Design by Contract

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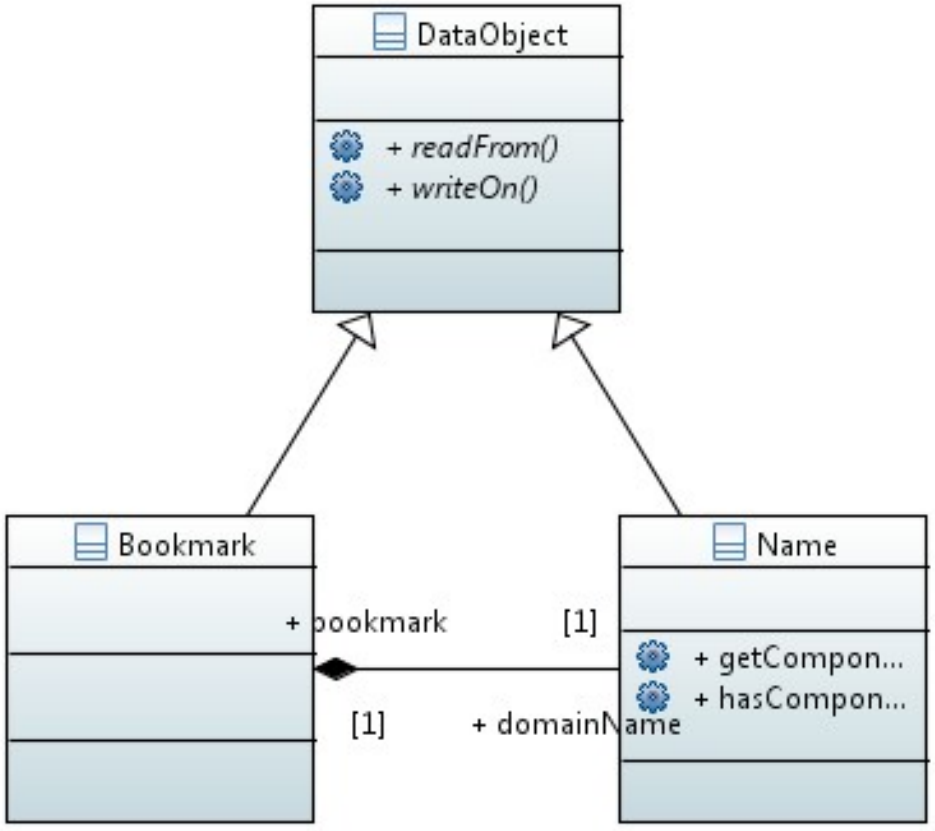
ADAP C05

Design by contract views software design as a succession of contracting decisions [M91].

Design by Contract is method for specifying interfaces as contracts to clarify responsibilities and minimize programming effort while improving reliability [DR].

Classes Specify Object Collaborations



Contracts

- A contract specifies rights (benefits) and obligations
  - Between a client (consumer) and contractor (supplier)
  - Contracts are (ideally) exhaustive; there are no hidden clauses
- Rights and obligations are mutual
  - A client obligation (precondition) is contractor right
  - A contractor obligation (postcondition) is a client right
- The contract protects both sides of the deal
  - The client is guaranteed a result
  - The contractor is guaranteed a specified operating environment
- **A contract is effectively an interface specification**

The AbstractName#insert(...) Method

```
public void insert(int i, String c) {
  assertClassInvariants();

  assertIsValidIndex(i, getNoComponents() + 1);
  assertIsNonNullArgument(c);
  int oldNoComponents = getNoComponents();

  doInsert(i, c);

  assert (oldNoComponents + 1) == getNoComponents() : "..."; // [1]

  assertClassInvariants();
}

protected abstract void doInsert(int i, String c);
```

[1] Please note that assertion checking using the assert keyword can be switched off; if you require the assertion be checked, do not use assert, but a classic if clause.

Contract for Name#insert(...)

	Rights	Obligations
Client	Receives Name object with component inserted	Ensures defined environment, i.e. index is valid and component != null
Contractor	Operates in defined environment	Provides Name object with component inserted

Defensive Programming

- Defensive programming
  - Wikipedia: “[...] the programmer never assumes a particular function call or library will work as advertised”
  - Meyer: “[...] protect every software module by as many checks as possible, even those which are redundant with checks made by the clients.”
- Problems with defensive programming
  - Multiplies the amount of checking code
  - Leads to bloated, hard-to-read, slow code
- **Redundant code is (mostly) a bad idea**
  - Design by contract makes code lean
  - Design by contract removes redundancy

Benefits of Design by Contract

- Leads to well-specified interfaces
- Leads to clean separation of work
- Makes software more reliable

Dilbert on Bugs

Expressing Design by Contract

1. Preconditions
2. Class invariants
3. Postconditions

Preconditions

- **A boolean condition to be met for successful method entry**
  - The purpose is to guarantee a safe operating environment
  - If violated, the method should not be executed
- The client must make sure preconditions are met
  - A violation in the preconditions indicates a bug in the client
- Preconditions are method-level components of a contract

Preconditions of Name#insert(...)

```
public void insert(int i, String c) {
  assertClassInvariants();

  assertIsValidIndex(i, getNoComponents() + 1);
  assertIsNonNullArgument(c);
  int oldNoComponents = getNoComponents();

  doInsert(i, c);

  assert (oldNoComponents + 1) == getNoComponents() : "...";

  assertClassInvariants();
}

protected abstract void doInsert(int i, String c);
```

Postconditions

- **A boolean condition guaranteed after successful method exit**
  - If violated, the method failed to provide the service
- The method must make sure postconditions are met
  - A violation of a postcondition indicates a bug in the method
- Postconditions are method-level components of a contract

Postconditions of Name#insert(...)

```
public void insert(int i, String c) {
  assertClassInvariants();

  assertIsValidIndex(i, getNoComponents() + 1);
  assertIsNonNullArgument(c);
  int oldNoComponents = getNoComponents();

  doInsert(i, c);

  assert (oldNoComponents + 1) == getNoComponents() : "...";

  assertClassInvariants();
}

protected abstract void doInsert(int i, String c);
```

Class Invariants

- **A boolean condition that is true for any valid object**
  - Permanent violation of the class invariant indicates a broken object
  - Temporary violation is possible during method execution
- Class invariants are constraints on the object's state space
  - The class (implementation) must make sure its invariants are maintained
- Class invariants are class-level components of a contract

Class Invariants of Name

```
public void insert(int i, String c) {
  assertClassInvariants();

  assertIsValidIndex(i, getNoComponents() + 1);
  assertIsNonNullArgument(c);
  int oldNoComponents = getNoComponents();

  doInsert(i, c);

  assert (oldNoComponents + 1) == getNoComponents() : "...";

  assertClassInvariants();
}

protected abstract void doInsert(int i, String c);

protected void assertClassInvariants() {
  assert getNoComponents() >= 0;
  ...
}
```

Realizing Design by Contract

- Annotate interface with class invariants
- Annotate methods with pre- and postconditions

Implementing Design by Contract

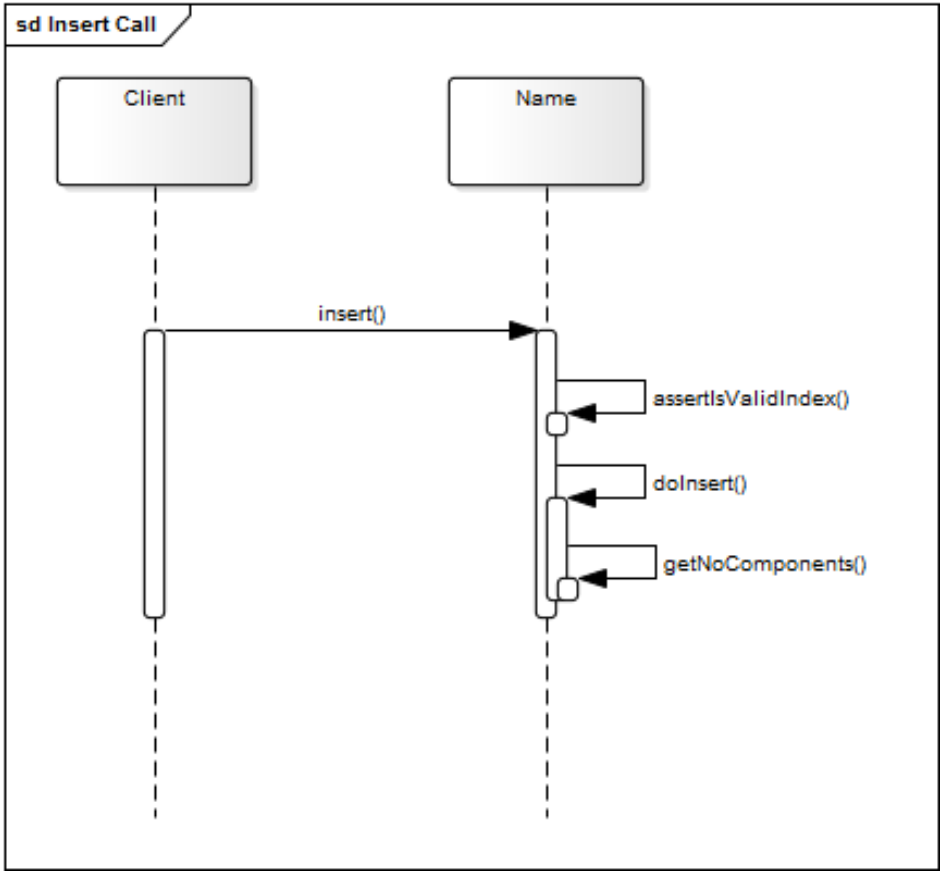
- In Java, use **`assert`** or assertion methods
  - Preconditions guard the entry to the method
  - Postconditions ensure successful completion
  - Class invariants add to postconditions
- **Assertions should be side-effect free**
  - Do not call mutation methods

Use of Assertion Methods

- Use dedicated assertion method if …
  - the assertion is used more than twice
  - a generic assertion failure exception is insufficient
  - you want to avoid that your assertion checking can be switched off

```
protected void assertIsValidIndex(int i, int upperLimit)
  throws IndexOutOfBoundsException {
  if ((i < 0) || (i >= upperLimit)) {
    String msg = String.valueOf(i) + "(of " +
      String.valueOf(getNoComponents()) +")";
    throw new IndexOutOfBoundsException(msg);
  }
}
```

Design by Contract and Assertions



Semantics of Various Exceptions

- IllegalArgumentException
- IndexOutOfBoundsException
- NullPointerException
- IllegalStateException
- ...

Pragmatics of Design by Contract

- Use design by contract ...
  - for code that needs to be highly reliable
  - for code that is called often
- **Focus on preconditions ...**
  - **to protect method operations**
  - **to document expectations**
- Why not postconditions and class invariants?
  - One method’s postconditions are another method’s precondition
  - Class invariants are implied postconditions for all methods
  - Pragmatically, tests already check for contract fulfillment

Design by Contract and Multithreading

```
public void insert(int i, String c) {
  assertIsValidIndex(i, getNoComponents() + 1);
  assertIsNonNullArgument(c);
  int oldNoComponents = getNoComponents();
  doInsert(i, c);
  assert (oldNoComponents + 1) == getNoComponents() : "...";
}
```

```
protected void doInsert(int index, String component) {
  int newSize = getNoComponents() + 1;
  String[] newComponents = new String[newSize];
  for (int i = 0, j = 0; j < newSize; j++) {
    if (j != index) {
      newComponents[j] = components[i++];
    } else {
      newComponents[j] = component;
    }
  }
  components = newComponents;
}
```

Design by Contract and Inheritance

- Preconditions may “accept more cases”
  - Subclasses may require less (weaken preconditions)
    - Preconditions get disjunctively (“or”) connected
  - Subclasses may **contravariantly redefine method argument types**
- Postconditions may “provide better results”
  - Subclasses may provide more (strengthen postconditions)
    - Postconditions get conjunctively (“and”) connected
  - Subclasses may **covariantly redefine return type**
- Class invariants may “provide better results”
  - Subclass invariants may not require less
  - If they provide more, they must refine superclass invariants

Preconditions and super.method() Calls

- Ensure preconditions of super.method(...) before using it

```
public Name AbstractName#insert(int index, String component) {
  assertIsValidIndex(index, getNoComponents() + 1);
  return doInsert(index, component);
}
```

```
public LazyName LazyName#insert(int index, String component) {
  ensureLength(index);
  return super.insert(index, componenht);
}

protected void ensureLength(int length) {
  // extend internal representation with empty components
  ...
}
```

Postconditions and Dual Hierarchies

- Covariant redefinition of return type strengthens postcondition

```
public Name AbstractName#insert(int index, String component) {
  assertIsValidIndex(index, getNoComponents() + 1);
  return doInsert(index, component);
}
```

```
public LazyName LazyName#insert(int index, String component) {
  ensureLength(index);
  return super.insert(index, component);
}

protected void ensureLength(int length) {
  // extend internal representation with empty components
  ...
}
```

Quiz: Violating Class Invariants

- Can you violate a class invariant in between two methods calls?
  - Yes
  - No

Normal vs. Abnormal Operation

- **Normal situation**
  - “All is good” about the program; system is performing its function
  - Program pointer is in regular code, not exception handling code
- **Abnormal situation**
  - A contract was violated; the system needs to recover from the violation
  - Violation is detected by failing pre- and postconditions, class invariants
- **Modern programming languages distinguish both modes**
  - Contract violation leads to exceptions being thrown
  - Exception handling takes place outside regular code

Contracts and Control Flow [1]

	Control Flow	
	Normal Return by `return`	Abnormal Return by Exception
Contract Fulfilled	X	–
Contract Not Fulfilled	–	X

[1] Meyer's first two "laws" of exception handling reframed.

Handling Contract Violations

Handling an Exception

- Resumption
- Organized Panic

More on this in lecture on error handling

Two Alternatives of Handling Violations

- Resumption
  - Try again
  - Try alternative implementation
- Organized panic
  - Clean up as far as possible
  - Repackage exception, pass on

Quiz: Switching off Assertions

- Should you switch off assertions? (If so, when?)
  - Yes
  - No

Review / Summary of Session

- Design by contract
  - Definition, benefits, and realization
  - DbC vs defensive programming
  - DbC implementation in Java
- Design-by-contract in context
  - Multi-threading
  - Inheritance

Thank you! Questions?

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