Code-level Techniques

(*to Explicitly Capture Design Intent in a Non-formal Way*)

EE382V – Software Architecture and Design Intent

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Outline

- General Picture
- What is “Design by Contract”?
- Eiffel
- Relation to Architecture and Intent

General Picture

Software Architecture:

The software architecture of a program or computing system is the structure or structures of the system, which comprise software components, the externally visible properties of those components, and the relationships among them.

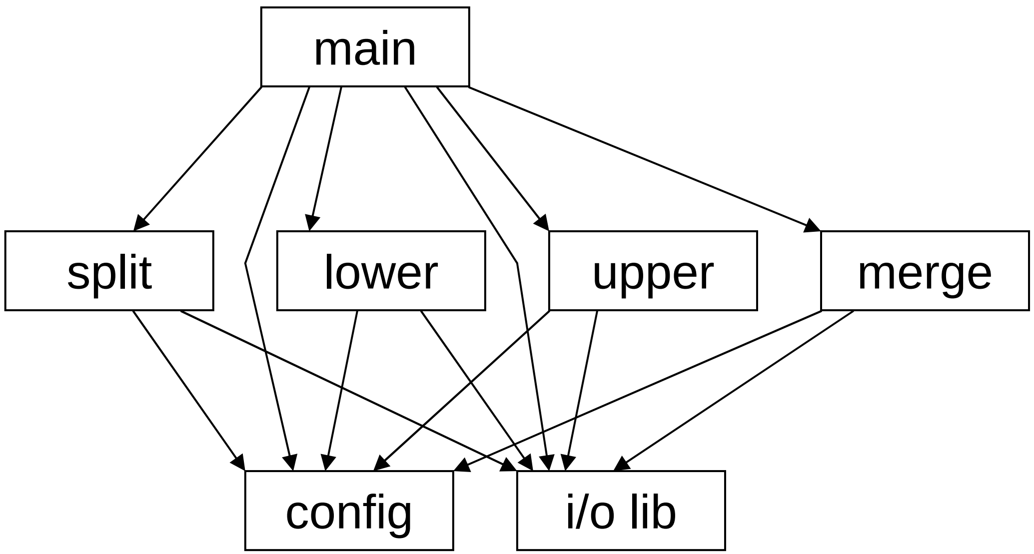
Design Intent:

Logical reasoning behind the mapping from the requirements domain to the architectural abstractions.

Implementation:

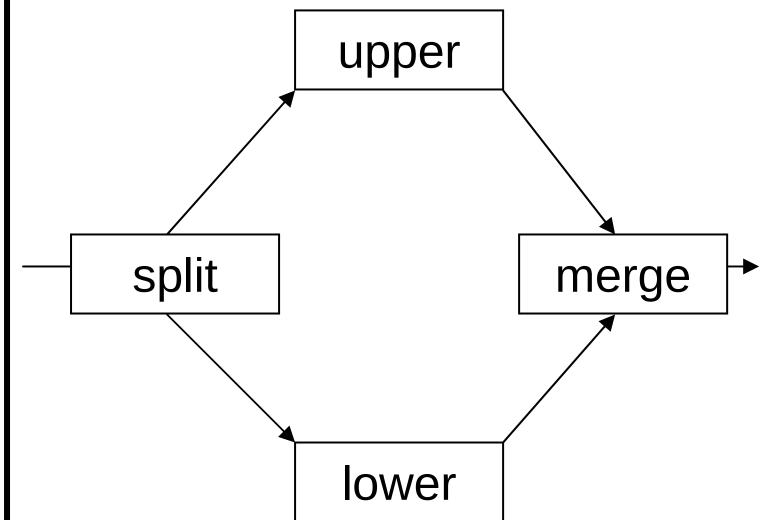
The process of constructing an actual artifact from a design.

Implementation vs. Interaction



(implementation description)

- indicates what modules are present and to what modules they refer
- fails to capture architectural composition
- lines represent programming language relationships



(architectural description)

- highlights architectural design
- reflects abstract interactions

Problems..?

- It limits the expressiveness of the architectural description only to those defined by the implementation language.
- Low-level entities used in the architecture makes it harder to reason about the architectural design.
- Algorithmic aspects of the program interfere with the architectural abstractions.

*Bertrand Meyer. "Applying **Design by Contract**". Computer, Vol. 25, No. 10, 1992, pp. 40-51.*

Design by Contract

- What is Design by Contract™ ?
  - A method of software construction that designs the components of a system so that they will cooperate on the basis of precisely defined contracts

- How does DbC work ?
  - For the execution of any routine
    - DbC ensures that before execution begins, all conditions required for correct execution are met.
    - Upon completion, it ensures that the routine actually has executed as expected.
    - DbC ensures that the instance is in a valid state at all critical times.

http://www.eiffel.com

Motivation

- Software failures are expensive
  - Reliability
    - Correctness - specification
    - Robustness - ?

- Software itself is expensive
  - Reusability

An Example Contract

Party	Obligations	Benefits
Client	Provide letter or package of no more than 5 kgs. each dimension no more than 2 meters. Pay 100 francs.	Get package delivered to recipient in four hours or less.
Supplier	Deliver package to recipient in four hours or less.	No need to deal with deliveries too big, too heavy, or unpaid.

```
if new = Void then
        ... Take care of special case ...
else
        ... Take care of standard case ...
end
```

```
routine_name (argument declarations) is
                -- Header comment
        require
                Precondition
        do
                Routine body, i.e. instructions
        ensure
                Postcondition
        end
```

```
put_child (new: NODE) is
                -- Add new to the children of current node
        require
                new /= Void
        do
                ... Insertion algorithm ...
        ensure
                new.parent = Current;
                child_count = old child_count + 1
        end -- put_child
```

Software Contract

- Pre-condition
- Post-condition
- Class invariant

Assertions

(result from bug; they are not special cases)

```
put_child (new: NODE) is
        -- Add new to the children of current node
    require
        new /= Void
    do
        ... Insertion algorithm ...
    ensure
        new.parent = Current;
        child_count = old child_count + 1
    end -- put_child
```

```
invariant
    left /= Void implies (left.parent = Current);
    right /= Void implies (right.parent = Current)
```

Four Key Benefits

- Constructing correct programs
- Automatic documentation
- Debugging and testing
- Exception handling
- Reusability

Eiffel

- Eiffel development methodology
  - Pure OO, focused on quality
- Eiffel programming language
  - Eiffel compiler (to ANSI C and MSIL)
- Development environment
  - EiffelStudio, Eiffel ENVisioN

Example (1)

- Class TIME_OF_DAY
  - Instances are valid times of day
    - Accurate to the second
    - In the range 00:00:00 – 23:59:59

Example (2)

- Class TIME_OF_DAY
  - Queries
    - `hour: INTEGER`
    - `minute: INTEGER`
    - `second: INTEGER`
    - `is_before (other: TIME_OF_DAY): BOOLEAN`
  - Commands
    - `set_hour (h: INTEGER)`
    - `set_minute (m: INTEGER)`
    - `set_second (s: INTEGER)`

Example (3)

- Decision: How to represent the time of day in internal state within instances of TIME_OF_DAY

1. Keep three integer attributes:
   1. `hour: INTEGER`
   2. `minute: INTEGER`
   3. `second: INTEGER`

2. Keep one integer attibute:
   1. `seconds_since_midnight: INTEGER`

Example (4)

- Decision: How to represent the time of day in internal state within instances of TIME_OF_DAY

  1. Keep three integer attributes:
     1. **hour**: INTEGER
     2. **minute**: INTEGER
     3. **second**: INTEGER

  2. Keep one integer attribute:
     1. **seconds_since_midnight**: INTEGER

Example (5)

Implementation in TIME_OF_DAY:

```
set_hour (h: INTEGER) is
                -- Set the hour from `h'
          do
                hour := h
          end
```

Client code in some other class:

```
 coffee_time: TIME_OF_DAY
                    .
                    .
          coffee_time.set_hour (10)
```

(118)

Example (6)

- For any routine:

```
set_hour (h: INTEGER)
```

  - State the conditions that must be true before the routine can work correctly

```
0 <= h and h <= 23
```

  - State the conditions that will be true after execution, if the routine has worked correctly

```
hour = h
```

Example (7)

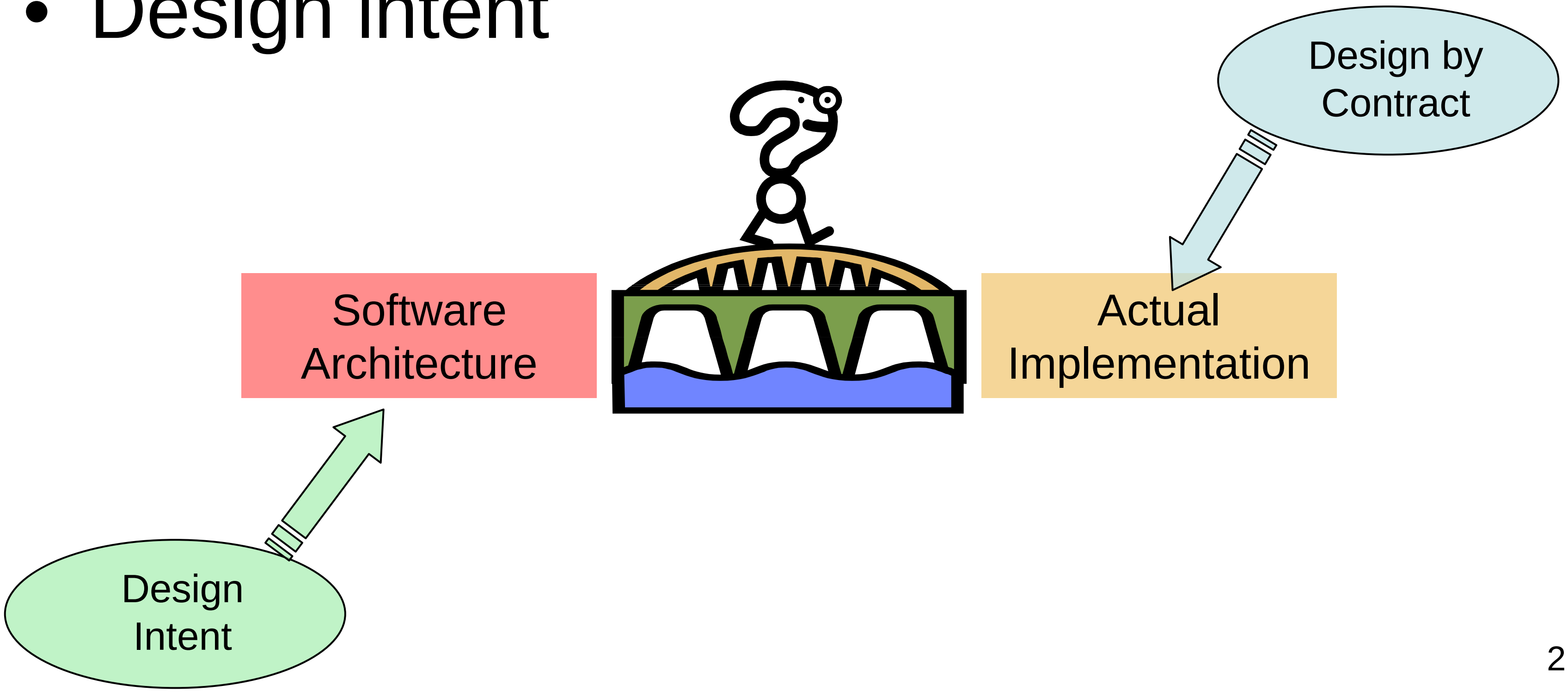
```
set_hour (h: INTEGER) is
          -- Set the hour from `h'
     require
          valid_h: 0 <= h and h <= 23
     do
          hour := h
     ensure
          hour_set: hour = h
          minute_unchanged: minute = old minute
          second_unchanged: second = old second
     end
```

Benefits

- Documentation
  - *automatic documentation of the contract*
- Reusability
  - *well-defined contracts*
- Correctness
  - pre-/post-conditions, class invariants
- Easier software development

What is the relation..?

- Design by contract
- Software architecture
- Design intent



*Sarfraz Khurshid, Darko Marinov and Daniel Jackson. "**An Analyzable Annotation Language**". In Proceedings of the 17th ACM Conference on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA), 2002, pp. 231-245.*

Alloy Annotation Language

- Invariants
- Specifications
  - Preconditions (requires)
  - Postconditions (ensures)
- Method Behavior (does)
  - built from specification
  - built from code

Alloy

- First-order, declarative language
- Based on sets and relations
- Checks assertions within a set scope

Static Checking

Invariants

- The equals() method of the Java Object class

javadoc spec of equals

```
package java.lang;
Class Object {
  /** The “equals” method implements an equivalence relation:
     *) It is reflexive: for any reference value “o”,
              “o.equals(o)” should return true.
     *) It is symmetric: …
     *) It is transitive: …
     …
  */
  boolean equals(Object o) {
     return (this == 0);
  }
}
```

AAL spec of equals

```
package java.lang;
Class Object {
  //@ invariant {
  //@   // reflexive
  //@   all o: Object - null | o.equals(o)
  //@   // symmetric
  //@    all o, o’: Object - null | o.equals(o’) => o’.equals(o)
  //@   // transitive
  //@   all o1, o2, o3: Object - null |
  //@      o1.equals(o2) && o2.equals(o3) => o1.equals(o3)
  //@ }
  boolean equals(Object o) {
     return (this == 0);
  }
}
```

Overriding equals

```
Package java.awt;
class Dimension {
  int width, height;

  //@ does {
  //@   \result = (obj instanceof Dimension
  //@               && this.width = obj.width
  //@               && this.height = obj.height)
  //@ }
  boolean equals(Object o) {
    if (!(o instanceof Dimension))
      return false;
    Dimension d = (Dimension)o;
    return (width == d.width) &&
           (height == d.height);
  }
}
```

```
class Dimension3D extends Dimension {
  int depth;

  //@ does {
  //@   \result = (obj instanceof Dimension3D
  //@               super..equals(obj) &&
  //@               this.depth = obj.depth)
  //@ }
boolean equals(Object o) {
    if (!(o instanceof Dimension3D))
      return false;
    Dimension3D d = (Dimension3D)o;
    return super.equals(o) &&
           (depth == d.depth);
  }
}
```

Counterexample

O1: Dimension {width = 0, height = 1}

O2: Dimension3D {width = 0, height = 1, depth = 3}

Symmetry violated: o1.equals(o2) and not o2.equals(o1)

```
Package java.awt;
class Dimension {
  int width, height;

  //@ does {
  //@   \result = (obj instanceof Dimension
  //@              && this.width = obj.width
  //@              && this.height = obj.height)
  //@ }
  boolean equals(Object o) {
    ...
  }
}
```

```
class Dimension3D extends Dimension {
  int depth;

  //@ does {
  //@   \result = (obj instanceof Dimension3D
  //@              super..equals(obj) &&
  //@              this.depth = obj.depth)
  //@ }
boolean equals(Object o) {
    …
  }
}
```

Possible Fixes

- Disable subclassing

```
final class Dimension {
  …
}
```

- Check concrete class

```
boolean Dimension.equals(Object o) {
  if (!(o.getClass() == this.getClass()))
    return false;
  …
}
```

Method Behavior

- annotations can come from one of two sources
  - Specification
  - Code translation
- Therefore, we can check both the specification and the code against invariants

Code Conformance

- Static Checking
- Dynamic Checking

Static Code Conformance

```
all s, s': State |
  valid(s) && pre(s) && body(s, s')
    => valid(s') && post(s, s')
```

Dynamic Code Conformance

- Unit testing
  - Alloy generates test inputs using invariants and preconditions
  - Execute each input
  - Checks output against postcondition
- Runtime checking