

# Inheritance

Readings: OOSCS2 Chapters 14 – 16



EECS3311 A: Software Design  
Winter 2020

CHEN-WEI WANG

- **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
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**

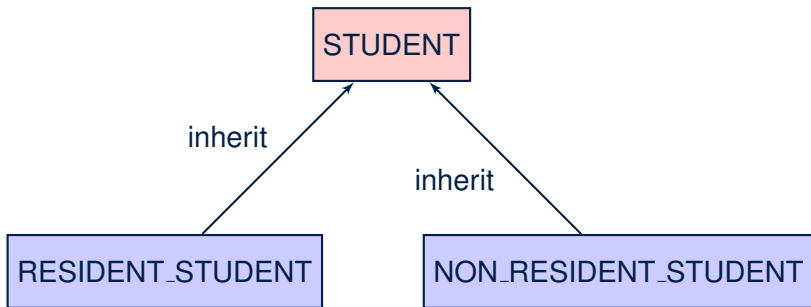
# No Inheritance: A Collection of Various Kinds of Students

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

```
1  class STUDENT
2  create make
3  feature -- Attributes
4    name: STRING
5    courses: LINKED_LIST[COURSE]
6  feature -- Commands that can be used as constructors.
7    make (n: STRING) do name := n ; create courses.make end
8  feature -- Commands
9    register (c: COURSE) do courses.extend (c) end
10 feature -- Queries
11  tuition: REAL
12    local base: REAL
13    do base := 0.0
14      across courses as c loop base := base + c.item.fee end
15    Result := base
16  end
17 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.

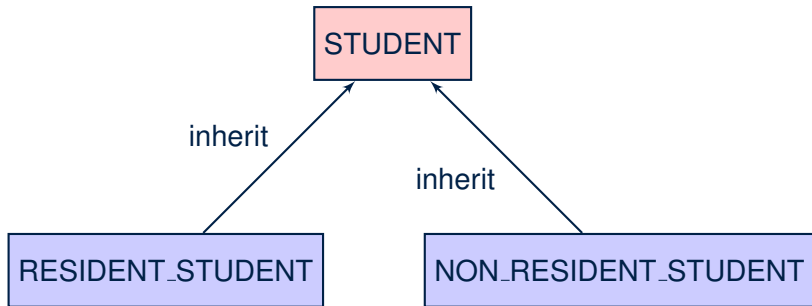
# Inheritance:

## 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");
```

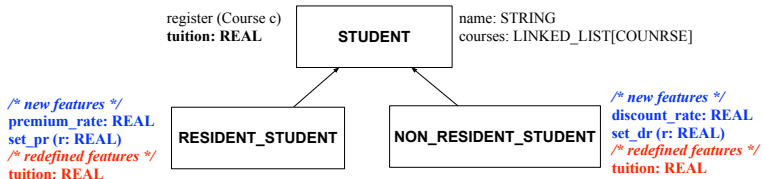
- In Eiffel:

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

- In Eiffel, the *dynamic type* can be 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]

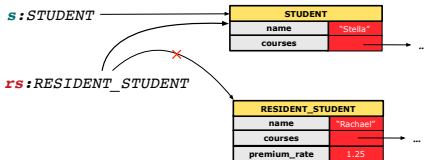
# Polymorphism: Intuition (2)

```

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`  
 $\therefore$  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**

$\therefore$  `rs.premium_rate` is *undefined*!!

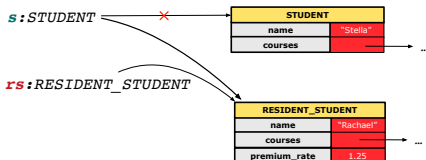
# Polymorphism: Intuition (3)

```

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**

$\therefore$  `s.premium_rate` is just *never used*!!

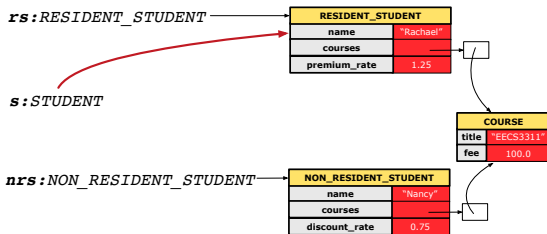
# Dynamic Binding: Intuition (1)

```

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`.





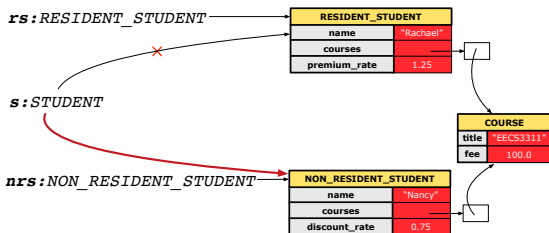
# Dynamic Binding: Intuition (2)

```

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`.

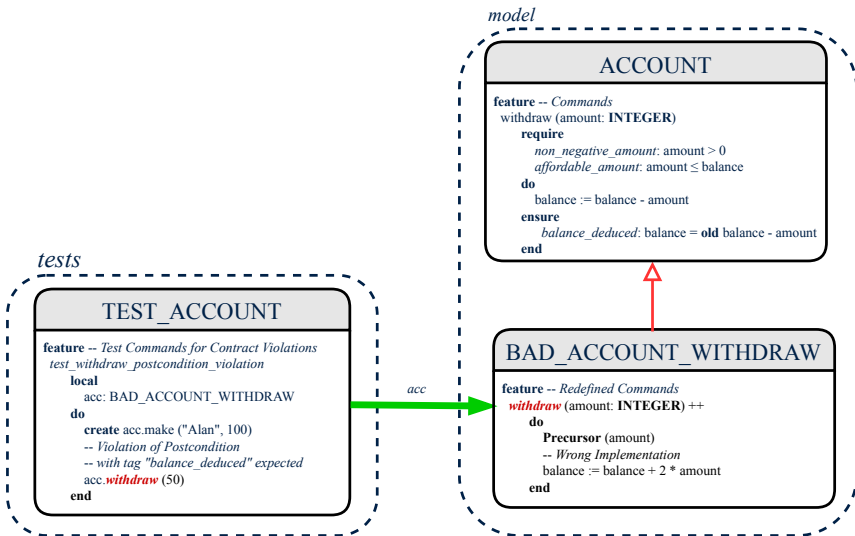


# DbC: Contract View of Supplier

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)

```
1 class TEST_ACCOUNT
2 inherit ES_TEST
3 create make
4 feature -- Constructor for adding tests
5   make
6   do
7     add_violation_case_with_tag ("balance_deducted",
8       agent test_withdraw_postcondition_violation)
9   end
10 feature -- Test commands (test to fail)
11   test_withdraw_postcondition_violation
12   local
13     acc: BAD_ACCOUNT_WITHDRAW
14   do
15     comment ("test: expected postcondition violation of withdraw")
16     create acc.make ("Alan", 100)
17     -- Postcondition Violation with tag "balance_deducted" to occur.
18     acc.withdraw (50)
19   end
20 end
```

## Exercise

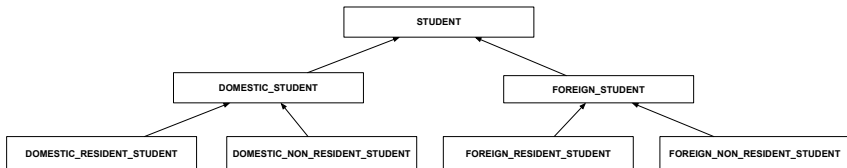
Recall from the “Writing Complete Postconditions” lecture:

```
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
end
```

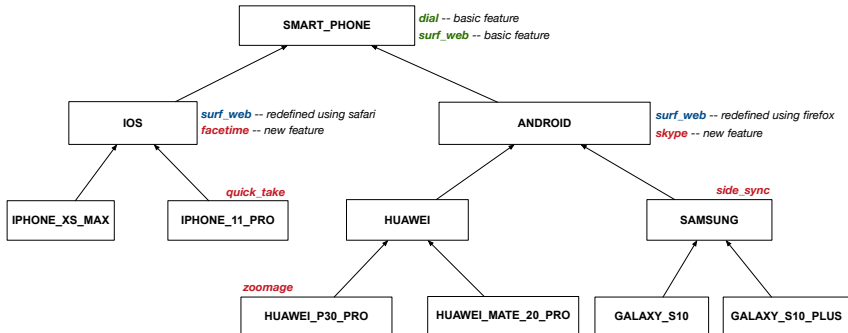
How do you create a “bad” descendant of BANK that violates this postcondition?

```
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
end
```

# Multi-Level Inheritance Architecture (1)



# Multi-Level Inheritance Architecture (2)





# Inheritance Forms a Type Hierarchy

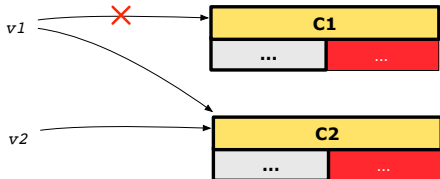
- A (data) **type** denotes a set of related *runtime values*.
  - Every *class* can be used as a type: the set of runtime *objects*.
- Use of *inheritance* creates a **hierarchy** of classes:
  - (Implicit) Root of the hierarchy is ANY.
  - Each `inherit` declaration corresponds to an upward arrow.
  - 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 IPHONE\_XS\_MAX or IPHONE\_11\_PRO.
  - $\therefore$  Each **descendant class** of  $A$  is guaranteed to contain all code of (non-private) attributes, commands, and queries defined in  $A$ .
  - $\therefore$  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 SMART\_PHONE, because the `facetime` feature is not supported in an ANDROID phone.
  - $\therefore$  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.tuioion; /* 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
43 of 63
```

# 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 approximately the same as 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)

- `check attached {C} y then ... end` *always compiles*
- What if `C` is not an **ancestor** of `y`'s **DT**?
  - ⇒ A **runtime** assertion violation occurs!
  - ∴ `y`'s **DT** cannot fulfill the expectation of `C`.

## Notes on Type Cast (2)

- Given **v** of static type **ST**, it is **violation-free** 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 create an **alias** of the object pointed by **v**, with the new **static type C**.  
 ⇒ All features that are defined in **C** can be called.

```

my_phone: IOS
create {IPHONE_11_PRO} my_phone.make
  -- can only call features defined in IOS on myPhone
  -- dial, surf_web, facetime ✓ quick_take, skype, side_sync, zoomage ✗
check attached {SMART_PHONE} my_phone as sp then
  -- can now call features defined in SMART_PHONE on sp
  -- dial, surf_web ✓ facetime, quick_take, skype, side_sync, zoomage ✗
end
check attached {IPHONE_11_PRO} my_phone as ip11_pro then
  -- can now call features defined in IPHONE_11_PRO on ip11_pro
  -- dial, surf_web, facetime, quick_take ✓ skype, side_sync, zoomage ✗
end
  
```

## Notes on Type Cast (3)

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 {HUAWEI} mine.make
  -- ST of mine is ANDROID; DT of mine is HUAWEI
  check attached {SMART_PHONE} mine as sp then ... end
  -- ST of sp is SMART_PHONE; DT of sp is HUAWEI
  check attached {HUAWEI} mine as huawei then ... end
  -- ST of huawei is HUAWEI; DT of huawei is HUAWEI
  check attached {SAMSUNG} mine as samsung then ... end
  -- Assertion violation
  -- ∴ SAMSUNG is not ancestor of mine's DT (HUAWEI)
  check attached {HUAWEI_P30_PRO} mine as p30_pro then ... end
  -- Assertion violation
  -- ∴ HUAWEI_P30_PRO is not ancestor of mine's DT (HUAWEI)
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.  $\therefore$  RHS's ST *RESIDENT\_STUDENT* is a *descendant class* of LHS's ST *STUDENT*.
- Say we have a STUDENT\_MANAGEMENT\_SYSTEM object `sms`:
  - $\therefore$  *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:
  - Type of queries:

```
f(a: T)
```

```
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 Eiffel 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
<code>x := y</code>	y's <b>ST</b> a <b>descendant</b> of x's <b>ST</b>
<code>x.f(y)</code>	Feature <i>f</i> defined in x's <b>ST</b> y's <b>ST</b> a <b>descendant</b> of <i>f</i> 's parameter's <b>ST</b>
<code>z := x.f(y)</code>	Feature <i>f</i> defined in x's <b>ST</b> y's <b>ST</b> a <b>descendant</b> of <i>f</i> 's parameter's <b>ST</b> <b>ST</b> of <i>m</i> 's return value a <b>descendant</b> of z's <b>ST</b>
<code>check attached {C} y</code>	Always compiles
<code>check attached {C} y as temp then x := temp end</code>	C a <b>descendant</b> of x's <b>ST</b>
<code>check attached {C} y as temp then x.f(temp) end</code>	Feature <i>f</i> defined in x's <b>ST</b> C a <b>descendant</b> of <i>f</i> 's parameter's <b>ST</b>

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

# Index (1)

---

**Aspects of Inheritance**

**Why Inheritance: A Motivating Example**

**The COURSE Class**

**No Inheritance: RESIDENT\_STUDENT Class**

**No Inheritance: NON\_RESIDENT\_STUDENT Class**

**No Inheritance: Testing Student Classes**

**No Inheritance:**

**Issues with the Student Classes**

**No Inheritance: Maintainability of Code (1)**

**No Inheritance: Maintainability of Code (2)**

## Index (2)

---

**No Inheritance:**

**A Collection of Various Kinds of Students**

**Inheritance Architecture**

**Inheritance: The STUDENT Parent Class**

**Inheritance:**

**The RESIDENT\_STUDENT Child Class**

**Inheritance:**

**The NON\_RESIDENT\_STUDENT Child Class**

**Inheritance Architecture Revisited**

**Using Inheritance for Code Reuse**

**Testing the Two Student Sub-Classes**

**Static Type vs. Dynamic Type**

## Index (3)

---

**Inheritance Architecture Revisited**

**Polymorphism: Intuition (1)**

**Polymorphism: Intuition (2)**

**Polymorphism: Intuition (3)**

**Dynamic Binding: Intuition (1)**

**Dynamic Binding: Intuition (2)**

**DbC: Contract View of Supplier**

**ES\_TEST: Expecting to Fail Postcondition (1)**

**ES\_TEST: Expecting to Fail Postcondition (2.1)**

**ES\_TEST: Expecting to Fail Postcondition (2.2)**

**Exercise**

## **Index (4)**

---

**Multi-Level Inheritance Architecture (1)**

**Multi-Level Inheritance Architecture (2)**

**Inheritance Forms a Type Hierarchy**

**Inheritance Accumulates Code for Reuse**

**Substitutions via Assignments**

**Rules of Substitution**

**Reference Variable: Static Type**

**Reference Variable: Dynamic Type**

**Reference Variable:**

**Changing Dynamic Type (1)**

**Reference Variable:**

**Changing Dynamic Type (2)**

## Index (5)

---

- Polymorphism and Dynamic Binding (1)**
- Polymorphism and Dynamic Binding (2.1)**
- Polymorphism and Dynamic Binding (2.2)**
- Reference Type Casting: Motivation**
- Reference Type Casting: Syntax**
- Notes on Type Cast (1)**
- Notes on Type Cast (2)**
- Notes on Type Cast (3)**
- Polymorphism: Feature Call Arguments (1)**
- Polymorphism: Feature Call Arguments (2)**

## Index (6)

---

**Why Inheritance:**

**A Polymorphic Collection of Students**

**Polymorphism and Dynamic Binding:**

**A Polymorphic Collection of Students**

**Polymorphism: Return Values (1)**

**Polymorphism: Return Values (2)**

**Design Principle: Polymorphism**

**Static Type vs. Dynamic Type:**

**When to consider which?**

**Summary: Type Checking Rules**