# Object-Oriented Software Construction

Bertrand Meyer

## Lecture 12:

## Design by Contract™

## Contracts: run-time effect



- Compilation options (per class, in Eiffel):
  - No assertion checking
  - Preconditions only
  - Preconditions and postconditions
  - Preconditions, postconditions, class invariants
  - All assertions

## The contract language

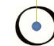


- Language of boolean expressions (plus **old**):
  - No predicate calculus (i.e. no quantifiers, ∀ or ∃).
  - Function calls permitted (e.g. in a *STACK* class):

```
put (x: G) is
        -- Push x on top of stack.
    require
        not is_full
    do
        …
    ensure
        not is_empty
    end
```

```
remove (x: G) is
        -- Pop top of stack.
    require
        not is_empty
    do
        …
    ensure
        not is_full
    end
```





## The contract language (cont'd)



- First order predicate calculus may be desirable, but not sufficient anyway.
- Example: "The graph has no cycles".
- In assertions, use only side-effect-free functions.
- Use of iterators provides the equivalent of first-order predicate calculus in connection with a library such as EiffelBase or STL. For example (Eiffel agents, i.e. routine objects):

```
my_integer_list.for_all (agent is_positive (?))
```

with

```
is_positive (x: INTEGER): BOOLEAN is
    do
        Result := (x > 0)
    end
```

## The imperative and the applicative



| **do** *balance* := *balance* - *sum* | **ensure** *balance* = **old** *balance* - *sum* |
|---|---|
| PRESCRIPTIVE | DESCRIPTIVE |
| How? | What? |
| Operational | Denotational |
| Implementation | Specification |
| Command | Query |
| Instruction | Expression |
| Imperative | Applicative |



## What are contracts good for?



- Writing correct software (analysis, design, implementation, maintenance, reengineering).
- Documentation (the "contract" form of a class).
- Effective reuse.
- Controlling inheritance.
- Preserving the work of the best developers.

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- Quality assurance, testing, debugging (especially in connection with the use of libraries) .
- Exception handling .



## A contract violation is not a special case



- For special cases (e.g. "if the sum is negative, report an error...")
  use standard control structures (e.g. **if** ... **then** ... **else**...).
- A run-time assertion violation is something else: the manifestation of

  A DEFECT ("BUG")



## Contracts and quality assurance



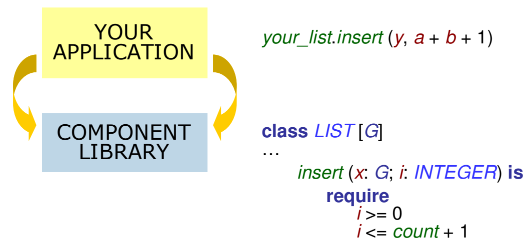
- Precondition violation: Bug in the client.
- Postcondition violation: Bug in the supplier.
- Invariant violation: Bug in the supplier.

$\{P\}\ A\ \{Q\}$

## Contracts and bug types



- Preconditions are particularly useful to find bugs in client code:




```
your_list.insert (y, a + b + 1)

class LIST [G]
...
    insert (x: G; i: INTEGER) is
        require
            i >= 0
            i <= count + 1
```



## Contracts and quality assurance



- Use run-time assertion monitoring for quality assurance, testing, debugging.
- Compilation options (reminder):
  - No assertion checking
  - Preconditions only
  - Preconditions and postconditions
  - Preconditions, postconditions, class invariants
  - All assertions



## Contracts missed



- Ariane 5 (see Jézéquel & Meyer, IEEE Computer, January 1997)
- Lunar Orbiter Vehicle
- Failure of air US traffic control system, November 2000
- Y2K
- etc. etc. etc.



## Contracts and quality assurance



- Contracts enable QA activities to be based on a precise description of what they expect.
- Profoundly transform the activities of testing, debugging and maintenance.

*"I believe that the use of Eiffel-like module contracts is the most important non-practice in software world today. By that I mean there is no other candidate practice presently being urged upon us that has greater capacity to improve the quality of software produced. ... This sort of contract mechanism is the sine-qua-non of sensible software reuse. "*

Tom de Marco, IEEE Computer, 1997

## Debugging with contracts: an example

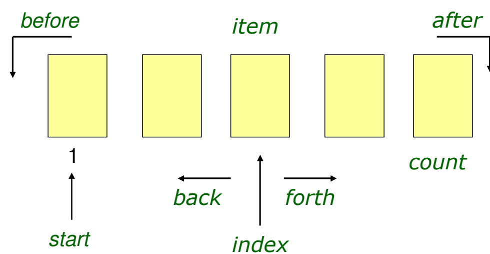


- This example will use a live demo from EiffelStudio, with a "planted" error leading to a precondition violation.
- The example uses both the browsing and debugging mechanisms.



## To understand the example: list conventions

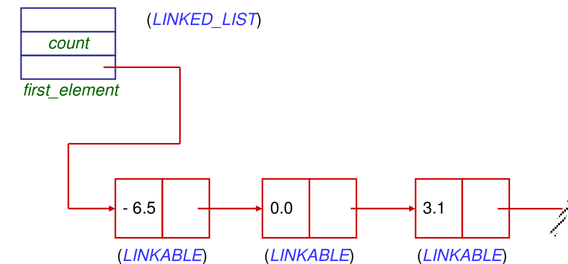







## Linked list representation








## Adding and catching a bug



- In class *STARTER*, procedure *make_a_list*, replace the first call to *extend* by a call to *put*.
- Execute system. What happens?
- Use browsing mechanisms to find out what's wrong (violated precondition).
- To understand, consider what the diagram of page 16 becomes when the number of list items goes to zero.

## Contract monitoring



- Enabled or disabled by compile-time options.
- Default: preconditions only.
- In development: use “all assertions” whenever possible.
- During operation: normally, should disable monitoring. But have an assertion-monitoring version ready for shipping.
- Result of an assertion violation: exception.
- Ideally: static checking (proofs) rather than dynamic monitoring.



## Contracts and documentation



Recall example class:

```
class ACCOUNT create
    make
feature {NONE} -- Implementation
    add (sum: INTEGER) is
                -- Add sum to the balance (secret procedure).
        do
                balance := balance + sum
        ensure
                increased: balance = old balance + sum
        end
    deposits: DEPOSIT_LIST
    withdrawals: WITHDRAWAL_LIST
```



## Class example (cont’d)



```
feature {NONE} -- Initialization
    make (initial_amount: INTEGER) is
                -- Set up account with initial_amount.
        require
                large_enough: initial_amount >= Minimum_balance
        do
                deposit (initial_amount)
                create deposits.make
                create withdrawals.make
        ensure
                balance_set: balance = initial_amount
        end
feature -- Access
    balance: INTEGER
        -- Balance
    Minimum_balance: INTEGER is 1000
        -- Minimum balance
```



## Class example (cont’d)



```
feature -- Deposit and withdrawal operations
    deposit (sum: INTEGER) is
                -- Deposit sum into the account.
        require
                not_too_small: sum >= 0
        do
                add (sum)
                deposits.extend (create {DEPOSIT}.make (sum))
        ensure
                increased: balance = old balance + sum
        end
```

## Class example (cont'd)



```
withdraw (sum: INTEGER) is
        -- Withdraw sum from the account.
    require
        not_too_small: sum >= 0
        not_too_big: sum <= balance – Minimum_balance
    do
        add (– sum)
        withdrawals.extend (create {WITHDRAWAL}.make (sum))
    ensure
        decreased: balance = old balance – sum
        one_more: withdrawals.count = old withdrawals.count + 1
    end
```

## Class example (end)



```
    may_withdraw (sum: INTEGER): BOOLEAN is
            -- Is it permitted to withdraw sum from the
            -- account?
        do
            Result := (balance - sum >= Minimum_balance)
        end

invariant

    not_under_minimum: balance >= Minimum_balance
    consistent: balance = deposits.total – withdrawals.total

end
```

## Contract form: Definition



- Simplified form of class text, retaining interface elements only:
  - Remove any non-exported (private) feature.
- For the exported (public) features:
  - Remove body (do clause).
  - Keep header comment if present.
  - Keep contracts: preconditions, postconditions, class invariant.
  - Remove any contract clause that refers to a secret feature. (This raises a problem; can you see it?)

## Export rule for preconditions



- In

```
feature {A, B, C}
  r (…) is
      require
          some_property
```

- *some_property* must be exported (at least) to *A*, *B* and *C*!
- No such requirement for postconditions and invariants.

# Contract form of ACCOUNT class



```
class interface ACCOUNT create
    make
feature
    balance: INTEGER
            -- Balance

    Minimum_balance: INTEGER is 1000
            -- Minimum balance

    deposit (sum: INTEGER)
                    -- Deposit sum into the account.
            require
                    not_too_small: sum >= 0
            ensure
                    increased: balance = old balance + sum
```



# Contract form (cont'd)



```
    withdraw (sum: INTEGER)
                    -- Withdraw sum from the account.
            require
                    not_too_small: sum >= 0
                    not_too_big: sum <= balance – Minimum_balance
            ensure
                    decreased: balance = old balance – sum
                    one_more: withdrawals.count = old withdrawals.count + 1

    may_withdraw (sum: INTEGER): BOOLEAN
                    -- Is it permitted to withdraw sum from the
                    -- account?

invariant

    not_under_minimum: balance >= Minimum_balance
    consistent: balance = deposits.total – withdrawals.total

end
```



# Flat, interface



- Flat form of a class: reconstructed class with all the features at the same level (immediate and inherited). Takes renaming, redefinition etc. into account.
- The flat form is an inheritance-free client-equivalent form of the class.
- Interface form: the contract form of the flat form. Full interface documentation.



# Uses of the contract and interface forms



- Documentation, manuals
- Design
- Communication between developers
- Communication between developers and managers

## Contracts and reuse



- The contract form — i.e. the set of contracts governing a class — should be the standard form of library documentation.

- Reuse without a contract is sheer folly.

- See the Ariane 5 example.
- See Jézéquel & Meyer, IEEE *Computer*, January 1997.

End of lecture 12