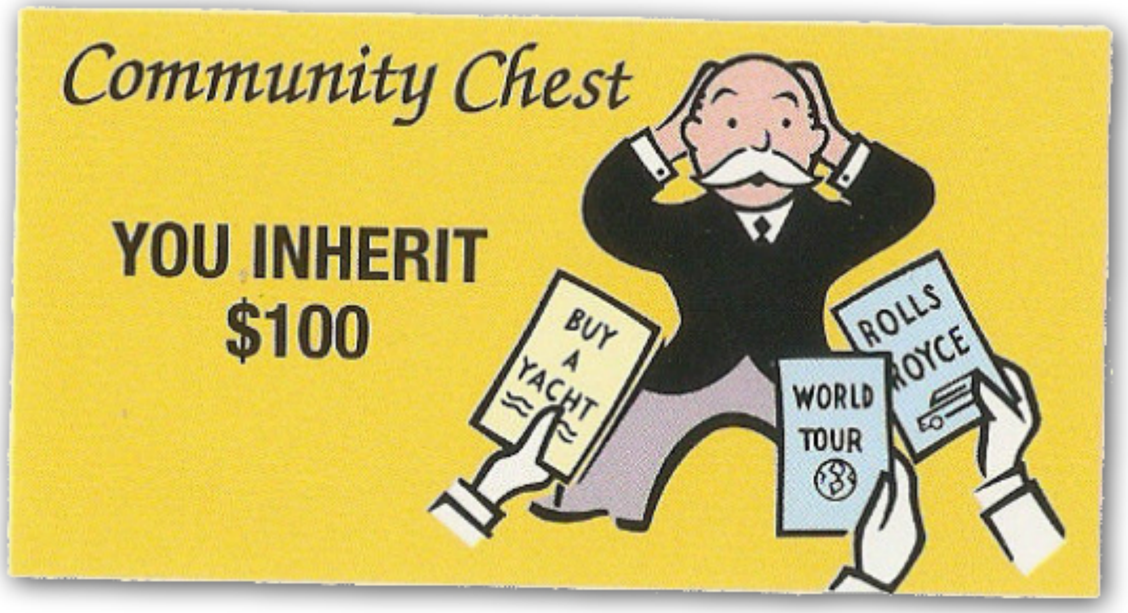
CS 106B

Lecture 27: Inheritance and Polymorphism in C++

Monday, June 5, 2017



Programming Abstractions
Spring 2017
Stanford University
Computer Science Department

Lecturer: Chris Gregg

reading:
Programming Abstractions in C++, Chapter 19

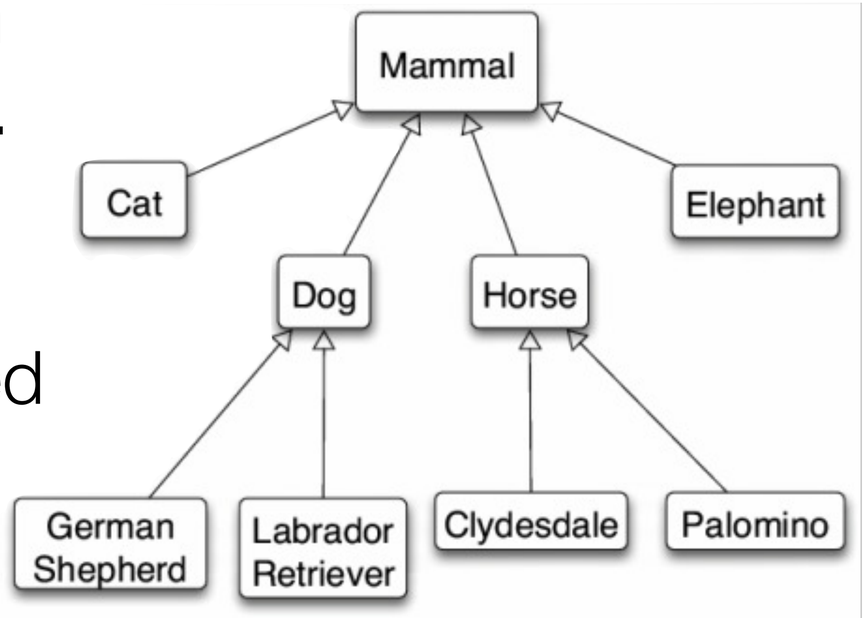
Today's Topics

- Logistics
  - Final Exam prep online: http://web.stanford.edu/class/cs106b/handouts/final.html
  - Final exam is on Friday, June 9th at 8:30am.
  - Course evaluations now open on Axess

- Inheritance and Polymorphism in C++

Inheritance in C++

inheritance: A way to form new classes based on existing classes, taking on their attributes/behavior.



- a way to indicate that classes are related
- a way to share code between two or more related classes (a **hierarchy**)

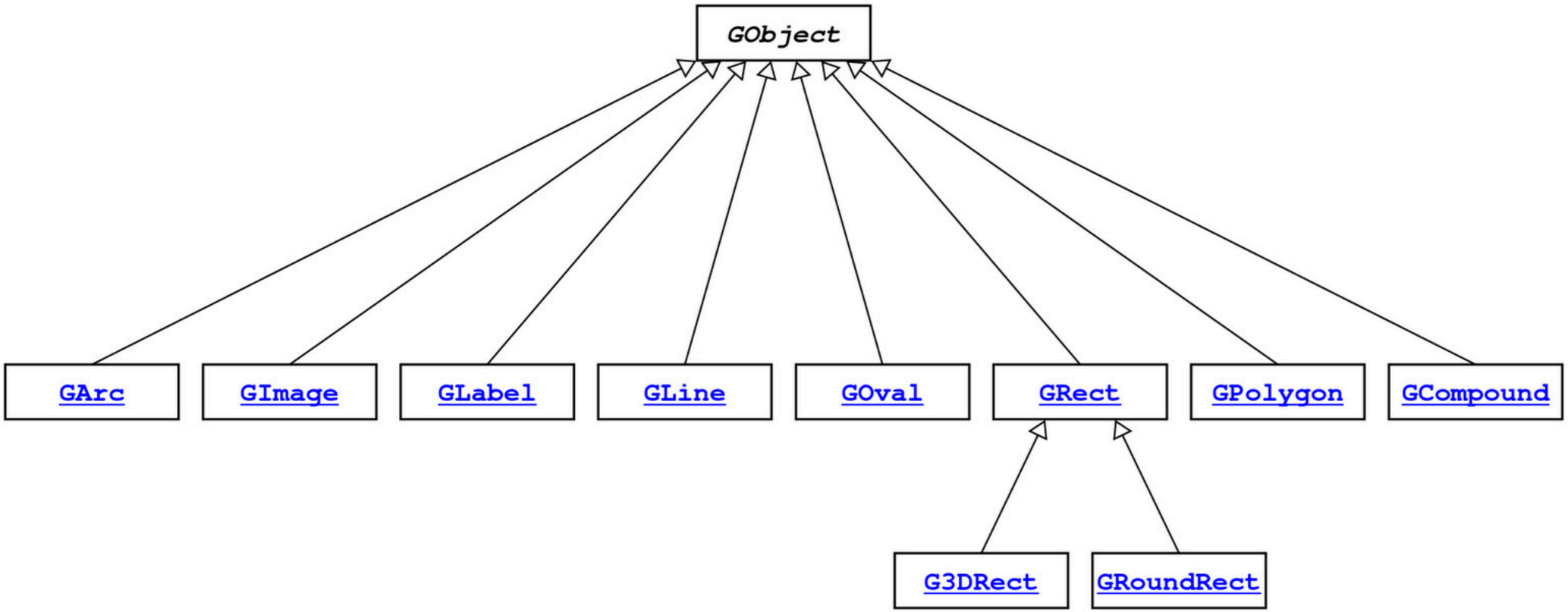
One class can *extend* another, absorbing its data/behavior.

- **superclass** (base class): Parent class that is being extended.
- **subclass** (derived class): Child class that inherits from the superclass.
  - Subclass gets a copy of every field and method from superclass.
  - Subclass can add its own behavior, and/or change inherited behavior.

GObject Hierarchy

The Stanford C++ library contains a hierarchy of graphical objects based on a common base class named `GObject`.

- `GArc, GCompound, GImage, GLabel, GLine, GOval, GPolygon, GRect, G3DRect, GRoundRect, ...`



GObject Members

`GObject` defines the state and behavior common to all shapes:

- `contains(x, y)`
- `getColor(), setColor(color)`
- `getHeight(), getWidth(), getLocation(), setLocation(x, y)`
- `getX(), getY(), setX(x), setY(y), move(dx, dy)`
- `setVisible(visible)`
- `toString()`

The subclasses add state and behavior unique to them:

`GLabel:`
- `get/setFont`
- `get/setLabel`
- ...

`GLine:`
- `get/setStartPoint`
- `get/setEndPoint`
- ...

`GPolygon:`
- `addEdge`
- `addVertex`
- `get/setFillColor`
- ...

Example: Employees

Imagine a company with the following **employee regulations**:

- All employees work 40 hours / week.
- Employees make $40,000 per year plus $500 for each year worked,
  - except for lawyers who get twice the usual pay,
    and programmers who get the same $40k base but $2000 for each year worked.
- Employees have 2 weeks of paid vacation days per year,
  - except for programmers who get an extra week (a total of 3).
- Employees should use a yellow form to apply for leave,
  - except for programmers who use a pink form.

Each type of employee has some unique behavior:

- **Lawyers** know how to sue.
- **Programmers** know how to write code.
- **Secretaries** know how to take dictation.
- **Legal Secretaries** know how to take dictation and how to file legal briefs.

Employee Class

```
// Employee.h
class Employee {
public:
    Employee(string name, int years);
    virtual int hours() const;
    virtual string name() const;
    virtual double salary() const;
    virtual int vacationDays() const;
    virtual string vacationForm() const;
    virtual int years() const;

private:
    string myName;
    int myYears;
};
```

```
// Employee.cpp
Employee::Employee(string name, int years) {
    myName = name;
    myYears = years;
}

int Employee::hours() const {
    return 40;
}

string Employee::name() const {
    return myName;
}

double Employee::salary() const {
    return 40000.0 + (500 * myYears);
}

int Employee::vacationDays() const {
    return 10;
}

string Employee::vacationForm() const {
    return "yellow";
}

int Employee::years() const {
    return myYears;
}
```

Exercise: Employees

Exercise: Implement classes Lawyer and Programmer.

Lawyer

- A Lawyer remembers what **law school** he/she went to.
- Lawyers make twice as much **salary** as normal employees.
- Lawyers know how to **sue** people (unique behavior).

Programmer

- Programmers make the same base salary as normal employees, but they earn a **bonus of $2k/year** instead of $500/year.
- Programmers fill out the **pink form** rather than yellow for vacations.
- Programmers get **3 weeks of vacation** rather than 2.
- Programmers know how to write **code** (unique behavior).

Overriding

- **override**: To replace a superclass's member function by writing a new version of that function in a subclass.
- **virtual function**: One that is allowed to be overridden.
  - Must be declared with `virtual` keyword in superclass.

```
// Employee.h
virtual string vacationForm();


// Employee.cpp
string Employee::vacationForm() {
    return "yellow";
}
```

```
// Programmer.h
virtual string vacationForm();


// Programmer.cpp
string Programmer::vacationForm() {
    return "pink";   // override!
}
```

If you "override" a non-virtual function, it actually just puts a second copy of that function in the subclass, which can be confusing later.

* Virtual has some subtleties. For example, destructors in inheritance hierarchies should always be declared virtual or else memory may not get cleaned up properly; ugh.

Calling the Superclass Constructor

```
SubclassName::SubclassName(params) : SuperclassName(params) {
    statements;
}
```

To call a superclass constructor from subclass constructor, use an *initialization list*, with a colon after the constructor declaration.

Example:

```
Lawyer::Lawyer(string name, string lawSchool, int years) :
            Employee(name, years) {
    // calls Employee constructor first
    mylawSchool = lawSchool;
}
```

Calling the Superclass Member

`SuperclassName::memberName(params)`

To call a superclass overridden member from subclass member.

Example:

```
double Lawyer::salary() { // paid twice as much
    return Employee::salary() * 2;
}
```

Notes:

- Subclass cannot access private members of the superclass.
- You only need to use this syntax when the superclass's member has been overridden.
- If you just want to call one member from another, even if that member came from the superclass, you don't need to write `Superclass::` .

Lawyer.h

PDF: http://web.stanford.edu/class/cs106b//lectures/27-Inheritance/code/InheritancePolymorphismExamples.pdf

One typo: cross out line 195

```
#pragma once

#include "Employee.h"
#include <string>

class Lawyer : public Employee {
    // I now have an hours, name, salary, etc. method. yay!
public:
    Lawyer(string name, string lawSchool, int years);
    virtual double salary() const;
    void sue(string person);

private:
    string myLawSchool;
};
```

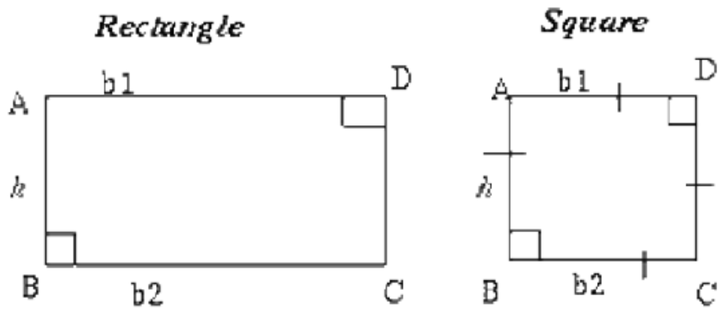
Lawyer.cpp

```
#include "Lawyer.h"

// call the constructor of Employee superclass?
Lawyer::Lawyer(string name, string lawSchool, int years)
: Employee(name, years) {
    myLawSchool = lawSchool;
}

// overriding: replace version from Employee class
double Lawyer::salary() const {
    return Employee::salary() * 2;
}

void Lawyer::sue(string person) {
    cout << "See you in court, " << person << endl;
}
```

Perils of Inheritance (i.e., think before you inherit!)

Consider the following places you might use inheritance:

- class `Point3D` extends `Point2D` and adds z-coordinate
- class `Square` extends `Rectangle` (or vice versa?)
- class `SortedVector` extends `Vector`, keeps it in sorted order



What's wrong with these examples? Is inheritance good here?

- `Point2D`'s `distance()` function is wrong for 3D points
- `Rectangle` supports operations a `Square` shouldn't (e.g. `setWidth`)
- `SortedVector` might confuse client; they call insert at an index, then check that index, and the element they inserted is elsewhere!

Private Inheritance

```
class Name : private SuperclassName { ...
```

private inheritance: Copies code from superclass but does not publicly advertise that your class extends that superclass.

- Good for cases where you want to inherit another class's code, but you don't want outside clients to be able to randomly call it.
- Example: Have `Point3D` privately extend `Point2D` and add z-coordinate functionality.
- Example: Have `SortedVector` privately extend `Vector` and add only the public members it feels are appropriate (e.g., no `insert`).

Pure Virtual Functions

virtual **returntype name(params)** = 0;

pure virtual function: Declared in superclass's .h file and set to 0 (null). An absent function that has not been implemented.

- Must be implemented by any subclass, or it cannot be used.
- A way of forcing subclasses to add certain important behavior.

```
class Employee {
    ...
    virtual void work() = 0;  // every employee does
                              // some kind of work
};
```

FYI: In Java, this is called an *abstract method*.

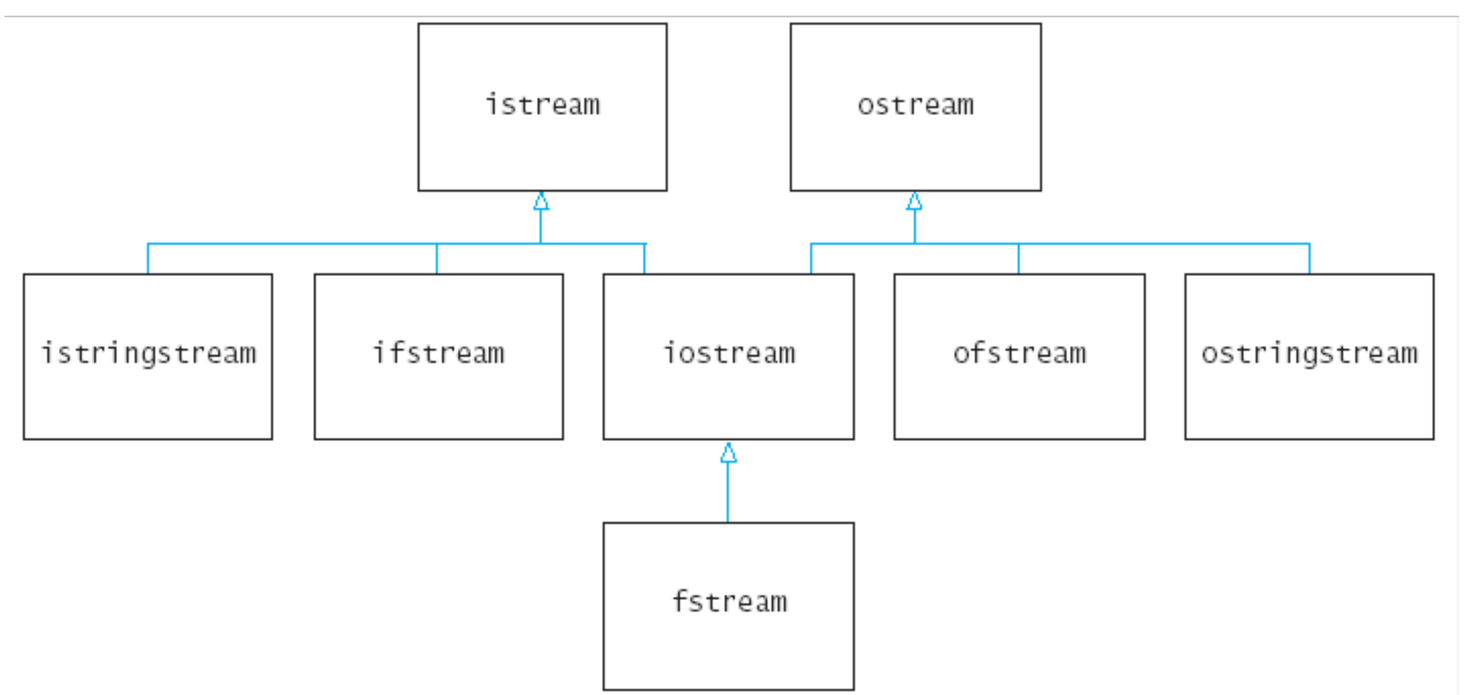
Multiple Inheritance

class ***Name*** : public ***Superclass1***, public ***Superclass2***, ...

multiple inheritance: When one subclass has multiple superclasses.

- Forbidden in many OO languages (e.g. Java) but allowed in C++.
- Convenient because it allows code sharing from multiple sources.
- Can be confusing or buggy, e.g. when both superclasses define a member with the same name.

Example: The C++ I/O streams use multiple inheritance:

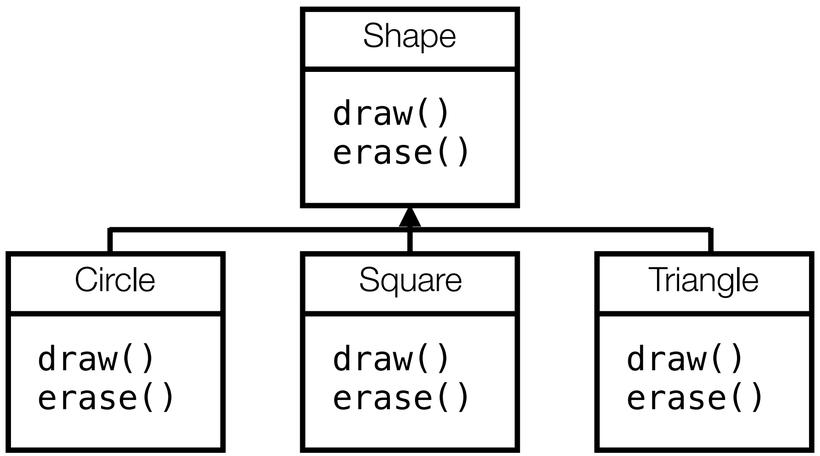


Polymorphism

polymorphism: Ability for the same code to be used with different types of objects and behave differently with each.

- Templates provide *compile-time* polymorphism. Inheritance provides *run-time* polymorphism.

Idea: Client code can call a method on different kinds of objects, and the resulting behavior will be different.



Polymorphism and Pointers

A pointer of type *T* can point to any subclass of *T*.

```
Employee* edna = new Lawyer("Edna", "Harvard", 5);
Secretary* steve = new LegalSecretary("Steve", 2);
World* world     = new WorldMap("map-stanford.txt");
```

When a member function is called on edna, it behaves as a Lawyer.

- (This is because the employee functions are declared virtual.)
- You can *not* call any `Lawyer`-only members on `edna` (e.g. `sue`).
  You can *not* call any `LegalSecretary`-only members on `steve` (e.g. `fileLegalBriefs`).

Polymorphism Example

You can use the object's extra functionality by casting.

```
Employee* edna = new Lawyer("Edna", "Harvard", 5);
edna->vacationDays();                              // ok
edna->sue("Stuart");                               // compiler error
((Lawyer*) edna)->sue("Stuart");                   // ok
```

You should not cast a pointer to something that it is not.

- It will compile, but the code will crash (or behave unpredictably) when you try to run it

```
Employee* paul = new Programmer("Paul", 3);
paul->code();                                  // compiler error
((Programmer*) paul)->code();                  // ok
((Lawyer*) paul)->sue("Marty");                // crash!
```

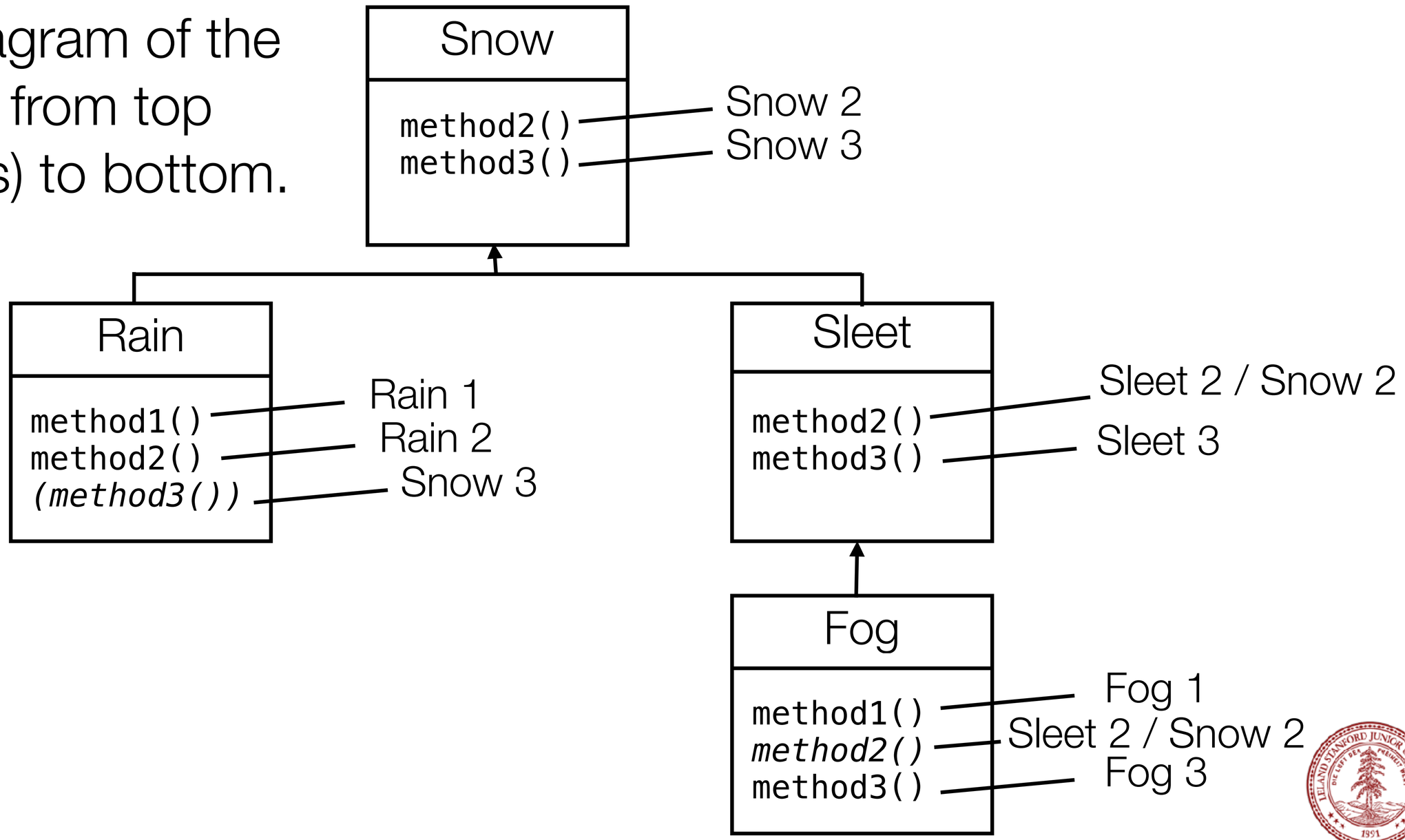
Polymorphism Mystery

```
class Snow {
public:
    virtual void method2() {
        cout << "Snow 2" << endl;
    }
    virtual void method3() {
        cout << "Snow 3" << endl;
    }
};

class Rain : public Snow {
public:
    virtual void method1() {
        cout << "Rain 1" << endl;
    }
    virtual void method2() {
        cout << "Rain 2" << endl;
    }
};
```

```
class Sleet : public Snow {
public:
    virtual void method2() {
        cout << "Sleet 2" << endl;
        Snow::method2();
    }
    virtual void method3() {
        cout << "Sleet 3" << endl;
    }
};

class Fog : public Sleet {
public:
    virtual void method1()   {
        cout << "Fog 1" <<   endl;
    }
    virtual void method3()   {
        cout << "Fog 3" <<   endl;
    }
};
```

Diagramming classes

Draw a diagram of the classes from top (superclass) to bottom.



Mystery Problem

```
Snow* var1 = new Sleet();
var1->method2(); // What's the output?
```

To find the behavior/output of calls like the one above:

1. Look at the variable's type.
   If that type does not have that member: COMPILER ERROR.
2. Execute the member.
   Since the member is virtual: behave like the object's type,
   not like the variable's type.

Example 1

Q: What is the result of the following call?

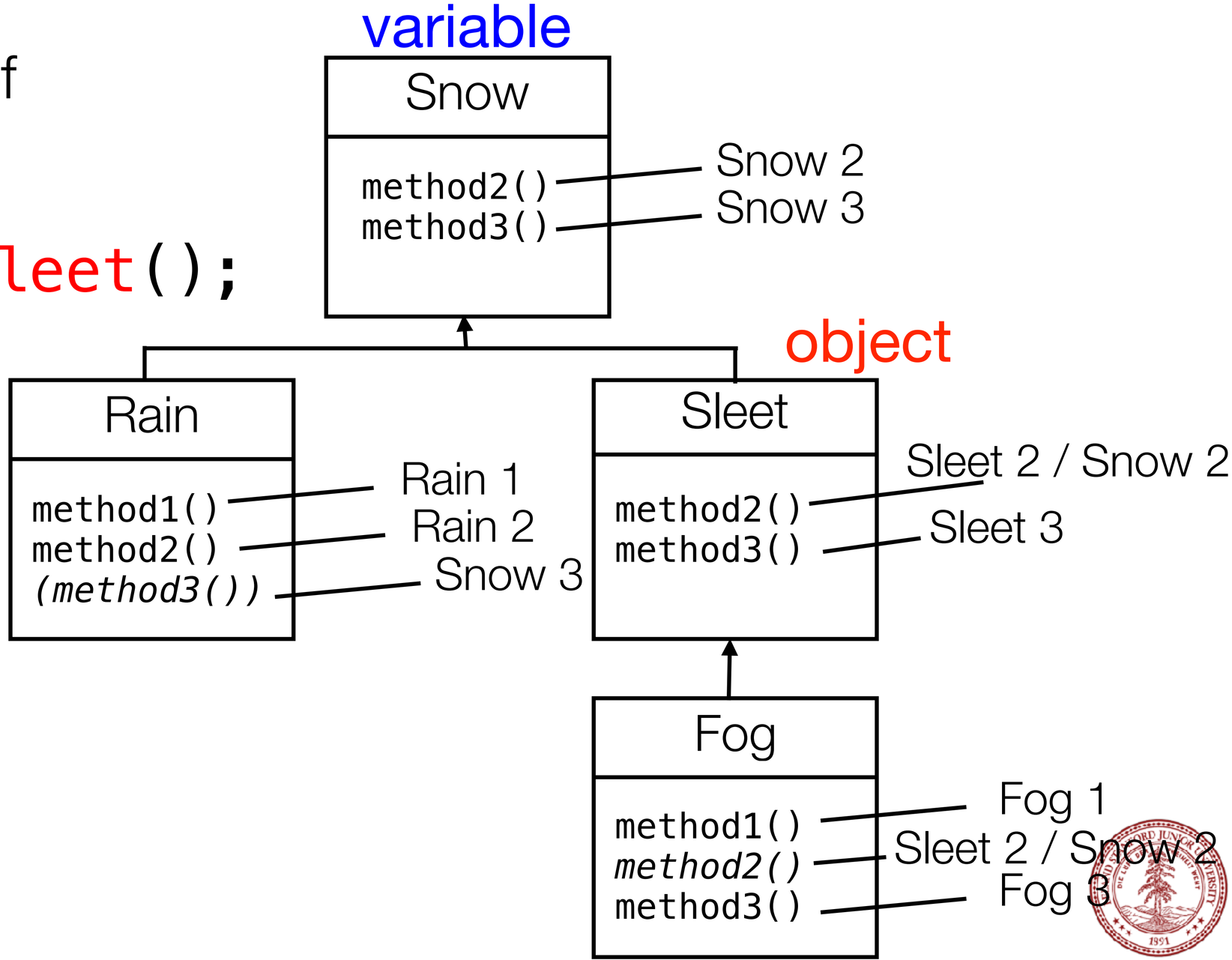
```
Snow* var1 = new Sleet();
var1->method2();
```

A. Snow 2

B. Rain 2

C. Sleet 2
   Snow 2

D. COMPILER ERROR



Example 1

Q: What is the result of the following call?

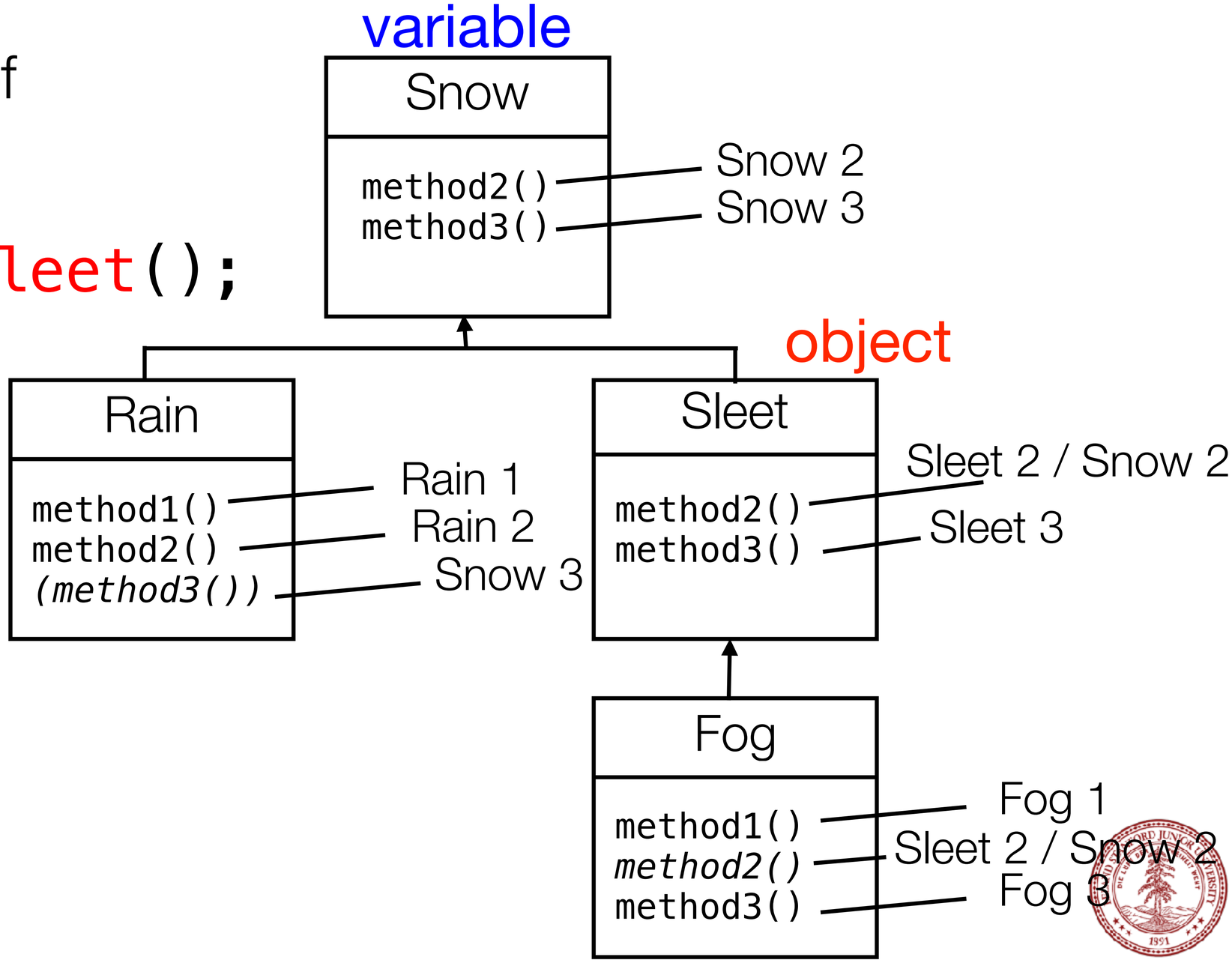
```
Snow* var1 = new Sleet();
var1->method2();
```

A. Snow 2

B. Rain 2

C. Sleet 2
   Snow 2

D. COMPILER ERROR



Example 2

Q: What is the result of the following call?

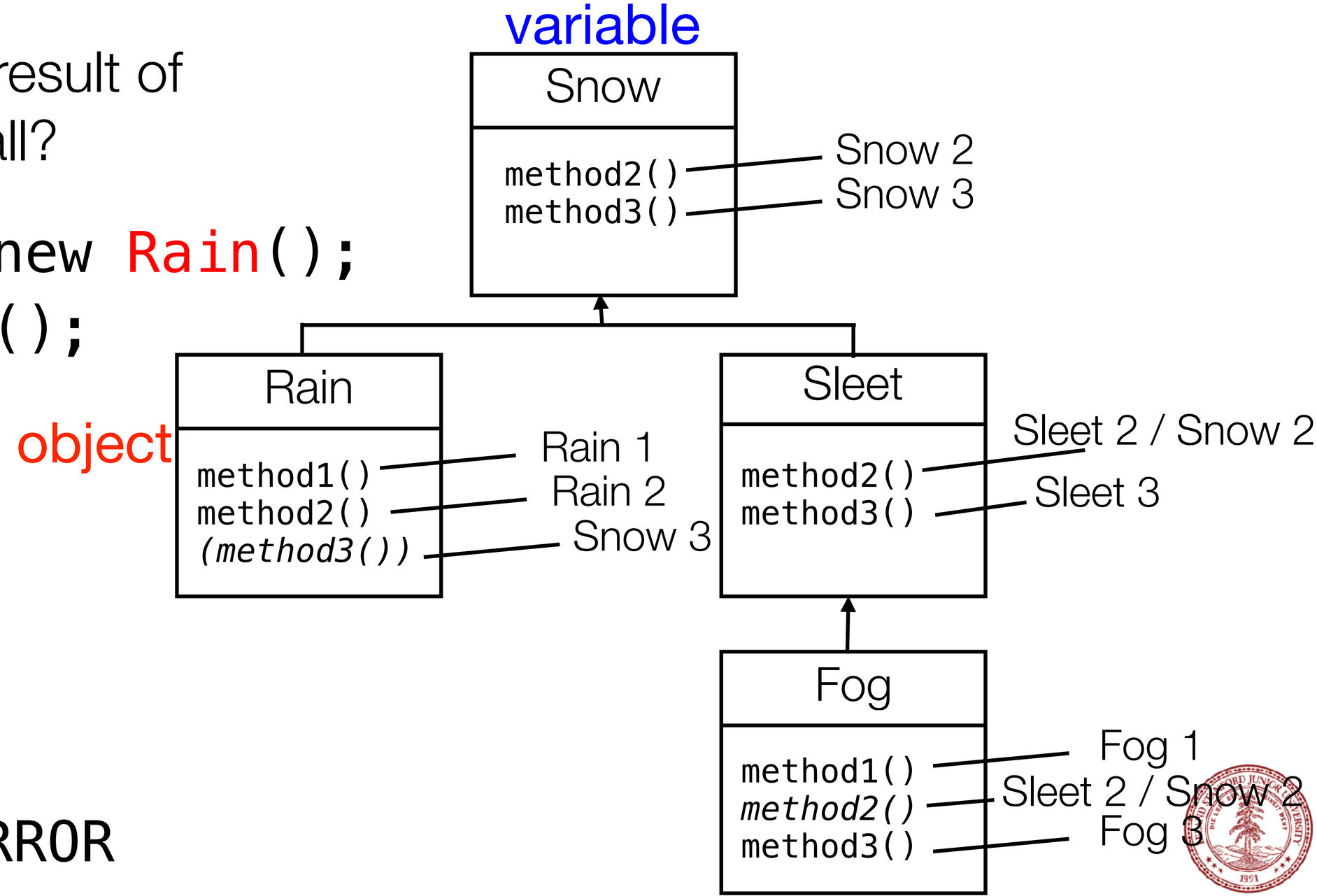
```
Snow* var2 = new Rain();
var2->method1();
```

A. Snow 1

B. Rain 1

C. Snow 1
   Rain 1

D. COMPILER ERROR



Example 2

Q: What is the result of the following call?

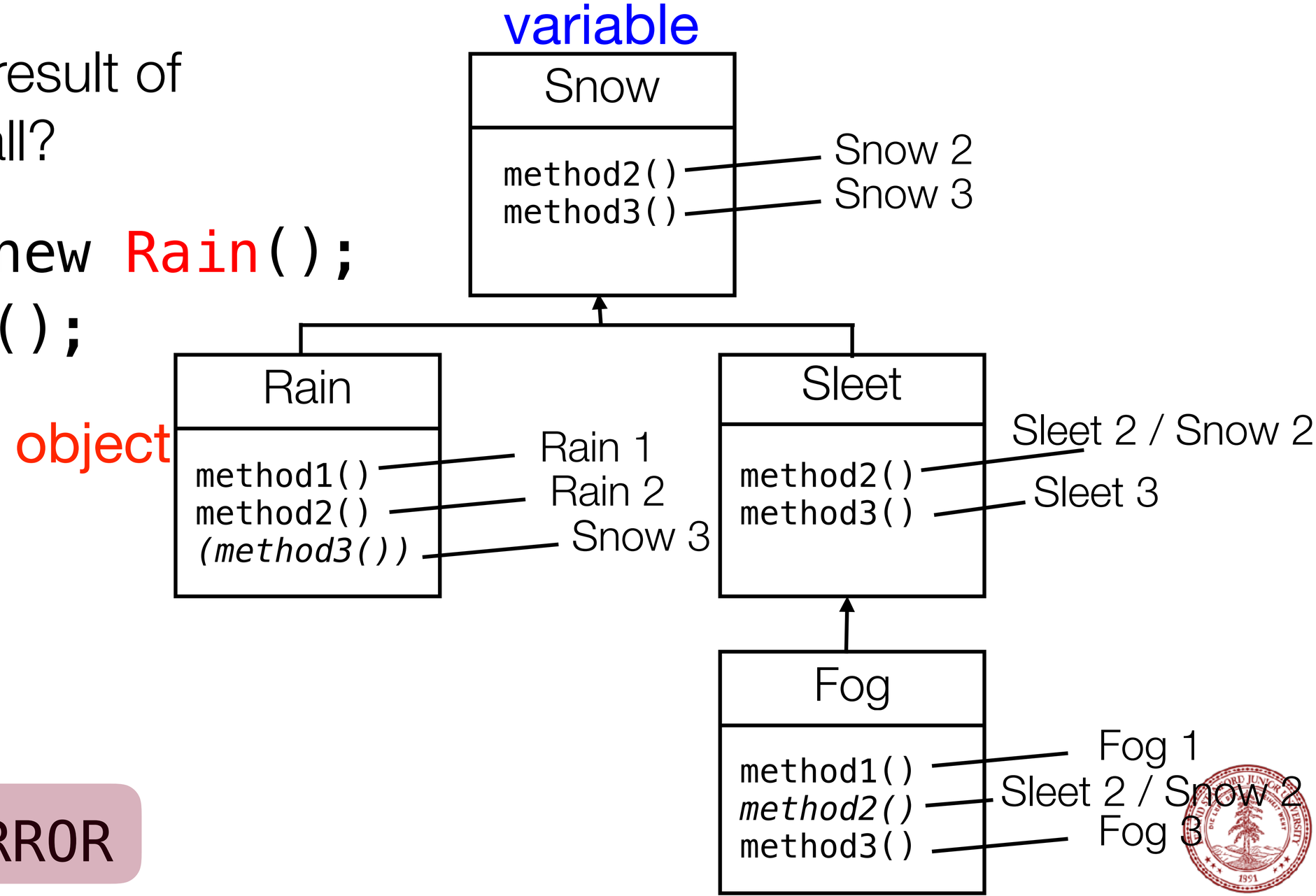
```
Snow* var2 = new Rain();
var2->method1();
```

A. Snow 1

B. Rain 1

C. Snow 1
   Rain 1

D. COMPILER ERROR



Example 3

Q: What is the result of the following call?

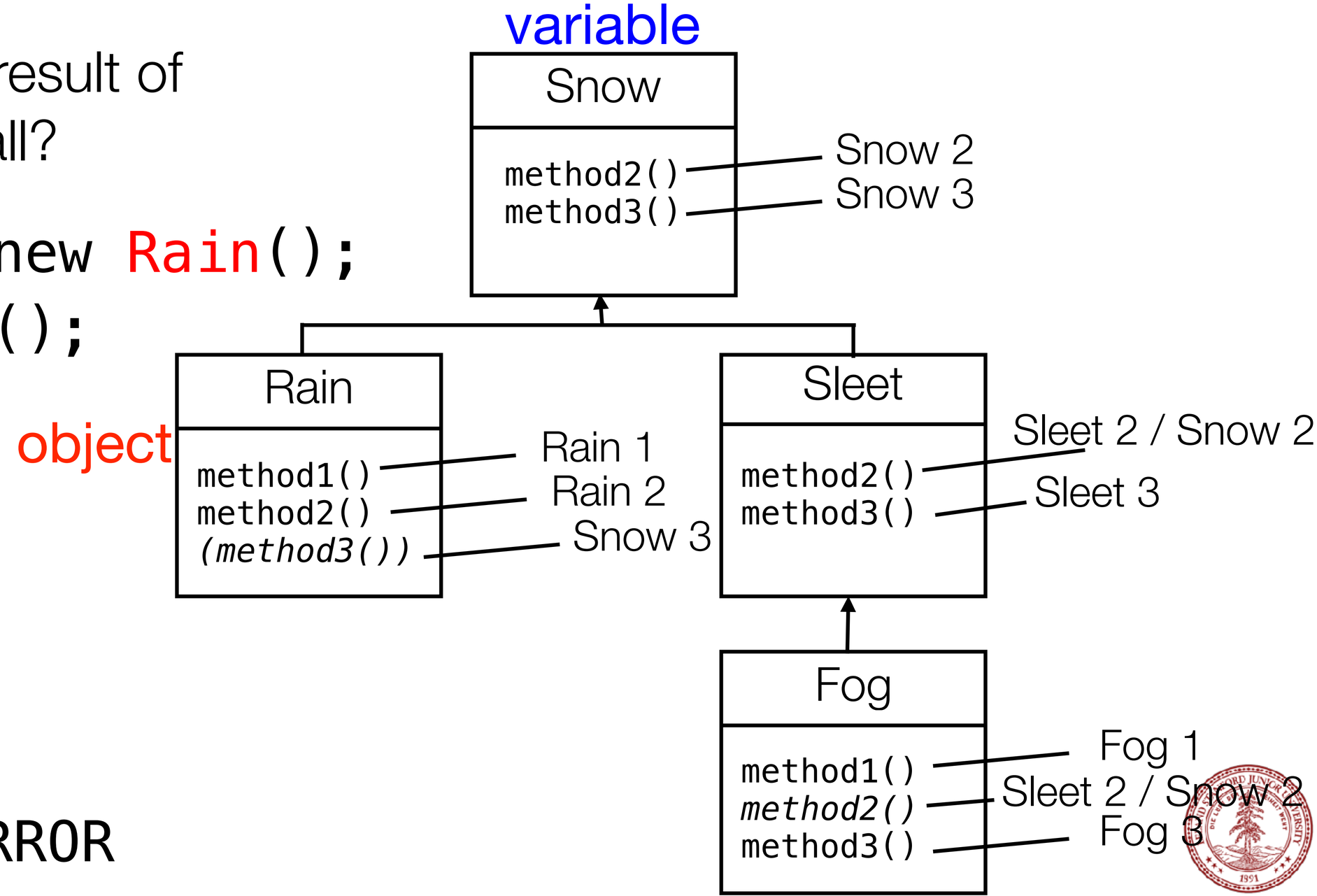
```
Snow* var3 = new Rain();
var3->method2();
```

A. Snow 2

B. Rain 2

C. Sleet 2
   Snow 2

D. COMPILER ERROR



Example 3

Q: What is the result of the following call?

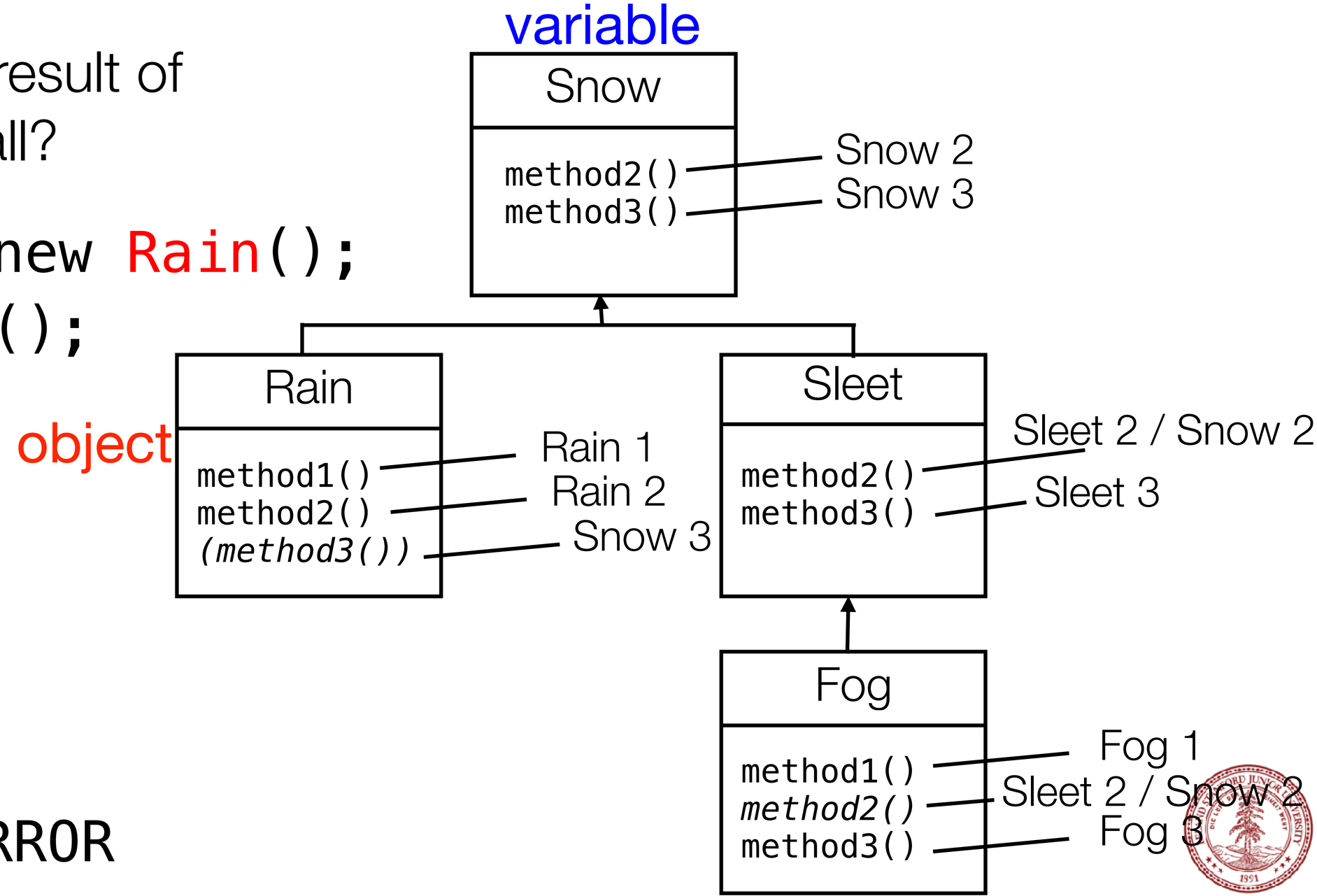
```
Snow* var3 = new Rain();
var3->method2();
```

A. Snow 2

B. Rain 2

C. Sleet 2
   Snow 2

D. COMPILER ERROR



Mystery with type cast

```
Snow* var4 = new Rain();
((Rain *) var4->method1(); // What's the output?
```

If the mystery problem has a type cast, then:

1. Look at the cast type.
   If that type does not have the method: COMPILER ERROR.

   (Note: if the object's type was not equal to or a subclass of the cast type, the code would CRASH / have unpredictable behavior.)
2. Execute the member.
   Since the member is virtual: behave like the object's type, not like the variable's type.

Example 4

Q: What is the result of the following call?

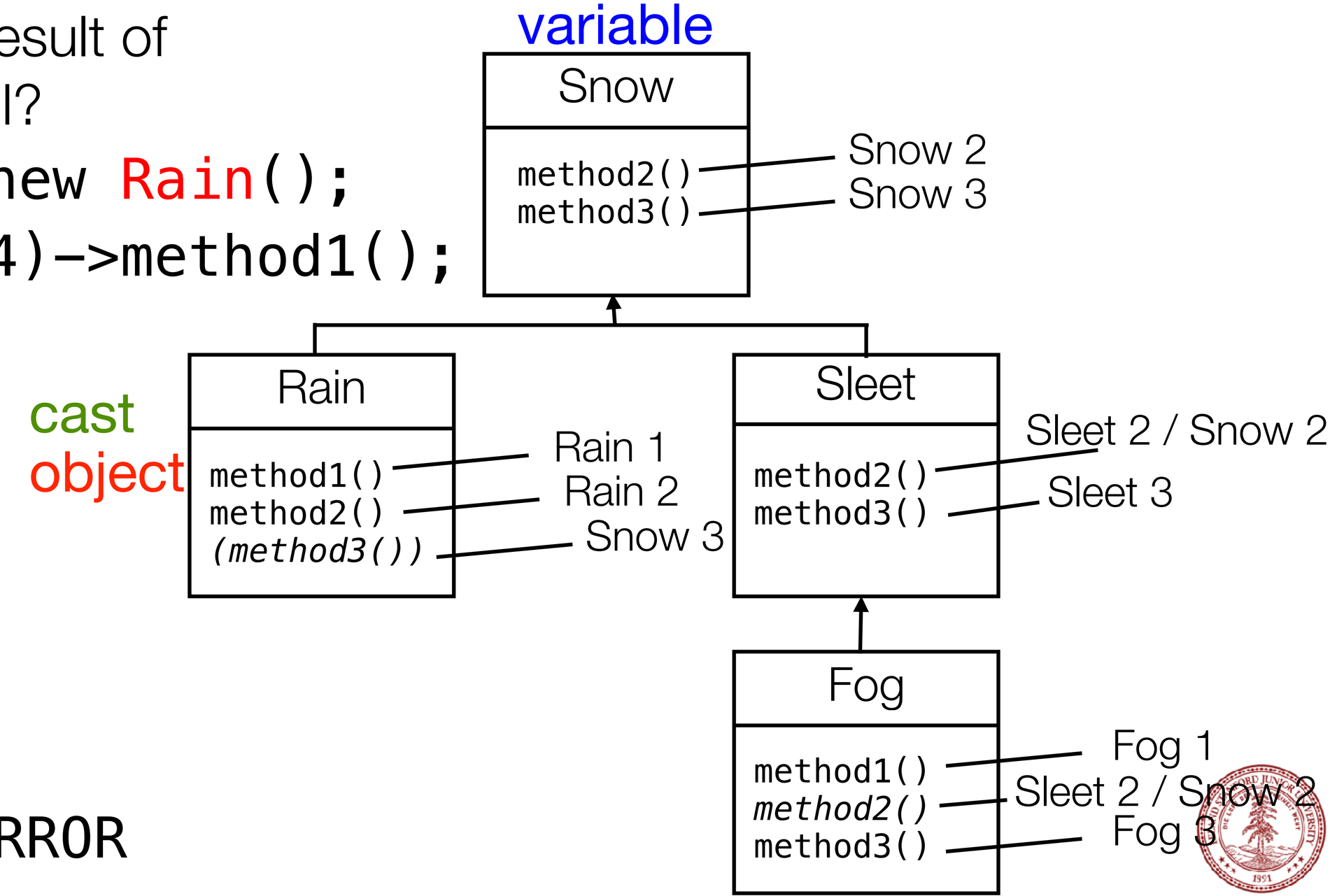
```
Snow* var4 = new Rain();
((Rain *) var4)->method1();
```

A. Snow 1

B. Rain 1

C. Sleet 1

D. COMPILER ERROR



Example 4

Q: What is the result of the following call?

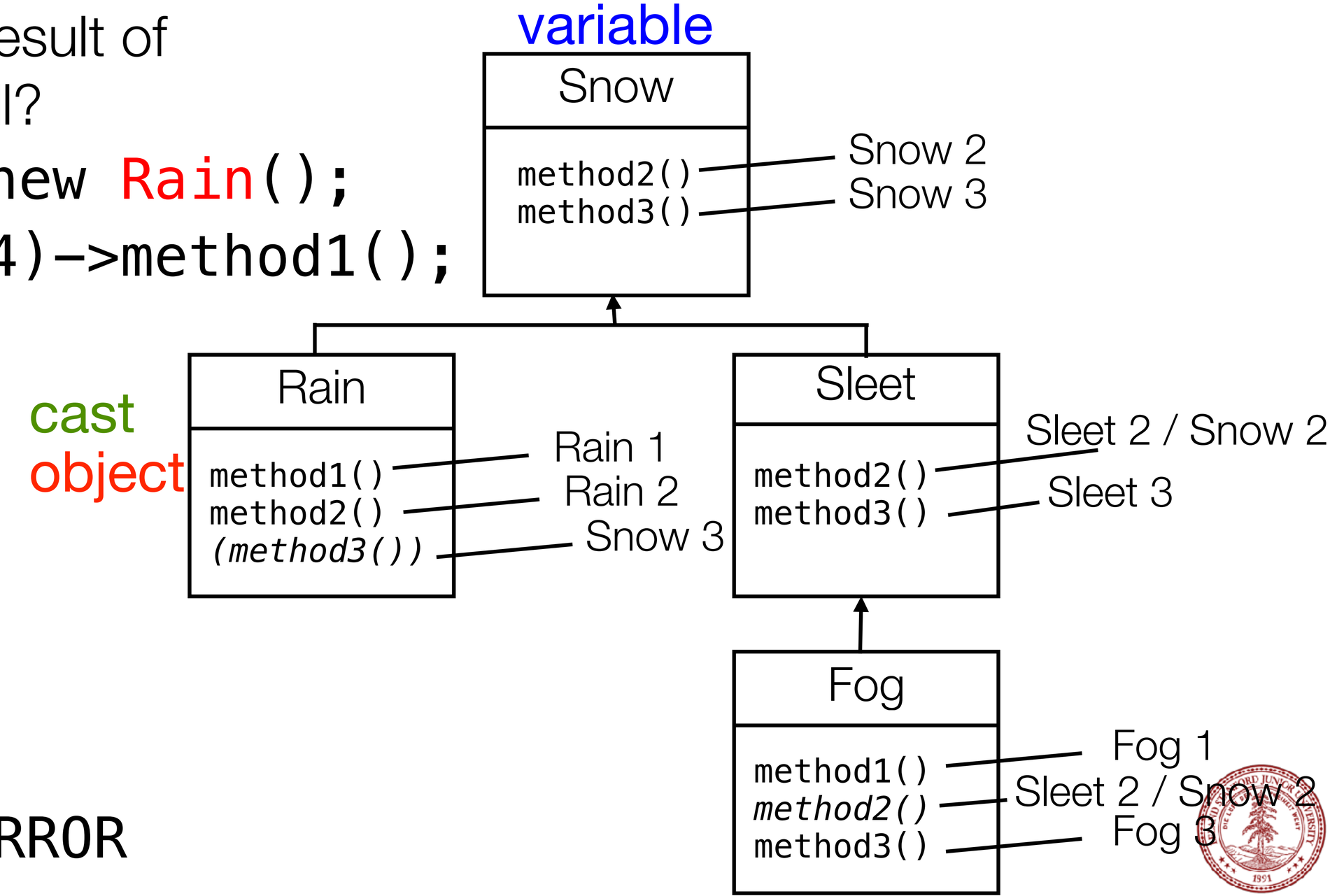
```
Snow* var4 = new Rain();
((Rain *) var4)->method1();
```

A. Snow 1

B. Rain 1

C. Sleet 1

D. COMPILER ERROR



Example 5

Q: What is the result of the following call?

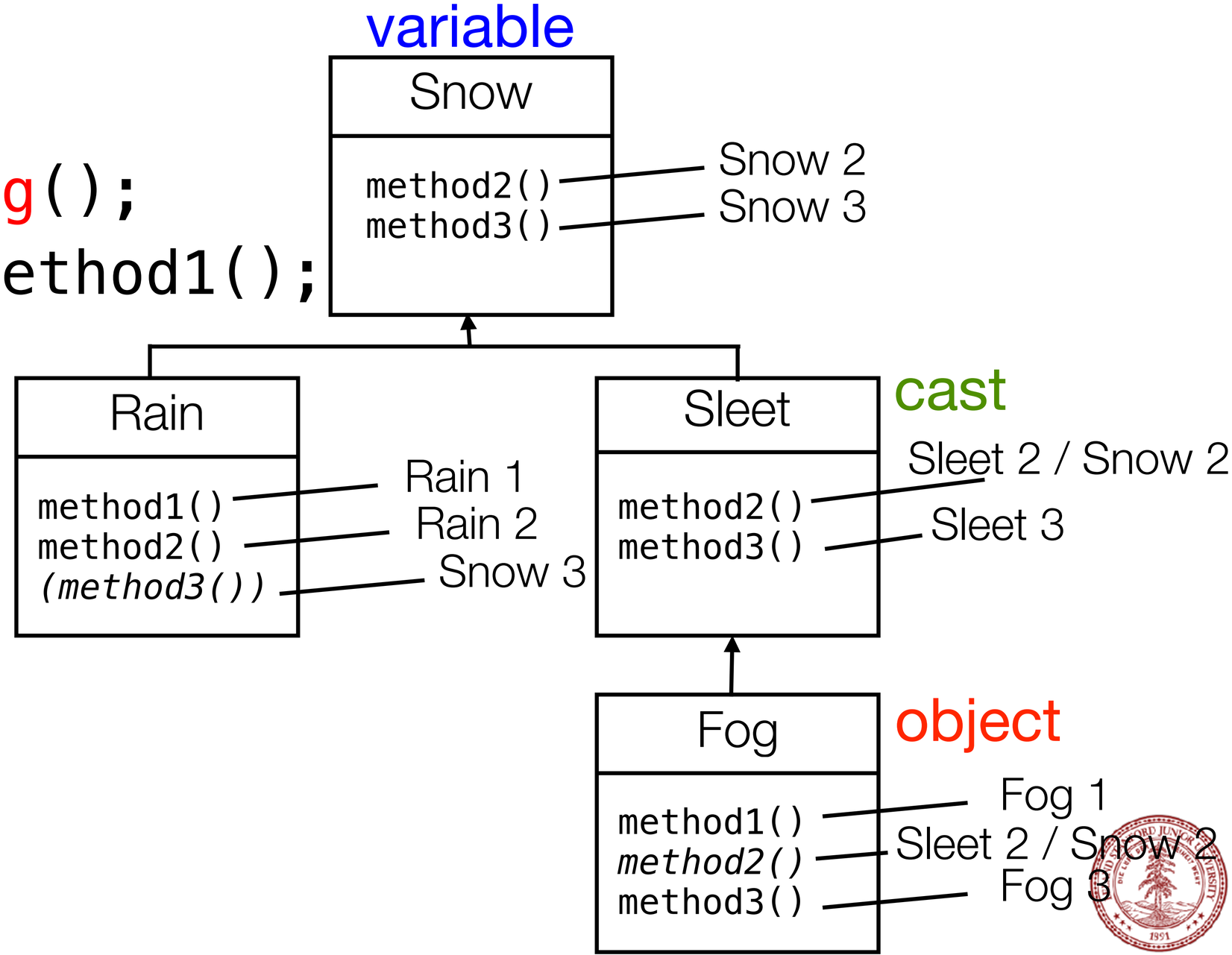
```
Snow* var5 = new Fog();
((Sleet *) var5)->method1();
```

A. Snow 1

B. Sleet 1

C. Fog 1

D. COMPILER ERROR



Example 5

Q: What is the result of the following call?

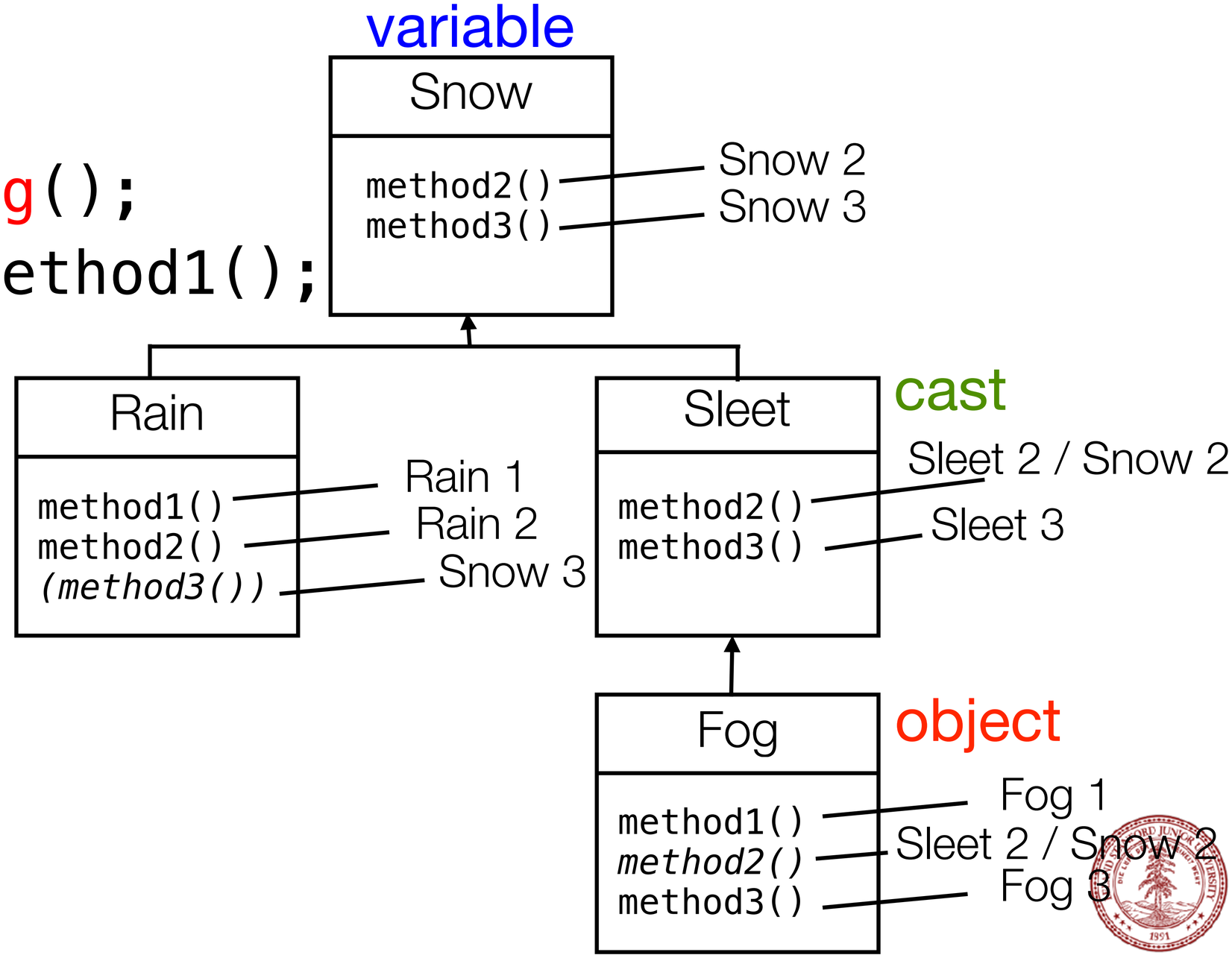
```
Snow* var5 = new Fog();
((Sleet *) var5)->method1();
```

A. Snow 1

B. Sleet 1

C. Fog 1

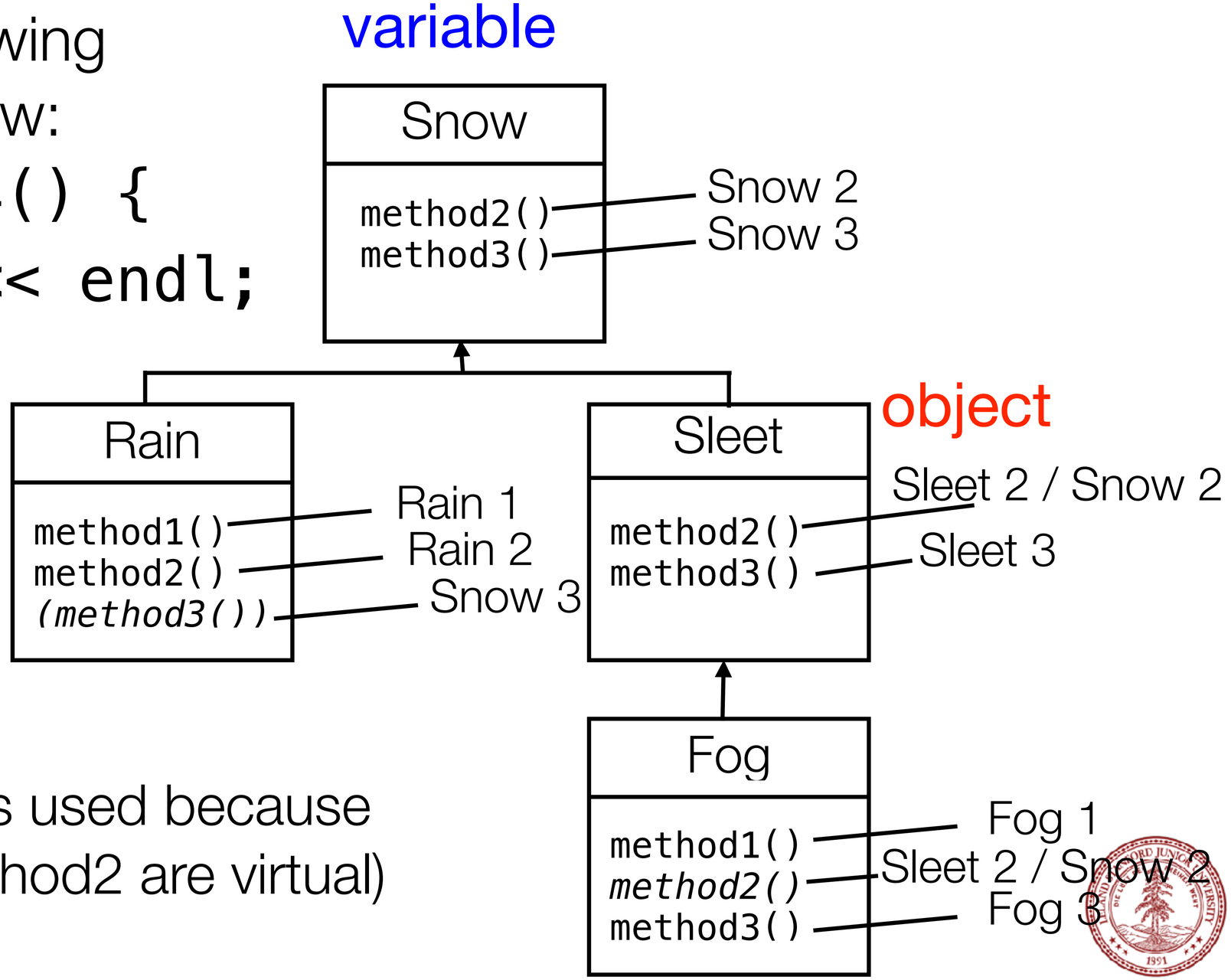
D. COMPILER ERROR



Example 6

Suppose we add the following method to base class Snow:

```
virtual void method4() {
  cout << "Snow 4" << endl;
  method2();
}
```



What is the output?

```
Snow* var6 = new Sleet();
var6->method4();
```

Answer?

```
Snow 4
Sleet 2
Snow 2
```

(Sleet's method2 is used because method 4 and method2 are virtual)

Example 7

What is the output of the following call?

```
Snow* var7 = new Sleet();
((Rain*) var7)->method1();
```

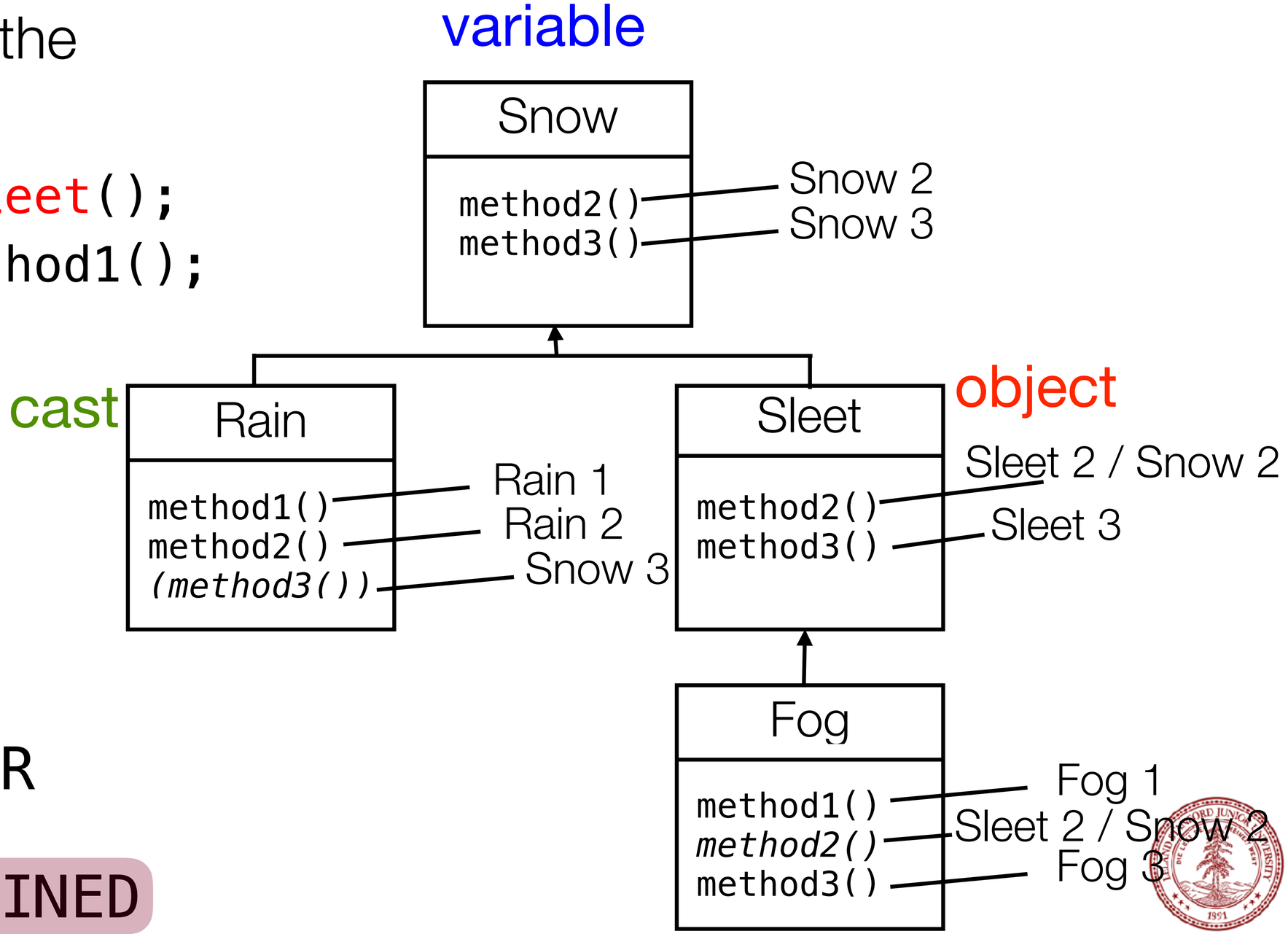
A. Snow 1

B. Sleet 1

C. Fog 1

D. COMPILER ERROR

E. CRASH / UNDEFINED



References and Advanced Reading

- **References:**
  - C++ Inheritance: https://www.tutorialspoint.com/cplusplus/cpp_inheritance.htm
  - C++ Polymorphism: https://www.tutorialspoint.com/cplusplus/cpp_polymorphism.htm

- **Advanced Reading:**
  - http://stackoverflow.com/questions/5854581/polymorphism-in-c
  - https://www.codingunit.com/cplusplus-tutorial-polymorphism-and-abstract-base-class