Lecture 19

Character Behavior
Take Away for Today

• 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?
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
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

```c
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;
}
```

```java
case WEST:
    x = 1;
    break;
}
```
S-T-A: Reducing Dependencies

Actor1
Controller

GameState

Actor2
Controller

Actor1

Actor2
S-T-A: Reducing Dependencies

Actor1
Controller

Actor2
Controller

GameState

Actor1

Actor2

Compute Sensing
S-T-A: Reducing Dependencies

Compute Thinking

Actor1
Controller

GameState

Actor2
Controller

Actor1

Actor2
S-T-A: Reducing Dependencies

Actor1
Controller

Compute
Actions

GameState

Actor2
Controller

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*

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

Sequential Actions are Bad

Choose Action; Apply Later

NPC 1
↓
NPC 2
↓
NPC 3
↓
NPC 4

Think (Choose) & Act (Apply)

Think (Choose)
↓
Act (Apply)
↓
NPC 1
↓
NPC 2

Character Behavior
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

```plaintext
if (sense₁) {
    if (sense₁₁) { ... 
    } else if (sense₁₂){ ... 
    } else if (sense₁₃){ ... 
    } else {...
}
else if (sense₂) {
    if (sense₂₁) { ... 
    } else if (sense₂₂){ ... 
    } else {...
    }
} else if (sense₃) { ... 
}
```
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

---

Character Behavior
Rule-Based AI

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

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

\[ \text{R}_1: \text{if A, B, C, then} \]
\[ \text{R}_2: \text{if A, B, D, then} \]
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.*

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

R₁: if event₁ then act₁
R₂: if event₂ then act₂
R₅: if event₅ then act₅
R₃: if event₃ then act₃
R₄: if event₄ then act₄
R₆: if event₆ then act₆
R₇: if event₇ then act₇
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*

Diagram:
- Match
- Act
- Resolve Conflicts
- Updated State
- Matching Rules
- Selected Rule
- 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

Slide courtesy of John Laird
Finite State Machines

Only check rules for *outgoing* edges

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

Slide courtesy of John Laird
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
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
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**
    - **takeoff**
    - **hop**
    - **float**
  - **land**
Complex Example: Jumping

- **Jump Press**
  - Stand
  - Stand2Crouch
    - Crouch
    - Jump Release
    - Takeoff
    - Near Ground
    - Float
    - Land
  - Hop
  - Jump Release
Complex Example: Jumping

Transition state needed to align the sequences

Character Behavior
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
LibGDX Interfaces

**StateMachine<E>**
- Attached to an entity
- Constructor
- Automatically calls `update()`
- Updates current state.
- Does not transition!
- 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
- 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

Slide courtesy of John Laird
Problems with FSMs

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

Requires a redundant state

Slide courtesy of John Laird
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

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

Adding a new feature can double states

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

Start Here

D?
  t  |  f
  Spawn
  t  |  f
  L?
    t  |  f
    Retreat  |  Attack
    t  |  f
    Retreat  |  Chase

E?
  f
  E?
  t
  S?
    t
    Wander
    f
    L?
      t
      Retreat
      f
      Chase

Action

Slide courtesy of John Laird
Decision Tree Example

Start Here

D?

E?

L?

S?

Wander

Retreat

Attack

Chase

Retreat

Action

Single AI Rule

Slide courtesy of John Laird

Character Behavior
FSMs vs. Decision Trees

### Finite State Machines
- Not limited to attributes
- Allow “arbitrary” behavior
- Explode in size very fast

### Decision Trees
- Only attribute selection
- Much more manageable
- Mixes w/ machine learning
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

Retreat Engage Idle

Rule Outcome

Flee Hide Shoot Charge Grenade Wander Guard

Ordered Rules with Actions

Character Behavior
Behavior Trees

Ordered Rules
- Retreat
- Engage
- Idle

Ordered Rules with Actions
- Flee
- Hide
- Shoot
- Charge
- Grenade
- Wander
- Guard

Act
Rule Outcome
Impulses Reorder
56 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
  - Will push to 3152 next year
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