

Design by Contract

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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

- 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, component);  
}  
  
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 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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