Writing Complete Contracts

EECS3311: Software Design
Fall 2017

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How are contracts checked at runtime?

- All contracts are specified as Boolean expressions.
- Right **before** a feature call (e.g., *acc.withdraw(10)*):
  - The current state of *acc* is called its ***pre-state***.
  - Evaluate *pre-condition* using ***current values*** of attributes/queries.
  - Cache values of *all expressions involving the **old** keyword* in the *post-condition*.

    e.g., cache the value of **old** *balance* via *old_balance* := *balance*
- Right **after** the feature call:
  - The current state of *acc* is called its ***post-state***.
  - Evaluate *invariant* using ***current values*** of attributes and queries.
  - Evaluate *post-condition* using both ***current values*** and ***"cached" values*** of attributes and queries.

When are contracts complete?

- In *post-condition*, for *each attribute*, specify the relationship between its ***pre-state*** value and its ***post-state*** value.
  - Eiffel supports this purpose using the **old** keyword.
- This is tricky for attributes whose structures are **composite** rather than **simple**:

  e.g., *ARRAY*, *LINKED_LIST* are composite-structured.
  e.g., *INTEGER*, *BOOLEAN* are simple-structured.
- **Rule of thumb:** For an attribute whose structure is composite, we should specify that after the update:
  1. The intended change is present; **and**
  2. *The rest of the structure is unchanged*.
- The second contract is much harder to specify:
  - Reference aliasing [ref copy vs. shallow copy vs. deep copy]
  - Iterable structure [use `across`]

Account

```
class
  ACCOUNT
inherit
  ANY
    redefine is_equal end
create
  make

feature
  owner: STRING
  balance: INTEGER

  make (n: STRING)
    do
      owner := n
      balance := 0
    end
```

```
  deposit(a: INTEGER)
    do
      balance := balance + a
    ensure
      balance = old balance + a
    end

  is_equal(other: ACCOUNT): BOOLEAN
    do
      Result :=
           owner ~ other.owner
        and balance = other.balance
    end
end
```

Bank

```
class BANK
create make
feature
  accounts: ARRAY[ACCOUNT]
  make do create accounts.make_empty end
  account_of (n: STRING): ACCOUNT
    require
      existing: across accounts as acc some acc.item.owner ~ n end
    do ...
    ensure Result.owner ~ n
    end
  add (n: STRING)
    require
      non_existing:
        across accounts as acc all acc.item.owner /~ n end
    local new_account: ACCOUNT
    do
      create new_account.make (n)
      accounts.force (new_account, accounts.upper + 1)
    end
end
```

Roadmap of Illustrations

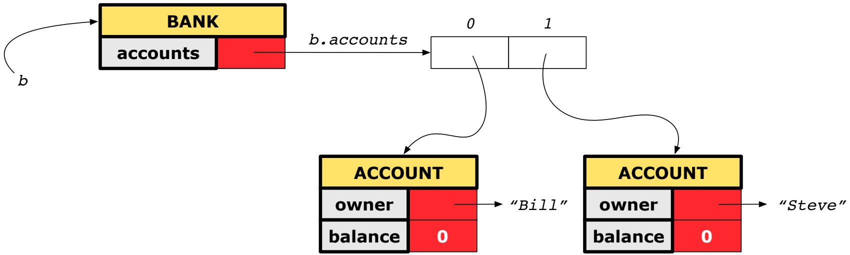
We examine 5 different versions of a command

$$deposit\_on\ (n : STRING;\ a : INTEGER)$$

VERSION	IMPLEMENTATION	CONTRACTS	SATISFACTORY?
1	*Correct*	*Incomplete*	*No*
2	*Wrong*	*Incomplete*	*No*
3	*Wrong*	*Complete* (reference copy)	*No*
4	*Wrong*	*Complete* (shallow copy)	*No*
5	*Wrong*	*Complete* (deep copy)	*Yes*

Object Structure for Illustration

We will test each version by starting with the same runtime object structure:



Version 1:
Incomplete Contracts, Correct Implementation

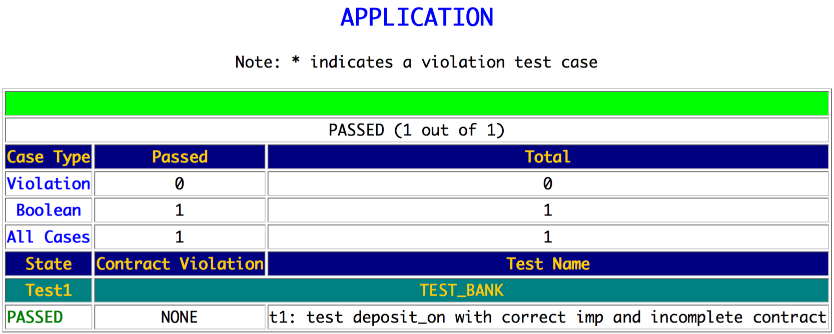
```
class BANK
 deposit_on_v1 (n: STRING; a: INTEGER)
  require across accounts as acc some acc.item.owner ~ n end
  local i: INTEGER
  do
   from i := accounts.lower
   until i > accounts.upper
   loop
    if accounts[i].owner ~ n then accounts[i].deposit(a) end
    i := i + 1
   end
  ensure
   num_of_accounts_unchanged:
    accounts.count = old accounts.count
   balance_of_n_increased:
    account_of (n).balance = old account_of (n).balance + a
  end
end
```

Test of Version 1

```
class TEST_BANK
 test_bank_deposit_correct_imp_incomplete_contract: BOOLEAN
   local
     b: BANK
   do
     comment("t1: correct imp and incomplete contract")
     create b.make
     b.add ("Bill")
     b.add ("Steve")

     -- deposit 100 dollars to Steve's account
     b.deposit_on_v1 ("Steve", 100)
     Result :=
          b.account_of ("Bill").balance = 0
      and b.account_of ("Steve").balance = 100
     check Result end
 end
end
```

Test of Version 1: Result



APPLICATION

Note: * indicates a violation test case

🟩		
PASSED (1 out of 1)		
Case Type	Passed	Total
Violation	0	0
Boolean	1	1
All Cases	1	1
State	Contract Violation	Test Name
Test1	TEST_BANK	
PASSED	NONE	t1: test deposit_on with correct imp and incomplete contract

Version 2:
Incomplete Contracts, Wrong Implementation

```
class BANK
 deposit_on_v2 (n: STRING; a: INTEGER)
   require across accounts as acc some acc.item.owner ~ n end
   local i: INTEGER
   do
     -- same loop as in version 1

     -- wrong implementation: also deposit in the first account
     accounts[accounts.lower].deposit(a)
   ensure
     num_of_accounts_unchanged:
       accounts.count = old accounts.count
     balance_of_n_increased:
       account_of (n).balance = old account_of (n).balance + a
   end
end
```

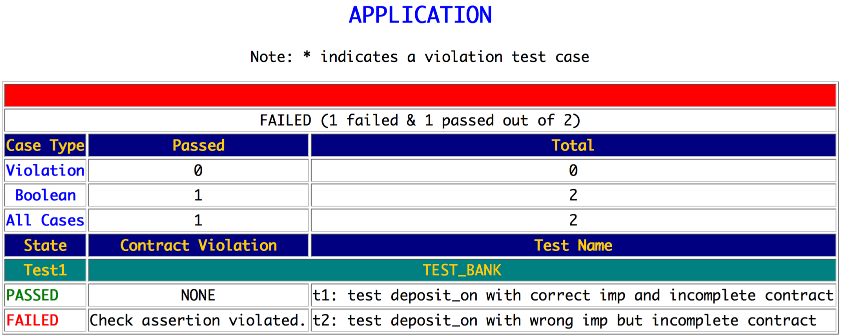
Current postconditions lack a check that accounts other than `n` are unchanged.

Test of Version 2

```
class TEST_BANK
test_bank_deposit_wrong_imp_incomplete_contract: BOOLEAN
  local
    b: BANK
  do
    comment("t2: wrong imp and incomplete contract")
    create b.make
    b.add ("Bill")
    b.add ("Steve")

    -- deposit 100 dollars to Steve's account
    b.deposit_on_v2 ("Steve", 100)
    Result :=
          b.account_of ("Bill").balance = 0
      and b.account_of ("Steve").balance = 100
    check Result end
  end
end
```

Test of Version 2: Result



APPLICATION

Note: * indicates a violation test case

FAILED (1 failed & 1 passed out of 2)		
Case Type	Passed	Total
Violation	0	0
Boolean	1	2
All Cases	1	2
State	Contract Violation	Test Name
Test1	TEST_BANK	
PASSED	NONE	t1: test deposit_on with correct imp and incomplete contract
FAILED	Check assertion violated.	t2: test deposit_on with wrong imp but incomplete contract

Version 3: Complete Contracts with Reference Copy

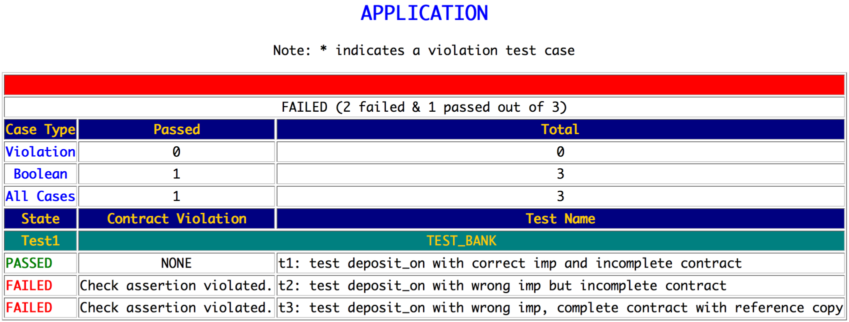
```
class BANK
  deposit_on_v3 (n: STRING; a: INTEGER)
    require across accounts as acc some acc.item.owner ~ n end
    local i: INTEGER
    do
      -- same loop as in version 1
      -- wrong implementation: also deposit in the first account
      accounts[accounts.lower].deposit(a)
    ensure
      num_of_accounts_unchanged: accounts.count = old accounts.count
      balance_of_n_increased:
        account_of(n).balance = old account_of(n).balance + a
      others_unchanged :
        across old accounts as cursor
        all cursor.item.owner /~ n implies
              cursor.item ~ account_of (cursor.item.owner)
        end
    end
end
```

Test of Version 3

```
class TEST_BANK
 test_bank_deposit_wrong_imp_complete_contract_ref_copy: BOOLEAN
   local
     b: BANK
   do
     comment("t3: wrong imp and complete contract with ref copy")
     create b.make
     b.add ("Bill")
     b.add ("Steve")

     -- deposit 100 dollars to Steve's account
     b.deposit_on_v3 ("Steve", 100)
     Result :=
          b.account_of ("Bill").balance = 0
      and b.account_of ("Steve").balance = 100
     check Result end
   end
end
```

Test of Version 3: Result



APPLICATION

Note: * indicates a violation test case

FAILED (2 failed & 1 passed out of 3)		
Case Type	Passed	Total
Violation	0	0
Boolean	1	3
All Cases	1	3
State	Contract Violation	Test Name
Test1	TEST_BANK	
PASSED	NONE	t1: test deposit_on with correct imp and incomplete contract
FAILED	Check assertion violated.	t2: test deposit_on with wrong imp but incomplete contract
FAILED	Check assertion violated.	t3: test deposit_on with wrong imp, complete contract with reference copy

Version 4: Complete Contracts with Shallow Object Copy

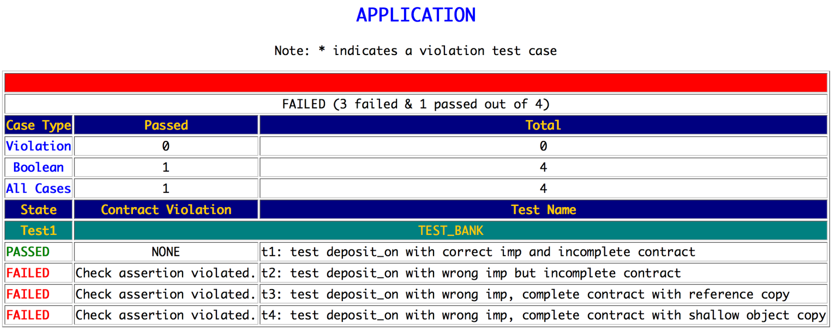
```
class BANK
  deposit_on_v4 (n: STRING; a: INTEGER)
    require across accounts as acc some acc.item.owner ~ n end
    local i: INTEGER
    do
      -- same loop as in version 1
      -- wrong implementation: also deposit in the first account
      accounts[accounts.lower].deposit(a)
    ensure
      num_of_accounts_unchanged: accounts.count = old accounts.count
      balance_of_n_increased:
        account_of (n).balance = old account_of (n).balance + a
      others_unchanged :
        across old accounts.twin as cursor
        all cursor.item.owner /~ n implies
             cursor.item ~ account_of (cursor.item.owner)
      end
    end
end
```

Test of Version 4

```
class TEST_BANK
 test_bank_deposit_wrong_imp_complete_contract_shallow_copy: BOOLEAN
   local
     b: BANK
   do
     comment("t4: wrong imp and complete contract with shallow copy")
     create b.make
     b.add ("Bill")
     b.add ("Steve")

     -- deposit 100 dollars to Steve's account
     b.deposit_on_v4 ("Steve", 100)
     Result :=
          b.account_of ("Bill").balance = 0
      and b.account_of ("Steve").balance = 100
     check Result end
   end
end
```

Test of Version 4: Result



APPLICATION

Note: * indicates a violation test case

🟥		
FAILED (3 failed & 1 passed out of 4)		
Case Type	Passed	Total
Violation	0	0
Boolean	1	4
All Cases	1	4
State	Contract Violation	Test Name
Test1	TEST_BANK	
PASSED	NONE	t1: test deposit_on with correct imp and incomplete contract
FAILED	Check assertion violated.	t2: test deposit_on with wrong imp but incomplete contract
FAILED	Check assertion violated.	t3: test deposit_on with wrong imp, complete contract with reference copy
FAILED	Check assertion violated.	t4: test deposit_on with wrong imp, complete contract with shallow object copy

Version 5: Complete Contracts with Deep Object Copy

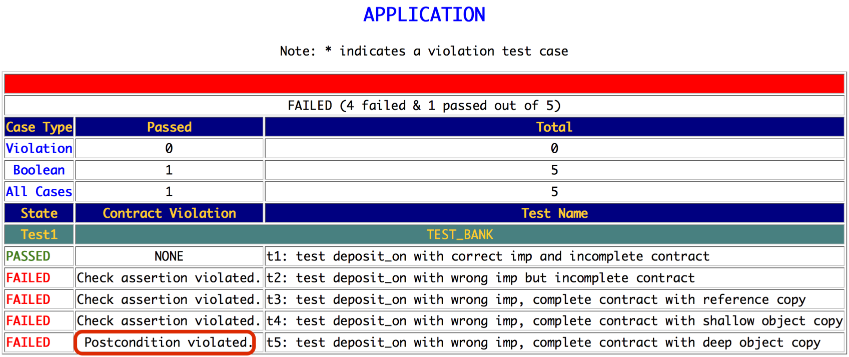
```
class BANK
 deposit_on_v5 (n: STRING; a: INTEGER)
  require across accounts as acc some acc.item.owner ~ n end
   local i: INTEGER
  do
   -- same loop as in version 1
   -- wrong implementation: also deposit in the first account
   accounts[accounts.lower].deposit(a)
  ensure
   num_of_accounts_unchanged: accounts.count = old accounts.count
   balance_of_n_increased:
    account_of (n).balance = old account_of (n).balance + a
   others_unchanged :
    across old accounts.deep_twin as cursor
    all cursor.item.owner /~ n implies
       cursor.item ~ account_of (cursor.item.owner)
    end
  end
end
```

Test of Version 5

```
class TEST_BANK
  test_bank_deposit_wrong_imp_complete_contract_deep_copy: BOOLEAN
    local
      b: BANK
    do
      comment("t5: wrong imp and complete contract with deep copy")
      create b.make
      b.add ("Bill")
      b.add ("Steve")

      -- deposit 100 dollars to Steve's account
      b.deposit_on_v5 ("Steve", 100)
      Result :=
           b.account_of ("Bill").balance = 0
        and b.account_of ("Steve").balance = 100
      check Result end
    end
end
```

Test of Version 5: Result



APPLICATION

Note: * indicates a violation test case

FAILED (4 failed & 1 passed out of 5)		
Case Type	Passed	Total
Violation	0	0
Boolean	1	5
All Cases	1	5
State	Contract Violation	Test Name
Test1	TEST_BANK	
PASSED	NONE	t1: test deposit_on with correct imp and incomplete contract
FAILED	Check assertion violated.	t2: test deposit_on with wrong imp but incomplete contract
FAILED	Check assertion violated.	t3: test deposit_on with wrong imp, complete contract with reference copy
FAILED	Check assertion violated.	t4: test deposit_on with wrong imp, complete contract with shallow object copy
FAILED	Postcondition violated.	t5: test deposit_on with wrong imp, complete contract with deep object copy

Exercise

- Consider the query *account_of (n: STRING)* of *BANK*.
- How do we specify (part of) its postcondition to assert that the state of the bank remains unchanged:
  - `accounts = old accounts` [×]
  - `accounts = old accounts.twin` [×]
  - `accounts = old accounts.deep_twin` [×]
  - `accounts ~ old accounts` [×]
  - `accounts ~ old accounts.twin` [×]
  - `accounts ~ old accounts.deep_twin` [✓]
- Which equality of the above is appropriate for the postcondition?
- Why is each one of the other equalities not appropriate?

Index (1)

Index (2)