# Types: Reference vs. Expanded
# Copies: Reference vs. Shallow vs. Deep
# Writing Complete Postconditions


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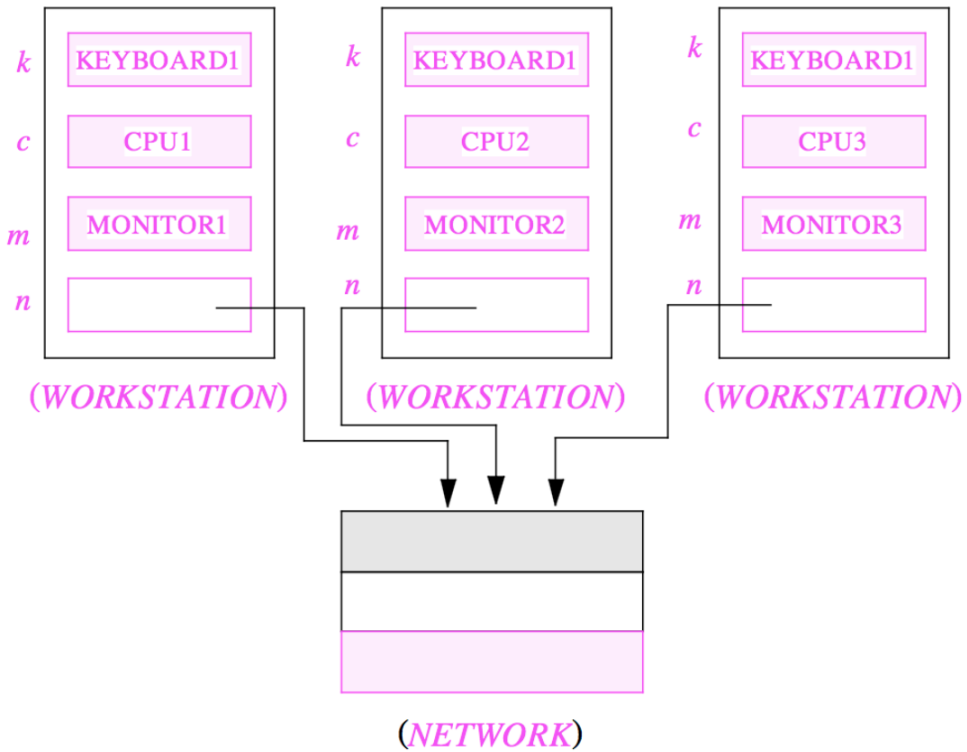
# Expanded Class: Modelling

- We may want to have objects which are:
  - Integral parts of some other objects
  - ***Not*** shared among objects

  e.g., Each workstation has its own CPU, monitor, and keyword. All workstations share the same network.



# Expanded Class: Programming (2)

```
class KEYBOARD ... end class CPU ... end
class MONITOR ... end class NETWORK ... end
class WORKSTATION
  k: expanded KEYBOARD
  c: expanded CPU
  m: expanded MONITOR
  n: NETWORK
end
```

Alternatively:

```
expanded class KEYBOARD ... end
expanded class CPU ... end
expanded class MONITOR ... end
class NETWORK ... end
class WORKSTATION
  k: KEYBOARD
  c: CPU
  m: MONITOR
  n: NETWORK
end
```

# Expanded Class: Programming (3)

```
expanded class
  B
feature
  change_i (ni: INTEGER)
    do
      i := ni
    end
feature
  i: INTEGER
end
```

```
1  test_expanded: BOOLEAN
2   local
3     eb1, eb2: B
4   do
5     Result := eb1.i = 0 and eb2.i = 0
6     check Result end
7     Result := eb1 = eb2
8     check Result end
9     eb2.change_i (15)
10    Result := eb1.i = 0 and eb2.i = 15
11    check Result end
12    Result := eb1 /= eb2
13    check Result end
14  end
```

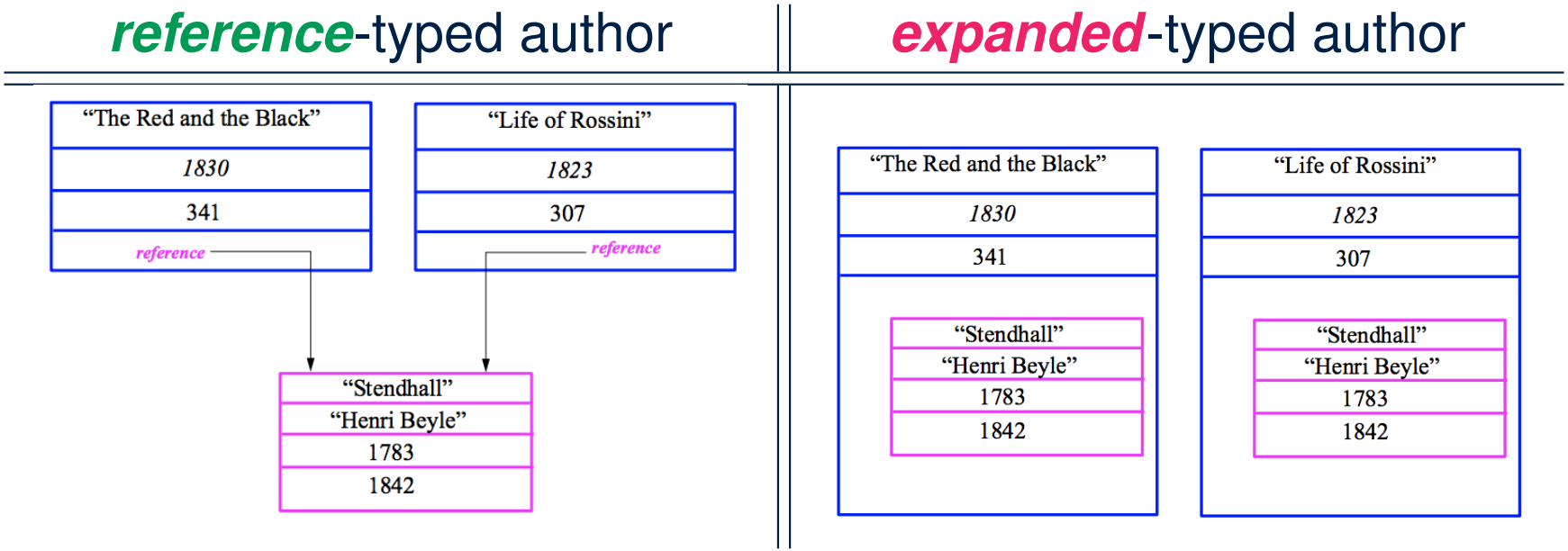
- **L5**: object of expanded type is automatically initialized.
- **L9 & L10**: no sharing among objects of expanded type.
- **L7 & L12**: = between expanded objects compare their contents.

# Reference vs. Expanded (1)

- Every entity must be declared to be of a certain type (based on a class).
- Every type is either ***referenced*** or ***expanded***.
- In ***reference*** types:
  - `y` denotes ***a reference*** to some object
  - `x := y` attaches `x` to same object as does `y`
  - `x = y` compares references
- In ***expanded*** types:
  - `y` denotes ***some object*** (of expanded type)
  - `x := y` copies contents of `y` into `x`
  - `x = y` compares contents `[x ~ y]`

# Reference vs. Expanded (2)

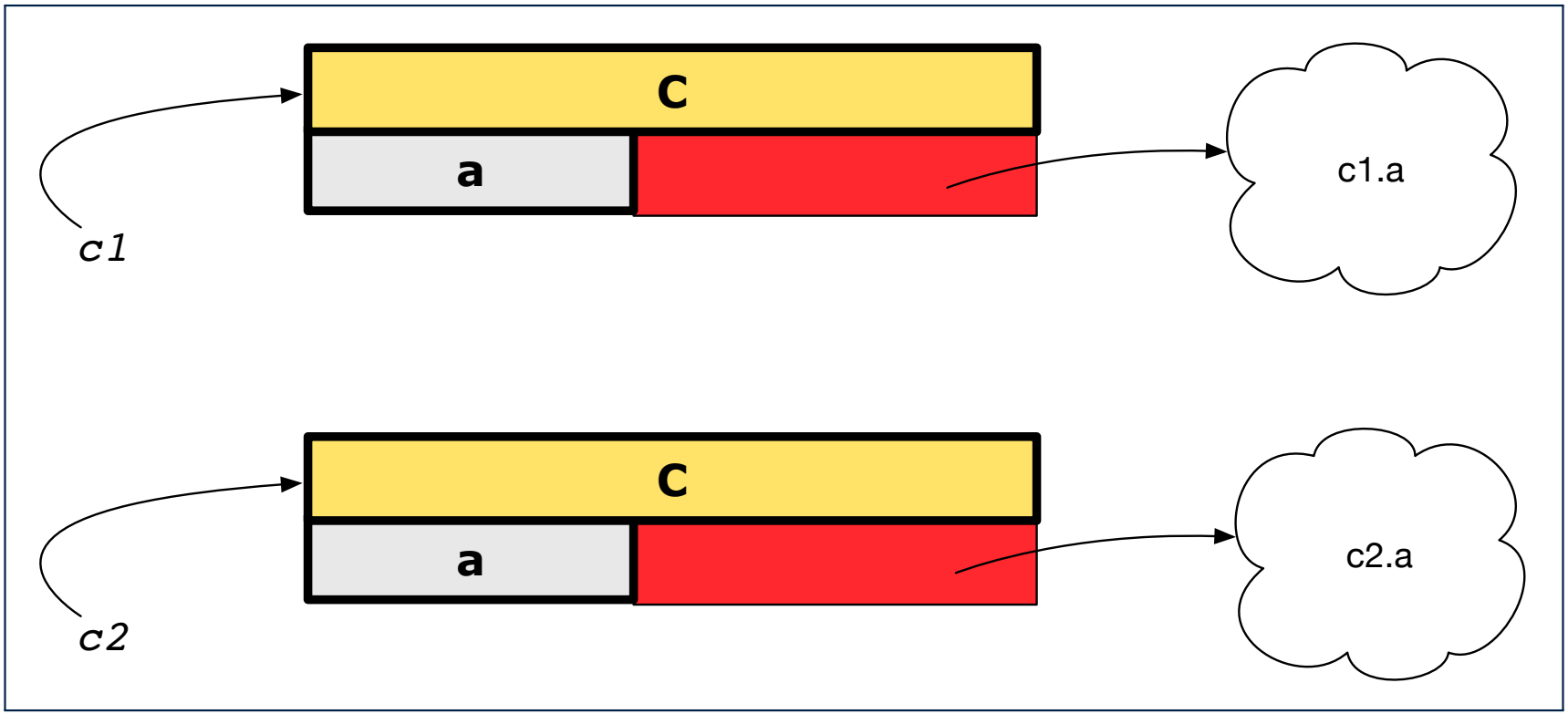
**Problem**: Every published book has an author. Every author may publish more than one books. Should the author field of a book ***reference***-typed or ***expanded***-typed?



# Copying Objects

Say variables `c1` and `c2` are both declared of type `C`. [ *c1, c2: C* ]

- There is only one attribute `a` declared in class `C`.
- `c1.a` and `c2.a` may be of either:
  - ***expanded*** type or
  - ***reference*** type

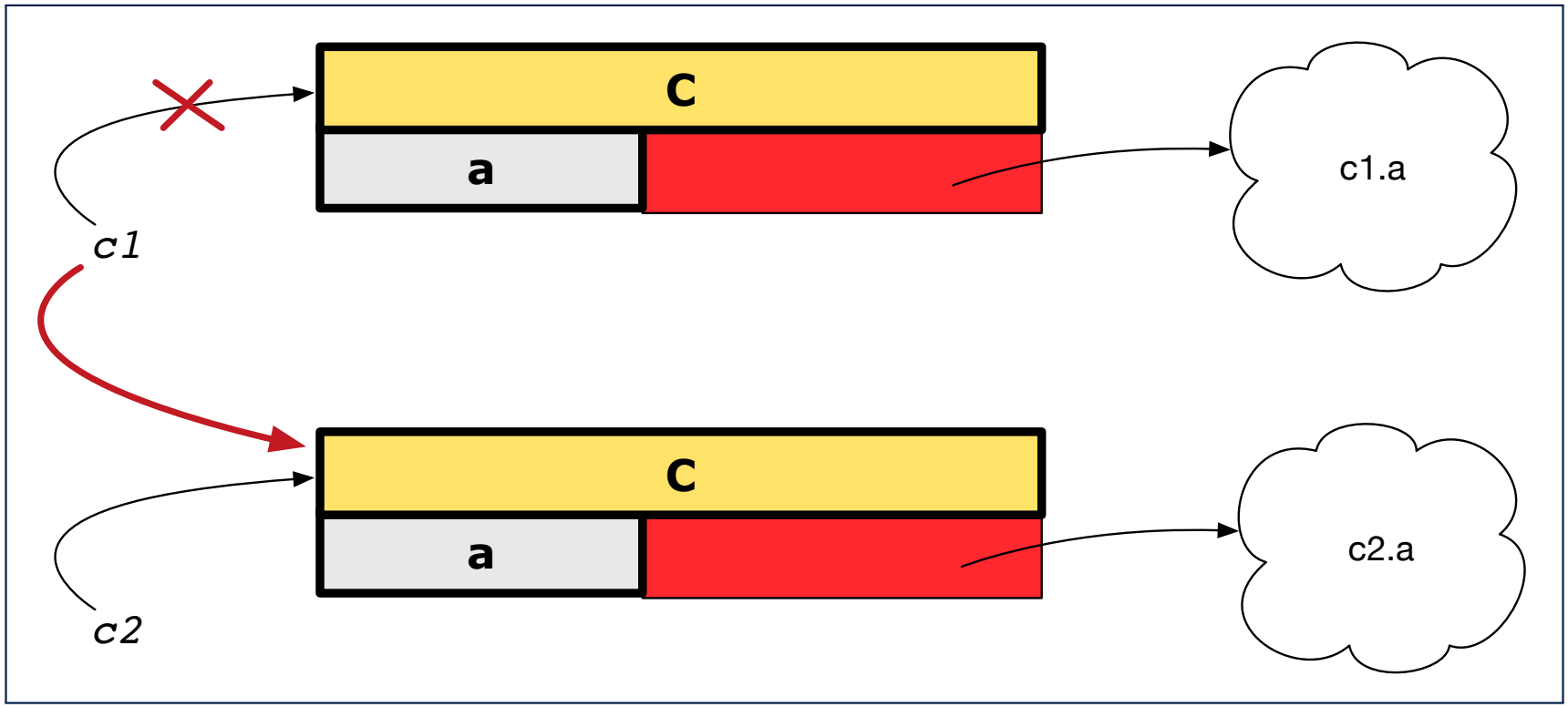


# Copying Objects: Reference Copy

*Reference Copy*

`c1 := c2`

- Copy the address stored in variable `c2` and store it in `c1`.
  ⇒ Both `c1` and `c2` point to the same object.
  ⇒ Updates performed via `c1` also visible to `c2`. [ ***aliasing*** ]



# Copying Objects: Shallow Copy

## *Shallow Copy*

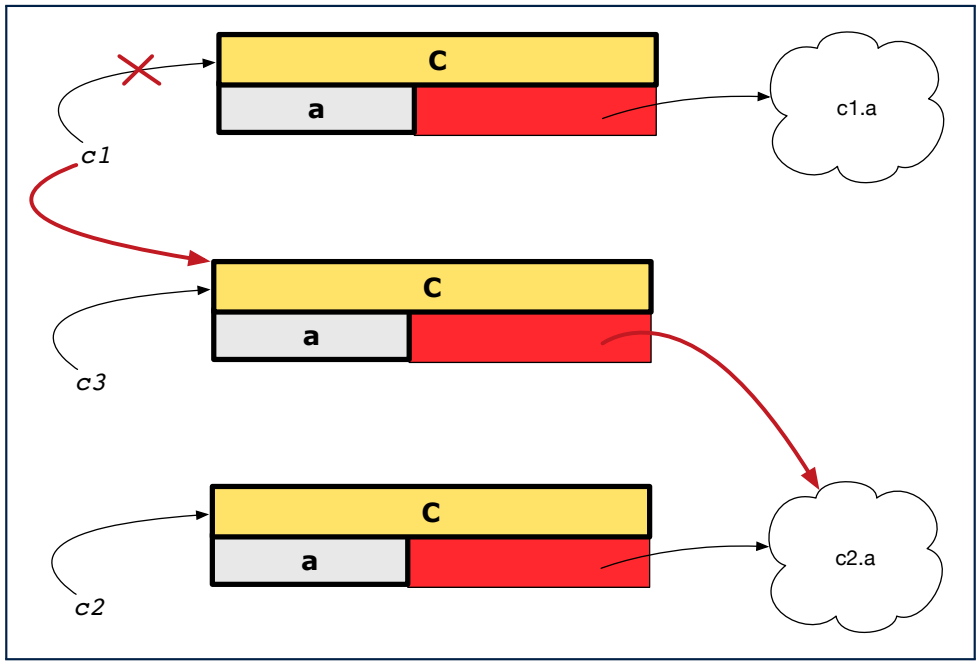
`c1 := c2.twin`

- Create a temporary, behind-the-scene object `c3` of type `C`.
- Initialize each attribute `a` of `c3` via ***reference copy***: `c3.a := c2.a`
- Make a ***reference copy*** of `c3`: `c1 := c3`

  ⇒ `c1` and `c2` ***are not*** pointing to the same object. [ `c1 /= c2` ]

  ⇒ `c1.a` and `c2.a` ***are*** pointing to the same object.

  ⇒ ***Aliasing*** still occurs: at 1st level (i.e., attributes of `c1` and `c2`)



# Copying Objects: Deep Copy

*Deep Copy*

`c1 := c2.deep_twin`

- Create a temporary, behind-the-scene object `c3` of type `C`.
- *Recursively* initialize each attribute `a` of `c3` as follows:

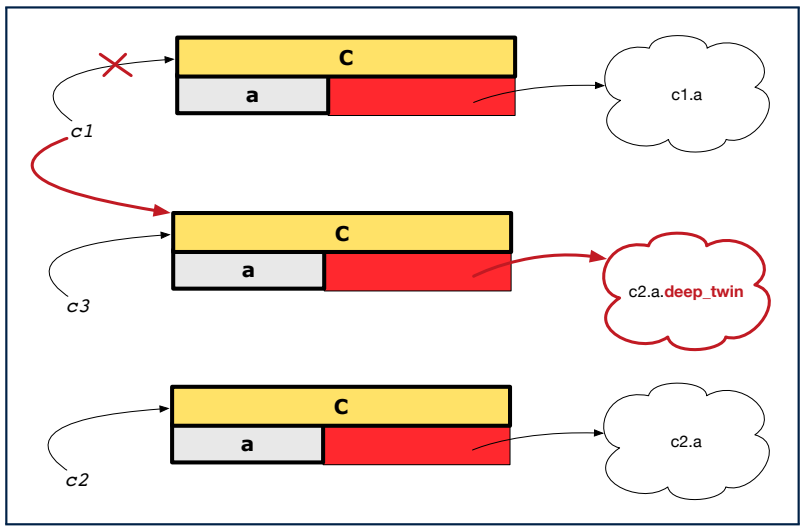
  **Base Case**: `a` is expanded (e.g., `INTEGER`). ⇒ `c3.a := c2.a`.

  **Recursive Case**: `a` is referenced. ⇒ `c3.a := c2.a.deep_twin`
- Make a ***reference copy*** of `c3`: `c1 := c3`

  ⇒ `c1` and `c2` ***are not*** pointing to the same object.

  ⇒ `c1.a` and `c2.a` ***are not*** pointing to the same object.

  ⇒ ***No aliasing*** occurs at any levels.



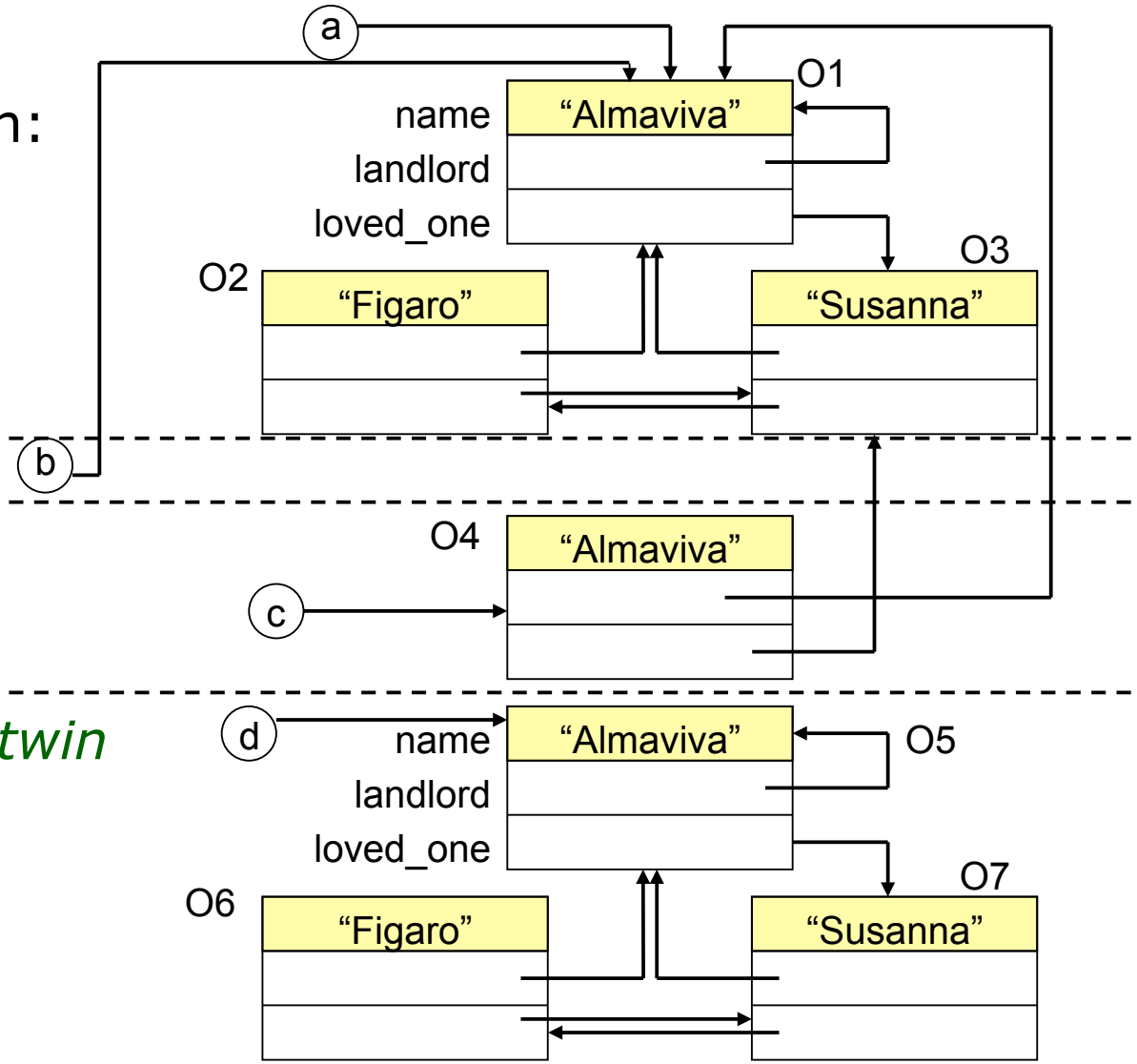
# Copying Objects

- Initial situation:
- Result of:

*b* := *a*

*c* := *a.twin*

*d* := *a.deep_twin*



# Example: Collection Objects (1)

- In any OOPL, when a variable is declared of a ***type*** that corresponds to a ***known class*** (e.g., `STRING`, `ARRAY`, `LINKED_LIST`, etc.):

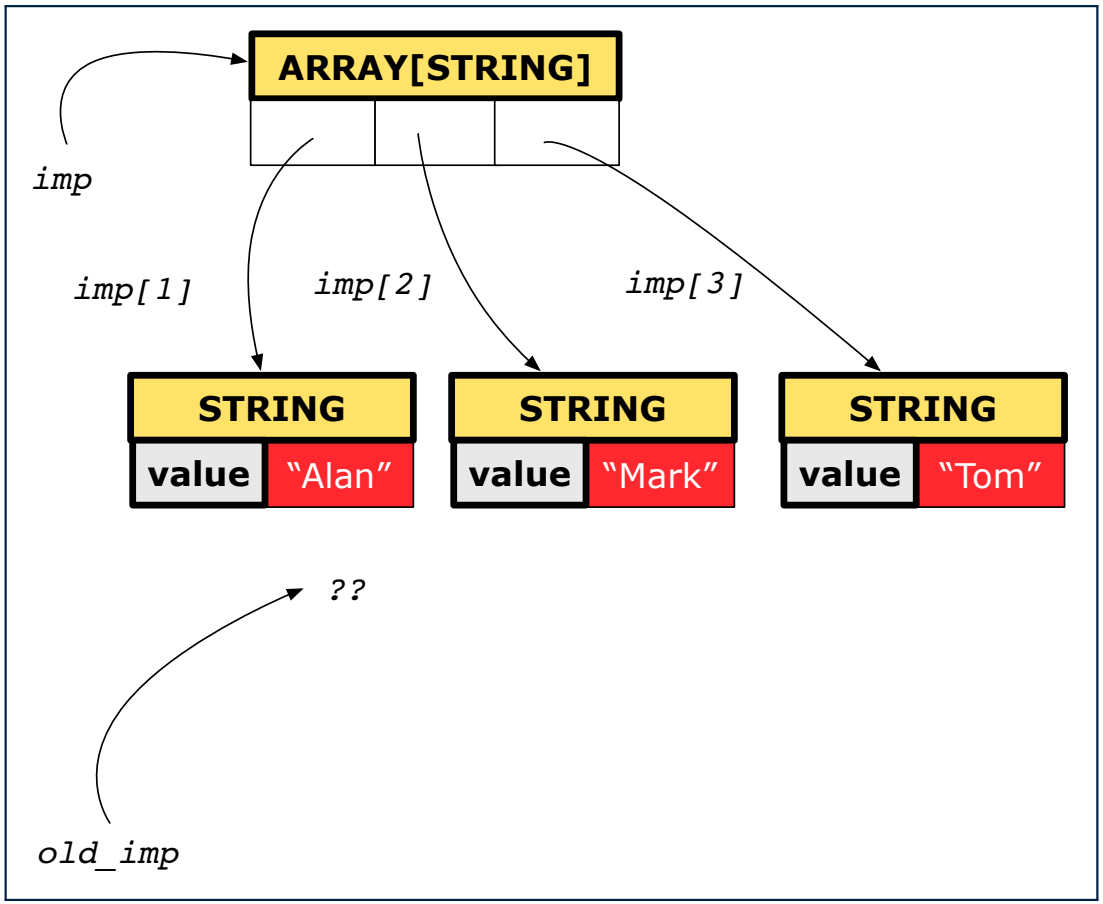
  At *runtime*, that variable stores the *address* of an object of that type (as opposed to storing the object in its entirety).

- Assume the following variables of the same type:

```
...
local
  imp : ARRAY[STRING]
  old_imp: ARRAY[STRING]
do
  create {ARRAY[STRING]} imp.make_empty
  imp.force("Alan", 1)
  imp.force("Mark", 2)
  imp.force("Tom", 3)
  ...
```

# Example: Collection Objects (2)

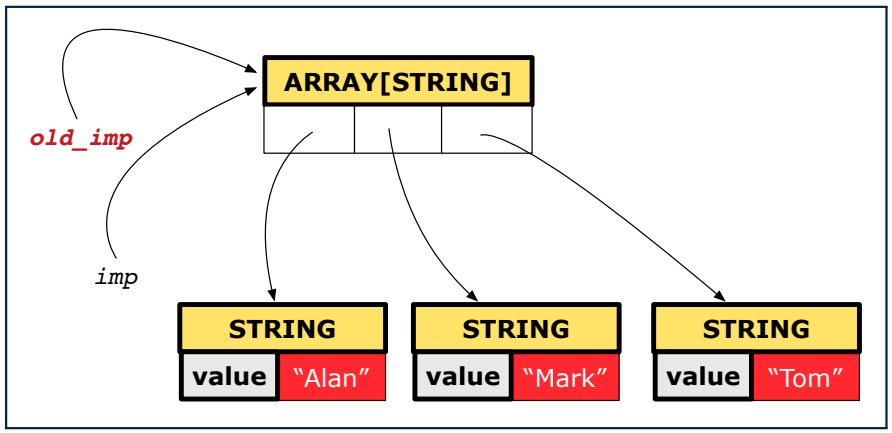
- Variables `imp` and `old_imp` store address(es) of some array(s).
- Each "slot" of these arrays stores a `STRING` object's address.



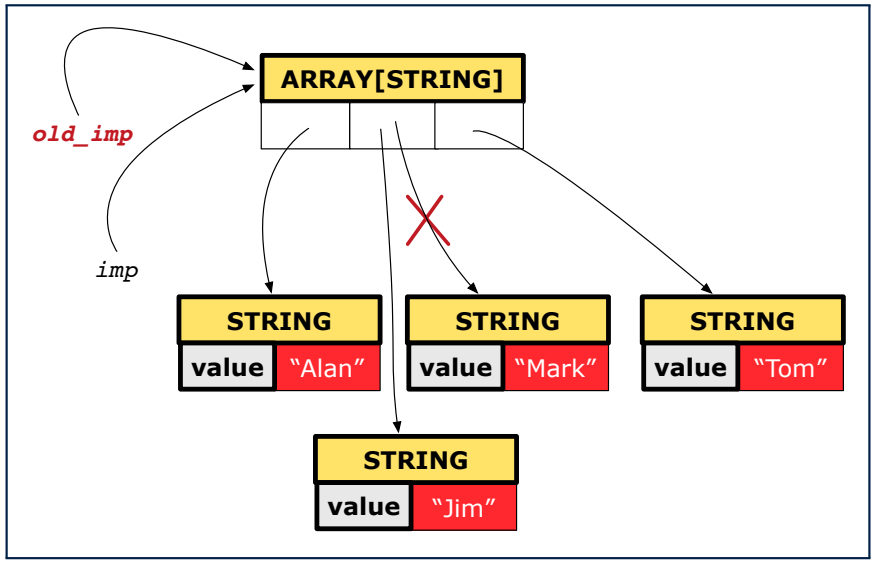
# Reference Copy of Collection Object

```
1  old_imp := imp
2  Result := old_imp = imp   -- Result = true
3  imp[2] := "Jim"
4  Result :=
5    across 1 |..| imp.count as j
6    all imp [j.item] ~ old_imp [j.item]
7    end -- Result = true
```

## Before Executing L3



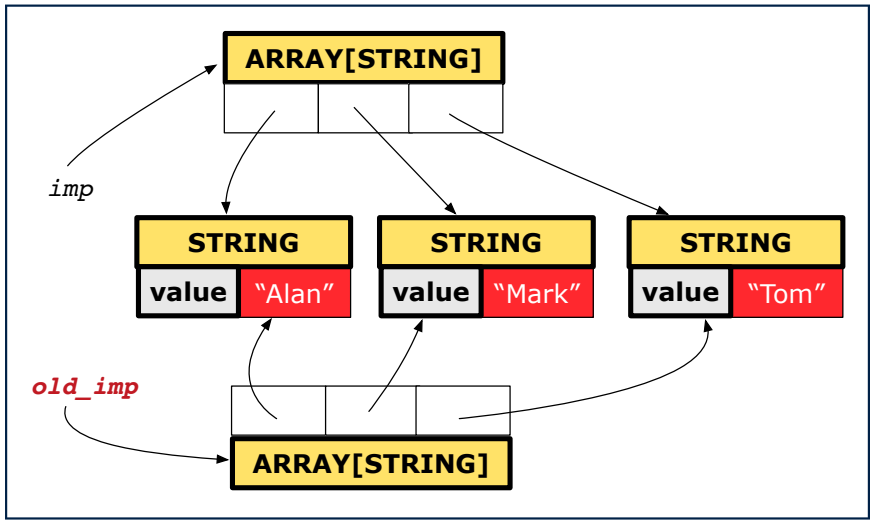

## After Executing L3



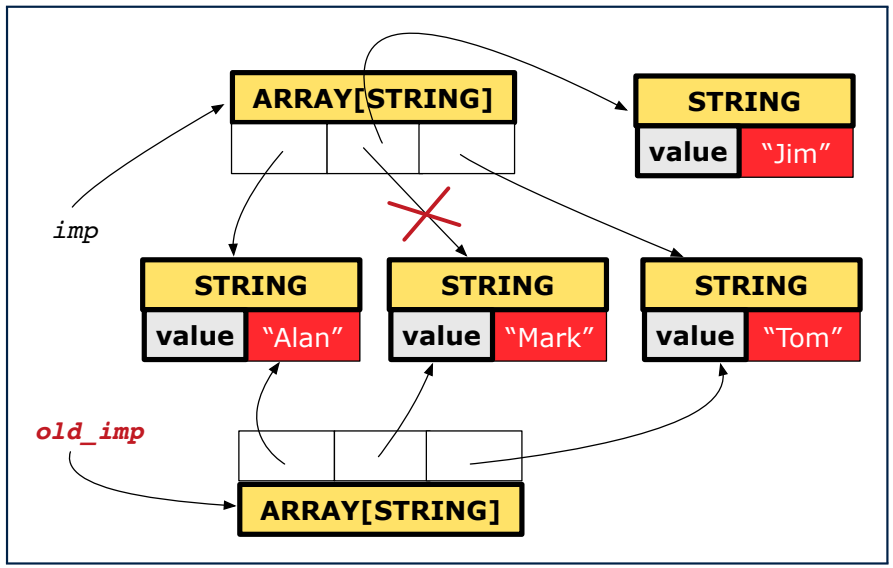
# Shallow Copy of Collection Object (1)

```
1  old_imp := imp.twin
2  Result := old_imp = imp   -- Result = false
3  imp[2] := "Jim"
4  Result :=
5    across 1 |..| imp.count as j
6    all imp [j.item] ~ old_imp [j.item]
7    end -- Result = false
```

## Before Executing L3



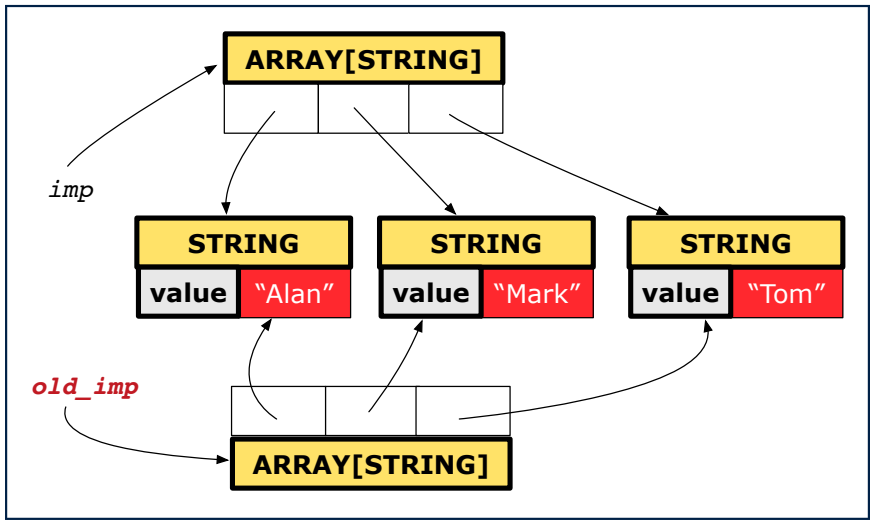

## After Executing L3



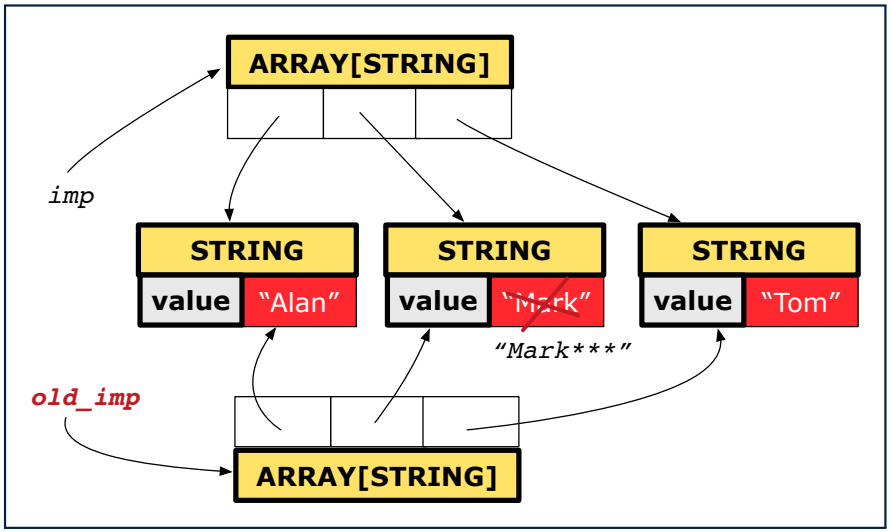
# Shallow Copy of Collection Object (2)

```
1  old_imp := imp.twin
2  Result := old_imp = imp   -- Result = false
3  imp[2].append ("***")
4  Result :=
5    across 1 |..| imp.count as j
6    all imp [j.item] ~ old_imp [j.item]
7    end -- Result = true
```

## Before Executing L3



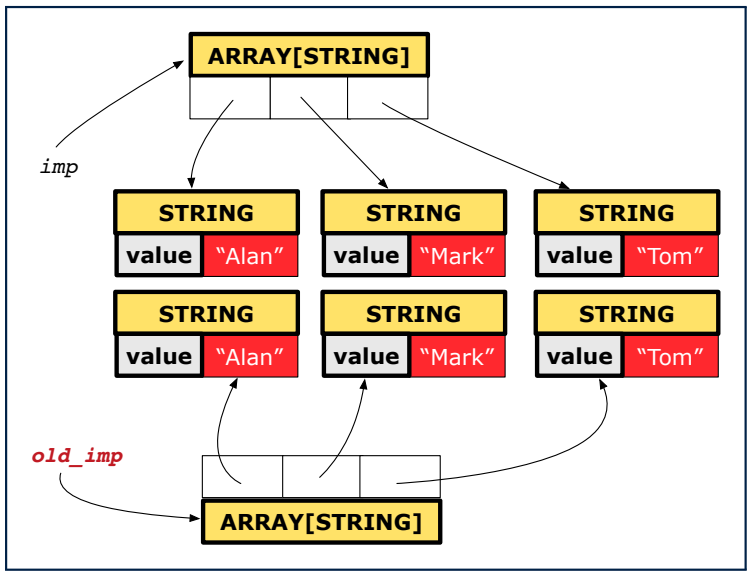

## After Executing L3



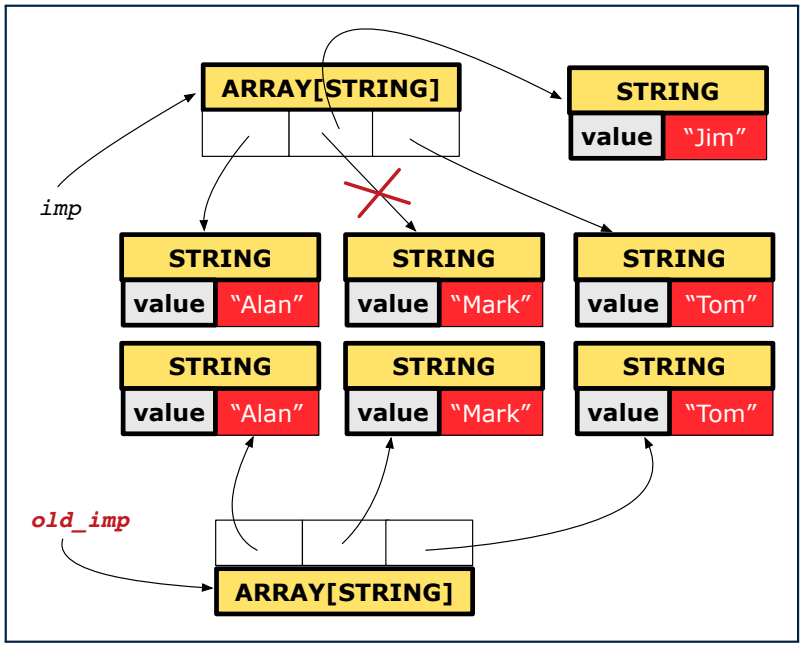
# Deep Copy of Collection Object (1)

```
1  old_imp := imp.deep_twin
2  Result := old_imp = imp   -- Result = false
3  imp[2] := "Jim"
4  Result :=
5    across 1 |..| imp.count as j
6    all imp [j.item] ~ old_imp [j.item] end -- Result = false
```

## Before Executing L3



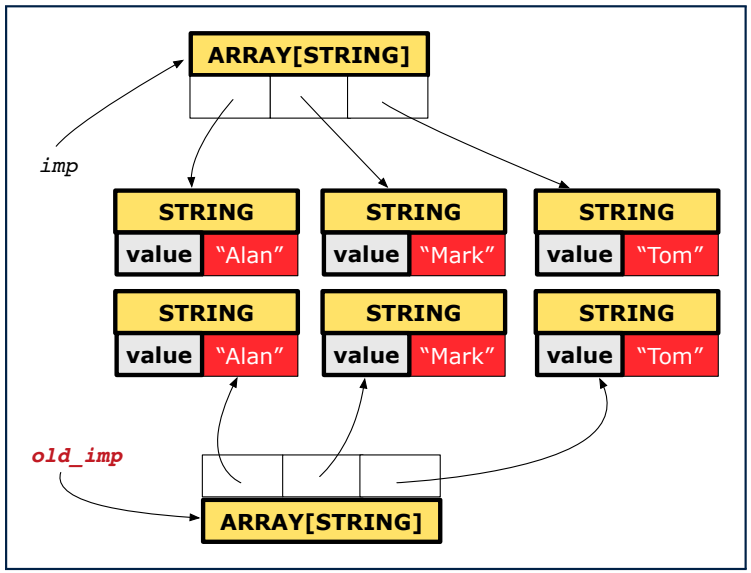

## After Executing L3



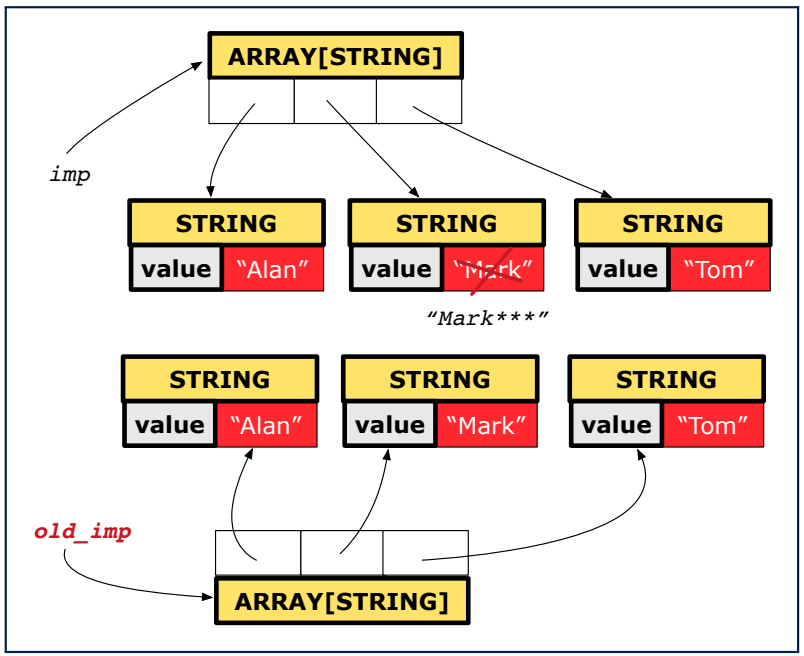
# Deep Copy of Collection Object (2)

```
1  old_imp := imp.deep_twin
2  Result := old_imp = imp   -- Result = false
3  imp[2].append ("***")
4  Result :=
5    across 1 |..| imp.count as j
6    all imp [j.item] ~ old_imp [j.item] end -- Result = false
```

## Before Executing L3




## After Executing L3



# 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, via :=, of ***old*** *expressions* in the *post-condition*.

| | |
|---|---|
| e.g., **old** *balance* = *balance* – *a* | [ *old_balance* := *balance* ] |
| e.g., **old** *accounts[i].id* | [ *old_accounts_i_id* := *accounts[i].id* ] |
| e.g., (**old** *accounts[i]*).*id* | [ *old_accounts_i* := *accounts[i]* ] |
| e.g., (**old** *accounts*)[*i*].*id* | [ *old_accounts* := *accounts* ] |
| e.g., (**old** *Current*).*accounts*[*i*].*id* | [ *old_current* := *Current* ] |

- 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 -- Attributes
  owner: STRING
  balance: INTEGER

feature -- Commands
  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 -- the input name exists
      existing: across accounts as acc some acc.item.owner ~ n end
        -- not (across accounts as acc all acc.item.owner /~ n end)
    do ...
    ensure Result.owner ~ n
    end
  add (n: STRING)
    require -- the input name does not exist
      non_existing: across accounts as acc all acc.item.owner /~ n end
        -- not (across accounts as acc some 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

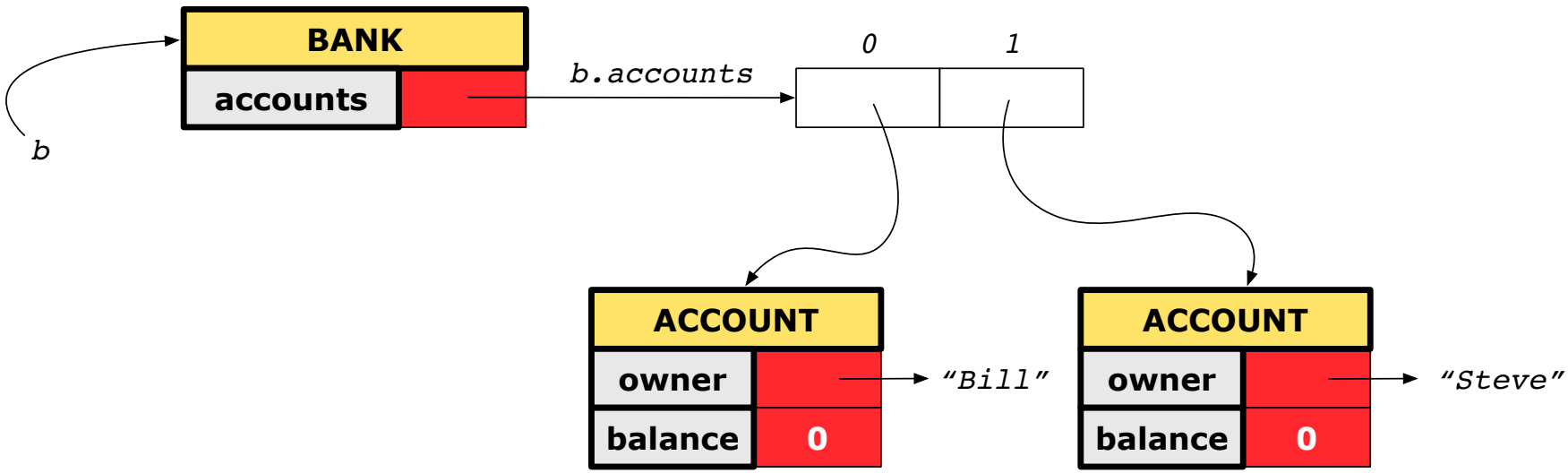
We examine 5 different versions of a command

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

| 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)

# Index (3)