Inheritance

Readings: OOSCS2 Chapters 14 – 16

EECS3311: Software Design
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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: 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*

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

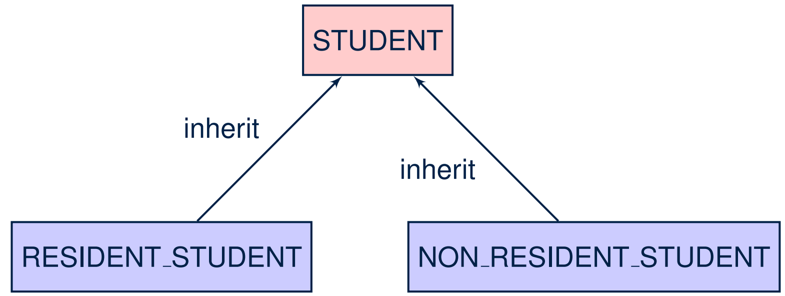
How do you define a class `StudentManagementSystem` that contains a list of *resident* and *non-resident* students?

```
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
```

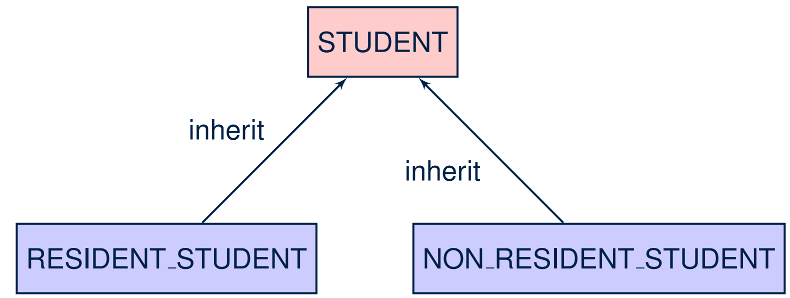
- **L3**: RESIDENT_STUDENT inherits all features from STUDENT.
- There is no need to repeat the register command
- **L14**: *Precursor* returns the value from query tuition in STUDENT.

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*.

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");
```

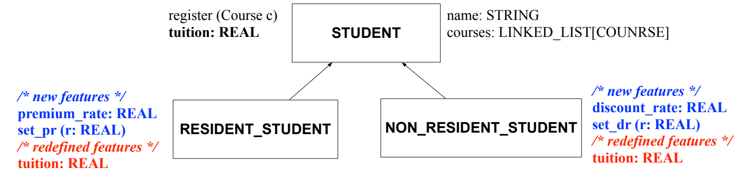
- In Eiffel:

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

  - In Eiffel, the *dynamic type* can be ignored 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")
```

<table>
<tr><th></th><th>name</th><th>courses</th><th>reg</th><th>tuition</th><th>pr</th><th>set_pr</th><th>dr</th><th>set_dr</th></tr>
<tr><td>s1.</td><td colspan="4">✓</td><td colspan="4">×</td></tr>
<tr><td>s2.</td><td colspan="4">✓</td><td colspan="4">×</td></tr>
<tr><td>s3.</td><td colspan="4">✓</td><td colspan="4">×</td></tr>
<tr><td>rs.</td><td colspan="4">✓</td><td colspan="2">✓</td><td colspan="2">×</td></tr>
<tr><td>nrs.</td><td colspan="4">✓</td><td colspan="2">×</td><td colspan="2">✓</td></tr>
</table>

Polymorphism: Intuition (1)

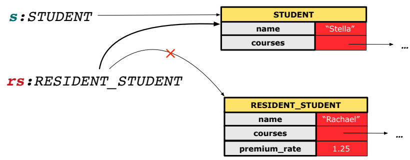
```
1 local
2   s: STUDENT
3   rs: RESIDENT_STUDENT
4 do
5   create s.make ("Stella")
6   create rs.make ("Rachael")
7   rs.set_pr (1.25)
8   s := rs /* Is this valid? */
9   rs := s /* Is this valid? */
```

- 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*:

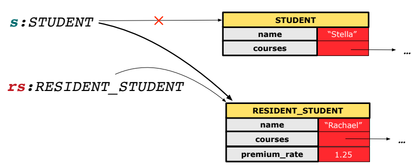


- *rs* declared of type RESIDENT_STUDENT
  ∴ calling *rs.set_pr(1.50)* can be expected.
- *rs* is now pointing to a STUDENT object.
- Then, what would happen to *rs.set_pr(1.50)*?
  CRASH ∵ *rs*.premium_rate is *undefined*!!

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*:

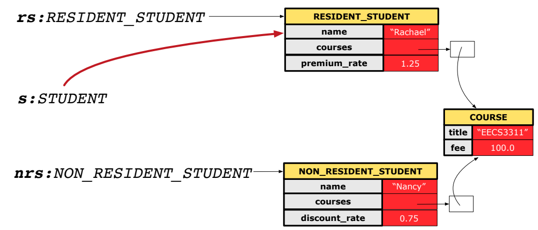


- Since *s* is declared of type STUDENT, a subsequent call *s.set_pr(1.50)* is *never* expected.
- *s* is now pointing to a RESIDENT_STUDENT object.
- Then, what would happen to *s.tuition*?
  OK ∵ *s*.premium_rate is just *never used*!!

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
```

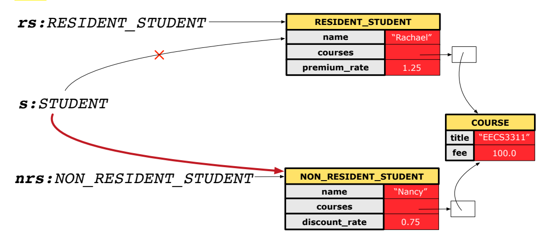
After s := rs (**L7**), s points to a RESIDENT_STUDENT object.
⇒ Calling s.tuition applies the premium_rate.



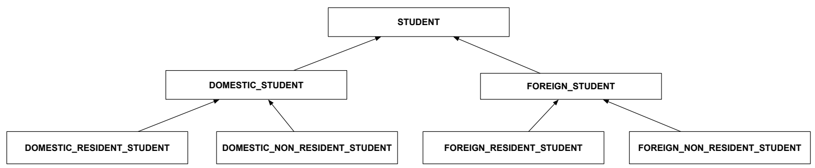
Dynamic Binding: Intuition (2)

```
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
```

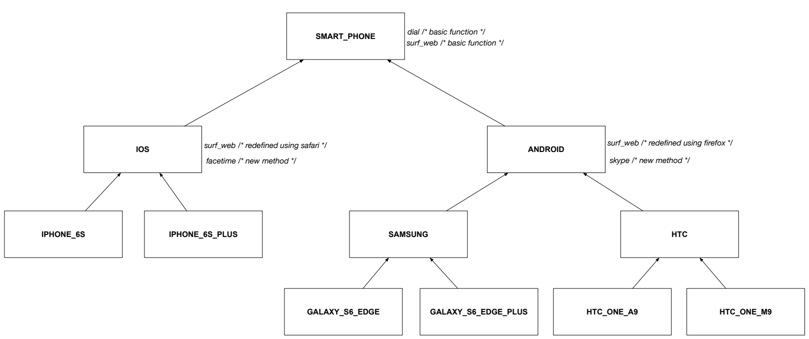
After s:=nrs (**L8**), s points to a NON_RESIDENT_STUDENT object.
⇒ Calling s.tuition applies the discount_rate.



Multi-Level Inheritance Architecture (1)



Multi-Level Inheritance Architecture (2)



Inheritance Forms a Type Hierarchy

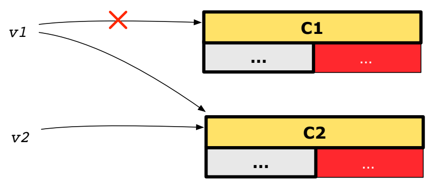
- A (data) *type* denotes a set of related *runtime values*.
  - Every *class* can be used as a type: the set of runtime *objects*.
- Use of *inheritance* creates a *hierarchy* of classes:
  - (Implicit) Root of the hierarchy is `ANY`.
  - Each `inherit` declaration corresponds to an upward arrow.
  - 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
end
rs.set_pr (1.5)
```


Reference Type Casting: Syntax

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

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_jim = (ResidentStudent) jim; }
else { throw new Exception("Illegal Cast"); }
rs.set_pr (1.5)
```


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 android 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
```


Why Inheritance: A Collection of Various Kinds 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 Collection of Various Kinds 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: 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 reference*, `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
```


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`

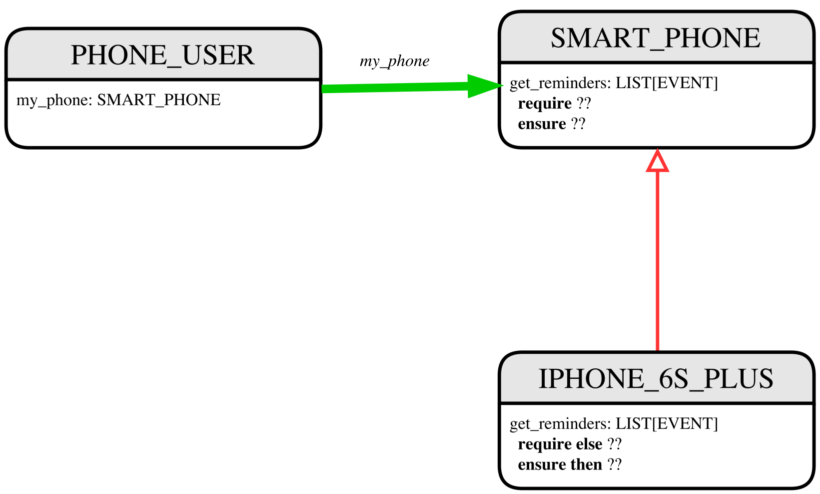
Inheritance and Contracts (1)

- The fact that we allow *polymorphism* :

```
local my_phone: SMART_PHONE
      i_phone: IPHONE_6S_PLUS
      samsung_phone: GALAXY_S6_EDGE
      htc_phone: HTC_ONE_A9
do my_phone := i_phone
   my_phone := samsung_phone
   my_phone := htc_phone
```

  suggests that these instances may *substitute* for each other.
- Intuitively, when expecting SMART_PHONE, we can substitute it by instances of any of its **descendant** classes.
  ∵ Descendants *accumulate code* from its ancestors and can thus *meet expectations* on their ancestors.
- Such *substitutability* can be reflected on contracts, where a *substitutable instance* will:
  - ***Not*** require more from clients for using the services.
  - ***Not*** ensure less to clients for using the services.

Inheritance and Contracts (2.1)



Inheritance and Contracts (2.2)

```
class SMART_PHONE
  get_reminders: LIST[EVENT]
    require
      α: battery_level ≥ 0.1 -- 10%
    ensure
      β: ∀e : Result | e happens today
end
```

```
class IPHONE_6S_PLUS
inherit SMART_PHONE redefine get_reminders end
  get_reminders: LIST[EVENT]
    require else
      γ: battery_level ≥ 0.05 -- 5%
    ensure then
      δ: ∀e : Result | e happens today between 9am and 5pm
end
```

Contracts in descendant class *IPHONE_6S_PLUS* are *suitable*.

- ***Require the same or less*** $\alpha \Rightarrow \gamma$
  Clients satisfying the precondition for *SMART_PHONE* are ***not*** shocked by not being to use the same feature for *IPHONE_6S_PLUS*.

Inheritance and Contracts (2.3)

```
class SMART_PHONE
  get_reminders: LIST[EVENT]
    require
      α: battery_level ≥ 0.1 -- 10%
    ensure
      β: ∀e : Result | e happens today
end
```

```
class IPHONE_6S_PLUS
inherit SMART_PHONE redefine get_reminders end
  get_reminders: LIST[EVENT]
    require else
      γ: battery_level ≥ 0.05 -- 5%
    ensure then
      δ: ∀e : Result | e happens today between 9am and 5pm
end
```

Contracts in descendant class *IPHONE_6S_PLUS* are *suitable*.

- ***Ensure the same or more*** $\delta \Rightarrow \beta$
  Clients benefiting from *SMART_PHONE* are ***not*** shocked by failing to gain at least those benefits from same feature in *IPHONE_6S_PLUS*.

Inheritance and Contracts (2.4)

```
class SMART_PHONE
  get_reminders: LIST[EVENT]
    require
      α: battery_level ≥ 0.1 -- 10%
    ensure
      β: ∀e : Result | e happens today
end
```

```
class IPHONE_6S_PLUS
inherit SMART_PHONE redefine get_reminders end
  get_reminders: LIST[EVENT]
    require else
      γ: battery_level ≥ 0.15 -- 15%
    ensure then
      δ: ∀e : Result | e happens today or tomorrow
end
```

Contracts in descendant class `IPHONE_6S_PLUS` are *not suitable*.

($battery\_level \geq 0.1 \Rightarrow battery\_level \geq 0.15$) is not a tautology.

e.g., A client able to get reminders on a `SMART_PHONE`, when batter level is 12%, will fail to do so on an `IPHONE_6S_PLUS`.

Inheritance and Contracts (2.5)

```
class SMART_PHONE
  get_reminders: LIST[EVENT]
    require
      α: battery_level ≥ 0.1 -- 10%
    ensure
      β: ∀e : Result | e happens today
end
```

```
class IPHONE_6S_PLUS
inherit SMART_PHONE redefine get_reminders end
  get_reminders: LIST[EVENT]
    require else
      γ: battery_level ≥ 0.15 -- 15%
    ensure then
      δ: ∀e : Result | e happens today or tomorrow
end
```

Contracts in descendant class `IPHONE_6S_PLUS` are *not suitable*.

(`e happens ty. or tw.`) ⇒ (`e happens ty.`) not tautology.

e.g., A client receiving today's reminders from `SMART_PHONE` are shocked by tomorrow-only reminders from `IPHONE_6S_PLUS`.

Contract Redeclaration Rule (1)

- In the context of some feature in a descendant class:
  - Use `require else` to redeclare its precondition.
  - Use `ensure then` to redeclare its precondition.
- The resulting *runtime assertions checks* are:
  - `original_pre or else new_pre`

    ⇒ Clients ***able to satisfy*** *original_pre* will not be shocked.

    ∵ ***true*** ∨ *new_pre* ≡ ***true***

    A *precondition violation* will ***not*** occur as long as clients are able to satisfy what is required from the ancestor classes.
  - `original_post and then new_post`

    ⇒ ***Failing to gain*** *original_post* will be reported as an issue.

    ∵ ***false*** ∧ *new_post* ≡ ***false***

    A *postcondition violation* occurs (as expected) if clients do not receive at least those benefits promised from the ancestor classes.

Contract Redeclaration Rule (2)

```
class FOO
  f require
      original_pre
    do ...
    end
end
```

```
class BAR
inherit FOO redefine f end
  f
    do ...
    end
end
```

- Unspecified *new_pre* is as if declaring `require else false`

  ∵ *original_pre* ∨ ***false*** ≡ *original_pre*

```
class FOO
  f
    do ...
    ensure
      original_post
    end
end
```

```
class BAR
inherit FOO redefine f end
  f
    do ...
    end
end
```

- Unspecified *new_post* is as if declaring `ensure then true`

  ∵ *original_post* ∧ ***true*** ≡ *original_post*

Invariant Accumulation

- Every class inherits *invariants* from all its ancestor classes.
- Since invariants are like postconditions of all features, they are "*conjoined*" to be checked at runtime.

```
class POLYGON
  vertices: ARRAY[POINT]
invariant
  vertices.count ≥ 3
end
```

```
class RECTANGLE
inherit POLYGON
invariant
  vertices.count = 4
end
```

- What is checked on a RECTANGLE instance at runtime:

$$(vertices.count \geq 3) \wedge (vertices.count = 4) \equiv (vertices.count = 4)$$

- Can PENTAGON be a descendant class of RECTANGLE?

$$(vertices.count = 5) \wedge (vertices.count = 4) \equiv \textit{false}$$

Inheritance and Contracts (3)

```
class FOO
  f
    require
      original_pre
    ensure
      original_post
    end
end
```

```
class BAR
inherit FOO redefine f end
  f
    require else
      new_pre
    ensure then
      new_post
    end
end
```

(Static) ***Design Time*** :

- $original\_pre \Rightarrow new\_pre$ should prove as a tautology
- $new\_post \Rightarrow original\_post$ should prove as a tautology

(Dynamic) ***Runtime*** :

- $original\_pre \vee new\_pre$ is checked
- $original\_post \wedge new\_post$ is checked

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