

# Inheritance



EECS2030 B & E: Advanced  
Object Oriented Programming  
Fall 2021

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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**

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## Why Inheritance: A Motivating Example



**Problem:** A student management system stores data about students. There are two kinds of university students: resident students and non-resident students. Both kinds of students have a name and a list of registered courses. Both kinds of students are restricted to register for no more than 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.

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## Why Inheritance: A Motivating Example



**Problem:** A *student management system* stores data about students. There are two kinds of university students: *resident* students and *non-resident* students. Both kinds of students have a *name* and a list of *registered courses*. Both kinds of students are restricted to *register* for no more than 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.

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## No Inheritance: Resident Student 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;
    }
}
```

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## No Inheritance: Testing Student Classes



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

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());
    }
}
```

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## No Inheritance: NonResident Student Class



```
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;
    }
}
```

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## 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**.

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## 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!

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## 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**!

a polymorphic collection of students

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## 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 * ...;
}
```

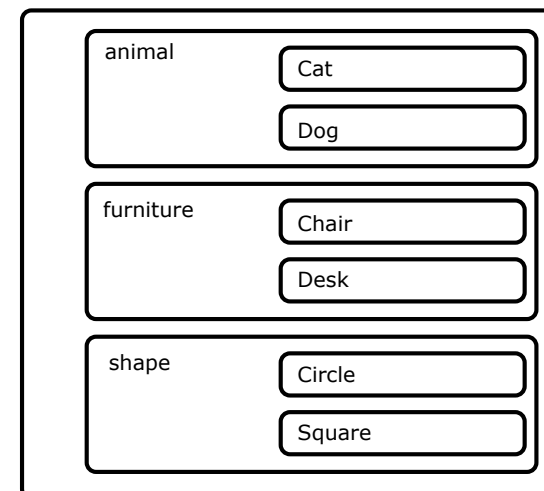
Changes needed for getTuition method in **both** student classes!

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## Visibility: Project, Packages, Classes



CollectionOfStuffs



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## Visibility of Classes



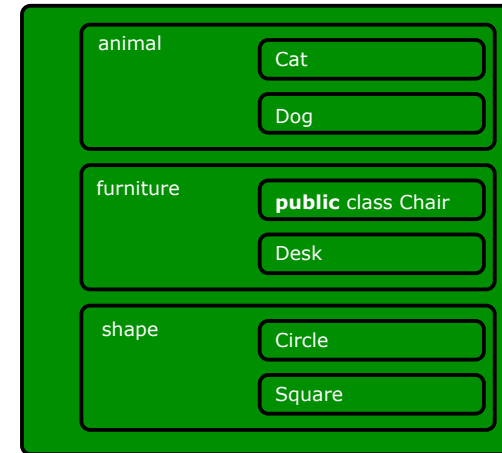
- Only one modifier for declaring visibility of classes: **public**.
- Use of **private** is forbidden for declaring a class.  
e.g., `private class Chair` is **not** allowed!!
- **Visibility** of a class may be declared using a modifier, indicating that it is accessible:
  1. Across classes within its residing package [ no modifier ]  
e.g., Declare `class Chair { ... }`
  2. Across packages [ **public** ]  
e.g., Declare `public class Chair { ... }`
- Consider class `Chair` which resides in:
  - package `furniture`
  - project `CollectionOfStuffs`

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



CollectionOfStuffs

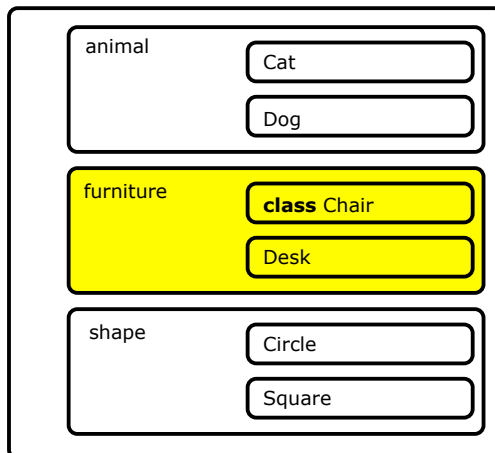


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## Visibility of Classes: Across All Classes Within the Resident Package (no modifier)



CollectionOfStuffs



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## Visibility of Attributes/Methods: Using Modifiers to Define Scopes



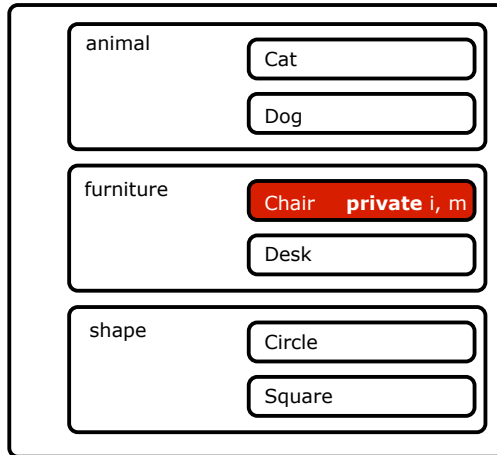
- Two modifiers for declaring visibility of attributes/methods: **public** and **private**
- **Visibility** of an attribute or a method may be declared using a modifier, indicating that it is accessible:
  1. Within its residing class (**most** restrictive) [ **private** ]  
e.g., Declare attribute `private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

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



CollectionOfStuffs

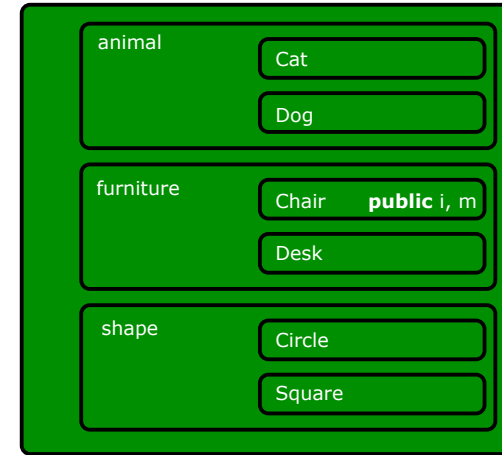


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## Visibility of Attr./Meth.: Across All Packages Within the Resident Project (`public`)



CollectionOfStuffs

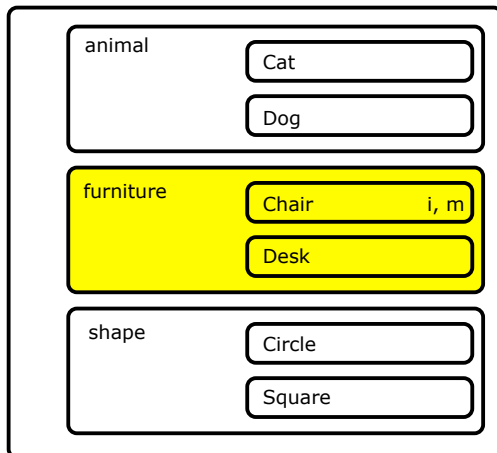


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## Visibility of Attr./Meth.: Across All Classes Within the Resident Package (no modifier)



CollectionOfStuffs



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## Use of the `protected` Modifier

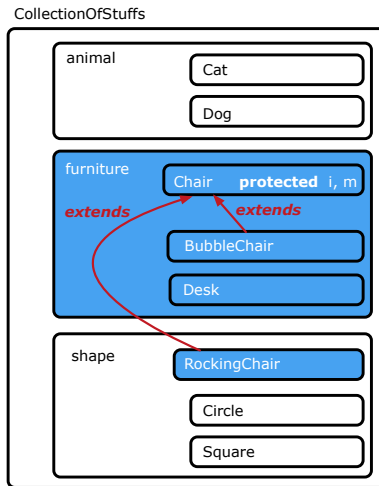


- **private** attributes are not inherited to subclasses.
- package-level attributes (i.e., with **no modifier**) and project-level attributes (i.e., **public**) are inherited.
- What if we want attributes to be:
  - **visible** to sub-classes outside the current package, but still
  - **invisible**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

Use **protected**!

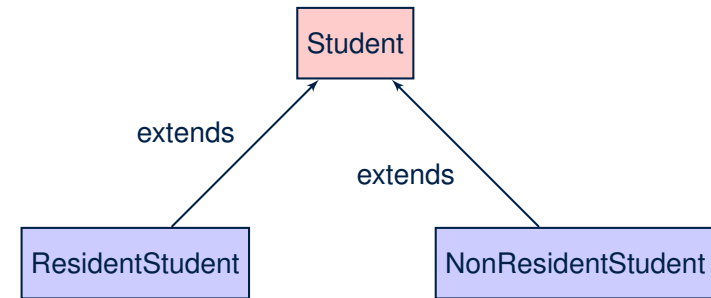
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## Visibility of Attr./Meth.: Across All Methods Same Package and Sub-Classes (protected)



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## Inheritance Architecture



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## Visibility of Attributes/Methods



modifier \ scope	CLASS	PACKAGE	SUBCLASS (same pkg)	SUBCLASS (different pkg)	NON-SUBCLASS (across Project)
public	Green	Green	Green	Green	Green
protected	Green	Green	Green	Green	Red
no modifier	Green	Red	Green	Red	Red
private	Green	Red	Red	Red	Red

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.

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## 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 */
    }
}
    
```

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## Inheritance: The Resident Student 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 }

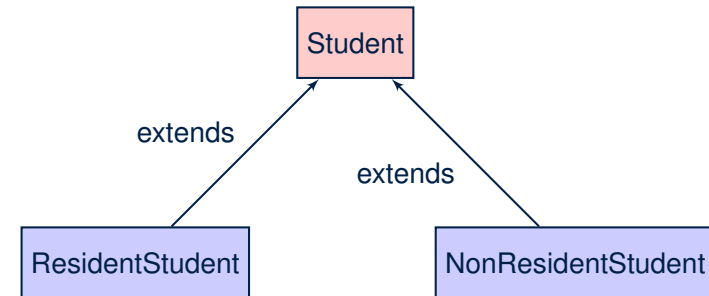
```

- 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 L4 is as if calling Student (name)
- Use of *super* in L8 returns what getTuition() in Student returns.
- Use *super* to refer to attributes/methods defined in the super class:

```
super.name, super.register(c).
```

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## 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.

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## Inheritance: The NonResident Student 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 L4 is as if calling Student (name)
- Use of *super* in L8 returns what getTuition() in Student returns.
- Use *super* to refer to attributes/methods defined in the super class:

```
super.name, super.register(c).
```

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## 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

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## 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.

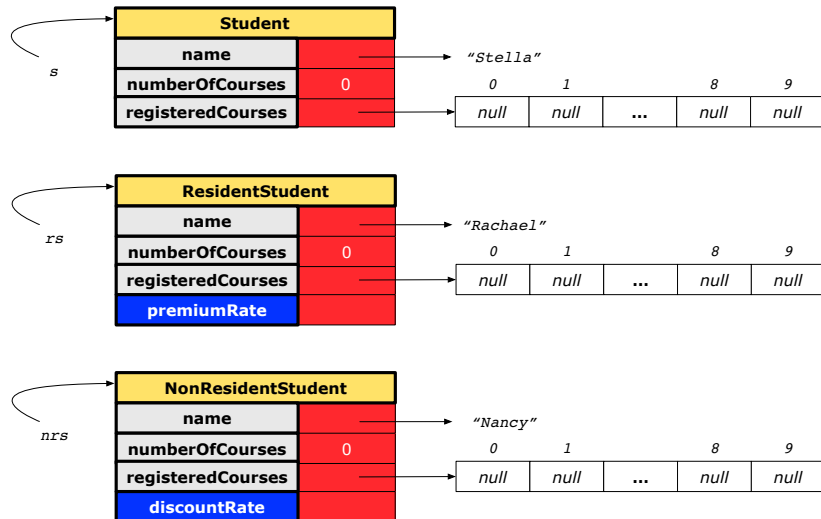
Consider the following instantiations:

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

- How will these initial objects look like?

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## Visualizing Parent/Child Objects (2)



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## Testing the Two Student Sub-Classes

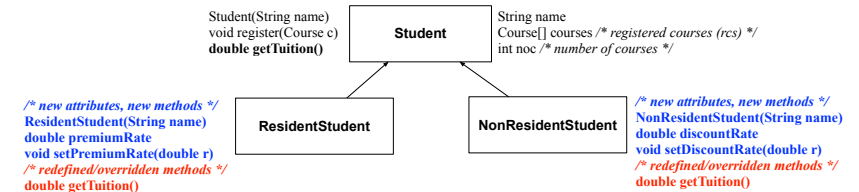


```
public class StudentTester {
    public static void main(String[] args) {
        Course c1 = new Course("EECS2030", 500.00); /* title and fee */
        Course c2 = new Course("EECS3311", 500.00); /* title and fee */
        ResidentStudent jim = new ResidentStudent("J. Davis");
        jim.setPremiumRate(1.25);
        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**.

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## Inheritance Architecture: Static Types & Expectations



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

	name	rcs	noc	reg	getT	pr	setPR	dr	setDR
<i>s</i> .			✓					✗	
<i>rs</i> .			✓			✓			✗
<i>nrs</i> .			✓				✗		✓

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## 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]

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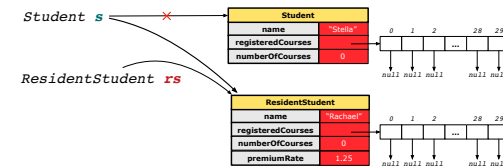
## Polymorphism: Intuition (3)



```

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*!!

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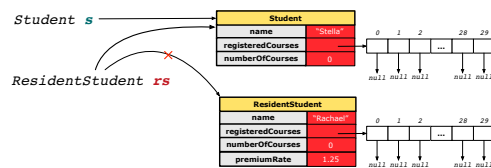
## Polymorphism: Intuition (2)



```

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**

∴ *rs*.premiumRate is *undefined*!!

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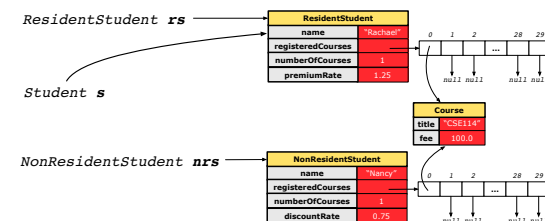
## Dynamic Binding: Intuition (1)



```

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.



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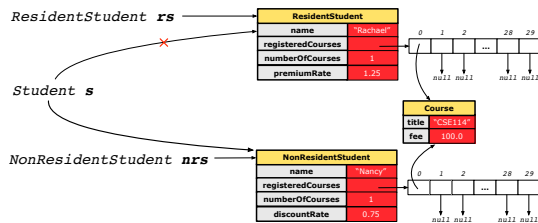
## Dynamic Binding: Intuition (2)

```

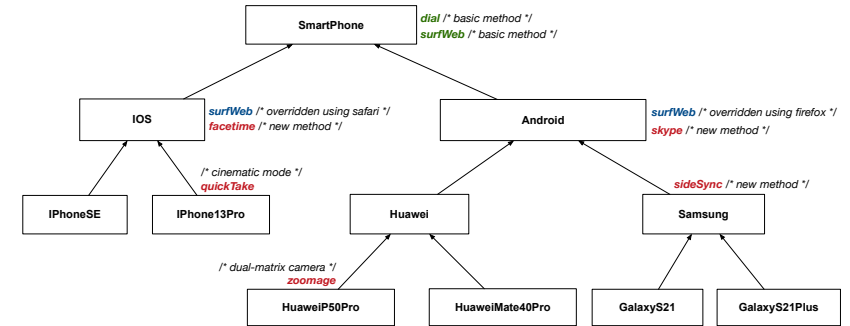
1 Course eecs2030 = new Course("EECS2030", 100.0);
2 Student s;
3 ResidentStudent rs = new ResidentStudent("Rachael");
4 NonResidentStudent nrs = new NonResidentStudent("Nancy");
5 rs.setPremiumRate(1.25); rs.register(eecs2030);
6 nrs.setDiscountRate(0.75); nrs.register(eecs2030);
7 s = rs; System.out.println(s.getTuition());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

```

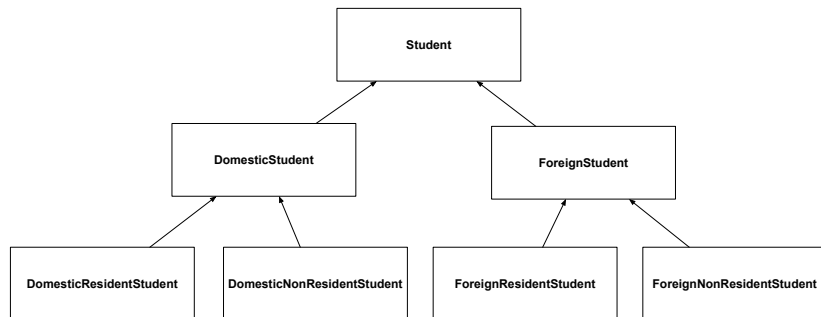
After `s = nrs` (L8), `s` points to a `NonResidentStudent` object.  
 ⇒ Calling `s.getTuition()` applies the `discountRate`.



## Multi-Level Inheritance Hierarchy: Smart Phones



## Multi-Level Inheritance Architecture



## 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



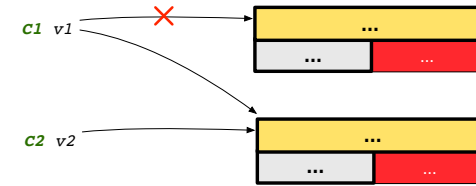
- The **lower** a class is in the type hierarchy, the **more code** it accumulates from its **ancestor classes**:
  - A **descendant class** inherits all code from its **ancestor classes**.
  - A **descendant class** may also:
    - Declare new attributes
    - Define new methods
    - Redefine / Override** 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!).

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## 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!**

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## 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** `C` defines the **expected usages of `v` as a context object**.
- A method call `v.m(...)` is **compilable** if `m` is defined in `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`

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## 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`).
  - $\therefore$  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`).
  - $\therefore$  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`  $\therefore$  `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`  $\therefore$  `facetime` not supported in Android phone.

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## 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.

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## Reference Variable: Changing Dynamic Type (1)

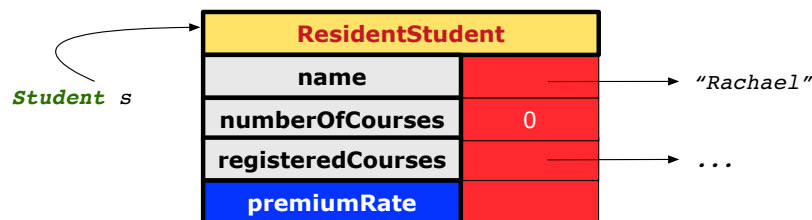


Re-assigning a reference variable to a newly-created object:

- 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 Student is **not a descendant class** of the **static type** of jeremy (i.e., ResidentStudent).

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## 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`).

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## 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 ResidentStudent(...);
NonResidentStudent 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` ✗

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## 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 */
```

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## 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 eeecs2030 = 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 */
    NonResidentStudent nrs = new NonResidentStudent("J. Davis");
    nrs.setDiscountRate(0.5);
    jim = nrs;
    System.out.println(jim.getTuition()); /* 250.0 */
}
}
```

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## Polymorphism and Dynamic Binding (2.1)



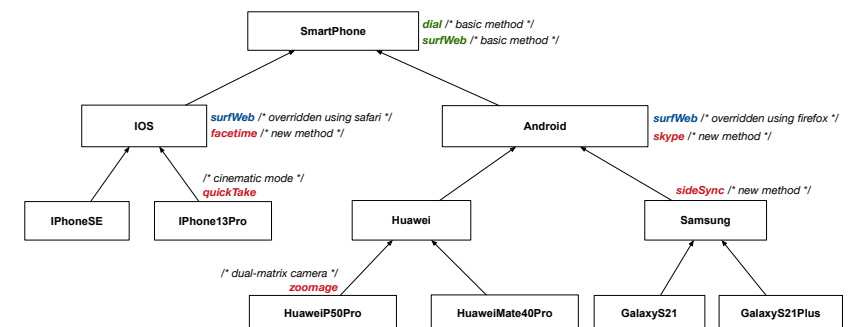
```
class Student {...}
class ResidentStudent extends Student {...}
class NonResidentStudent extends Student {...}
```

```
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 */

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

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## Polymorphism and Dynamic Binding (3.1)



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## 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 */
    }
}
```

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## 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 */
    }
}
```

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## 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` ( $\therefore$  **DT** of rs is `ResidentStudent`).

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## Reference Type Casting: Motivation (1.2)



ST: ResidentStudent      valid substitution      ST: Student

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

an alias whose ST is ResidentStudent

- Variable rs is declared of **static type (ST)** ResidentStudent.
- Variable jim is declared of **ST** Student.
- The cast `(ResidentStudent) 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.

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## 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` ( $\therefore$  **DT** of forHeeyeon is `iPhone13Pro`).

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## 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**  $\equiv$  `(iPhone13Pro) (aPhone.facetime())`: Call, then cast.  
 $\Rightarrow$  This does **not** compile  $\therefore$  `facetime()` is **not** declared in the **static type** of aPhone (`SmartPhone`).

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## Reference Type Casting: Motivation (2.2)

ST: <code>iPhone13Pro</code>	valid substitution	ST: <code>SmartPhone</code>
<code>iPhone13Pro forHeeyeon</code>	=	<code>(iPhone13Pro) aPhone</code> ;
		an alias whose ST is <code>iPhone13Pro</code>

- Variable `forHeeyeon` is declared of **static type** (**ST**) `iPhone13Pro`.
- Variable `aPhone` is declared of **ST** `SmartPhone`.
- The cast `(iPhone13Pro) aPhone` creates for aPhone **a temporary alias**, whose **ST** corresponds to the **cast type** (`iPhone13Pro`).  
 $\Rightarrow$  Such a cast makes the assignment **valid**.  
 $\therefore$  RHS's **ST** (`iPhone13Pro`) is a **descendant** of LHS's **ST** (`iPhone13Pro`).  
 $\Rightarrow$  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`.

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## Notes on Type Cast (1)

- Given variable `v` of **static type** `STv`, it is **compilable** to cast `v` to `C`, as long as `C` is an **ancestor** or **descendant** of `STv`.
- Without cast, we can **only** call methods defined in `STv` 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 ✓ */

```

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## 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.

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## 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.

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## 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).

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## 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).

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## 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 `DTv`.

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`.

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## Required Reading: Static Types, Dynamic Types, Casts



[https://www.eecs.yorku.ca/~jackie/teaching/lectures/2021/F/EECS2030/notes/EECS2030\\_F21\\_Notes\\_Static\\_Types\\_Cast.pdf](https://www.eecs.yorku.ca/~jackie/teaching/lectures/2021/F/EECS2030/notes/EECS2030_F21_Notes_Static_Types_Cast.pdf)

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## 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`

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## 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**!

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## 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 **descendant** of iPhone13Pro.  
**FALSE** ∴ 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**!

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## 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.

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## 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.

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## Static Types, Casts, Polymorphism (1.1)



```
class SmartPhone {
    void dial() { ... }
}
class IOS extends SmartPhone {
    void facetime() { ... }
}
class iPhone13Pro extends IOS {
    void quickTake() { ... }
}
```

```
1 SmartPhone sp = new iPhone13Pro(); ✓
2 sp.dial(); ✓
3 sp.facetime(); ✗
4 sp.quickTake(); ✗
```

**Static type** of  $sp$  is SmartPhone

⇒ can only call methods defined in SmartPhone on  $sp$

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## Static Types, Casts, Polymorphism (1.2)



```
class SmartPhone {
    void dial() { ... }
}
class IOS extends SmartPhone {
    void facetime() { ... }
}
class iPhone13Pro extends IOS {
    void quickTake() { ... }
}
```

```
1 IOS ip = new iPhone13Pro(); ✓
2 ip.dial(); ✓
3 ip.facetime(); ✓
4 ip.quickTake(); ✗
```

**Static type** of *ip* is IOS

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

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## 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();
```

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## Static Types, Casts, Polymorphism (1.3)



```
class SmartPhone {
    void dial() { ... }
}
class IOS extends SmartPhone {
    void facetime() { ... }
}
class iPhone13Pro extends IOS {
    void quickTake() { ... }
}
```

```
1 iPhone13Pro ip6sp = new iPhone13Pro(); ✓
2 ip6sp.dial(); ✓
3 ip6sp.facetime(); ✓
4 ip6sp.quickTake(); ✓
```

**Static type** of *ip6sp* is iPhone13Pro

⇒ can call all methods defined in iPhone13Pro on *ip6sp*

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## 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 instanceof check and a cast.

```
Course eeecs2030 = new Course("EECS2030", 500.0);
Student s = new ResidentStudent("Jim");
s.register(eeecs2030);
if (s instanceof ResidentStudent) {
    ((ResidentStudent) s).setPremiumRate(1.75);
    System.out.println(((ResidentStudent) s).getTuition());
}
```

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## 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.  $\therefore$  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*.

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## 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!  
 $\therefore$  `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`.

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## 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); ✓
```

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## 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!  
 $\therefore$  `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`.

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## 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); ×
```

- o 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).
- o And, there will be **no ClassCastException** at runtime!  
∴ s' **DT** (ResidentStudent) is **descendant** of ResidentStudent.
- o 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.

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## 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)
        }
    }
}
```

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a collection of students without inheritance

## 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).

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



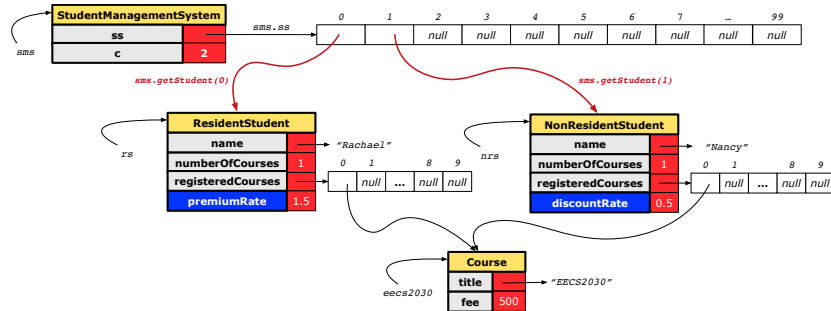
```
1 ResidentStudent rs = new ResidentStudent("Rachael");
2 rs.setPremiumRate(1.5);
3 NonResidentStudent nrs = new NonResidentStudent("Nancy");
4 nrs.setDiscountRate(0.5);
5 StudentManagementSystem sms = new StudentManagementSystem();
6 sms.addStudent(rs); /* polymorphism */
7 sms.addStudent(nrs); /* polymorphism */
8 Course eeecs2030 = new Course("EECS2030", 500.0);
9 sms.registerAll(eeecs2030);
10 for(int i = 0; i < sms.numberOfStudents; i++) {
11     /* Dynamic Binding:
12     * Right version of getTuition will be called */
13     System.out.println(sms.students[i].getTuition());
14 }
```

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## 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**



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## Polymorphism: Return Types (2)

```

1 Course eece2030 = new Course("EECS2030", 500);
2 ResidentStudent rs = new ResidentStudent("Rachael");
3 rs.setPremiumRate(1.5); rs.register(eece2030);
4 NonResidentStudent nrs = new NonResidentStudent("Nancy");
5 nrs.setDiscountRate(0.5); nrs.register(eece2030);
6 StudentManagementSystem sms = new StudentManagementSystem();
7 sms.addStudent(rs); sms.addStudent(nrs);
8 Student s = sms.getStudent(0); /* dynamic type of s? */

          static return type: Student
9 print(s instanceof Student && s instanceof ResidentStudent); /*true*/
10 print(s instanceof NonResidentStudent); /* false */
11 print(s.getTuition()); /*Version in ResidentStudent called:750*/
12 ResidentStudent rs2 = sms.getStudent(0); ×
13 s = sms.getStudent(1); /* dynamic type of s? */

          static return type: Student
14 print(s instanceof Student && s instanceof NonResidentStudent); /*true*/
15 print(s instanceof ResidentStudent); /* false */
16 print(s.getTuition()); /*Version in NonResidentStudent called:250*/
17 NonResidentStudent nrs2 = sms.getStudent(1); ×

```

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## 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?

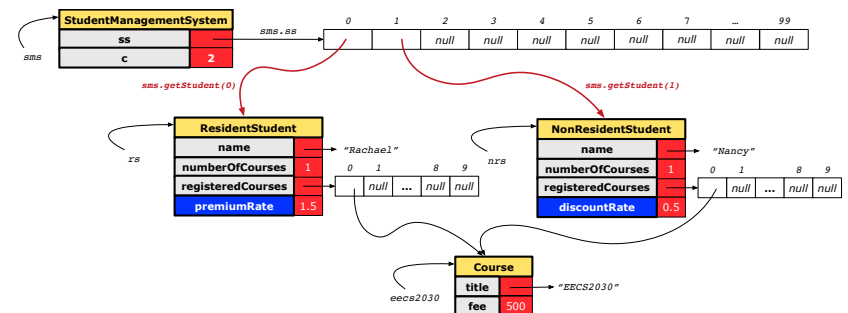
Answer: All descendant classes of Student.

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## 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**



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



- **Whether or not Java code compiles** depends only on the **static types** of relevant variables.
  - ∴ Inferring the **dynamic type** statically is an **undecidable** problem that is inherently impossible to solve.
- **The behaviour of Java code being executed at runtime** (e.g., which version of method is called due to dynamic binding, whether or not a `ClassCastException` will occur, etc.) 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).

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## Summary: Type Checking Rules



CODE	CONDITION TO BE TYPE CORRECT
<code>x = y</code>	Is <code>y</code> 's <b>ST</b> a <b>descendant</b> of <code>x</code> 's <b>ST</b> ?
<code>x.m(y)</code>	Is method <code>m</code> defined in <code>x</code> 's <b>ST</b> ? Is <code>y</code> 's <b>ST</b> a <b>descendant</b> of <code>m</code> 's parameter's <b>ST</b> ?
<code>z = x.m(y)</code>	Is method <code>m</code> defined in <code>x</code> 's <b>ST</b> ? Is <code>y</code> 's <b>ST</b> a <b>descendant</b> of <code>m</code> 's parameter's <b>ST</b> ? Is <b>ST</b> of <code>m</code> 's return value a <b>descendant</b> of <code>z</code> 's <b>ST</b> ?
<code>(C) y</code>	Is <code>C</code> an <b>ancestor</b> or a <b>descendant</b> of <code>y</code> 's <b>ST</b> ?
<code>x = (C) y</code>	Is <code>C</code> an <b>ancestor</b> or a <b>descendant</b> of <code>y</code> 's <b>ST</b> ? Is <code>C</code> a <b>descendant</b> of <code>x</code> 's <b>ST</b> ?
<code>x.m((C) y)</code>	Is <code>C</code> an <b>ancestor</b> or a <b>descendant</b> of <code>y</code> 's <b>ST</b> ? Is method <code>m</code> defined in <code>x</code> 's <b>ST</b> ? Is <code>C</code> a <b>descendant</b> of <code>m</code> 's parameter's <b>ST</b> ?

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

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## 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`.

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## Overriding and Dynamic Binding (1)

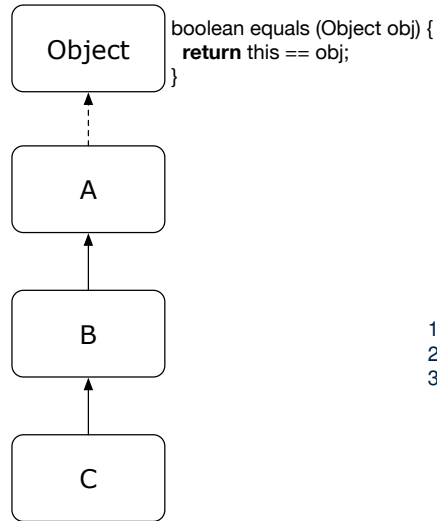


`Object` is the common parent/super class of every class.

- 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.

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## 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*/
}
  
```

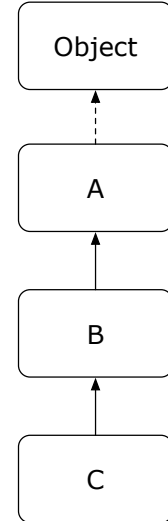
```

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

L3 calls which version of equals? [Object]

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## Overriding and Dynamic Binding (2.3)



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

```

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

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

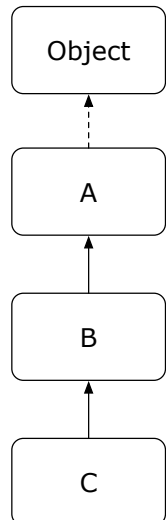
```

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

L3 calls which version of equals? [B]

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## Overriding and Dynamic Binding (2.2)



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

```

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]

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

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## 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.

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## 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)

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## Behaviour of Inherited toString Method (3)



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

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## 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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## Index (1)



### 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)

No Inheritance: Maintainability of Code (2)

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## Index (2)



**No Inheritance:**  
**A Collection of Various Kinds of Students**

**Visibility: Project, Packages, Classes**

**Visibility of Classes**

**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**

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

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## Index (3)



**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**

**Visibility of Attr./Meth.: Across All Methods**  
**Within the Resident Package and Sub-Classes (`protected`)**

**Visibility of Attr./Meth.**

**Inheritance Architecture**

**Inheritance: The `Student` Parent/Super Class**

**Inheritance:**  
**The `ResidentStudent` Child/Sub Class**

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## Index (4)



**Inheritance:**  
**The `NonResidentStudent` Child/Sub Class**

**Inheritance Architecture Revisited**

**Using Inheritance for Code Reuse**

**Visualizing Parent/Child Objects (1)**

**Visualizing Parent/Child Objects (2)**

**Testing the Two Student Sub-Classes**

**Inheritance Architecture:**  
**Static Types & Expectations**

**Polymorphism: Intuition (1)**

**Polymorphism: Intuition (2)**

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## Index (5)



**Polymorphism: Intuition (3)**

**Dynamic Binding: Intuition (1)**

**Dynamic Binding: Intuition (2)**

**Multi-Level Inheritance Architecture**

**Multi-Level Inheritance Hierarchy:**  
**Smart Phones**

**Inheritance Forms a Type Hierarchy**

**Inheritance Accumulates Code for Reuse**

**Static Types Determine Expectations**

**Substitutions via Assignments**

**Rules of Substitution**

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## Index (6)



Reference Variable: Dynamic Type

Visualizing Static Type vs. Dynamic Type

Reference Variable:

Changing Dynamic Type (1)

Reference Variable:

Changing Dynamic Type (2)

Polymorphism and Dynamic Binding (1)

Polymorphism and Dynamic Binding (2.1)

Polymorphism and Dynamic Binding (2.2)

Polymorphism and Dynamic Binding (3.1)

Polymorphism and Dynamic Binding (3.2)

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## Index (7)



Polymorphism and Dynamic Binding (3.3)

Reference Type Casting: Motivation (1.1)

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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## Index (8)



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)

Notes on the instanceof Operator (1)

Notes on the instanceof Operator (2)

Static Types, Casts, Polymorphism (1.1)

Static Types, Casts, Polymorphism (1.2)

Static Types, Casts, Polymorphism (1.3)

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Static Types, Casts, Polymorphism (1.4)

Static Types, Casts, Polymorphism (2)

Polymorphism: Method Parameters (1)

Polymorphism: Method Parameters (2.1)

Polymorphism: Method Parameters (2.2)

Polymorphism: Method Parameters (2.3)

Polymorphism: Method Parameters (2.4)

Polymorphism: Method Parameters (2.5)

Why Inheritance:

A Polymorphic Collection of Students

Polymorphism and Dynamic Binding:

A Polymorphic Collection of Students (1)

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**Polymorphism and Dynamic Binding:**

**A Polymorphic Collection of Students (2)**

**Polymorphism: Return Types (1)**

**Polymorphism: Return Types (2)**

**Polymorphism: Return Types (3)**

**Static Type vs. Dynamic Type:**

**When to consider which?**

**Summary: Type Checking Rules**

**Root of the Java Class Hierarchy**

**Overriding and Dynamic Binding (1)**

**Overriding and Dynamic Binding (2.1)**

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**Overriding and Dynamic Binding (2.2)**

**Overriding and Dynamic Binding (2.3)**

**Behaviour of Inherited toString Method (1)**

**Behaviour of Inherited toString Method (2)**

**Behaviour of Inherited toString Method (3)**

**Beyond this lecture...**

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