - Choose an action
  - Often merged with sense
  - **Example:** fight or flee

- **Act:**
  - Update the state
  - Simple and fast
  - **Example:** reduce health
Actions: Short and Simple

- Mainly use **assignments**
  - Avoid loops, conditionals
  - Similar to getters/setters
  - Complex code in **thinking**
- Helps with **serializability**
  - Record and undo actions
- Helps with **networking**
  - Keep doing last action
  - Recall: *dead reckoning*

```java
move(int direction) {
    switch (direction) {
    case NORTH:
        y -= 1;
        break;
    case EAST:
        x += 1;
    case SOUTH:
        y += 1;
    case WEST:
        x -= 1;
    }

move(int dx, int dy) {
    x += dx;
    y += dy;
    }
```

Character Behavior
Delaying Actions

Sequential Actions are Bad

NPC 1
NPC 2
NPC 3
NPC 4

Think (Choose) & Act (Apply)

Choose Action; Apply Later

NPC 1
NPC 2

Think (Choose)

NPC 1
NPC 2

Act (Apply)
Thinking: Primary Challenge

- A mess of conditionals
  - “Spaghetti” code
  - Difficult to modify
- Abstraction requirements:
  - Easy to visualize models
  - Mirror “cognitive thought”
- Want to separate talent
  - **Sensing**: Programmers
  - **Thinking**: *Designers*
  - **Actions**: Programmers

```java
if (sense_1) {
    if (sense_{11}) { ... 
    } else if (sense_{12}) { ... 
    } else if (sense_{13}) { ... 
    } else { ... 
}
else if (sense_2) {
    if (sense_{21}) { ... 
    } else if (sense_{22}) { ... 
    } else { ... 
}
else if (sense_3) { ... 
}
```
Thinking: Primary Challenge

- A mess of conditionals
  - “Spaghetti” code
  - Difficult to modify
- Abstraction requirements:
  - Easy to visualize models
  - Mirror “cognitive thought”
- Want to separate talent
  - **Sensing**: Programmers
  - **Thinking**: Designers
  - **Actions**: Programmers

```java
if (sense_1) {
    if (sense_{11}) { ...
    } else if (sense_{12}) { ... 
    } else if (sense_{13}) { ... 
    } else { ...
}
else if (sense_2) {
    if (sense_{21}) { ...
    } else if (sense_{22}) { ... 
    } else { ...
    }
} else if (sense_3) { ...
```
If $X$ is true, Then do $Y$

Three-Step Process

- **Match**
  - For each rule, check *if*
  - Return *all* matches

- **Resolve**
  - Can only use one rule
  - Use metarule to pick one

- **Act**
  - Do *then*-part
Rule-Based AI

If $X$ is true, Then do $Y$

- **Thinking**: Providing a list of several rules
  - But what happens if there is more than one rule?
  - Which rule do we choose?
Rule-Based AI

If $X$ is true, Then do $Y$

- **Thinking**: Providing a list of several rules
  - But what happens if there is more than one rule?
  - Which rule do we choose?
Simplicity of Rule-Based AI
Conflict Resolution

- Often resolve by order
  - Each rule has a priority
  - Higher priorities go first
  - “Flattening” conditionals

- Problems:
  - Predictable
    Same events = same rules
  - Total order
    Sometimes no preference
  - Performance
    On average, go far down list

\[
\begin{align*}
R_1 &: \text{if event}_1 \text{ then act}_1 \\
R_2 &: \text{if event}_2 \text{ then act}_2 \\
R_3 &: \text{if event}_3 \text{ then act}_3 \\
R_4 &: \text{if event}_4 \text{ then act}_4 \\
R_5 &: \text{if event}_5 \text{ then act}_5 \\
R_6 &: \text{if event}_6 \text{ then act}_6 \\
R_7 &: \text{if event}_7 \text{ then act}_7
\end{align*}
\]
Conflict Resolution

- **Specificity:**
  - Rule w/ most “components”

- **Random:**
  - Select randomly from list
  - May “weight” probabilities

- **Refractory Inhibition:**
  - Do not repeat recent rule
  - Can combine with ordering

- **Data Recency:**
  - Select most recent update

\[ R_1: \text{if } A, B, C, \text{ then} \]
\[ R_2: \text{if } A, B, D, \text{ then} \]
Impulses

• Correspond to certain events
  • **Global**: not tied to NPC
  • Must also have duration

• Used to **reorder** rules
  • Event makes rule important
  • Temporarily up the priority
  • Restore when event is over

• Preferred conflict resolution
  • Simple but flexible
  • Used in *Halo 3* AI.

$$\begin{align*}
R_1 &: \text{if } \text{event}_1 \text{ then } \text{act}_1 \\
R_2 &: \text{if } \text{event}_2 \text{ then } \text{act}_2 \\
R_3 &: \text{if } \text{event}_3 \text{ then } \text{act}_3 \\
R_4 &: \text{if } \text{event}_4 \text{ then } \text{act}_4 \\
R_5 &: \text{if } \text{event}_5 \text{ then } \text{act}_5 \\
R_6 &: \text{if } \text{event}_6 \text{ then } \text{act}_6 \\
R_7 &: \text{if } \text{event}_7 \text{ then } \text{act}_7
\end{align*}$$
Impulses

- Correspond to certain events
  - **Global**: not tied to NPC
  - Must also have duration
- Used to **reorder** rules
  - Event makes rule important
  - Temporarily up the priority
  - Restore when event is over
- Preferred conflict resolution
  - Simple but flexible
  - Used in *Halo 3* AI.

\[
\begin{align*}
R_1 & : \text{if } \text{event}_1 \text{ then } \text{act}_1 \\
R_2 & : \text{if } \text{event}_2 \text{ then } \text{act}_2 \\
R_5 & : \text{if } \text{event}_5 \text{ then } \text{act}_5 \\
R_3 & : \text{if } \text{event}_3 \text{ then } \text{act}_3 \\
R_4 & : \text{if } \text{event}_4 \text{ then } \text{act}_4 \\
R_6 & : \text{if } \text{event}_6 \text{ then } \text{act}_6 \\
R_7 & : \text{if } \text{event}_7 \text{ then } \text{act}_7
\end{align*}
\]
Rule-Based AI: Performance

- Matching = **sensing**
  - If-part is expensive
  - Test *every* condition
  - Many unmatched rules

- Improving performance
  - Optimize sensing (make if-part cheap)
  - Limit number of rules
  - Other solutions?

- Most games limit rules
  - Reason for *state machines*
Rule-Based AI: Performance

- Matching = **sensing**
  - If-part is expensive
  - Test *every* condition
  - Many unmatched rules

- Improving performance
  - Optimize sensing (make if-part cheap)
  - Limit number of rules
  - Other solutions?

- Most games limit rules
  - Reason for *state machines*

90-95% of time
Making the Rules Manageable

Character Behavior
Making the Rules Manageable

Limited number of rules per page

Switching page is an action
Finite State Machines

Events
- E = Enemy Seen
- S = Sound Heard
- D = Die

Character Behavior
Finite State Machines

Only check rules for outgoing edges

Events
- E=Enemy Seen
- S=Sound Heard
- D=Die

Character Behavior
Implementation: Model-View-Controller

- Games have **thin** models
  - Methods = get/set/update
  - Controllers are heavyweight
- AI is a **controller**
  - Uniform process over NPCs
- But behavior is **personal**
  - Diff. NPCs = diff. behavior
  - Do not want unique code
- What can we do?
  - Data-Driven Design
Implementation: Model-View-Controller

- **Actions** go in the model
  - Lightweight updates
  - Specific to model or role
- **Controller** is framework for general **sensing**, **thinking**
  - Standard FSM engine
  - Or FSM alternatives (later)
- **Process** stored in a model
  - Represent thinking as **graph**
  - Controller processes graph
An Aside: Animations

- AI may need many actions
  - Run, jump, duck, slide
  - Fire weapons, cast spells
  - Fidget while idling

- Want animations for all
  - Is loop appropriate for each?
  - How do we transition?

- **Idea**: shared boundaries
  - End of loop = start of another
  - Treat like advancing a frame
An Aside: Animations

- AI may need many actions
  - Run, jump, duck, slide
  - Fire weapons, cast spells
  - Fidget while idling
- Want animations for all
  - Is loop appropriate for each?
  - How do we transition?
- **Idea**: shared boundaries
  - End of loop = start of another
  - Treat like advancing a frame

---

Character Behavior
An Aside: Animations

- AI may need many actions
  - Run, jump, duck, slide
  - Fire weapons, cast spells
  - Fidget while idling

- Want animations for all
  - Is loop appropriate for each?
  - How do we transition?

- **Idea**: shared boundaries
  - End of loop = start of another
  - Treat like advancing a frame

---

Character Behavior
Animation and State Machines

- **Idea**: Each sequence a state
  - Do sequence while in state
  - Transition when at end
  - Only loop if loop in graph

- A graph edge means...
  - Boundaries match up
  - Transition is allowable

- Similar to data driven AI
  - Created by the designer
  - Implemented by programmer
  - Modern engines have tools
Animation and State Machines

- **Idea**: Each sequence a state
  - Do sequence while in state
  - Transition when at end
  - Only loop if loop in graph

- A graph edge means…
  - Boundaries match up
  - Transition is allowable

- Similar to data driven AI
  - Created by the designer
  - Implemented by programmer
  - Modern engines have tools
Complex Example: Jumping

- **stand**
- **stand2crouch**
- **crouch**
- **hop**
- **takeoff**
- **float**
- **land**

Character Behavior
Complex Example: Jumping

Stand \rightarrow \text{Jump Press} \rightarrow \text{Stand2Crouch} \rightarrow \text{Crouch} \rightarrow \text{Takeoff} \rightarrow \text{Near Ground} \rightarrow \text{Float} \rightarrow \text{Land} \rightarrow \text{Hop} \rightarrow \text{Jump Release} \rightarrow \text{Jump Release} \rightarrow \text{Stand2Crouch} \rightarrow \text{Stand}
Complex Example: Jumping

Transition state needed to align the sequences
## LibGDX Interfaces

### StateMachine<E>
- Attached to an entity
  - Set the entity in constructor
  - New entity, new state machine
- Must implement methods
  - `update()`
  - `changeState(State<A> state)`
  - `revertToPreviousState()`
  - `getCurrentState()`
  - `isInState(State<A> state)`
- `DefaultStateMachine` provided

### State<E>
- Not attached to an entity
  - StateMachine sets state
  - StateMachine passes entity
- Must implement methods
  - `enter(E entity)`
    When machine enters state
  - `exit(E entity)`
    When machine enters state
  - `update(E entity)`
    When machine stays in state

---

Character Behavior
### LibGDX Interfaces

**StateMachine<E>**
- Attached to an entity
- Constructor: `StateMachine(E entity)`
- StateMachine sets state
- States are transitions
- Must implement methods:
  - `update()`
  - `changeState(State<A> state)`
  - `revertToPreviousState()`
  - `getCurrentState()`
  - `isInState(State<A> state)`
- **DefaultStateMachine** provided

**State<E>**
- Not attached to an entity
- StateMachine passes entity
- Must implement methods:
  - `enter(E entity)`
    - When machine enters state
  - `exit(E entity)`
    - When machine enters state
  - `update(E entity)`
    - When machine stays in state

**Transition logic external to the state machine.**
Problems with FSMs

Events

- E = Enemy Seen
- S = Sound Heard
- D = Die

No edge from Attack to Chase

Event Diagram:

- E = Enemy Seen
- S = Sound Heard
- D = Die

Slide courtesy of John Laird
Problems with FSMs

Events
- E=Enemy Seen
- S=Sound Heard
- D=Die

Slide courtesy of John Laird

Character Behavior
Problems with FSMs

Events

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

Adding a new feature can double states

Slide courtesy of John Laird
Problems with FSMs

Adding a new feature can double states

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

Might as Well Go Back to Rule Based AI

Slide courtesy of John Laird
An Observation

- Each state has a set of **global attributes**
  - Different attributes may have same actions
  - Reason for redundant behavior

- Currently just cared about attributes
  - Not really using the full power of a FSM
  - Why don’t we just check attributes directly?

- Attribute-based selection: *decision trees*
Decision Trees

- **Thinking** *encoded as a tree*
  - Attributes = tree nodes
  - Left = true, right = false
  - Actions = leaves (reach from the root)

- **Classify by** *descending* from root to a leaf
  - Start with the test at the root
  - Descend the branch according to the test
  - Repeat until a leaf is reached
Decision Tree Example

Slide courtesy of John Laird
Decision Tree Example

Slide courtesy of John Laird

Character Behavior
## FSMs vs. Decision Trees

<table>
<thead>
<tr>
<th>Finite State Machines</th>
<th>Decision Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Not limited to attributes</td>
<td>• Only attribute selection</td>
</tr>
<tr>
<td>• Allow “arbitrary” behavior</td>
<td>• Much more manageable</td>
</tr>
<tr>
<td>• Explode in size very fast</td>
<td>• Mixes w/ machine learning</td>
</tr>
</tbody>
</table>

### FSM Diagram

- Initial State: Blue circle
- State: Green circle
- Transitions:
  - +E to Green circle
  - -E to Red circle

### Decision Tree

- Decision Node: Green rectangle
- Outcomes:
  - t: Orange rectangle
  - f: Green rectangle
Behavior Trees

- Part rule-based
- Part decision tree
- Freedom of FSM (almost)

- Node is a list of actions
- Select action using rules
- Action leads to subactions
Behavior Trees

Ordered Rules

Rule Outcome

Act
Root

Ordered Rules with Actions

Flee  Hide

Shoot  Charge  Grenade

Wander  Guard

Character Behavior
Behavior Trees

Ordered Rules

Root

Act

Engage

Idle

Retreat

Ordered Rules with Actions

Rule Outcome

Flee

Hide

Shoot

Charge

Grenade

Wander

Guard

Impulses Reorder

Character Behavior
LibGDX Behavior Trees

- Base actions are defined at the leaves
- Internal nodes to select or even combine tasks
LibGDX Behavior Trees

- Base actions are defined at the leaves
- Internal nodes to select or even combine tasks

Use classes in LibGDX
(sub)Classes you create

Can be either condition (if) or an action (then)
LibGDX Rules

- **Selector** rules
  - Tests each subtask for success
  - Tasks are tried independently
  - Chooses first one to succeed

- **Sequence** rules
  - Tests each subtask for success
  - Tasks are tried in order
  - Does all if succeeds; else none

- **Parallel** rules
  - Tests each subtask for success
  - Tasks are tried simultaneously
  - Does all if succeeds; else none
This is the **Wrong Model**

- **Conflates** actions/selection
- Want way to pick subtask
- Distinct from performing it

- **Actions must be** **instant**
- Can switch each frame
- Action unaware of switch
- No way to suspend/recover

- Have a **new API** in 4152
  - Still being tested in class
  - Bring to 3152 eventually
Summary

- Character AI is a **software engineering** problem
  - Sense-think-act aids code reuse and ease of design
  - Least standardized aspect of game architecture

- **Rule-based AI** is the foundation for all character AI
  - Simplified variation of sense-think-act
  - Alternative systems made to limit number of rules

- Games use **graphical models** for data-driven AI
  - Controller outside of NPC model processes AI
  - Graph stored in NPC model tailors AI to individuals