Inheritance

EECS2030 B & G: Advanced Object Oriented Programming
Fall 2025

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Learning Outcomes

This module is designed to help you learn about:

- Alternative designs to **inheritance**
- Using **inheritance** for code reuse
- ***Static Types***, Expectations, ***Dynamic Types***
- *Polymorphism*
  (variable assignments, method arguments & return values)
- *Dynamic Binding*
- ***Type Casting***

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 10 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: Write Java 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.

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 10 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: Write Java 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.

No Inheritance: `ResidentStudent` Class

```
public class ResidentStudent {
  private String name;
  private Course[] courses; private int noc;
  private double premiumRate; /* assume a mutator for this */
  public ResidentStudent (String name) {
    this.name = name;
    this.courses = new Course[10];
  }
  public void register(Course c) {
    this.courses[this.noc] = c;
    this.noc ++;
  }
  public double getTuition() {
    double tuition = 0;
    for(int i = 0; i < this.noc; i ++) {
      tuition += this.courses[i].fee;
    }
    return tuition * this.premiumRate;
  }
}
```

No Inheritance: `NonResidentStudent` Class

```java
public class NonResidentStudent {
  private String name;
  private Course[] courses; private int noc;
  private double discountRate; /* assume a mutator for this */
  public NonResidentStudent (String name) {
    this.name = name;
    this.courses = new Course[10];
  }
  public void register(Course c) {
    this.courses[this.noc] = c;
    this.noc ++;
  }
  public double getTuition() {
    double tuition = 0;
    for(int i = 0; i < this.noc; i ++) {
      tuition += this.courses[i].fee;
    }
    return tuition * this. discountRate ;
  }
}
```

No Inheritance: Testing Student Classes

```java
public class Course {
  private String title; private double fee;
  public Course(String title, double fee) {
    this.title = title; this.fee = fee;
  }
}
```

```java
public class StudentTester {
  public static void main(String[] args) {
    Course c1 = new Course("EECS2030", 500.00); /* title and fee */
    Course c2 = new Course("EECS3311", 500.00); /* title and fee */
    ResidentStudent jim = new ResidentStudent("J. Davis");
    jim.setPremiumRate(1.25);
    jim.register(c1); jim.register(c2);
    NonResidentStudent jeremy = new NonResidentStudent("J. Gibbons");
    jeremy.setDiscountRate(0.75);
    jeremy.register(c1); jeremy.register(c2);
    System.out.println("Jim pays " + jim.getTuition());
    System.out.println("Jeremy pays " + jeremy.getTuition());
  }
}
```

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?

  Hint. Maintenance of code
- 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 so-called ***single-choice design principle***.

No Inheritance: Maintainability of Code (1)

What if the way for registering a course changes?

e.g.,

```
public void register(Course c) throws TooManyCoursesException {
  if (this.noc >= MAX_ALLOWANCE) {
    throw new TooManyCoursesException("Too many courses");
  }
  else {
    this.courses[this.noc] = c;
    this.noc ++;
  }
}
```

Changes needed for `register` method in ***both*** student classes!

No Inheritance: Maintainability of Code (2)

What if the way for calculating the base tuition changes?

e.g.,

```
public double getTuition() {
  double tuition = 0;
  for(int i = 0; i < this.noc; i ++) {
    tuition += this.courses[i].fee;
  }
  /* ... can be premiumRate or discountRate */
  return tuition * inflationRate * ...;
}
```

Changes needed for `getTuition` method in ***both*** student classes!

No Inheritance: A Collection of Various Kinds of Students

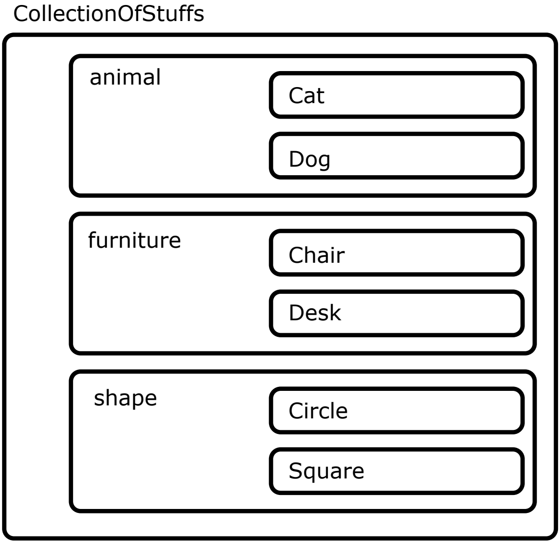
How can we define a class `StudentManagementSystem` that contains a list of *resident* and *non-resident* students?

```
public class StudentManagementSystem {
  private ResidentStudent[] rss;
  private NonResidentStudent[] nrss;
  private int nors; /* number of resident students */
  private int nonrs; /* number of non-resident students */
  public void addRS(ResidentStudent rs){ rss[nors]=rs; nors++; }
  public void addNRS(NonResidentStudent nrs){ nrss[nonrs]=nrs;nonrs++; }
  public void registerAll(Course c) {
    for(int i = 0; i < nors; i ++) { rss[i].register(c); }
    for(int i = 0; i < nonrs; i ++) { nrss[i].register(c); }
  }
}
```

But what if we later on introduce ***more kinds of students***?

Very ***inconvenient*** to handle each list of students ***separately***!

Visibility: Project, Packages, Classes



Visibility of Classes

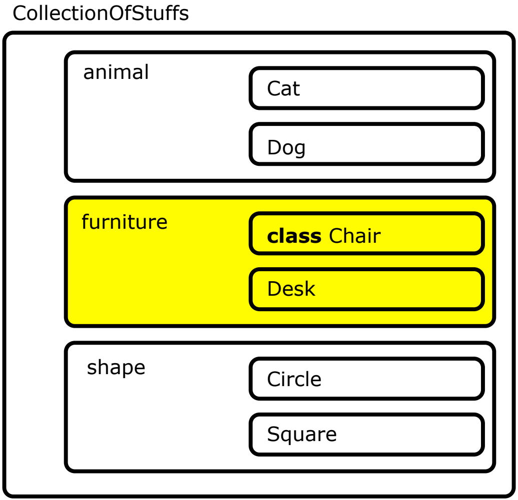
- Only <u>one</u> modifier for declaring visibility of classes: ***public***.
- Use of ***private*** is forbidden for declaring a class.

  e.g., $\boxed{\textit{private}\ \texttt{class}\ \text{Chair}}$ is **not** allowed!!
- **Visibility** of <u>a class</u> may be declared using a <u>modifier</u>, indicating that it is accessible:
  1. Across <u>classes</u> within its residing package [no modifier]

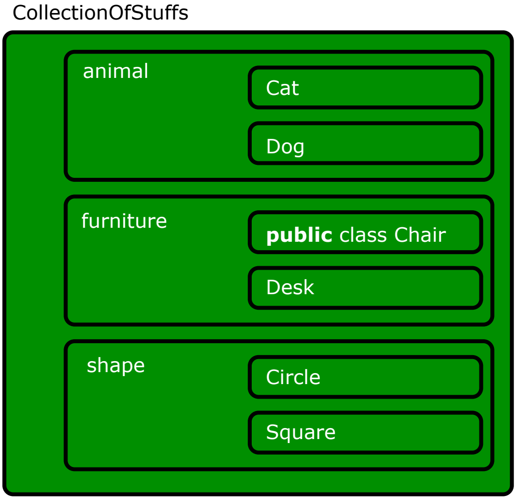
     e.g., Declare $\boxed{\textbf{class}\ \text{Chair}\ \{\ \dots\ \}}$
  2. Across <u>packages</u> [***public***]

     e.g., Declare $\boxed{\textit{public}\ \textbf{class}\ \text{Chair}\ \{\ \dots\ \}}$
- Consider class `Chair` which resides in:
  - package `furniture`
  - project `CollectionOfStuffs`

Visibility of Classes: Across All Classes Within the Resident Package (no modifier)



Visibility of Classes: Across All Classes Within the Resident Package (no modifier)



Visibility of Attributes/Methods: Using Modifiers to Define Scopes

- Two modifiers for declaring visibility of attributes/methods: ***public*** and ***private***
- **Visibility** of an attribute or a method may be declared using a modifier, indicating that it is accessible:
  1. Within its residing class (***most*** restrictive) [***private***]

     e.g., Declare attribute `private int i;`

     e.g., Declare method `private void m(){};`
  2. Across classes within its residing package [no modifier]

     e.g., Declare attribute `int i;`

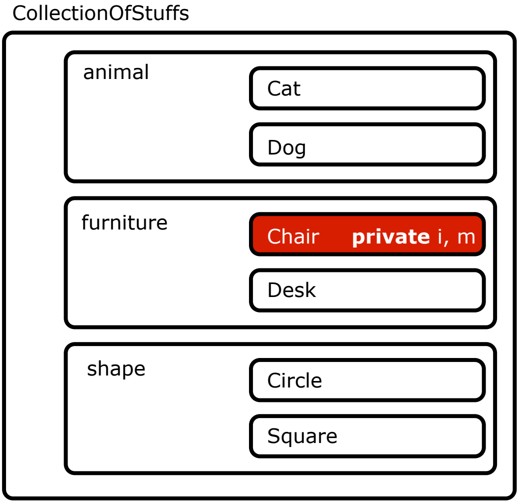
     e.g., Declare method `void m(){};`
  3. Across packages (***least*** restrictive) [***public***]

     e.g., Declare attribute `public int i;`

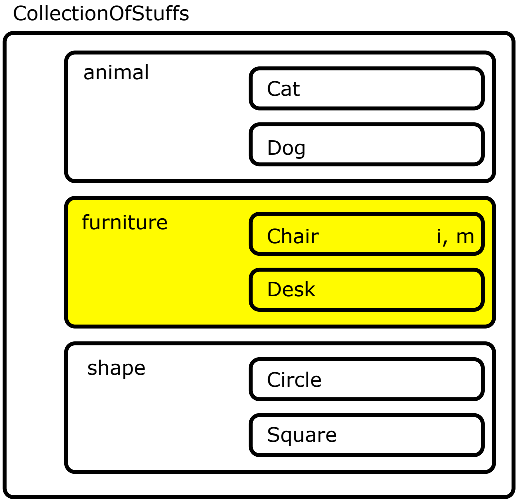
     e.g., Declare method `public void m(){};`
- Consider attributes `i` and `m` residing in:

  Class `Chair`; Package `furniture`; Project `CollectionOfStuffs`.

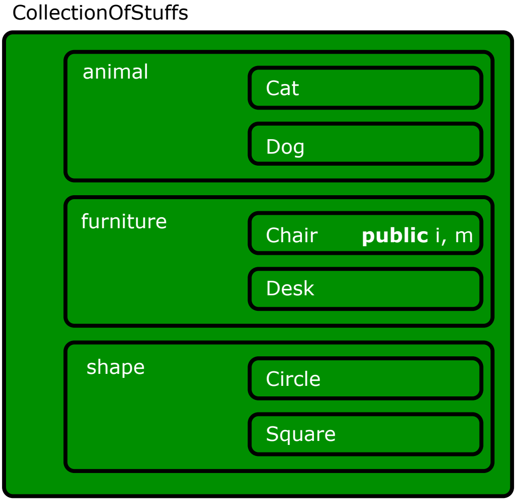
Visibility of Attr./Meth.: Across All Methods Within the Resident Class (`private`)



Visibility of Attr./Meth.: Across All Classes Within the Resident Package (no modifier)



Visibility of Attr./Meth.: Across All Packages Within the Resident Project (`public`)

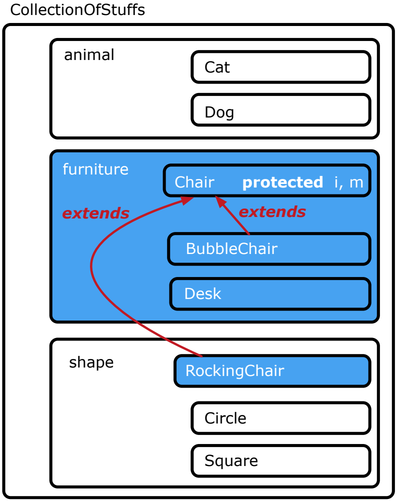


Use of the `protected` Modifier

- ***private*** attributes are not inherited to subclasses.
- package-level attributes (i.e., with **no modifier**) and project-level attributes (i.e., ***public***) are inherited.
- What if we want attributes to be:
  - *visible* to sub-classes outside the current package, but still
  - *invisible* to other non-sub-classes outside the current package?

  Use ***protected***!

Visibility of Attr./Meth.: Across All Methods Same Package and Sub-Classes (`protected`)



Visibility of Attributes/Methods

scope / modifier	CLASS	PACKAGE	SUBCLASS (same pkg)	SUBCLASS (different pkg)	NON-SUBCLASS (across Project)
`public`					
`protected`					
no modifier					
`private`					

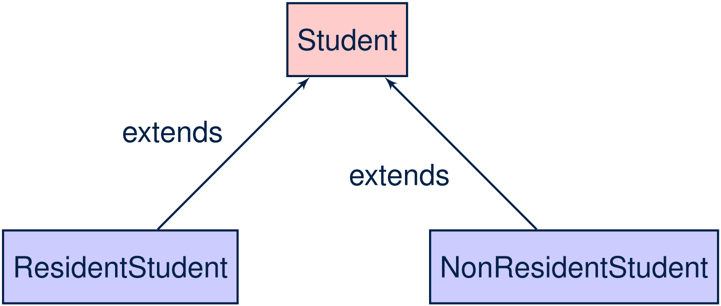
For the rest of this lecture, for simplicity, we assume that:

All relevant parent/child classes are in the same package .

⇒ Attributes with **no modifiers** (***package***-level visibility) suffice.

⇒ Methods with **no modifiers** (***package***-level visibility) suffice.

Inheritance Architecture



Inheritance: The `Student` Parent/Super Class

```
class Student {
  String name;
  Course[] courses; int noc;
  Student (String name) {
    this.name = name;
    this.courses = new Course[10];
  }
  void register(Course c) {
    this.courses[this.noc] = c;
    this.noc ++;
  }
  double getTuition() {
    double tuition = 0;
    for(int i = 0; i < this.noc; i ++) {
      tuition += this.courses[i].fee;
    }
    return tuition; /* base amount only */
  }
}
```

Inheritance: The `ResidentStudent` Child/Sub Class

```
1 class ResidentStudent extends Student {
2   double premiumRate; /* there's a mutator method for this */
3   ResidentStudent (String name) { super(name); }
4   /* register method is inherited */
5   double getTuition() {
6     double base = super.getTuition();
7     return base * premiumRate;
8   }
9 }
```

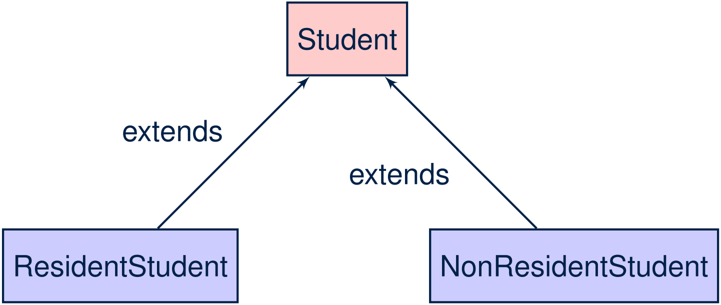
- **L1** declares that `ResidentStudent` inherits all attributes and methods (except constructors) from `Student`.
- There is no need to repeat the `register` method
- Use of *super* in **L3** is as if calling `Student(name)`
- Use of *super* in **L6** returns what `getTuition()` in `Student` returns.
- Use *super* to refer to attributes/methods defined in the super class: `super.name`, `super.register(c)`.

Inheritance: The `NonResidentStudent` Child/Sub Class

```
1 class NonResidentStudent extends Student {
2   double discountRate; /* there's a mutator method for this */
3   NonResidentStudent (String name) { super(name); }
4   /* register method is inherited */
5   double getTuition() {
6     double base = super.getTuition();
7     return base * discountRate;
8   }
9 }
```

- **L1** declares that `NonResidentStudent` inherits all attributes and methods (except constructors) from `Student`.
- There is no need to repeat the `register` method
- Use of *super* in **L3** is as if calling `Student(name)`
- Use of *super* in **L6** returns what `getTuition()` in `Student` returns.
- Use *super* to refer to attributes/methods defined in the super class: `super.name`, `super.register(c)`.

Inheritance Architecture Revisited



- The class that defines the common attributes and methods is called the *parent* or *super* class.
- Each “extended” class is called a *child* or *sub* class.

Using Inheritance for Code Reuse

Inheritance in Java allows you to:

- Define ***common attributes and methods*** in a separate class.
  e.g., the `Student` class
- Define an "extended" version of the class which:
  - ***inherits*** definitions of all attributes and methods
    e.g., `name`, `courses`, `noc`
    e.g., `register`
    e.g., base amount calculation in `getTuition`
    This means code reuse and elimination of code duplicates!
  - ***defines*** **new** attributes and methods if necessary
    e.g., `setPremiumRate` for `ResidentStudent`
    e.g., `setDiscountRate` for `NonResidentStudent`
  - ***redefines***/***overrides*** methods if necessary
    e.g., compounded tuition for `ResidentStudent`
    e.g., discounted tuition for `NonResidentStudent`

Visualizing Parent/Child Objects (1)

- A child class inherits ***all*** non-private attributes from its parent class.

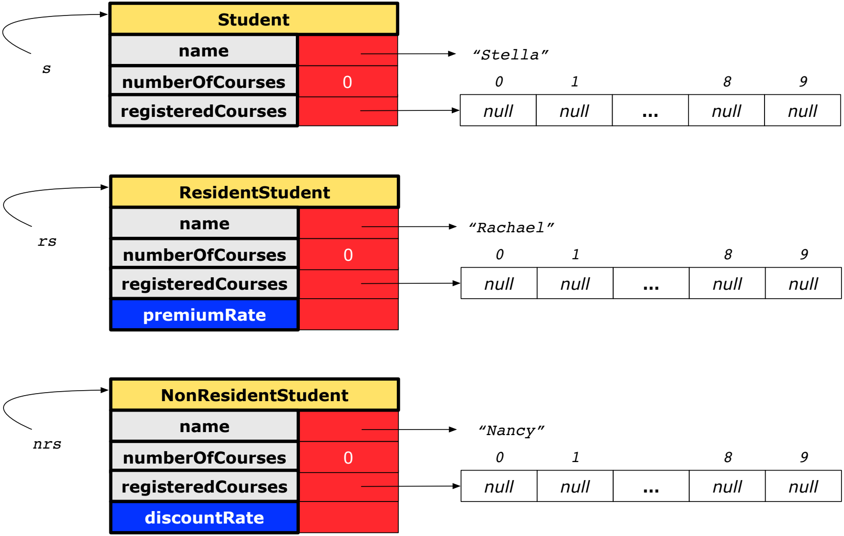
  ⇒ A child instance has ***at least as many*** attributes as an instance of its parent class.

  Consider the following instantiations:

```
Student s = new Student("Stella");
ResidentStudent rs = new ResidentStudent("Rachael");
NonResidentStudent nrs = new NonResidentStudent("Nancy");
```

- How will these initial objects look like?

Visualizing Parent/Child Objects (2)



Testing the Two Student Sub-Classes

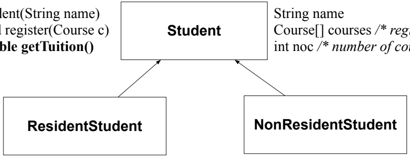
```
public class StudentTester {
  public static void main(String[] args) {
    Course c1 = new Course("EECS2030", 500.00); /* title and fee */
    Course c2 = new Course("EECS3311", 500.00); /* title and fee */
    ResidentStudent jim = new ResidentStudent("J. Davis");
    jim.setPremiumRate(1.25);
    jim.register(c1); jim.register(c2);
    NonResidentStudent jeremy = new NonResidentStudent("J. Gibbons");
    jeremy.setDiscountRate(0.75);
    jeremy.register(c1); jeremy.register(c2);
    System.out.println("Jim pays " + jim.getTuition());
    System.out.println("Jeremy pays " + jeremy.getTuition());
  }
}
```

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

Inheritance Architecture: Static Types & Expectations

Student(String name)
void register(Course c)
double getTuition()

String name
Course[] courses /* *registered courses (rcs)* */
int noc /* *number of courses* */



/* new attributes, new methods */
ResidentStudent(String name)
double premiumRate
void setPremiumRate(double r)
/* redefined/overridden methods */
double getTuition()

/* new attributes, new methods */
NonResidentStudent(String name)
double discountRate
void setDiscountRate(double r)
/* redefined/overridden methods */
double getTuition()

```
Student s = new Student("Stella");
ResidentStudent rs = new ResidentStudent("Rachael");
NonResidentStudent nrs = new NonResidentStudent("Nancy");
```

<table>
<tr><th></th><th>name</th><th>rcs</th><th>noc</th><th>reg</th><th>getT</th><th>pr</th><th>setPR</th><th>dr</th><th>setDR</th></tr>
<tr><td>s.</td><td colspan="5">✓</td><td colspan="4">×</td></tr>
<tr><td>rs.</td><td colspan="5">✓</td><td colspan="2">✓</td><td colspan="2">×</td></tr>
<tr><td>nrs.</td><td colspan="5">✓</td><td colspan="2">×</td><td colspan="2">✓</td></tr>
</table>

Polymorphism: Intuition (1)

```
1 Student s = new Student("Stella");
2 ResidentStudent rs = new ResidentStudent("Rachael");
3 rs.setPremiumRate(1.25);
4 s = rs; /* Is this valid? */
5 rs = s; /* Is this valid? */
```

- Which one of **L4** and **L5** is *valid*? Which one is *invalid*?
- **Hints**:
  - **L1**: What *kind* of address can `s` store? [`Student`]

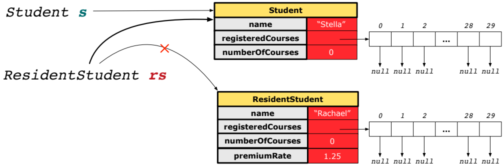
    ∴ The context object `s` is *expected* to be used as:
    - `s.register(eecs2030)` and `s.getTuition()`
  - **L2**: What *kind* of address can `rs` store? [`ResidentStudent`]

    ∴ The context object `rs` is *expected* to be used as:
    - `rs.register(eecs2030)` and `rs.getTuition()`
    - `rs.setPremiumRate(1.50)` [increase premium rate]

Polymorphism: Intuition (2)

```
1 Student s = new Student("Stella");
2 ResidentStudent rs = new ResidentStudent("Rachael");
3 rs.setPremiumRate(1.25);
4 s = rs; /* Is this valid? */
5 rs = s; /* Is this valid? */
```

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



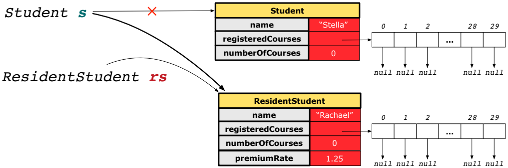
- Since `rs` is declared of type `ResidentStudent`, a subsequent call `rs.setPremiumRate(1.50)` can be expected.
- `rs` is now pointing to a `Student` object.
- Then, what would happen to `rs.setPremiumRate(1.50)`?

CRASH $\because$ `rs.premiumRate` is *undefined*!!

Polymorphism: Intuition (3)

```
1 Student s = new Student("Stella");
2 ResidentStudent rs = new ResidentStudent("Rachael");
3 rs.setPremiumRate(1.25);
4 s = rs; /* Is this valid? */
5 rs = s; /* Is this valid? */
```

- **s** = **rs** (**L4**) should be *valid*:



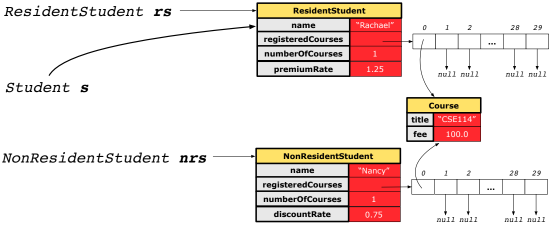
- Since `s` is declared of type `Student`, a subsequent call `s.setPremiumRate(1.50)` is *never* expected.
- `s` is now pointing to a `ResidentStudent` object.
- Then, what would happen to `s.getTuition()`?

OK ∵ `s.premiumRate` is *never directly used*!!

Dynamic Binding: Intuition (1)

```
1  Course eecs2030 = new Course("EECS2030", 100.0);
2  Student s;
3  ResidentStudent rs = new ResidentStudent("Rachael");
4  NonResidentStudent nrs = new NonResidentStudent("Nancy");
5  rs.setPremiumRate(1.25); rs.register(eecs2030);
6  nrs.setDiscountRate(0.75); nrs.register(eecs2030);
7  s = rs; System.out.println( s .getTuition()); /* 125.0 */
8  s = nrs; System.out.println( s .getTuition()); /* 75.0 */
```

After `s = rs` (**L7**), `s` points to a `ResidentStudent` object.
⇒ Calling `s .getTuition()` applies the `premiumRate`.

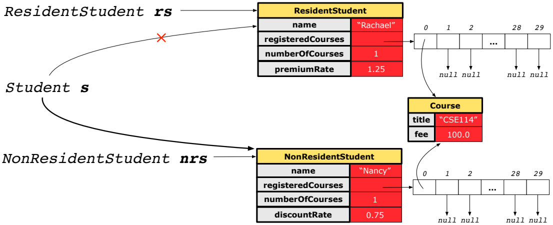


Dynamic Binding: Intuition (2)

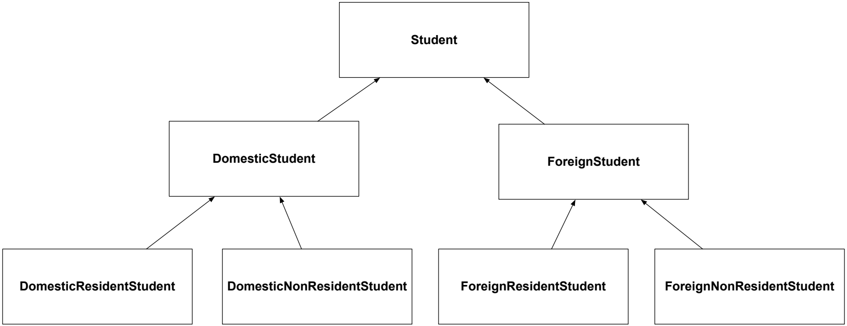
```
1 Course eecs2030 = new Course("EECS2030", 100.0);
2 Student s;
3 ResidentStudent rs = new ResidentStudent("Rachael");
4 NonResidentStudent nrs = new NonResidentStudent("Nancy");
5 rs.setPremiumRate(1.25); rs.register(eecs2030);
6 nrs.setDiscountRate(0.75); nrs.register(eecs2030);
7 s = rs; System.out.println( s .getTuition()); /* 125.0 */
8 s = nrs; System.out.println( s .getTuition()); /* 75.0 */
```

After `s = nrs` (**L8**), `s` points to a `NonResidentStudent` object.

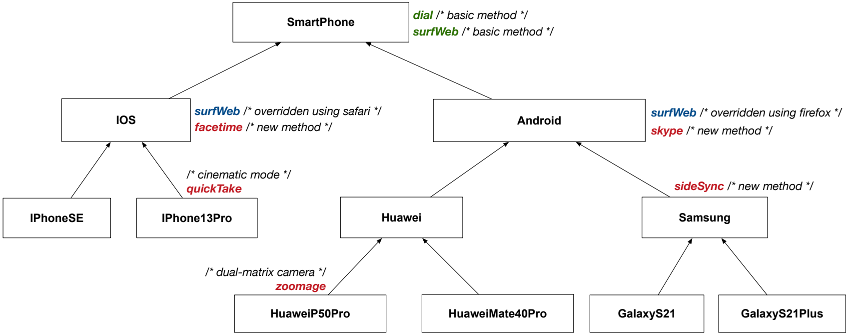
⇒ Calling `s .getTuition()` applies the `discountRate`.



Multi-Level Inheritance Architecture



Multi-Level Inheritance Hierarchy: Smart Phones



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 `Object`.
  - Each `extends` declaration corresponds to an upward arrow.
  - The `extends` relationship is ***transitive***: when `A` extends `B` and `B` extends C, we say `A` *indirectly* extends `C`.
    e.g., Every class implicitly `extends` the `Object` class.
- ***Ancestor*** vs. ***Descendant*** classes:
  - The *ancestor classes* of a class `A` are: `A` itself and all classes that `A` directly, or indirectly, extends.
    - `A` inherits all code (attributes and methods) from its ***ancestor classes***.
      ∴ `A`'s instances have a ***wider range of expected usages*** (i.e., attributes and methods) than instances of its ***ancestor*** classes.
  - The *descendant classes* of a class `A` are: `A` itself and all classes that directly, or indirectly, extends `A`.
    - Code defined in `A` is inherited to all its ***descendant classes***.

Inheritance Accumulates Code for Reuse

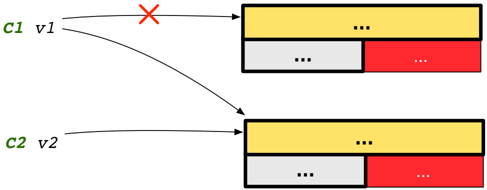
- The ***lower*** a class is in the type hierarchy, the ***more code*** it accumulates from its ***ancestor classes***:
  - A ***descendant class*** inherits all code from its ***ancestor classes***.
  - A ***descendant class*** may also:
    - Declare new attributes
    - Define new methods
    - *Redefine* / *Override* inherited methods
- Consequently:
  - When being used as *context objects*, instances of a class' ***descendant classes*** have a ***wider range of expected usages*** (i.e., attributes and methods).
  - Given a ***reference variable***, expected to store the address of an object of a particular class, we may *substitute* it with (*re-assign* it to) an object of any of its ***descendant classes***.
  - e.g., When expecting a `SmartPhone` object, we may substitute it with either a `IPhone13Pro` or a `Samsung` object.
  - **Justification**: A ***descendant class*** contains *at least as many* methods as defined in its ***ancestor classes*** (but not vice versa!).

Static Types Determine Expectations

- A reference variable's *static type* is what we declare it to be.
  - `Student jim` declares `jim`'s ST as `Student`.
  - `SmartPhone myPhone` declares `myPhone`'s ST as `SmartPhone`.
  - The *static type* of a reference variable *never changes*.
- For a reference variable *v*, its *static type* $\boxed{C}$ defines the *expected usages of v as a context object*.
- A method call `v.m(...)` is ***compilable*** if ***m*** is defined in $\boxed{C}$.
  - e.g., After declaring `Student jim`, we
    - **may** call `register` and `getTuition` on `jim`
    - **may *not*** call `setPremiumRate` (specific to a resident student) or `setDiscountRate` (specific to a non-resident student) on `jim`
  - e.g., After declaring `SmartPhone myPhone`, we
    - **may** call `dial` and `surfWeb` on `myPhone`
    - **may *not*** call `facetime` (specific to an IOS phone) or `skype` (specific to an Android phone) on `myPhone`

Substitutions via Assignments

- By declaring ***C1*** `v1`, ***reference variable*** `v1` will store the ***address*** of an object "of class `C1`" at runtime.
- By declaring ***C2*** `v2`, ***reference variable*** `v2` will store the ***address*** of an object "of class `C2`" at runtime.
- Assignment `v1 = v2` ***copies 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 (***static***) type `C1` by an object of (***static***) type `C2`.
- *Substitutions* are subject to ***rules***!

Rules of Substitution

When expecting an object of ***static type*** `A`:

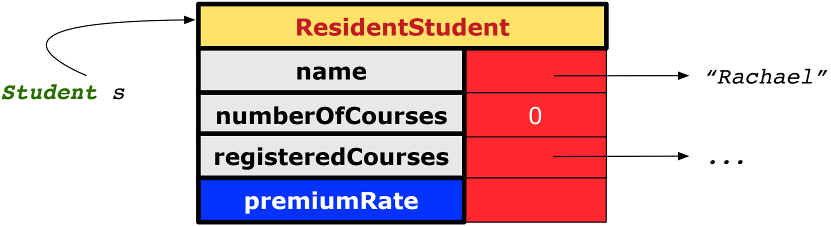
- It is ***safe*** to *substitute* it with an object whose ***static type*** is any of the *descendant class* of `A` (including `A`).
  - ∵ Each *descendant class* of `A`, being the new substitute, is guaranteed to contain all (non-private) attributes/methods defined in `A`.
  - e.g., When expecting an `IOS` phone, you ***can*** substitute it with either an `IPhoneSE` or `IPhone13Pro`.
- It is ***unsafe*** to *substitute* it with an object whose ***static type*** is any of the *ancestor classes of `A`'s parent* (excluding `A`).
  - ∵ Class `A` may have defined new methods that do not exist in any of its *parent's ancestor classes*.
  - e.g., When expecting `IOS` phone, ***unsafe*** to substitute it with a `SmartPhone` ∵ `facetime` not supported in `Android` phone.
- It is also ***unsafe*** to *substitute* it with an object whose ***static type*** is neither an ancestor nor a descendant of `A`.
  - e.g., When expecting `IOS` phone, ***unsafe*** to substitute it with a `HuaweiP50Pro` ∵ `facetime` not supported in `Android` 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.

Visualizing Static Type vs. Dynamic Type



- Each segmented box denotes a *runtime* object.
- Arrow denotes a variable (e.g., `s`) storing the object's address.

  Usually, when the context is clear, we leave the variable's ***static type*** implicit (***Student***).
- Title of box indicates type of runtime object, which denotes the ***dynamic type*** of the variable (***ResidentStudent***).

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., `Student jim = new ResidentStudent(...)` changes the ***dynamic type*** of `jim` to `ResidentStudent`.
- e.g., `jim = new NonResidentStudent(...)` changes the ***dynamic type*** of `jim` to `NonResidentStudent`.
- e.g., `ResidentStudent jeremy = new Student(...)` is illegal because `Studnet` is **not** a *descendant class* of the ***static type*** of `jeremy` (i.e., `ResidentStudent`).

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., Say we declare

```
Student jim = new Student(...);
ResidentStudent rs = new ResidentStudnet(...);
NonResidentStudnet nrs = new NonResidentStudent(...);
```

- `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`
- `rs = jim` ×
- `nrs = jim` ×

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 method that may be called.
    - e.g., A ***Student*** variable may have the ***dynamic type*** of **Student**, **ResidentStudent**, or **NonResidentStudent**,
    - This means that there are three possible versions of the `getTuition()` that may be called.
- *Dynamic binding* : When a method `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.

```
Student jim = new ResidentStudent(...);
jim.getTuition(); /* version in ResidentStudent */
jim = new NonResidentStudent(...);
jim.getTuition(); /* version in NonResidentStudent */
```

Polymorphism and Dynamic Binding (2.1)

```
class Student {...}
class ResidentStudent extends Student {...}
class NonResidentStudent extends Student {...}
```

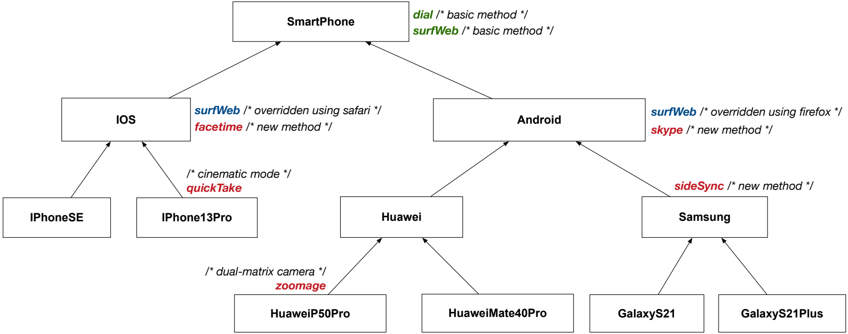
```
class StudentTester1 {
 public static void main(String[] args) {
   Student jim = new Student("J. Davis");
   ResidentStudent rs = new ResidentStudent("J. Davis");
   jim = rs;  /* legal */
   rs = jim;  /* illegal */

   NonResidentStudnet nrs = new NonResidentStudent("J. Davis");
   jim = nrs;  /* legal */
   nrs = jim;  /* illegal */
 }
}
```

Polymorphism and Dynamic Binding (2.2)

```
class Student {...}
class ResidentStudent extends Student {...}
class NonResidentStudent extends Student {...}
```

```
class StudentTester2 {
 public static void main(String[] args) {
  Course eecs2030 = new Course("EECS2030", 500.0);
  Student jim = new Student("J. Davis");
  ResidentStudent rs = new ResidentStudent("J. Davis");
  rs.setPremiumRate(1.5);
  jim = rs ;
  System.out.println( jim.getTuition() );  /* 750.0 */
  NonResidentStudnet nrs = new NonResidentStudent("J. Davis");
  nrs.setDiscountRate(0.5);
  jim = nrs ;
  System.out.println( jim.getTuition() );  /* 250.0 */
 }
}
```

Polymorphism and Dynamic Binding (3.1)



Polymorphism and Dynamic Binding (3.2)

```
class SmartPhoneTest1 {
  public static void main(String[] args) {
    SmartPhone myPhone;
    IOS ip = new IPhoneSE();
    Samsung ss = new GalaxyS21Plus();
    myPhone = ip;  /* legal */
    myPhone = ss;  /* legal */

    IOS presentForHeeyeon;
    presentForHeeyeon = ip;  /* legal */
    presentForHeeyeon = ss;  /* illegal */
  }
}
```

Polymorphism and Dynamic Binding (3.3)

```
class SmartPhoneTest2 {
  public static void main(String[] args) {
    SmartPhone myPhone;
    IOS ip = new IPhone13Pro();
    myPhone = ip;
    myPhone. surfWeb (); /* version of surfWeb in IPhone13Pro */

    Samsung ss = new GalaxyS21();
    myPhone = ss;
    myPhone. surfWeb (); /* version of surfWeb in GalaxyS21 */
  }
}
```

Reference Type Casting: Motivation (1.1)

```
1 Student jim = new ResidentStudent("J. Davis");
2 ResidentStudent rs = jim;
3 rs.setPremiumRate(1.5);
```

- **L1** is *legal*: `ResidentStudent` is a **descendant class** of the ***static type*** of `jim` (i.e., `Student`).
- **L2** is *illegal*: `jim`'s ***ST*** (i.e., `Student`) is ***not*** a **descendant class** of `rs`'s ***ST*** (i.e., `ResidentStudent`).

  Java compiler is *unable to infer* that `jim`'s ***dynamic type*** in **L2** is `ResidentStudent`!
- Force the Java compiler to believe so via a cast in **L2**:

```
ResidentStudent rs = (ResidentStudent) jim;
```

  - The cast (***ResidentStudent***) jim creates for `jim` ***a temporary alias*** whose ***ST*** corresponds to the ***cast type*** (***ResidentStudent***).
  - Alias `rs` of ***ST*** **`ResidentStudent`** is then created via an assignment. **Note**. `jim`'s ***ST*** always remains **`Student`**.
- *dynamic binding*: After the *cast*, **L3** will execute the correct version of `setPremiumRate` (∵ ***DT*** of `rs` is ***`ResidentStudent`***).

Reference Type Casting: Motivation (1.2)

$$\overbrace{\textit{ResidentStudent}\ \ rs}^{\texttt{ST: ResidentStudent}} \overbrace{=}^{\texttt{valid substitution}} \underbrace{(\texttt{ResidentStudent})\ \overbrace{jim}^{\texttt{ST: Student}}}_{\texttt{an alias whose ST is ResidentStudent}} ;$$

- Variable `rs` is declared of ***static type*** (***ST***) `ResidentStudent`.
- Variable `jim` is declared of ***ST*** `Student`.
- The cast $\boxed{(\textbf{\textit{ResidentStudent}})\ \text{jim}}$ creates for `jim` a **temporary alias**, whose ***ST*** corresponds to the ***cast type*** (`ResidentStudent`).

  ⇒ Such a cast makes the assignment valid.

  ∵ RHS's ***ST*** (`ResidentStudent`) is a descendant of LHS's ***ST*** (`ResidentStudent`).

  ⇒ The assignment creates an alias `rs` with ***ST*** `ResidentStudent`.
- **No** new object is created.

  Only an ***alias*** `rs` with a different ***ST*** (`ResidentStudent`) is created.
- After the assignment, `jim`'s ***ST*** **remains** `Student`.

Reference Type Casting: Motivation (2.1)

```
1 SmartPhone aPhone = new IPhone13Pro();
2 IPhone13Pro forHeeyeon = aPhone;
3 forHeeyeon.facetime(1.5);
```

- **L1** is *legal*: `IPhone13Pro` is a **descendant class** of the ***static type*** of `aPhone` (i.e., `SmartPhone`).
- **L2** is *illegal*: `aPhone`'s ***ST*** (i.e., `SmartPhone`) is ***not*** a **descendant class** of `forHeeyeon`'s ***ST*** (i.e., `IPhone13Pro`).

  Java compiler is *unable to infer* that `aPhone`'s ***dynamic type*** in **L2** is `IPhone13Pro`!
- Force the Java compiler to believe so via a cast in **L2**:

  ```
  IPhone13Pro forHeeyeon = (IPhone13Pro) aPhone;
  ```

  - The cast (***IPhone13Pro***) aPhone creates for `aPhone` ***a temporary alias*** whose ***ST*** corresponds to the ***cast type*** (***IPhone13Pro***).
  - Alias `forHeeyeon` of ***ST*** **`IPhone13Pro`** is then created via an assignment.

    Note. `aPhone`'s ***ST*** always remains **`SmartPhone`**.
- *dynamic binding* : After the *cast* , **L3** will execute the correct version of `facetime` (∵ ***DT*** of `forHeeyeon` is ***`IPhone13Pro`***).

Reference Type Casting: Motivation (2.2)

$$\overbrace{\text{IPhone13Pro forHeeyeon}}^{\texttt{ST: IPhone13Pro}} \overbrace{=}^{\texttt{valid substitution}} \underbrace{(\texttt{IPhone13Pro})\ \overbrace{\text{aPhone}}^{\texttt{ST: SmartPhone}}}_{\texttt{an alias whose ST is IPhone13Pro}} ;$$

- Variable `forHeeyeon` is declared of ***static type*** (***ST***) `IPhone13Pro`.
- Variable `aPhone` is declared of ***ST*** `SmartPhone`.
- The cast $\boxed{\text{(\textit{IPhone13Pro}) aPhone}}$ creates for `aPhone` a **temporary alias**, whose ***ST*** corresponds to the ***cast type*** (`IPhone13Pro`).

  ⇒ Such a cast makes the assignment valid.

  ∵ RHS's ***ST*** (`IPhone13Pro`) is a descendant of LHS's ***ST*** (`IPhone13Pro`).

  ⇒ The assignment creates an alias `forHeeyeon` with ***ST*** `IPhone13Pro`.
- **No** new object is created.

  Only an ***alias*** `forHeeyeon` with a different ***ST*** (`IPhone13Pro`) is created.
- After the assignment, `aPhone`'s ***ST*** **remains** `SmartPhone`.

Type Cast: Named or Anonymous

Named Cast: Use intermediate variable to store the cast result.

```
SmartPhone aPhone = new IPhone13Pro();
IOS forHeeyeon = (IPhone13Pro) aPhone;
forHeeyeon.facetime();
```

Anonymous Cast: Use the cast result directly.

```
SmartPhone aPhone = new IPhone13Pro();
((IPhone13Pro) aPhone).facetime();
```

Common Mistake:

```
1 SmartPhone aPhone = new IPhone13Pro();
2 (IPhone13Pro) aPhone.facetime();
```

L2 ≡ `(IPhone13Pro) (aPhone.facetime())`: Call, then cast.

⇒ This does **not** compile ∵ `facetime()` is **not** declared in the *static type* of `aPhone` (`SmartPhone`).

Notes on Type Cast (1)

- Given variable **v** of ***static type*** ST_v, it is *compilable* to cast **v** to C, as long as C is an **ancestor** or **descendant** of ST_v.
- Without cast, we can **only** call methods defined in ST_v on v.
- Casting v to C creates for v an alias with ***ST*** C.
  $\Rightarrow$ All methods that are defined in C can be called.

```
Android myPhone = new GalaxyS21Plus();
/* can call methods declared in Android on myPhone
 * dial, surfweb, skype  ✓  sideSync  × */
SmartPhone sp = (SmartPhone) myPhone;
/* Compiles OK ∵ SmartPhone is an ancestor class of Android
 * expectations on sp narrowed to methods in SmartPhone
 * sp.dial, sp.surfweb  ✓  sp.skype, sp.sideSync  × */
GalaxyS21Plus ga = (GalaxyS21Plus) myPhone;
/* Compiles OK ∵ GalaxyS21Plus is a descendant class of Android
 * expectations on ga widened to methods in GalaxyS21Plus
 * ga.dial, ga.surfweb, ga.skype, ga.sideSync  ✓ */
```

Reference Type Casting: Danger (1)

```
1 Student jim = new NonResidentStudent("J. Davis");
2 ResidentStudent rs = (ResidentStudent) jim;
3 rs.setPremiumRate(1.5);
```

- **L1** is *legal*: `NonResidentStudent` is a **descendant** of the static type of `jim` (`Student`).
- **L2** is *legal* (where the cast type is `ResidentStudent`):
  - cast type is **descendant** of `jim`'s ST (`Student`).
  - cast type is **descendant** of `rs`'s ST (`ResidentStudent`).
- **L3** is *legal* ∵ `setPremiumRate` is in `rs`' ***ST*** `ResidentStudent`.
- Java compiler is *unable to infer* that `jim`'s *dynamic type* in **L2** is actually `NonResidentStudent`.
- Executing **L2** will result in a *`ClassCastException`*.
  ∵ Attribute `premiumRate` (expected from a ***ResidentStudent***) is *undefined* on the ***NonResidentStudent*** object being cast.

Reference Type Casting: Danger (2)

```
1 SmartPhone aPhone = new GalaxyS21Plus();
2 IPhone13Pro forHeeyeon = (IPhone13Pro) aPhone;
3 forHeeyeon.quickTake();
```

- **L1** is *legal*: `GalaxyS21Plus` is a **descendant** of the static type of `aPhone` (`SmartPhone`).
- **L2** is *legal* (where the cast type is `Iphone6sPlus`):
  - cast type is **descendant** of `aPhone`'s ST (`SmartPhone`).
  - cast type is **descendant** of `forHeeyeon`'s ST (`IPhone13Pro`).
- **L3** is *legal* ∵ `quickTake` is in `forHeeyeon`' ***ST*** `IPhone13Pro`.
- Java compiler is *unable to infer* that `aPhone`'s *dynamic type* in **L2** is actually `GalaxyS21Plus`.
- Executing **L2** will result in a *`ClassCastException`*.
  ∵ Methods `facetime`, `quickTake` (expected from an ***IPhone13Pro***) is *undefined* on the ***GalaxyS21Plus*** object being cast.

Notes on Type Cast (2.1)

Given a variable *v* of static type ST_v and dynamic type DT_v:

- `(C) v` is ***compilable*** if `C` is ST_v's **ancestor** or **descendant**.
- Casting `v` to `C`'s ***ancestor***/***descendant*** ***narrows***/***widens*** expectations.
- However, being ***compilable*** does not guarantee ***runtime-error-free***!

```
1 SmartPhone myPhone = new Samsung();
2 /* ST of myPhone is SmartPhone; DT of myPhone is Samsung */
3 GalaxyS21Plus ga = (GalaxyS21Plus) myPhone;
4 /* Compiles OK ∵ GalaxyS21Plus is a descendant class of SmartPhone
5  * can now call methods declared in GalaxyS21Plus on ga
6  * ga.dial, ga.surfweb, ga.skype, ga.sideSync  ✓ */
```

- Type cast in **L3** is ***compilable***.
- Executing **L3** will cause `ClassCastException`.

  L3: `myPhone`'s *DT* `Samsung` cannot meet expectations of the temporary *ST* `GalaxyS21Plus` (e.g., `sideSync`).

Notes on Type Cast (2.2)

Given a variable *v* of static type ST_v and dynamic type DT_v:

- `(C) v` is *compilable* if `C` is ST_v's **ancestor** or **descendant**.
- Casting `v` to `C`'s ***ancestor***/***descendant*** ***narrows***/***widens*** expectations.
- However, being *compilable* does not guarantee ***runtime-error-free***!

```
1 SmartPhone myPhone = new Samsung();
2 /* ST of myPhone is SmartPhone; DT of myPhone is Samsung */
3 IPhone13Pro ip = (IPhone13Pro) myPhone;
4 /* Compiles OK ∵ IPhone13Pro is a descendant class of SmartPhone
5  * can now call methods declared in IPhone13Pro on ip
6  * ip.dial, ip.surfweb, ip.facetime, ip.quickTake ✓ */
```

- Type cast in **L3** is *compilable*.
- Executing **L3** will cause `ClassCastException`.

  L3: `myPhone`'s *DT* `Samsung` cannot meet expectations of the temporary *ST* `IPhone13Pro` (e.g., `quickTake`).

Notes on Type Cast (2.3)

A cast `(C) v` is ***compilable*** and ***runtime-error-free*** if *C* is located along the **ancestor path** of DT_v.

e.g., Given **_Android_** myPhone = new **_Samsung_**();

- Cast `myPhone` to a class along the **ancestor path** of its ***DT Samsung***.
- Casting `myPhone` to a class with more expectations than its ***DT Samsung*** (e.g., `GalaxyS21Plus`) will cause `ClassCastException`.
- Casting `myPhone` to a class irrelevant to its ***DT Samsung*** (e.g., `HuaweiMate40Pro`) will cause `ClassCastException`.

Required Reading: Static Types, Dynamic Types, Casts

https://www.eecs.yorku.ca/~jackie/teaching/lectures/2024/F/EECS2030/notes/EECS2030_F24_Notes_Static_Types_Cast.pdf

Compilable Cast vs. Exception-Free Cast

```
class A { }
class B extends A { }
class C extends B { }
class D extends A { }
```

```
1 B b = new C();
2 D d = (D) b;
```

- After **L1**:
  - ***ST*** of `b` is `B`
  - ***DT*** of `b` is `C`
- Does **L2** compile? [NO]

  ∵ cast type `D` is neither an ancestor nor a descendant of `b`'s ***ST*** `B`
- Would `D d = (D) ((A) b)` fix **L2**? [YES]

  ∵ cast type `D` is an ancestor of `b`'s cast, temporary ***ST*** `A`
- `ClassCastException` when executing this fixed **L2**? [YES]

  ∵ cast type `D` is not an ancestor of `b`'s ***DT*** `C`

Reference Type Casting: Runtime Check (1)

```
1 Student jim = new NonResidentStudent("J. Davis");
2 if (jim instanceof ResidentStudent ) {
3   ResidentStudent rs = ( ResidentStudent ) jim;
4   rs.setPremiumRate(1.5);
5 }
```

- **L1** is *legal*: `NonResidentStudent` is a **descendant class** of the ***static type*** of `jim` (i.e., `Student`).
- **L2** checks if `jim`'s ***DT*** is a descendant of `ResidentStudent`.

  FALSE ∵ `jim`'s *dynamic type* is `NonResidentStudent`!
- **L3** is *legal*: `jim`'s cast type (i.e., `ResidentStudent`) is a **descendant class** of `rs`'s ***ST*** (i.e., `ResidentStudent`).
- **L3** will not be executed at runtime, hence no `ClassCastException`, thanks to the check in **L2**!

Reference Type Casting: Runtime Check (2)


```
1 SmartPhone aPhone = new GalaxyS21Plus();
2 if (aPhone instanceof IPhone13Pro) {
3   IOS forHeeyeon = (IPhone13Pro) aPhone;
4   forHeeyeon.facetime();
5 }
```

- **L1** is *legal*: `GalaxyS21Plus` is a **descendant class** of the static type of `aPhone` (i.e., `SmartPhone`).
- **L2** checks if `aPhone`'s ***DT*** is a <u>descendant</u> of `IPhone13Pro`.

  FALSE $\because$ `aPhone`'s *dynamic type* is `GalaxyS21Plus`!
- **L3** is *legal*: `aPhone`'s cast type (i.e., `IPhone13Pro`) is a **descendant class** of `forHeeyeon`'s ***static type*** (i.e., `IOS`).
- **L3** will not be executed at runtime, hence no `ClassCastException`, thanks to the check in **L2**!

Notes on the `instanceof` Operator (1)

Given a reference variable `v` and a class `C`, you write

`v instanceof C`

to check if the ***dynamic type*** of `v`, at the moment of being checked, is a **descendant class** of `C` (so that `(C) v` is safe).

```
SmartPhone myPhone = new Samsung();
println(myPhone instanceof Android);
/* true ∵ Samsung is a descendant of Android */
println(myPhone instanceof Samsung);
/* true ∵ Samsung is a descendant of Samsung */
println(myPhone instanceof GalaxyS21);
/* false ∵ Samsung is not a descendant of GalaxyS21 */
println(myPhone instanceof IOS);
/* false ∵ Samsung is not a descendant of IOS */
println(myPhone instanceof IPhone13Pro);
/* false ∵ Samsung is not a descendant of IPhone13Pro */
```

⇒ ***Samsung*** is the most specific type which `myPhone` can be **safely** cast to.

Notes on the `instanceof` Operator (2)

Given a reference variable `v` and a class `C`,

`v instanceof C` checks if the ***dynamic type*** of `v`, at the moment of being checked, is a `descendant class` of `C`.

```
1  SmartPhone myPhone = new Samsung();
2  /* ST of myPhone is SmartPhone; DT of myPhone is Samsung */
3  if(myPhone instanceof Samsung) {
4    Samsung samsung = (Samsung) myPhone;
5  }
6  if(myPhone instanceof GalaxyS21Plus) {
7    GalaxyS21Plus galaxy = (GalaxyS21Plus) myPhone;
8  }
9  if(myphone instanceof HuaweiMate40Pro) {
10   Huawei hw = (HuaweiMate40Pro) myPhone;
11 }
```

- **L3** evaluates to *true*. [*safe* to cast]
- **L6** and **L9** evaluate to *false*. [*unsafe* to cast]

  This prevents **L7** and **L10**, causing `ClassCastException` if executed, from being executed.

Static Types, Casts, Polymorphism (1.1)


```
class SmartPhone {
  void dial() { ... }
}
class IOS extends SmartPhone {
  void facetime() { ... }
}
class IPhone13Pro extends IOS {
  void quickTake() { ... }
}
```

```
SmartPhone sp = new IPhone13Pro();   ✓
sp.dial();   ✓
sp.facetime();   ×
sp.quickTake();   ×
```

Static type of *sp* is `SmartPhone`

⇒ can only call methods defined in `SmartPhone` on *sp*

Static Types, Casts, Polymorphism (1.2)

```
class SmartPhone {
  void dial() { ... }
}
class IOS extends SmartPhone {
  void facetime() { ... }
}
class IPhone13Pro extends IOS {
  void quickTake() { ... }
}
```

```
IOS ip = new IPhone13Pro();   ✓
ip.dial();   ✓
ip.facetime();   ✓
ip.quickTake();   ×
```

Static type of *ip* is `IOS`

⇒ can only call methods defined in `IOS` on *ip*

Static Types, Casts, Polymorphism (1.3)

```
class SmartPhone {
  void dial() { ... }
}
class IOS extends SmartPhone {
  void facetime() { ... }
}
class IPhone13Pro extends IOS {
  void quickTake() { ... }
}
```

```
IPhone13Pro ip6sp = new IPhone13Pro();   ✓
ip6sp.dial();   ✓
ip6sp.facetime();   ✓
ip6sp.quickTake();   ✓
```

Static type of *ip6sp* is `IPhone13Pro`

⇒ can call all methods defined in `IPhone13Pro` on *ip6sp*

Static Types, Casts, Polymorphism (1.4)

```
class SmartPhone {
  void dial() { ... }
}
class IOS extends SmartPhone {
  void facetime() { ... }
}
class IPhone13Pro extends IOS {
  void quickTake() { ... }
}
```

```
1 SmartPhone sp = new IPhone13Pro();     ✓
2 ((IPhone13Pro) sp).dial();     ✓
3 ((IPhone13Pro) sp).facetime();     ✓
4 ((IPhone13Pro) sp).quickTake();     ✓
```

L4 is equivalent to the following two lines:

```
IPhone13Pro ip6sp = (IPhone13Pro) sp;
ip6sp.quickTake();
```

Static Types, Casts, Polymorphism (2)

Given a reference variable declaration

```
C v;
```

- *Static type* of reference variable *v* is class *C*
- A method call `v.m` is valid if *m* is a method **defined** in class ***C***.
- Despite the *dynamic type* of *v*, you are only allowed to call methods that are defined in the *static type* `C` on *v*.
- If you are certain that *v*'s *dynamic type* can be expected **more** than its *static type*, then you may use an `insanceof` check and a cast.

```
Course eecs2030 = new Course("EECS2030", 500.0);
Student s = new ResidentStudent("Jim");
s.register(eecs2030);
if(s instanceof ResidentStudent) {
  ((ResidentStudent) s).setPremiumRate(1.75);
  System.out.println(((ResidentStudent) s).getTuition());
}
```

Polymorphism: Method Parameters (1)

```
1 class StudentManagementSystem {
2   Student [] ss; /* ss[i] has static type Student */ int c;
3   void addRS(ResidentStudent rs) { ss[c] = rs; c ++; }
4   void addNRS(NonResidentStudent nrs) { ss[c] = nrs; c++; }
5   void addStudent(Student s) { ss[c] = s; c++; } }
```

- **L3**: `ss[c] = rs` is valid. ∵ RHS's ST `ResidentStudent` is a *descendant class* of LHS's ST `Student`.
- Say we have a `StudentManagementSystem` object `sms`:
  - `sms.addRS(o)` attempts the following assignment (recall call by value), which replaces parameter `rs` by a copy of argument `o`:

    ```
    rs = o;
    ```

  - Whether this argument passing is valid depends on `o`'s *static type*.
- In the signature of a method `m`, if the type of a parameter is class `C`, then we may call method `m` by passing objects whose *static types* are `C`'s *descendants*.

Polymorphism: Method Parameters (2.1)

In the `StudentManagementSystemTester`:

```
Student s1 = new Student();
Student s2 = new ResidentStudent();
Student s3 = new NonResidentStudent();
ResidentStudent rs = new ResidentStudent();
NonResidentStudent nrs = new NonResidentStudent();
StudentManagementSystem sms = new StudentManagementSystem();
sms.addRS(s1);  ×
sms.addRS(s2);  ×
sms.addRS(s3);  ×
sms.addRS(rs);  ✓
sms.addRS(nrs);  ×
sms.addStudent(s1);  ✓
sms.addStudent(s2);  ✓
sms.addStudent(s3);  ✓
sms.addStudent(rs);  ✓
sms.addStudent(nrs);  ✓
```

Polymorphism: Method Parameters (2.2)

In the `StudentManagementSystemTester`:

```
1 Student s = new Student("Stella");
2 /* s' ST: Student; s' DT: Student */
3 StudentManagementSystem sms = new StudentManagementSystem();
4 sms.addRS(s); ×
```

- L4 ***compiles*** with a cast: `sms.addRS((ResidentStudent) s)`
  - *Valid* cast ∵ `(ResidentStudent)` is a descendant of `s`' ***ST***.
  - *Valid* call ∵ `s`' temporary ***ST*** (`ResidentStudent`) is now a descendant class of `addRS`'s parameter `rs`' ***ST*** (`ResidentStudent`).
- But, there will be a *`ClassCastException`* at runtime!
  ∵ `s`' ***DT*** (`Student`) is **not** a descendant of `ResidentStudent`.
- We should have written:

```
if(s instanceof ResidentStudent) {
  sms.addRS((ResidentStudent) s);
}
```

The **`instanceof`** expression will evaluate to *false*, meaning it is *unsafe* to cast, thus preventing `ClassCastException`.

Polymorphism: Method Parameters (2.3)

In the `StudentManagementSystemTester`:

```
1 Student s = new NonResidentStudent("Nancy");
2 /* s' ST: Student; s' DT: NonResidentStudent */
3 StudentManagementSystem sms = new StudentManagementSystem();
4 sms.addRS(s); ×
```

- **L4** ***compiles*** with a cast: `sms.addRS((ResidentStudent) s)`
  - *Valid* cast ∵ `(ResidentStudent)` is a descendant of `s`' ***ST***.
  - *Valid* call ∵ `s`' temporary ***ST*** (`ResidentStudent`) is now a descendant class of `addRS`'s parameter `rs`' ***ST*** (`ResidentStudent`).
- But, there will be a *`ClassCastException`* at runtime!
  ∵ `s`' ***DT*** (`NonResidentStudent`) **not** descendant of `ResidentStudent`.
- We should have written:

```
if(s instanceof ResidentStudent) {
  sms.addRS((ResidentStudent) s);
}
```

The **`instanceof`** expression will evaluate to *false*, meaning it is *unsafe* to cast, thus preventing `ClassCastException`.

Polymorphism: Method Parameters (2.4)

In the `StudentManagementSystemTester`:

```
1 Student s = new ResidentStudent("Rachael");
2 /* s' ST: Student; s' DT: ResidentStudent */
3 StudentManagementSystem sms = new StudentManagementSystem();
4 sms.addRS(s); ×
```

- **L4** ***compiles*** with a cast: `sms.addRS((ResidentStudent) s)`
  - *Valid* cast ∵ `(ResidentStudent)` is a descendant of `s`' ***ST***.
  - *Valid* call ∵ `s`' temporary ***ST*** (`ResidentStudent`) is now a descendant class of `addRS`'s parameter `rs`' ***ST*** (`ResidentStudent`).
- And, there will be **no** *`ClassCastException`* at runtime! ∵ `s`' ***DT*** (`ResidentStudent`) is descendant of `ResidentStudent`.
- We should have written:

```
if(s instanceof ResidentStudent) {
  sms.addRS((ResidentStudent) s);
}
```

The **`instanceof`** expression will evaluate to *true*, meaning it is *safe* to cast.

Polymorphism: Method Parameters (2.5)

In the `StudentManagementSystemTester`:

```
1 NonResidentStudent nrs = new NonResidentStudent();
2 /* ST: NonResidentStudent; DT: NonResidentStudent */
3 StudentManagementSystem sms = new StudentManagementSystem();
4 sms.addRS(nrs); ×
```

Will **L4** with a cast compile?

```
sms.addRS( (ResidentStudent) nrs)
```

NO ∵ `(ResidentStudent)` is ***not*** a descendant of `nrs`'s ***ST*** (`NonResidentStudent`).

Why Inheritance: A Polymorphic Collection of Students

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

```
class StudentManagementSystem {
  Student[] students;
  int numOfStudents;

  void addStudent(Student s) {
    students[numOfStudents] = s;
    numOfStudents ++;
  }

  void registerAll (Course c) {
    for(int i = 0; i < numberOfStudents; i ++) {
      students[i].register(c)
    }
  }
}
```

a collection of students without inheritance

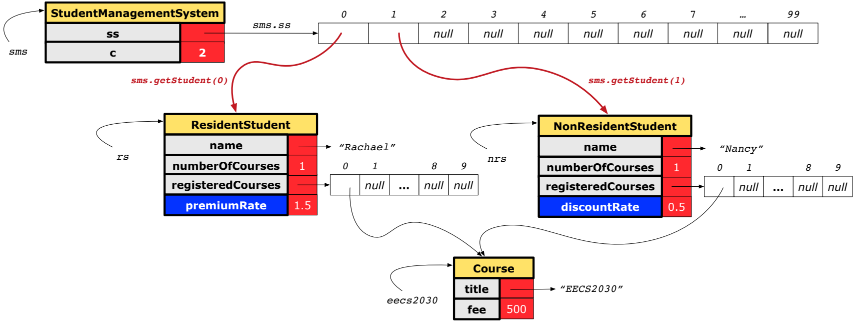
Polymorphism and Dynamic Binding: A Polymorphic Collection of Students (1)

```
ResidentStudent rs = new ResidentStudent("Rachael");
rs.setPremiumRate(1.5);
NonResidentStudent nrs = new NonResidentStudent("Nancy");
nrs.setDiscountRate(0.5);
StudentManagementSystem sms = new StudentManagementSystem();
sms.addStudent( rs ); /* polymorphism */
sms.addStudent( nrs ); /* polymorphism */
Course eecs2030 = new Course("EECS2030", 500.0);
sms.registerAll(eecs2030);
for(int i = 0; i < sms.numberOfStudents; i ++) {
  /* Dynamic Binding:
   * Right version of getTuition will be called */
  System.out.println(sms.students[i]. getTuition() );
}
```

Polymorphism and Dynamic Binding: A Polymorphic Collection of Students (2)

At runtime, attribute `sms.ss` is a *polymorphic* array:

- ***Static type*** of each item is as declared: ***Student***
- ***Dynamic type*** of each item is a **descendant** of ***Student***: ***ResidentStudent***, ***NonResidentStudent***



Polymorphism: Return Types (1)

```
1  class StudentManagementSystem {
2    Student[] ss; int c;
3    void addStudent(Student s) { ss[c] = s; c++; }
4    Student getStudent(int i) {
5      Student s = null;
6      if(i < 0 || i >= c) {
7        throw new InvalidStudentIndexException("Invalid index.");
8      }
9      else {
10       s = ss[i];
11     }
12     return s;
13   } }
```

L4: `Student` is ***static type*** of `getStudent`'s return value.

L10: `ss[i]`'s ST (`Student`) is **descendant** of `s`' ST (`Student`).

Question: What can be the ***dynamic type*** of `s` after **L10**?

Answer: All descendant classes of `Student`.

Polymorphism: Return Types (2)

```java
Course eecs2030 = new Course("EECS2030", 500);
ResidentStudent rs = new ResidentStudent("Rachael");
rs.setPremiumRate(1.5); rs.register(eecs2030);
NonResidentStudent nrs = new NonResidentStudent("Nancy");
nrs.setDiscountRate(0.5); nrs.register(eecs2030);
StudentManagementSystem sms = new StudentManagementSystem();
sms.addStudent(rs); sms.addStudent(nrs);
Student s = sms.getStudent(0) ; /* dynamic type of s? */
```

static return type: Student

```java
print(s instanceof Student && s instanceof ResidentStudent);/*true*/
print(s instanceof NonResidentStudent); /* false */
print( s.getTuition() );/*Version in ResidentStudent called:750*/
ResidentStudent rs2 = sms.getStudent(0); ×
s = sms.getStudent(1) ; /* dynamic type of s? */
```

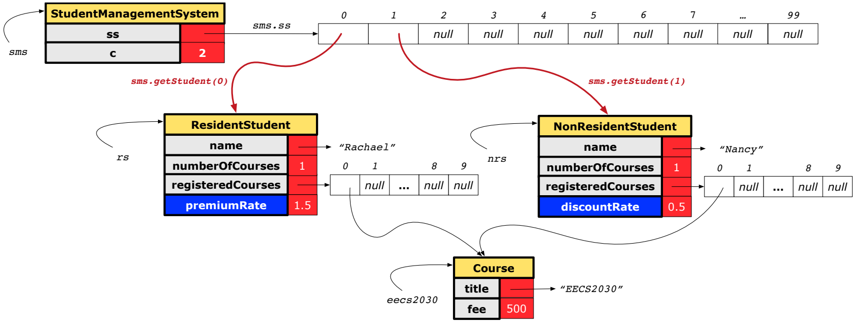
static return type: Student

```java
print(s instanceof Student && s instanceof NonResidentStudent);/*true*/
print(s instanceof ResidentStudent); /* false */
print( s.getTuition() );/*Version in NonResidentStudent called:250*/
NonResidentStudent nrs2 = sms.getStudent(1); ×
```

Polymorphism: Return Types (3)

At runtime, attribute `sms.ss` is a *polymorphic* array:

- ***Static type*** of each item is as declared: ***Student***
- ***Dynamic type*** of each item is a **descendant** of ***Student***: ***ResidentStudent***, ***NonResidentStudent***



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

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

  $\because$ 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 due to dynamic binding, whether or not a `ClassCastException` will occur, *etc.*) depends on the ***dynamic types*** of relevant variables.

  $\Rightarrow$ 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`	Is `y`'s ***ST*** a **descendant** of `x`'s ***ST***?
`x.m(y)`	Is method `m` defined in `x`'s ***ST***? Is `y`'s ***ST*** a **descendant** of `m`'s parameter's ***ST***?
`z = x.m(y)`	Is method `m` defined in `x`'s ***ST***? Is `y`'s ***ST*** a **descendant** of `m`'s parameter's ***ST***? Is ***ST*** of `m`'s return value a **descendant** of `z`'s ***ST***?
`(C) y`	Is `C` an **ancestor** or a **descendant** of `y`'s ***ST***?
`x = (C) y`	Is `C` an **ancestor** or a **descendant** of `y`'s ***ST***? Is `C` a **descendant** of `x`'s ***ST***?
`x.m((C) y)`	Is `C` an **ancestor** or a **descendant** of `y`'s ***ST***? Is method `m` defined in `x`'s ***ST***? Is `C` a **descendant** of `m`'s parameter's ***ST***?

Even if $\boxed{\texttt{(C) y}}$ compiles OK, there will be a runtime `ClassCastException` if `C` is not an **ancestor** of `y`'s ***DT***!

Root of the Java Class Hierarchy

- Implicitly:
  - Every class is a *child/sub* class of the `Object` class.
  - The `Object` class is the *parent/super* class of every class.
- There are two useful *accessor methods* that every class *inherits* from the `Object` class:
  - `boolean equals(Object other)`
    Indicates whether some other object is “equal to” this one.
    - The default definition inherited from `Object`:

```
boolean equals(Object other) {
  return (this == other); }
```

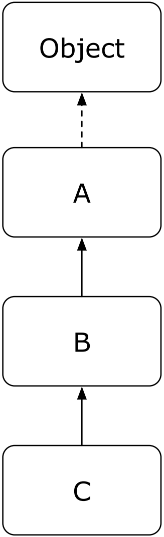
  - `String toString()`
    Returns a string representation of the object.
- Very often when you define new classes, you want to *redefine* / *override* the inherited definitions of `equals` and `toString`.

Overriding and Dynamic Binding (1)

`Object` is the common parent/super class of every class.

- Every class inherits the *default version* of `equals`
- Say a reference variable *v* has ***dynamic type*** *D*:
  - **Case 1** *D* *overrides* `equals`
    ⇒ *v.equals(...)* invokes the *overridden version* in *D*
  - **Case 2** *D* does *not override* `equals`
    Case 2.1 At least one ancestor classes of *D* *override* `equals`
    ⇒ *v.equals(...)* invokes the *overridden version* in the ***closest ancestor class***
    Case 2.2 No ancestor classes of *D* *override* `equals`
    ⇒ *v.equals(...)* invokes *default version* inherited from `Object`.
- Same principle applies to the `toString` method, and all overridden methods in general.

Overriding and Dynamic Binding (2.1)



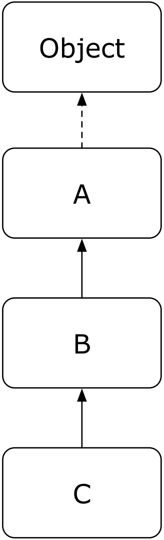
boolean equals (Object obj) {
  return this == obj;
}

```
class A {
  /*equals not overridden*/
}
class B extends A {
  /*equals not overridden*/
}
class C extends B {
  /*equals not overridden*/
}
```

```
1  Object c1 = new C();
2  Object c2 = new C();
3  println(c1.equals(c2));
```

L3 calls which version of `equals`? [`Object`]

Overriding and Dynamic Binding (2.2)




```
boolean equals (Object obj) {
  return this == obj;
}
```

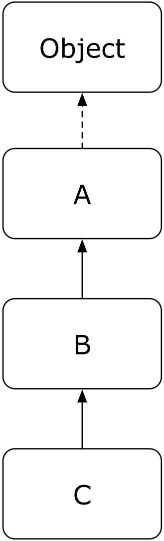
```
boolean equals (Object obj) {
  /* overridden version */
}
```

```
class A {
  /*equals not overridden*/
}
class B extends A {
  /*equals not overridden*/
}
class C extends B {
  boolean equals(Object obj) {
    /* overridden version */
  }
}
```

```
1 Object c1 = new C();
2 Object c2 = new C();
3 println(c1.equals(c2));
```

L3 calls which version of `equals`? [C]

Overriding and Dynamic Binding (2.3)




```
boolean equals (Object obj) {
  return this == obj;
}
```

```
boolean equals (Object obj) {
  /* overridden version */
}
```

```
class A {
  /*equals not overridden*/
}
class B extends A {
  boolean equals(Object obj) {
    /* overridden version */
  }
}
class C extends B {
  /*equals not overridden*/
}
```

```
1 Object c1 = new C();
2 Object c2 = new C();
3 println(c1.equals(c2));
```

L3 calls which version of `equals`? [B]

Behaviour of Inherited `toString` Method (1)

```
Point p1 = new Point(2, 4);
System.out.println(p1);
```

```
Point@677327b6
```

- Implicitly, the `toString` method is called inside the `println` method.
- By default, the address stored in `p1` gets printed.
- We need to *redefine* / *override* the `toString` method, inherited from the `Object` class, in the `Point` class.

Behaviour of Inherited `toString` Method (2)

```
class Point {
  double x;
  double y;
  public String toString() {
    return "(" + this.x + ", " + this.y + ")";
  }
}
```

After redefining/overriding the `toString` method:

```
Point p1 = new Point(2, 4);
System.out.println(p1);
```

```
(2, 4)
```

Behaviour of Inherited `toString` Method (3)

Exercise: Override the `equals` and `toString` methods for the `ResidentStudent` and `NonResidentStudent` classes.

Beyond this lecture. . .

- Implement the ***inheritance hierarchy*** of **Students** and reproduce all lecture examples.
- Implement the ***inheritance hierarchy*** of **Smart Phones** and reproduce all lecture examples.

  Hints. Pay attention to:
  - ***Valid***? ***Compiles***?
  - ***ClassCastException***?
- Study the `ExampleTypeCasts` example: draw the ***inheritance hierarchy*** and experiment with the various substitutions and casts.

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Learning Outcomes

Why Inheritance: A Motivating Example

Why Inheritance: A Motivating Example

No Inheritance: `ResidentStudent` Class

No Inheritance: `NonResidentClass`

No Inheritance: Testing Student Classes

No Inheritance:
Issues with the Student Classes

No Inheritance: Maintainability of Code (1)

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Within the Resident Package (no modifier)

Visibility of Classes: Across All Classes
Within the Resident Package (no modifier)

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Within the Resident Package (no modifier)

Visibility of Attr./Meth.: Across All Packages
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Use of the `protected` Modifier

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Visibility of Attr./Meth.

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Reference Type Casting: Motivation (1.2)

Reference Type Casting: Motivation (2.1)

Reference Type Casting: Motivation (2.2)

Type Cast: Named or Anonymous

Notes on Type Cast (1)

Reference Type Casting: Danger (1)

Reference Type Casting: Danger (2)

Notes on Type Cast (2.1)

Notes on Type Cast (2.2)

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Notes on Type Cast (2.3)

Required Reading:
Static Types, Dynamic Types, Casts

Compilable Cast vs. Exception-Free Cast

Reference Type Casting: Runtime Check (1)

Reference Type Casting: Runtime Check (2)

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Notes on the `instanceof` Operator (2)

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A Polymorphic Collection of Students

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Behaviour of Inherited `toString` Method (1)

Behaviour of Inherited `toString` Method (2)

Behaviour of Inherited `toString` Method (3)

Beyond this lecture...