Object-Oriented Software Construction

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Lecture 11:

Design by Contract™

Ariane 5, 1996

$500 million, not insured.

37 seconds into flight, exception in Ada program not processed; order given to abort the mission.

Exception was caused by an incorrect conversion: a 64-bit real value was incorrectly translated into a 16-bit integer.

- Not a design error.
- Not an implementation error.
- Not a language issue.
- Not really a testing problem.
- Only partly a quality assurance issue.

Systematic analysis had “proved” that the exception could not occur – the 64-bit value (“horizontal bias” of the flight) was proved to be always representable as a 16-bit integer !

Ariane-5 (Continued)

It was a REUSE error:

- The analysis was correct – for Ariane 4 !
- The assumption was documented – in a design document !

Design by Contract

- A discipline of analysis, design, implementation, management

Design by Contract (cont'd)

- Every software element is intended to satisfy a certain goal, for the benefit of other software elements (and ultimately of human users).
- This goal is the element's contract.
- The contract of any software element should be
  - Explicit.
  - Part of the software element itself.

Applications

- Getting the software right
- Analysis
- Design
- Implementation
- Debugging
- Testing
- Management
- Maintenance
- Documentation

Documentation Issues

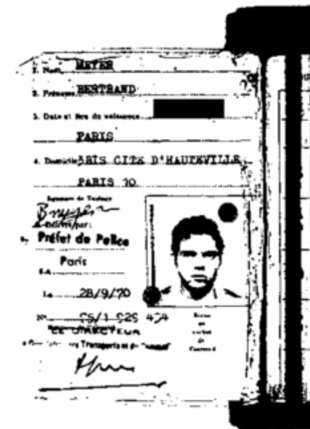
Who will do the program documentation (technical writers, developers) ?

How to ensure that it doesn't diverge from the code (the French driver's license / reverse Dorian Gray syndrome) ?

The Single Product principle

The product is the software

The French Driver's License issue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PARIS
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A human contract

deliver	OBLIGATIONS	BENEFITS
Client	(Satisfy precondition:) Bring package before 4 p.m.; pay fee.	(From postcondition:) Get package delivered by 10 a.m. next day.
Supplier	(Satisfy postcondition:) Deliver package by 10 a.m. next day.	(From precondition:) Not required to do anything if package delivered after 4 p.m., or fee not paid.

A view of software construction

- Constructing systems as structured collections of cooperating software elements — suppliers and clients — cooperating on the basis of clear definitions of obligations and benefits.
- These definitions are the contracts.

Properties of contracts

- A contract:
  - Binds two parties (or more): supplier, client.
  - Is explicit (written).
  - Specifies mutual obligations and benefits.
  - Usually maps obligation for one of the parties into benefit for the other, and conversely.
  - Has no hidden clauses: obligations are those specified.
  - Often relies, implicitly or explicitly, on general rules applicable to all contracts (laws, regulations, standard practices).

Contracts for analysis


```
deferred class PLANE inherit
    AIRCRAFT
feature
    start_take_off is
            -- Initiate take-off procedures.
        require
            controls.passed
            assigned_runway.clear
        deferred
        ensure
            assigned_runway.owner = Current
            moving
        end
    start_landing, increase_altitude, decrease_altitude, moving,
    altitude, speed, time_since_take_off
    ... [Other features] ...
invariant
    (time_since_take_off <= 20) implies (assigned_runway.owner = Current)
    moving = (speed > 10)
end
```

Precondition

-- i.e. specified only.
-- not implemented.

Postcondition

Class invariant

Contracts for analysis (cont'd)


```
deferred class VAT inherit
    TANK
feature
    in_valve, out_valve: VALVE
    fill is
            -- Fill the vat.
        require
            in_valve.open
            out_valve.closed
        deferred
        ensure
            in_valve.closed
            out_valve.closed
            is_full
        end
    empty, is_full, is_empty, gauge, maximum, ... [Other features] ...
invariant
    is_full = (gauge >= 0.97 * maximum) and (gauge <= 1.03 * maximum)
end
```

Precondition

-- i.e. specified only.

-- not implemented.

Postcondition

Class invariant

Contracts for analysis (cont'd)

fill	OBLIGATIONS	BENEFITS
Client	(Satisfy precondition:) Make sure input valve is open, output valve is closed.	(From postcondition:) Get filled-up vat, with both valves closed.
Supplier	(Satisfy postcondition:) Fill the vat and close both valves.	(From precondition:) Simpler processing thanks to assumption that valves are in the proper initial position.

So, is it like "assert.h"?

(Source: Reto Kramer)

- Design by Contract goes further:
  - "Assert" does not provide a contract.
  - Clients cannot see asserts as part of the interface.
  - Asserts do not have associated semantic specifications.
  - Not explicit whether an assert represents a precondition, post-conditions or invariant.
  - Asserts do not support inheritance.
  - Asserts do not yield automatic documentation.

Some benefits: technical

- Development process becomes more focused. Writing to spec.
- Sound basis for writing reusable software.
- Exception handling guided by precise definition of "normal" and "abnormal" cases.
- Interface documentation always up-to-date, can be trusted.
- Documentation generated automatically.
- Faults occur close to their cause. Found faster and more easily.
- Guide for black-box test case generation.

Some benefits: managerial

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- Library users can trust documentation.
- They can benefit from preconditions to validate their own software.
- Test manager can benefit from more accurate estimate of test effort.
- Black-box specification for free.
- Designers who leave bequeath not only code but intent.
- Common vocabulary between all actors of the process: developers, managers, potentially customers.
- Component-based development possible on a solid basis.

Correctness in software

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- Correctness is a relative notion: consistency of implementation vis-à-vis specification. (This assumes there is a specification!)
- Basic notation: (*P*, *Q*: assertions, i.e. properties of the state of the computation. *A*: instructions).

{*P*} *A* {*Q*}

- "Hoare triple"
- What this means (total correctness):
  - Any execution of *A* started in a state satisfying *P* will terminate in a state satisfying *Q*.

Hoare triples: a simple example

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{n > 5} *n* := *n* + 9 {n > 13}

- Most interesting properties:
  - *Strongest* postcondition (from given precondition).
  - *Weakest* precondition (from given postcondition).
- "*P* is stronger than or equal to *Q*" means: *P* implies *Q*
- QUIZ: What is the strongest possible assertion? The weakest?

Specifying a square root routine

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{*x* >= 0}

... Square root algorithm to compute *y* ...

{*abs* (*y* ^ 2 – *x*) <= 2 * *epsilon* * *y*}

-- i.e.: *y* approximates exact square root of *x*

-- within *epsilon*

Software correctness

- Consider

  {*P*} *A* {*Q*}

- Take this as a job ad in the classifieds.
- Should a lazy employment candidate hope for a weak or strong *P*? What about *Q*?
- *Two special offers:*
  - 1. {*False*} *A* {...}
  - 2. {...} *A* {*True*}

A contract (from EiffelBase)


```
extend (new: G; key: H)
        -- Assuming there is no item of key key,
        -- insert new with key; set inserted.
    require
        key_not_present: not has (key)
    ensure
        insertion_done: item (key) = new
        key_present: has (key)
        inserted: inserted
        one_more: count = old count + 1
```


The contract

Routine	OBLIGATIONS	BENEFITS
Client	PRECONDITION	POSTCONDITION
Supplier	POSTCONDITION	PRECONDITION

A class without contracts


```
class ACCOUNT feature -- Access

    balance: INTEGER
            -- Balance

    Minimum_balance: INTEGER is 1000
            -- Minimum balance

feature {NONE} -- Implementation of deposit and withdrawal

    add (sum: INTEGER) is
            -- Add sum to the balance (secret procedure).
        do
            balance := balance + sum
        end
```

Without contracts (cont'd)


```
feature -- Deposit and withdrawal operations

    deposit (sum: INTEGER) is
            -- Deposit sum into the account.
        do
            add (sum)
        end

    withdraw (sum: INTEGER) is
            -- Withdraw sum from the account.
        do
            add (– sum)
        end

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


Introducing contracts


```
class ACCOUNT create

    make

feature {NONE} -- Initialization

    make (initial_amount: INTEGER) is
            -- Set up account with initial_amount.

        require
            large_enough: initial_amount >= Minimum_balance

        do
            balance := initial_amount

        ensure
            balance_set: balance = initial_amount

    end
```


Introducing contracts (cont'd)


```
feature -- Access

    balance: INTEGER
        -- Balance

    Minimum_balance: INTEGER is 1000
        -- Minimum balance

feature {NONE} -- Implementation of deposit and withdrawal

    add (sum: INTEGER) is
            -- Add sum to the balance (secret procedure).
        do
            balance := balance + sum
        ensure
            increased: balance = old balance + sum
        end
```


With contracts (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)
        ensure
            increased: balance = old balance + sum
        end
```

With contracts (cont'd)

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```
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)
            -- i.e. balance := balance – sum
    ensure
        decreased: balance = old balance - sum
    end
```


The contract

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withdraw	OBLIGATIONS	BENEFITS
Client	(Satisfy precondition:) Make sure *sum* is neither too small nor too big.	(From postcondition:) Get account updated with *sum* withdrawn.
Supplier	(Satisfy postcondition:) Update account for withdrawal of *sum*.	(From precondition:) Simpler processing: may assume *sum* is within allowable bounds.

The imperative and the applicative

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

With contracts (end)

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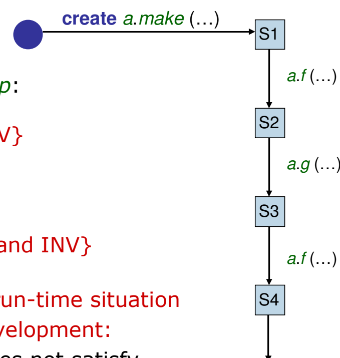
```
may_withdraw (sum: INTEGER): BOOLEAN is
        -- Is it permitted to withdraw sum from the
        -- account?
    do
        Result := (balance - sum >= Minimum_balance)
    end

invariant
    not_under_minimum: balance >= Minimum_balance
end
```

The class invariant

- Consistency constraint applicable to all instances of a class.
- Must be satisfied:
  - After creation.
  - After execution of any feature by any client. (Qualified calls only: *a*.*f* (...))

The correctness of a class



- For every creation procedure *cp*:

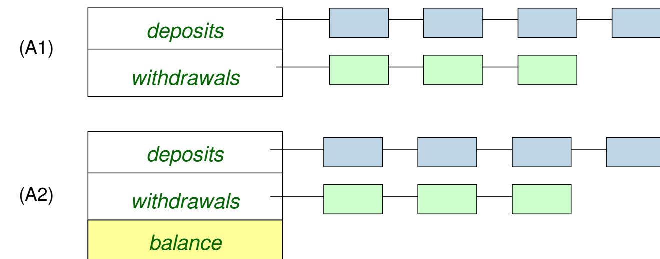
  {pre_{cp}} do_{cp} {$post_{cp}$ and INV}

- For every exported routine *r*:

  {INV and pre_r} do_r {$post_r$ and INV}

- The worst possible erroneous run-time situation in object-oriented software development:
  - Producing an object that does not satisfy the invariant of its own class.

Uniform Access



balance = *deposits*.*total* –*withdrawals*.*total*

A more sophisticated version


```
class ACCOUNT create

    make

feature {NONE} -- Implementation

    add (sum: INTEGER) is
                -- Add sum to the balance (secret procedure).
        do
                balance := balance + sum
        ensure
                balance_increased: balance = old balance + sum
        end

    deposits: DEPOSIT_LIST

    withdrawals: WITHDRAWAL_LIST
```

New version (cont'd)


```
feature {NONE} -- Initialization

   make (initial_amount: INTEGER) is
               -- Set up account with initial_amount.
         require
               large_enough: initial_amount >= Minimum_balance
         do
               balance := 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
```


New version (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
```


New version (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
```


New version (end)

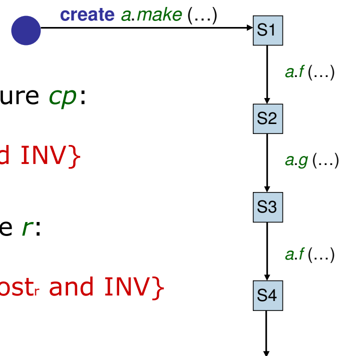

```
   may_withdraw (sum: INTEGER): BOOLEAN is
               -- Is it permitted to withdraw sum from the
               -- account?
         do
               Result := (balance - sum >= Minimum_balance)
         end

invariant

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

end
```

The correctness of a class



- For every creation procedure *cp*:

  $\{pre_{cp}\}$ do_{cp} $\{post_{cp}$ and $INV\}$

- For every exported routine *r*:

  $\{INV$ and $pre_r\}$ do_r $\{post_r$ and $INV\}$

Initial version


```
feature {NONE} -- Initialization

    make (initial_amount: INTEGER) is
                -- Set up account with initial_amount.
        require
                large_enough: initial_amount >= Minimum_balance
        do
                balance := initial_amount

                create deposits.make
                create withdrawals.make


        ensure
                balance_set: balance = initial_amount
        end
```


Correct version


```
feature {NONE} -- Initialization

    make (initial_amount: INTEGER) is
                -- Set up account with initial_amount.
        require
                large_enough: initial_amount >= Minimum_balance
        do


                create deposits.make
                create withdrawals.make

                deposit (initial_amount)

        ensure
                balance_set: balance = initial_amount
        end
```

End of lecture 11