Inheritance

Readings: OOSCS2 Chapters 14 – 16

EECS3311 M: Software Design
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Aspects of Inheritance

- ***Code Reuse***
- Substitutability
  - ***Polymorphism*** and ***Dynamic Binding***
    [compile-time type checks]
  - *Sub-contracting*
    [runtime behaviour checks]

Why Inheritance: A Motivating Example

Problem: A *student management system* stores data about students. There are two kinds of university students: *resident* students and *non-resident* students. Both kinds of students have a *name* and a list of *registered courses*. Both kinds of students are restricted to *register* for no more than 30 courses. When *calculating the tuition* for a student, a base amount is first determined from the list of courses they are currently registered (each course has an associated fee). For a non-resident student, there is a *discount rate* applied to the base amount to waive the fee for on-campus accommodation. For a resident student, there is a *premium rate* applied to the base amount to account for the fee for on-campus accommodation and meals.

Tasks: Design classes that satisfy the above problem statement. At runtime, each type of student must be able to register a course and calculate their tuition fee.

The COURSE Class

```
class
 COURSE

create -- Declare commands that can be used as constructors
 make

feature -- Attributes
 title: STRING
 fee: REAL

feature -- Commands
 make (t: STRING; f: REAL)
    -- Initialize a course with title 't' and fee 'f'.
  do
    title := t
    fee := f
  end
end
```

No Inheritance: RESIDENT_STUDENT Class

```
class RESIDENT_STUDENT
create make
feature -- Attributes
  name: STRING
  courses: LINKED_LIST[COURSE]
  premium_rate: REAL
feature -- Constructor
  make (n: STRING)
    do name := n ; create courses.make end
feature -- Commands
  set_pr (r: REAL) do premium_rate := r end
  register (c: COURSE) do courses.extend (c) end
feature -- Queries
  tuition: REAL
    local base: REAL
    do base := 0.0
       across courses as c loop base := base + c.item.fee end
       Result := base * premium_rate
    end
end
```


No Inheritance: NON_RESIDENT_STUDENT Class

```
class NON_RESIDENT_STUDENT
create make
feature -- Attributes
  name: STRING
  courses: LINKED_LIST[COURSE]
  discount_rate: REAL
feature -- Constructor
  make (n: STRING)
    do name := n ; create courses.make end
feature -- Commands
  set_dr (r: REAL) do discount_rate := r end
  register (c: COURSE) do courses.extend (c) end
feature -- Queries
  tuition: REAL
    local base: REAL
    do base := 0.0
       across courses as c loop base := base + c.item.fee end
       Result := base * discount_rate
    end
end
```


No Inheritance: Testing Student Classes

```
test_students: BOOLEAN
 local
  c1, c2: COURSE
  jim: RESIDENT_STUDENT
  jeremy: NON_RESIDENT_STUDENT
 do
  create c1.make ("EECS2030", 500.0)
  create c2.make ("EECS3311", 500.0)
  create jim.make ("J. Davis")
  jim.set_pr (1.25)
  jim.register (c1)
  jim.register (c2)
  Result := jim.tuition = 1250
  check Result end
  create jeremy.make ("J. Gibbons")
  jeremy.set_dr (0.75)
  jeremy.register (c1)
  jeremy.register (c2)
  Result := jeremy.tuition = 750
 end
```


No Inheritance: Issues with the Student Classes

- Implementations for the two student classes seem to work. But can you see any potential problems with it?
- The code of the two student classes share a lot in common.
- *Duplicates of code make it hard to maintain your software!*
- This means that when there is a change of policy on the common part, we need modify *more than one places*.

  ⇒ This violates the *Single Choice Principle*:

  when a ***change*** is needed, there should be ***a single place*** (or ***a minimal number of places***) where you need to make that change.

No Inheritance: Maintainability of Code (1)

What if a ***new*** way for course registration is to be implemented?

e.g.,

```
register(Course c)
  do
    if courses.count >= MAX_CAPACITY then
      -- Error: maximum capacity reached.
    else
      courses.extend (c)
    end
  end
```

We need to change the `register` commands in ***both*** student classes!

⇒ ***Violation*** of the *Single Choice Principle*

No Inheritance: Maintainability of Code (2)

What if a ***new*** way for base tuition calculation is to be implemented?

e.g.,

```
tuition: REAL
    local base: REAL
  do base := 0.0
     across courses as c loop base := base + c.item.fee end
     Result := base * inflation_rate * ...
  end
```

We need to change the `tuition` query in ***both*** student classes.

⇒ ***Violation*** of the *Single Choice Principle*

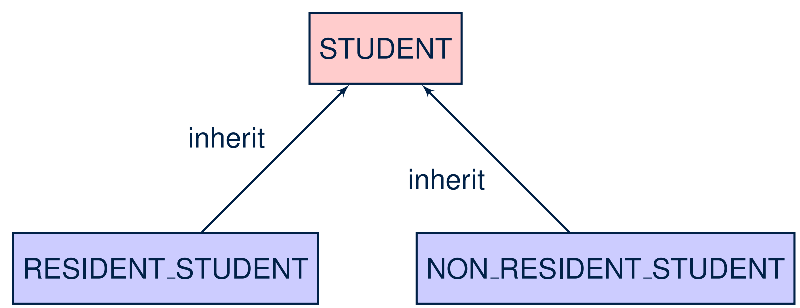
No Inheritance: A Collection of Various Kinds of Students

How do you define a class `StudentManagementSystem` that contains a list of *resident* and *non-resident* students?

```
class STUDENT_MANAGEMENT_SYSETM
  rs : LINKED_LIST[RESIDENT_STUDENT]
  nrs : LINKED_LIST[NON_RESIDENT_STUDENT]
  add_rs (rs: RESIDENT_STUDENT) do ... end
  add_nrs (nrs: NON_RESIDENT_STUDENT) do ... end
  register_all (Course c) -- Register a common course 'c'.
    do
      across rs as c loop c.item.register (c) end
      across nrs as c loop c.item.register (c) end
    end
end
```

But what if we later on introduce *more kinds of students*?
Inconvenient to handle each list of students, in pretty much the ***same*** manner, *separately*!

Inheritance Architecture



Inheritance: The `STUDENT` Parent Class

```
class STUDENT
create make
feature -- Attributes
  name: STRING
  courses: LINKED_LIST[COURSE]
feature -- Commands that can be used as constructors.
  make (n: STRING) do name := n ; create courses.make end
feature -- Commands
  register (c: COURSE) do courses.extend (c) end
feature -- Queries
  tuition: REAL
    local base: REAL
    do base := 0.0
       across courses as c loop base := base + c.item.fee end
       Result := base
    end
end
```


Inheritance: The `RESIDENT_STUDENT` Child Class

```
1  class
2    RESIDENT_STUDENT
3  inherit
4    STUDENT
5      redefine tuition end
6  create make
7  feature -- Attributes
8    premium_rate : REAL
9  feature -- Commands
10   set_pr (r: REAL) do premium_rate := r end
11 feature -- Queries
12   tuition: REAL
13     local base: REAL
14     do base := Precursor ; Result := base * premium_rate end
15 end
```

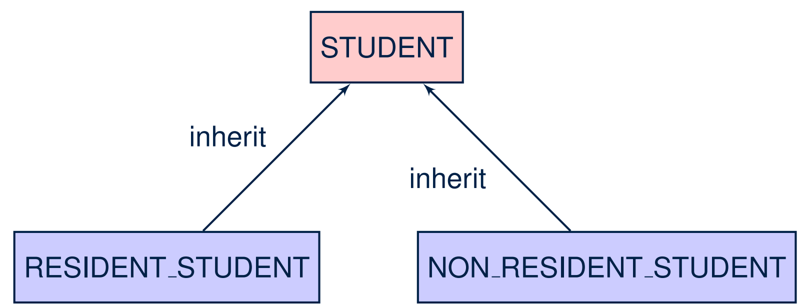
- **L3**: `RESIDENT_STUDENT` inherits all features from `STUDENT`.
- There is no need to repeat the `register` command
- **L14**: *Precursor* returns the value from query `tuition` in `STUDENT`.

Inheritance: The `NON_RESIDENT_STUDENT` Child Class

```
1  class
2    NON_RESIDENT_STUDENT
3  inherit
4    STUDENT
5      redefine tuition end
6  create make
7  feature -- Attributes
8    discount_rate : REAL
9  feature -- Commands
10   set_dr (r: REAL) do discount_rate := r end
11 feature -- Queries
12   tuition: REAL
13     local base: REAL
14     do base := Precursor ; Result := base * discount_rate end
15 end
```

- **L3**: `NON_RESIDENT_STUDENT` inherits all features from `STUDENT`.
- There is no need to repeat the `register` command
- **L14**: *Precursor* returns the value from query `tuition` in `STUDENT`.

Inheritance Architecture Revisited



- The class that defines the common features (attributes, commands, queries) is called the *parent*, *super*, or *ancestor* class.
- Each "specialized" class is called a *child*, *sub*, or *descendent* class.

Using Inheritance for Code Reuse

Inheritance in Eiffel (or any OOP language) allows you to:

- Factor out *common features* (attributes, commands, queries) in a separate class.
  e.g., the `STUDENT` class
- Define an "specialized" version of the class which:
  - *inherits* definitions of all attributes, commands, and queries
    e.g., attributes `name`, `courses`
    e.g., command `register`
    e.g., query on base amount in `tuition`
    This means code reuse and elimination of code duplicates!
  - *defines* **new** features if necessary
    e.g., `set_pr` for `RESIDENT_STUDENT`
    e.g., `set_dr` for `NON_RESIDENT_STUDENT`
  - *redefines* features if necessary
    e.g., compounded tuition for `RESIDENT_STUDENT`
    e.g., discounted tuition for `NON_RESIDENT_STUDENT`

Testing the Two Student Sub-Classes

```
test_students: BOOLEAN
 local
  c1, c2: COURSE
  jim: RESIDENT_STUDENT ; jeremy: NON_RESIDENT_STUDENT
 do
  create c1.make ("EECS2030", 500.0); create c2.make ("EECS3311", 500.0)
  create jim.make ("J. Davis")
  jim.set_pr (1.25) ; jim.register (c1); jim.register (c2)
  Result := jim.tuition = 1250
  check Result end
  create jeremy.make ("J. Gibbons")
  jeremy.set_dr (0.75); jeremy.register (c1); jeremy.register (c2)
  Result := jeremy.tuition = 750
 end
```

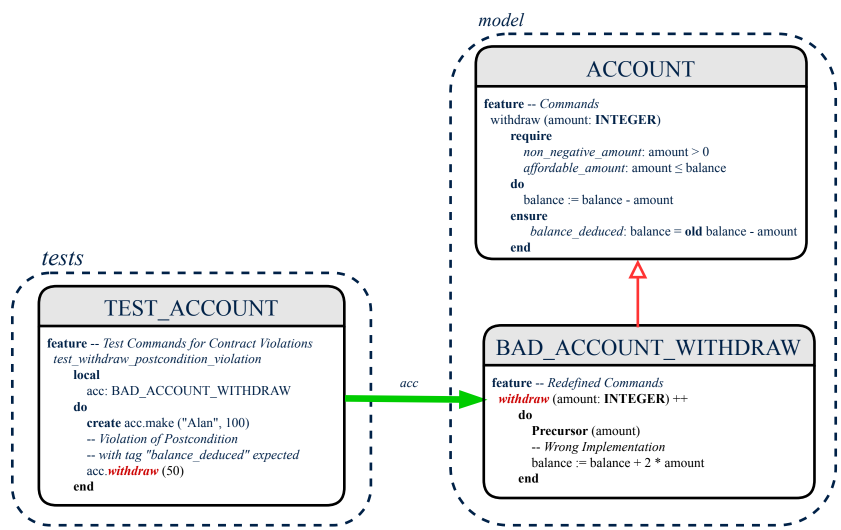
- The software can be used in exactly the same way as before (because we did not modify *feature signatures*).
- But now the internal structure of code has been made *maintainable* using *inheritance*.

DbC: Contract View of Supplier

Any potential **client** who is interested in learning about the kind of services provided by a **supplier** can look through the *contract view* (without showing any implementation details):

```
class ACCOUNT
create
        make
feature -- Attributes
        owner : STRING
        balance : INTEGER
feature -- Constructors
        make(nn: STRING; nb: INTEGER)
                require -- precondition
                        positive_balance: nb > 0
                end
feature -- Commands
        withdraw(amount: INTEGER)
                require -- precondition
                        non_negative_amount: amount > 0
                        affordable_amount: amount <= balance -- problematic, why?
                ensure -- postcondition
                        balance_deducted: balance = old balance - amount
                end
invariant -- class invariant
        positive_balance: balance > 0
end
```


ES_TEST: Expecting to Fail Postcondition (1)



ES_TEST: Expecting to Fail Postcondition (2.1)

```
1  class
2    BAD_ACCOUNT_WITHDRAW
3  inherit
4    ACCOUNT
5      redefine withdraw end
6  create
7    make
8  feature -- redefined commands
9    withdraw(amount: INTEGER)
10     do
11       Precursor(amount)
12       -- Wrong implementation
13       balance := balance + 2 * amount
14     end
15 end
```

- **L3–5**: BAD_ACCOUNT_WITHDRAW.withdraw inherits postcondition from ACCOUNT.withdraw: balance = **old** balance - amount.
- **L11** calls *correct* implementation from parent class ACCOUNT.
- **L13** makes overall implementation *incorrect*.

ES_TEST: Expecting to Fail Postcondition (2.2)

```
class TEST_ACCOUNT
inherit ES_TEST
create make
feature -- Constructor for adding tests
  make
    do
      add_violation_case_with_tag ("balance_deducted",
        agent test_withdraw_postcondition_violation)
    end
feature -- Test commands (test to fail)
  test_withdraw_postcondition_violation
    local
      acc: BAD_ACCOUNT_WITHDRAW
    do
      comment ("test: expected postcondition violation of withdraw")
      create acc.make ("Alan", 100)
      -- Postcondition Violation with tag "balance_deduced" to occur.
      acc.withdraw (50)
    end
end
```


Exercise

Recall from the "Writing Complete Postconditions" lecture:

```
class BANK
  deposit_on_v5 (n: STRING; a: INTEGER)
    do ... -- Put Correct Implementation Here.
    ensure
      ...
      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
```

How do you create a "bad" descendant of BANK that violates this postcondition?

```
class BAD_BANK_DEPOSIT
inherit BANK redefine deposit end
feature -- redefined feature
  deposit_on_v5 (n: STRING; a: INTEGER)
    do Precursor (n, a)
      accounts[accounts.lower].deposit(a)
    end
end
```


Static Type vs. Dynamic Type

- In *object orientation*, an entity has two kinds of types:
  - *static type* is declared at compile time [**unchangeable**]
    An entity's ***ST*** determines what features may be called upon it.
  - *dynamic type* is changeable at runtime
- In Java:

```
Student s = new Student("Alan");
Student rs = new ResidentStudent("Mark");
```

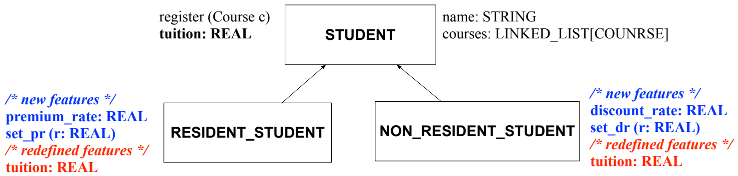
- In Eiffel:

```
local s: STUDENT
      rs: STUDENT
do create {STUDENT} s.make ("Alan")
   create {RESIDENT_STUDENT} rs.make ("Mark")
```

  - In Eiffel, the *dynamic type* can be omitted if it is meant to be the same as the *static type*:

```
local s: STUDENT
do create s.make ("Alan")
```

Inheritance Architecture Revisited




```
s1,s2,s3: STUDENT ; rs: RESIDENT_STUDENT ; nrs : NON_RESIDENT_STUDENT
create {STUDENT} s1.make ("S1")
create {RESIDENT_STUDENT} s2.make ("S2")
create {NON_RESIDENT_STUDENT} s3.make ("S3")
create {RESIDENT_STUDENT} rs.make ("RS")
create {NON_RESIDENT_STUDENT} nrs.make ("NRS")
```

	name	courses	reg	tuition	pr	set_pr	dr	set_dr
s1.	✓				×			
s2.	✓				×			
s3.	✓				×			
rs.	✓				✓		×	
nrs.	✓				×		✓	

Polymorphism: Intuition (1)

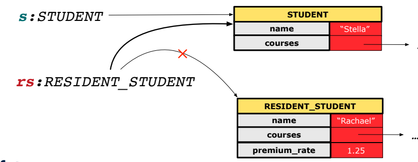
```
1 local
2   s: STUDENT
3   rs: RESIDENT_STUDENT
4 do
5   create s.make ("Stella")
6   create rs.make ("Rachael")
7   rs.set_pr (1.25)
8   s := rs /* Is this valid? */
9   rs := s /* Is this valid? */
```

- Which one of **L8** and **L9** is *valid*? Which one is *invalid*?
  - **L8**: What *kind* of address can **s** store? [STUDENT]
    ∴ The context object **s** is *expected* to be used as:
    - **s**.register(eecs3311) and **s**.tuition
  - **L9**: What *kind* of address can **rs** store? [RESIDENT_STUDENT]
    ∴ The context object **rs** is *expected* to be used as:
    - **rs**.register(eecs3311) and **rs**.tuition
    - **rs**.*set_pr (1.50)* [increase premium rate]

Polymorphism: Intuition (2)

```
1 local s: STUDENT ; rs: RESIDENT_STUDENT
2 do create {STUDENT} s.make ("Stella")
3    create {RESIDENT_STUDENT} rs.make ("Rachael")
4    rs.set_pr (1.25)
5    s := rs /* Is this valid? */
6    rs := s /* Is this valid? */
```

- **rs** := **s** (**L6**) should be *invalid*:

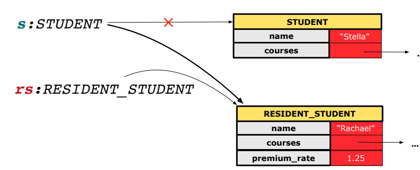


- **rs** declared of type RESIDENT_STUDENT
  ∴ calling **rs**.*set_pr(1.50)* can be expected.
- **rs** is now pointing to a STUDENT object.
- Then, what would happen to **rs**.*set_pr(1.50)*?
  CRASH ∵ **rs**.premium_rate is *undefined*!!

Polymorphism: Intuition (3)

```
1 local s: STUDENT ; rs: RESIDENT_STUDENT
2 do create {STUDENT} s.make ("Stella")
3    create {RESIDENT_STUDENT} rs.make ("Rachael")
4    rs.set_pr (1.25)
5    s := rs /* Is this valid? */
6    rs := s /* Is this valid? */
```

- **s** := **rs** (**L5**) should be *valid*:

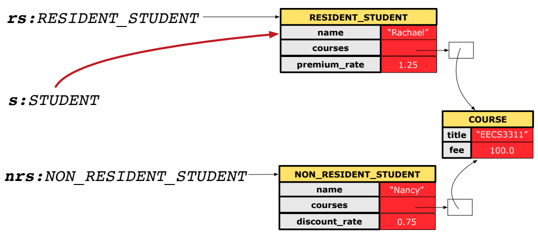


- Since **s** is declared of type STUDENT, a subsequent call **s**.*set_pr(1.50)* is *never* expected.
- **s** is now pointing to a RESIDENT_STUDENT object.
- Then, what would happen to **s**.*tuition*?
  OK ∵ **s**.premium_rate is just *never used*!!

Dynamic Binding: Intuition (1)

```
1 local c : COURSE ; s : STUDENT
2 do crate c.make ("EECS3311", 100.0)
3    create {RESIDENT_STUDENT} rs.make("Rachael")
4    create {NON_RESIDENT_STUDENT} nrs.make("Nancy")
5    rs.set_pr(1.25); rs.register(c)
6    nrs.set_dr(0.75); nrs.register(c)
7    s := rs; ; check s .tuition = 125.0 end
8    s := nrs; ; check s .tuition = 75.0 end
```

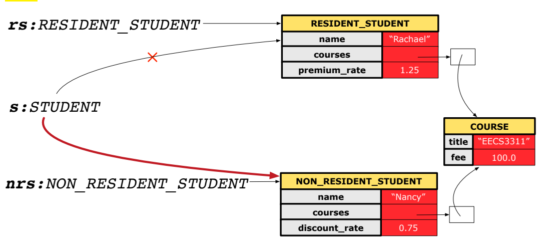
After s := rs (**L7**), s points to a RESIDENT_STUDENT object.
⇒ Calling s .tuition applies the premium_rate.



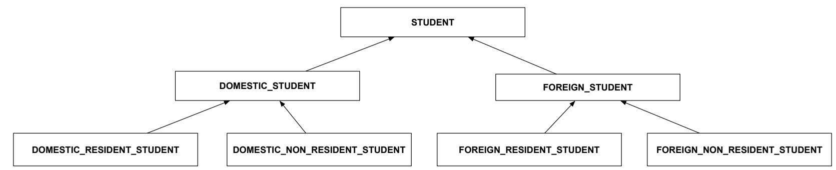
Dynamic Binding: Intuition (2)

```
1 local c : COURSE ; s : STUDENT
2 do crate c.make ("EECS3311", 100.0)
3    create {RESIDENT_STUDENT} rs.make("Rachael")
4    create {NON_RESIDENT_STUDENT} nrs.make("Nancy")
5    rs.set_pr(1.25); rs.register(c)
6    nrs.set_dr(0.75); nrs.register(c)
7    s := rs; ; check s .tuition = 125.0 end
8    s := nrs; ; check s .tuition = 75.0 end
```

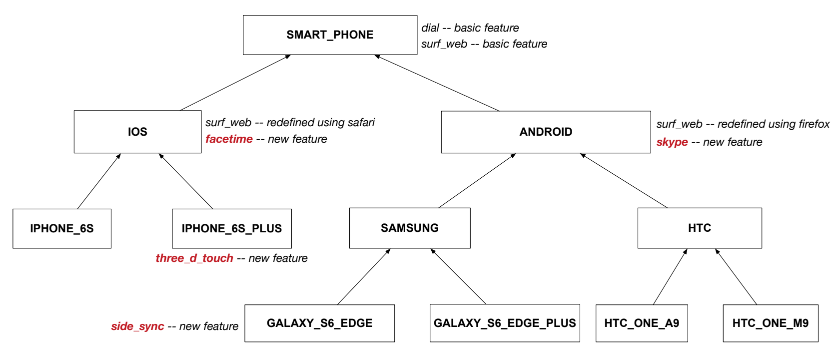
After s:=nrs (**L8**), s points to a NON_RESIDENT_STUDENT object.
⇒ Calling s .tuition applies the discount_rate.



Multi-Level Inheritance Architecture (1)



Multi-Level Inheritance Architecture (2)



Inheritance Forms a Type Hierarchy

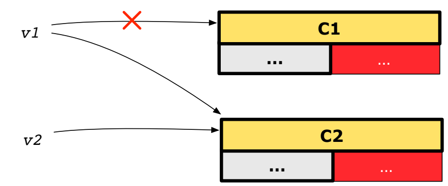
- A (data) **type** denotes a set of related *runtime values*.
  - Every *class* can be used as a type: the set of runtime *objects*.
- Use of *inheritance* creates a **hierarchy** of classes:
  - (Implicit) Root of the hierarchy is `ANY`.
  - Each `inherit` declaration corresponds to an upward arrow.
  - The `inherit` relationship is *transitive*: when `A` inherits `B` and `B` inherits C, we say `A` *indirectly* inherits `C`.
    e.g., Every class implicitly `inherits` the `ANY` class.
- *Ancestor* vs. *Descendant* classes:
  - The **ancestor classes** of a class `A` are: `A` itself and all classes that `A` directly, or indirectly, inherits.
    - `A` inherits all features from its *ancestor classes*.
      ∴ `A`'s instances have a ***wider range of expected usages*** (i.e., attributes, queries, commands) than instances of its *ancestor* classes.
  - The **descendant classes** of a class `A` are: `A` itself and all classes that directly, or indirectly, inherits `A`.
    - Code defined in `A` is inherited to all its *descendant classes*.

Inheritance Accumulates Code for Reuse

- The *lower* a class is in the type hierarchy, the *more code* it accumulates from its *ancestor classes*:
  - A *descendant class* inherits all code from its *ancestor classes*.
  - A *descendant class* may also:
    - Declare new attributes.
    - Define new queries or commands.
    - **Redefine** inherited queries or commands.
- Consequently:
  - When being used as **context objects**, instances of a class' *descendant classes* have a ***wider range of expected usages*** (i.e., attributes, commands, queries).
  - When expecting an object of a particular class, we may **substitute** it with an object of any of its *descendant classes*.
  - e.g., When expecting a `STUDENT` object, substitute it with either a `RESIDENT_STUDENT` or a `NON_RESIDENT_STUDENT` object.
  - **Justification**: A *descendant class* contains **at least as many** features as defined in its *ancestor classes* (but ***not vice versa***!).

Substitutions via Assignments

- By declaring `v1:C1`, *reference variable* `v1` will store the *address* of an object of class `C1` at runtime.
- By declaring `v2:C2`, *reference variable* `v2` will store the *address* of an object of class `C2` at runtime.
- Assignment `v1:=v2` *copies the address* stored in `v2` into `v1`.
  - `v1` will instead point to wherever `v2` is pointing to. [**object alias**]



- In such assignment `v1:=v2`, we say that we **substitute** an object of type `C1` with an object of type `C2`.
- **Substitutions** are subject to *rules*!

Rules of Substitution

Given an inheritance hierarchy:

1. When expecting an object of class `A`, it is *safe* to **substitute** it with an object of any **descendant class** of `A` (including `A`).
   - e.g., When expecting an `IOS` phone, you *can* substitute it with either an `IPhone6s` or `IPhone6sPlus`.
   - ∵ Each **descendant class** of `A` is guaranteed to contain all code of (non-private) attributes, commands, and queries defined in `A`.
   - ∴ All features defined in `A` are *guaranteed to be available* in the new substitute.
2. When expecting an object of class `A`, it is *unsafe* to **substitute** it with an object of any **ancestor class of `A`'s parent**.
   - e.g., When expecting an `IOS` phone, you *cannot* substitute it with just a `SmartPhone`, because the `facetime` feature is not supported in an `Android` phone.
   - ∵ Class `A` may have defined new features that do not exist in any of its **parent's ancestor classes**.

Reference Variable: Static Type

- A *reference variable*'s **static type** is what we declare it to be.
  - e.g., `jim:STUDENT` declares `jim`'s static type as `STUDENT`.
  - e.g., `my_phone:SMART_PHONE` declares a variable `my_phone` of static type `SmartPhone`.
  - The *static type* of a *reference variable never changes*.
- For a *reference variable v*, its *static type* `C` defines the *expected usages of v as a context object*.
- A feature call `v.m(...)` is ***compilable*** if ***m*** is defined in `C`.
  - e.g., After declaring `jim:STUDENT`, we
    - **may** call `register` and `tuition` on `jim`
    - **may *not*** call `set_pr` (specific to a resident student) or `set_dr` (specific to a non-resident student) on `jim`
  - e.g., After declaring `my_phone:SMART_PHONE`, we
    - **may** call `dial` and `surf_web` on `my_phone`
    - **may *not*** call `facetime` (specific to an IOS phone) or `skype` (specific to an Android phone) on `my_phone`

Reference Variable: Dynamic Type

A *reference variable*'s *dynamic type* is the type of object that it is currently pointing to at runtime.

- The *dynamic type* of a reference variable *may change* whenever we *re-assign* that variable to a different object.
- There are two ways to re-assigning a reference variable.

Reference Variable: Changing Dynamic Type (1)

Re-assigning a reference variable to a newly-created object:

- *Substitution Principle*: the new object's class must be a *descendant class* of the reference variable's *static type*.
- e.g., Given the declaration `jim:STUDENT`:
  - `create {RESIDENT_STUDENT} jim.make("Jim")` changes the *dynamic type* of `jim` to `RESIDENT_STUDENT`.
  - `create {NON_RESIDENT_STUDENT} jim.make("Jim")` changes the *dynamic type* of `jim` to `NON_RESIDENT_STUDENT`.
- e.g., Given an alternative declaration `jim:RESIDENT_STUDENT`:
  - e.g., `create {STUDENT} jim.make("Jim")` is illegal because `STUDENT` is not a *descendant class* of the *static type* of `jim` (i.e., `RESIDENT_STUDENT`).

Reference Variable: Changing Dynamic Type (2)

Re-assigning a reference variable `v` to an existing object that is referenced by another variable `other` (i.e., `v := other`):

- *Substitution Principle*: the static type of `other` must be a *descendant class* of `v`'s *static type*.
- e.g.,

```
jim: STUDENT ; rs: RESIDENT_STUDENT; nrs: NON_RESIDENT_STUDENT
create {STUDENT} jim.make (...)
create {RESIDENT_STUDENT} rs.make (...)
create {NON_RESIDENT_STUDENT} nrs.make (...)
```

- `rs := jim` ×
- `nrs := jim` ×
- `jim := rs` ✓ changes the *dynamic type* of `jim` to the dynamic type of `rs`
- `jim := nrs` ✓ changes the *dynamic type* of `jim` to the dynamic type of `nrs`

Polymorphism and Dynamic Binding (1)

- *Polymorphism*: An object variable may have *"multiple possible shapes"* (i.e., allowable *dynamic types*).
  - Consequently, there are *multiple possible versions* of each feature that may be called.
    - e.g., 3 possibilities of `tuition` on a ***STUDENT*** reference variable:
      In ***STUDENT***: base amount
      In ***RESIDENT_STUDENT***: base amount with `premium_rate`
      In ***NON_RESIDENT_STUDENT***: base amount with `discount_rate`
- *Dynamic binding*: When a feature `m` is called on an object variable, the version of `m` corresponding to its *"current shape"* (i.e., one defined in the *dynamic type* of *m*) will be called.

```
jim: STUDENT; rs: RESIDENT_STUDENT; nrs: NON_STUDENT
create {RESIDENT_STUDENT} rs.make (...)
create {NON_RESIDENT_STUDENT} nrs.nrs (...)
jim := rs
jim.tuitoion;  /* version in RESIDENT_STUDENT */
jim := nrs
jim.tuition;  /* version in NON_RESIDENT_STUDENT */
```


Polymorphism and Dynamic Binding (2.1)

```
1  test_polymorphism_students
2    local
3      jim: STUDENT
4      rs: RESIDENT_STUDENT
5      nrs: NON_RESIDENT_STUDENT
6    do
7      create {STUDENT} jim.make ("J. Davis")
8      create {RESIDENT_STUDENT} rs.make ("J. Davis")
9      create {NON_RESIDENT_STUDENT} nrs.make ("J. Davis")
10     jim := rs   ✓
11     rs := jim   ×
12     jim := nrs  ✓
13     rs := jim   ×
14   end
```

In (**L3**, **L7**), (**L4**, **L8**), (**L5**, **L9**), ***ST*** = ***DT***, so we may abbreviate:

L7: `create jim.make ("J. Davis")`

L8: `create rs.make ("J. Davis")`

L9: `create nrs.make ("J. Davis")`

Polymorphism and Dynamic Binding (2.2)

```
test_dynamic_binding_students: BOOLEAN
  local
    jim: STUDENT
    rs: RESIDENT_STUDENT
    nrs: NON_RESIDENT_STUDENT
    c: COURSE
  do
    create c.make ("EECS3311", 500.0)
    create {STUDENT} jim.make ("J. Davis")
    create {RESIDENT_STUDENT} rs.make ("J. Davis")
    rs.register (c)
    rs.set_pr (1.5)
    jim := rs
    Result := jim.tuition = 750.0
    check Result end
    create {NON_RESIDENT_STUDENT} nrs.make ("J. Davis")
    nrs.register (c)
    nrs.set_dr (0.5)
    jim := nrs
    Result := jim.tuition = 250.0
end
```


Reference Type Casting: Motivation

```
1 local jim: STUDENT; rs: RESIDENT_STUDENT
2 do create {RESIDENT_STUDENT} jim.make ("J. Davis")
3    rs := jim
4    rs.setPremiumRate(1.5)
```

- **Line 2** is *legal*: *RESIDENT_STUDENT* is a *descendant class* of the static type of `jim` (i.e., *STUDENT*).
- **Line 3** is *illegal*: `jim`'s static type (i.e., *STUDENT*) is ***not*** a *descendant class* of `rs`'s static type (i.e., *RESIDENT_STUDENT*).
- Eiffel compiler is *unable to infer* that `jim`'s *dynamic type* in **Line 4** is *RESIDENT_STUDENT*. [*Undecidable*]
- Force the Eiffel compiler to believe so, by replacing **L3**, **L4** by a *type cast* (which *temporarily* changes the ***ST*** of `jim`):

```
check attached {RESIDENT_STUDENT} jim as rs_jim then
  rs := rs_jim
  rs.set_pr (1.5)
end
```

Reference Type Casting: Syntax

```
1 check attached {RESIDENT_STUDENT} jim as rs_jim then
2   rs := rs_jim
3   rs.set_pr (1.5)
4 end
```

L1 is an assertion:

- `attached RESIDENT_STUDENT jim` is a Boolean expression that is to be evaluated at ***runtime***.
  - If it evaluates to ***true***, then the `as rs_jim` expression has the effect of assigning "the cast version" of `jim` to a new variable `rs_jim`.
  - If it evaluates to ***false***, then a runtime assertion violation occurs.
- *Dynamic Binding*: **Line 4** executes the correct version of `set_pr`.

- It is equivalent to the following Java code:

```
if(jim instanceof ResidentStudent) {
  ResidentStudent rs = (ResidentStudent) jim;
  rs.set_pr(1.5);
}
else { throw new Exception("Cast Not Done."); }
```


Notes on Type Cast (1)

- Given *v* of static type *ST*, it is ***compilable*** to cast *v* to *C*, as long as *C* is a descendant or ancestor class of *ST*.
- Why Cast?
  - Without cast, we can **only** call features defined in *ST* on *v*.
  - By casting *v* to *C*, we *change* the *static type* of *v* from *ST* to *C*.

    ⇒ All features that are defined in *C* can be called.

```
my_phone: IOS
create {IPHONE_6S_PLUS} my_phone.make
-- can only call features defined in IOS on myPhone
-- dial, surf_web, facetime ✓  three_d_touch, skype ×
check attached {SMART_PHONE} my_phone as sp then
  -- can now call features defined in SMART_PHONE on sp
  -- dial, surf_web ✓  facetime, three_d_touch, skype ×
end
check attached {IPHONE_6S_PLUS} my_phone as ip6s_plus then
  -- can now call features defined in IPHONE_6S_PLUS on ip6s_plus
  -- dial, surf_web, facetime, three_d_touch ✓  skype ×
end
```


Notes on Type Cast (2)

- A cast being ***compilable*** is not necessarily ***runtime-error-free***!
- A cast `check attached {C} v as ...` triggers an assertion violation if `C` is ***not*** along the **ancestor path** of `v`'s *DT*.

```
test_smart_phone_type_cast_violation
 local mine: ANDROID
 do create {SAMSUNG} mine.make
   -- ST of mine is ANDROID; DT of mine is SAMSUNG
   check attached {SMART_PHONE} mine as sp then ... end
   -- ST of sp is SMART_PHONE; DT of sp is SAMSUNG
   check attached {SAMSUNG} mine as samsung then ... end
   -- ST of samsung is SAMSNG; DT of samsung is SAMSUNG
   check attached {HTC} mine as htc then ... end
   -- Compiles ∵ HTC is descendant of mine's ST (ANDROID)
   -- Assertion violation
   -- ∵ HTC is not ancestor of mine's DT (SAMSUNG)
   check attached {GALAXY_S6_EDGE} mine as galaxy then ... end
   -- Compiles ∵ GALAXY_S6_EDGE is descendant of mine's ST (ANDROID)
   -- Assertion violation
   -- ∵ GALAXY_S6_EDGE is not ancestor of mine's DT (SAMSUNG)
end
```


Compilable Cast vs. Exception-Free Cast (1)

```
class A end
class B inherit A end
class C inherit B end
class D inherit A end
```

```
1  local b: B ; d: D
2  do
3    create {C} b.make
4    check attached {D} b as temp then d := temp end
5  end
```

- After **L3**: b's ***ST*** is `B` and b's ***DT*** is `C`.
- Does **L4** compile? [NO]

  ∵ cast type `D` is neither an ancestor nor a descendant of `b`'s ***ST*** `B`

Compilable Cast vs. Exception-Free Cast (2)

```
class A end
class B inherit A end
class C inherit B end
class D inherit A end
```

```
1  local b: B ; d: D
2  do
3    create {C} b.make
4    check attached {D} b as temp then d := temp end
5  end
```

- Would the following fix **L4**?

```
check attached {A} b as temp1 then
  check attached {D} temp1 as temp2 then d := temp2 end
end
```

  YES ∵ cast type `D` is an ancestor of `b`'s cast, temporary ***ST*** `A`
- What happens when executing this fix?
  Assertion Violation ∵ cast type `D` not an ancestor of `temp1`'s ***DT*** `C`

Polymorphism: Feature Call Arguments (1)

```
1  class STUDENT_MANAGEMENT_SYSTEM {
2    ss : ARRAY[STUDENT] -- ss[i] has static type Student
3    add_s (s: STUDENT) do ss[0] := s end
4    add_rs (rs: RESIDENT_STUDENT) do ss[0] := rs end
5    add_nrs (nrs: NON_RESIDENT_STUDENT) do ss[0] := nrs end
```

- **L4**: `ss[0]:=rs` is valid. ∵ RHS's ST ***RESIDENT_STUDENT*** is a *descendant class* of LHS's ST ***STUDENT***.
- Say we have a `STUDENT_MANAGEMENT_SYSETM` object `sms`:
  - ∵ *call by value*, `sms.add_rs(o)` attempts the following assignment (i.e., replace parameter `rs` by a copy of argument `o`):

    ```
    rs := o
    ```

  - Whether this argument passing is valid depends on `o`'s *static type*.

  Rule: In the signature of a feature `m`, if the type of a parameter is class `C`, then we may call feature `m` by passing objects whose *static types* are `C`'s *descendants*.

Polymorphism: Feature Call Arguments (2)

```
test_polymorphism_feature_arguments
 local
  s1, s2, s3: STUDENT
  rs: RESIDENT_STUDENT ; nrs: NON_RESIDENT_STUDENT
  sms: STUDENT_MANAGEMENT_SYSTEM
 do
  create sms.make
  create {STUDENT} s1.make ("s1")
  create {RESIDENT_STUDENT} s2.make ("s2")
  create {NON_RESIDENT_STUDENT} s3.make ("s3")
  create {RESIDENT_STUDENT} rs.make ("rs")
  create {NON_RESIDENT_STUDENT} nrs.make ("nrs")
  sms.add_s (s1) ✓ sms.add_s (s2) ✓ sms.add_s (s3) ✓
  sms.add_s (rs) ✓ sms.add_s (nrs) ✓
  sms.add_rs (s1) × sms.add_rs (s2) × sms.add_rs (s3) ×
  sms.add_rs (rs) ✓ sms.add_rs (nrs) ×
  sms.add_nrs (s1) × sms.add_nrs (s2) × sms.add_nrs (s3) ×
  sms.add_nrs (rs) × sms.add_nrs (nrs) ✓
 end
```


Why Inheritance: A Polymorphic Collection of Students

How do you define a class `STUDENT_MANAGEMENT_SYSETM` that contains a list of *resident* and *non-resident* students?

```
class STUDENT_MANAGEMENT_SYSETM
 students: LINKED_LIST[STUDENT]
 add_student(s: STUDENT)
  do
   students.extend (s)
  end
 registerAll (c: COURSE)
  do
   across
    students as s
   loop
    s.item.register (c)
   end
  end
end
```

Polymorphism and Dynamic Binding: A Polymorphic Collection of Students

```
test_sms_polymorphism: BOOLEAN
 local
  rs: RESIDENT_STUDENT
  nrs: NON_RESIDENT_STUDENT
  c: COURSE
  sms: STUDENT_MANAGEMENT_SYSTEM
 do
  create rs.make ("Jim")
  rs.set_pr (1.5)
  create nrs.make ("Jeremy")
  nrs.set_dr (0.5)
  create sms.make
  sms.add_s (rs)
  sms.add_s (nrs)
  create c.make ("EECS3311", 500)
  sms.register_all (c)
  Result := sms.ss[1].tuition = 750 and sms.ss[2].tuition = 250
 end
```


Polymorphism: Return Values (1)

```
1  class STUDENT_MANAGEMENT_SYSTEM {
2   ss: LINKED_LIST[STUDENT]
3   add_s (s: STUDENT)
4    do
5     ss.extend (s)
6    end
7   get_student(i: INTEGER): STUDENT
8    require 1 <= i and i <= ss.count
9    do
10    Result := ss[i]
11   end
12 end
```

- **L2**: ***ST*** of each stored item (`ss[i]`) in the list: [`STUDENT`]
- **L3**: ***ST*** of input parameter `s`: [`STUDENT`]
- **L7**: ***ST*** of return value (`Result`) of `get_student`: [`STUDENT`]
- **L11**: `ss[i]`'s ***ST*** is *descendant* of `Result`' ***ST***.

  Question: What can be the ***dynamic type*** of `s` after **Line 11**?

  Answer: All descendant classes of `Student`.

Polymorphism: Return Values (2)

```
1  test_sms_polymorphism: BOOLEAN
2  local
3   rs: RESIDENT_STUDENT ; nrs: NON_RESIDENT_STUDENT
4   c: COURSE ; sms: STUDENT_MANAGEMENT_SYSTEM
5  do
6   create rs.make ("Jim") ; rs.set_pr (1.5)
7   create nrs.make ("Jeremy") ; nrs.set_dr (0.5)
8   create sms.make ; sms.add_s (rs) ; sms.add_s (nrs)
9   create c.make ("EECS3311", 500) ; sms.register_all (c)
10  Result :=
11        get_student(1).tuition = 750
12    and get_student(2).tuition = 250
13 end
```

- **L11**: `get_student(1)`'s dynamic type? [*RESIDENT_STUDENT*]
- **L11**: Version of `tuition`? [*RESIDENT_STUDENT*]
- **L12**: `get_student(2)`'s dynamic type? [*NON_RESIDENT_STUDENT*]
- **L12**: Version of `tuition`? [*NON_RESIDENT_STUDENT*]

Design Principle: Polymorphism

- When declaring an attribute `a: T`

  ⇒ Choose ***static type*** `T` which "accumulates" all features that you predict you will want to call on `a`.

  e.g., Choose `s: STUDENT` if you do not intend to be specific about which kind of student `s` might be.

  ⇒ Let ***dynamic binding*** determine at runtime which version of `tuition` will be called.
- What if after declaring `s: STUDENT` you find yourself often needing to *cast* `s` to `RESIDENT_STUDENT` in order to access `premium_rate`?

```
check attached {RESIDENT_STUDENT} s as rs then rs.set_pr(...) end
```

  ⇒ Your design decision should have been: `s:RESIDENT_STUDENT`
- Same design principle applies to:
  - Type of feature parameters: `f(a: T)`
  - Type of queries: `q(...): T`

Static Type vs. Dynamic Type: When to consider which?

- *Whether or not an OOP code compiles* depends only on the ***static types*** of relevant variables.

  ∵ Inferring the ***dynamic type*** statically is an *undecidable* problem that is inherently impossible to solve.

- *The behaviour of Java code being executed at runtime*

  e.g., which version of method is called

  e.g., if a **check attached** {...} **as** ... **then** ... **end** assertion error will occur

  depends on the ***dynamic types*** of relevant variables.

  ⇒ Best practice is to visualize how objects are created (by drawing boxes) and variables are re-assigned (by drawing arrows).

Summary: Type Checking Rules

CODE	CONDITION TO BE TYPE CORRECT
`x := y`	y's ***ST*** a **descendant** of x's ***ST***
`x.f(y)`	Feature f defined in x's ***ST*** y's ***ST*** a **descendant** of f's parameter's ***ST***
`z := x.f(y)`	Feature f defined in x's ***ST*** y's ***ST*** a **descendant** of f's parameter's ***ST*** ***ST*** of m's return value a **descendant** of z's ***ST***
`check attached {C} y then ... end`	C an **ancestor** or a **descendant** of y's ***ST***
`check attached {C} y as temp then x := temp end`	C an **ancestor** or a **descendant** of y's ***ST*** C a **descendant** of x's ***ST***
`check attached {C} y as temp then x.f(temp) end`	C an **ancestor** or a **descendant** of y's ***ST*** Feature f defined in x's ***ST*** C a **descendant** of f's parameter's ***ST***

Even if `check attached {C} y then ... end` compiles, a runtime assertion error occurs if C is not an **ancestor** of y's ***DT***!

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