Lecture 9: Models

Poll: What review feedback would you give?

`util.h:`

```
using namespace std;
/**
 * Interpret a CipherString character as an integer modulo 35.
 *
 * @param c Character to convert to integer (must be in '0-9A-Z').
 * @return Integer corresponding to character (in 0..35).
 */
int charToInt(char const c);
...
```

Preview: static analysis

- Tools that identify likely problems just by looking at source code
  - Syntax errors
  - Likely bugs (non-trivial type coercions, deviation from standard patterns, unused code, …)
  - Violations of style guidelines
- Examples:
  - Compilers (C++: use at least -Wall -Wextra)
  - Linters
  - Formatters
  - FindBugs (Java)
  - CodeSonar

Lecture goals

- Conduct effective code reviews
- Select appropriate models to improve communication during multiple process steps (requirements, architecture, program design)
- Visualize models using UML

Models

Purpose of models

- Simplification of reality
- Facilitates communication during process steps
  - Requirements
  - Architecture (system design)
  - Program design
- Need multiple models

  - Different perspectives
  - Different levels of completeness, formality
- Larger, more complex projects benefit from more formality
- Most models are consumed by *humans*

Representing models

- UML: Unified Modeling Language
  - Models consist of diagrams and specifications
  - Many different diagram types
  - Particularly well suited to object-oriented design
- Can serve many purposes
  - Facilitate discussion
  - Provide documentation
  - Generate code
- Why not code?
  - Can have multiple models with simplifications serving different perspectives
  - Code usually must pick a single abstraction; can't manifestly show correctness for other perspectives
  - Code can introduce syntactic distractions, platform details
  - Sometimes, (pseudo)code is the clearest specification

Modeling perspectives

- External
  - Represent the (simplified) context of the system
- Interaction
  - How do user and component interactions proceed?
- Structural
  - How are system components organized?
  - How is data represented?
- Behavioral
  - How system responds to events, changes over time

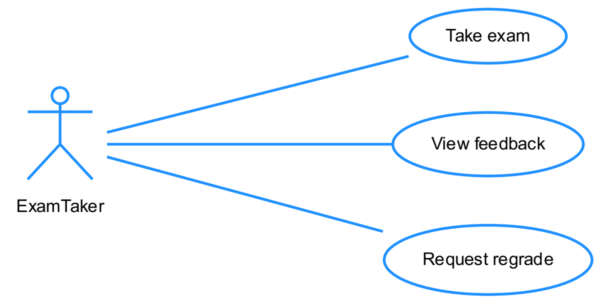
Interaction models

- Modeling user interactions helps catalog functional requirements
  - Use case diagrams
- Modeling inter-system interaction helps highlight potential communication problems
  - Sequence diagrams

Use cases

- Discrete task involving external interaction with the system

- Actor
  - A role, not an individual
  - Beneficiary or instigator
  - May be other systems
  - Use specific, not generic names
- Use case



Pair with textual description

- Metadata
  - Name of use case
  - Goal of use case
  - Actor(s)
  - Trigger
  - Preconditions
  - Postconditions
- Flow of events
  - Basic flow
  - Alternate flows
  - Exceptions

Example

Name: Take exam
Goal: Enables a student to take an exam online with a web browser
Actor(s): ExamTaker
Trigger: ExamTaker is notified that the exam is ready to be taken
Preconditions: ExamTaker is registered for course; ExamTaker has authentication credentials
Postconditions: Completed exam is ready to be graded
Basic flow ("Take exam" use case)

1. ExamTaker connects to sever via web browser
2. Server checks whether ExamTaker is already authenticated; if not, triggers authentication process
3. ExamTaker selects an exam from list
4. ExamTaker repeatedly selects a question and either types in a new solution, edits an existing solution, or uploads a file with a solution
5. ExamTaker either submits exam or saves current state
6. When exam is submitted, server checks that all questions have been attempted and sends acknowledgement to ExamTaker

Alternative flows

- Alternate flow
  - Alternative path to successful completion of use case
  - Example: Take exam

    - Resuming exam from saved state
    - Solution file format not accepted
    - Submission is incomplete
- Exceptions
  - Lead to failure of use case
  - Example: Take exam
    - Authentication failure

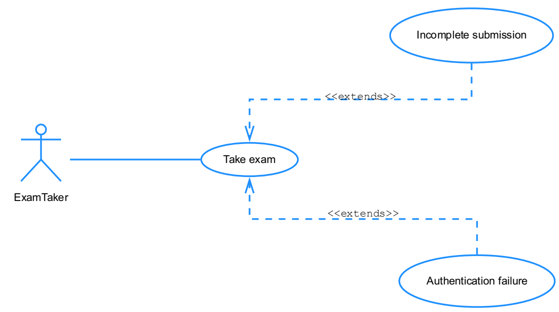
Relationships

<<extends>>

- Defer extra detail to other use cases
- Useful for alternate flows and exceptions

<<includes>>

- Include steps from another use case
- Useful when common procedure is required in multiple contexts



Sequence diagrams

- Show sequence of interactions (ordering, causal relationships) between actors and objects
  - Excellent for documenting communication protocols
  - See examples at https://www.eventhelix.com/networking/

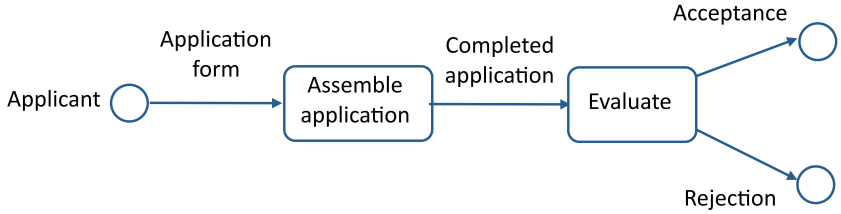
Behavioral models

- Model dynamic behavior of system during execution
- How does system process data or respond to events?
- Data-driven models
  - Show sequence of processing steps from input to output
- Event-driven models
  - How does system respond to events? (internal and external)
  - Assumes finite number of application states
  - Great for embedded, real-time systems

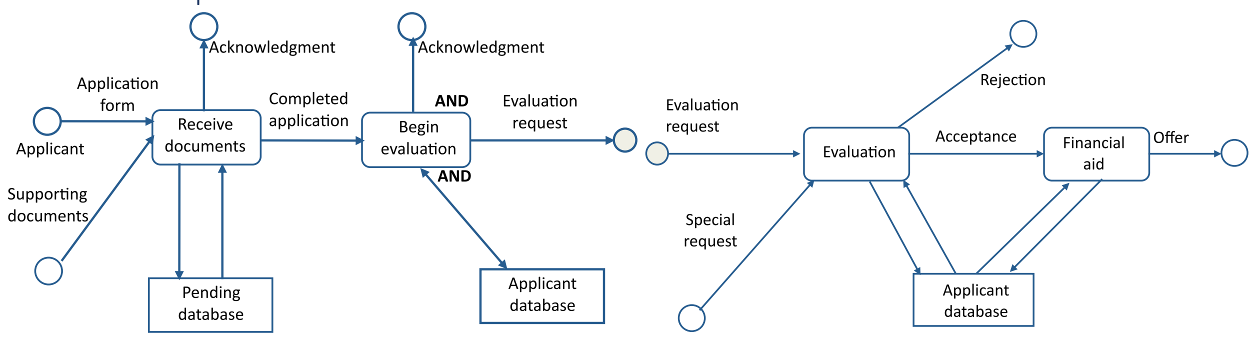
Data flow (activity) diagrams

- Activity: rounded rectangle
- Data: rectangle or labeled edge
- Data source/sink: rectangle
- Beginning/end: circle

Example: university admissions



Refined example



How to specify logic?

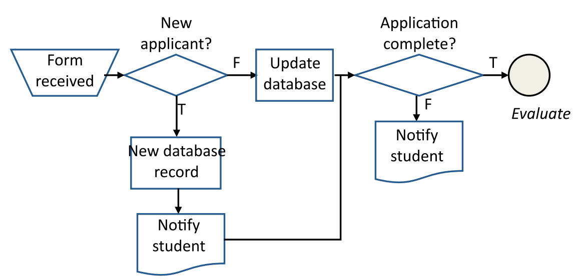
- Data flow & sequence diagrams show high-level flow; must be augmented by specifications for low-level behavior
- Decision table
    - Process columns from left to right
    - Rules are specific and testable
    - Can be clearer to clients than code

SAT > S1	T	F	F	F	F	F
GPA > G1	-	T	F	F	F	F
SAT between S1 and S2	-	-	T	T	F	F
GPA between G1 and G2	-	-	T	F	T	F
Accept	*X*	*X*	*X*			
Reject				*X*	*X*	*X*

Flowcharts and pseudocode

Flowchart

- Shows logic (not just flow)
- Used to specify computer programs before modern programming languages



Pseudocode

- Compact and precise
- Composable
- Easy to implement
- Harder to see flow

Mathematics

- Many systems are well-described by mathematical models
    - Differential equations
    - Probability distributions
    - Integrals
    - Filters

    - Interpolation
    - Curve fits
- Document progression of approximations and domain transformations
    - Frequency vs. time domain
    - Continuous vs. discrete
        - Differential vs. difference equations
        - Integration vs. quadrature
        - Root solve vs. Iteration
- Higher-level specifications give developers more flexibility, can improve maintainability

State charts / transition diagrams

- Model system as a finite set of states
- A transition moves the system from one state to another
    - Triggered by a condition
    - Mathematically, a function from $S \times C \rightarrow S$
- Can be hierarchical
- Also useful for user interface navigation

Transition tables

- Specify state transitions in textual form
- Useful when transitions are "dense" (most conditions are applicable in most states)
    - Example: physical buttons on embedded device
- Can visually check for completeness