Testing, and Debugging

Some reflections from TAs in office hours regarding struggling students:

- “I feel like they get stuck trying to figure it out by looking at their code instead of trying to get proactive and poke at their code”
- “They're checking that their code makes sense; sometimes they can't see the bug until it's being run.”

In lab 2, we talked about how debugging should be a scientific process.

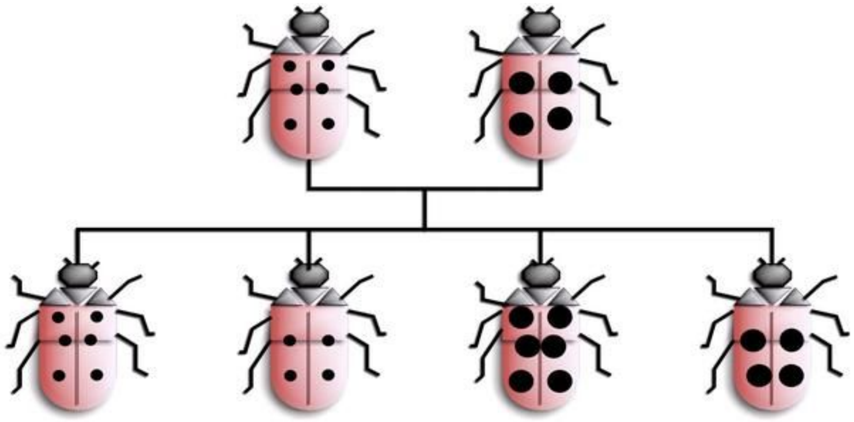
- Reading and re-reading your code is very very slow. It’s like trying to chop down a tree with a nail file. Yes, you’ll eventually succeed, but there are much better tools.

Using the debugger (especially with tests!) is **incredibly important**.

Project 1B

Project 1B is out. The goal is to give you some experience with a test-driven workflow, as well as to get some practice with the material from the inheritance1 and inheritance2 lectures.

- The programs you write in project 1B are pretty small, so workload shouldn't be too bad.
- The autograder is going to give you almost no details on tests you fail. It's up to you to write your own tests that are good enough to pass the tests.
- We will also test your tests: Make sure to cover interesting corner cases.



CS61B

Lecture 9: More Inheritance!

- Implementation Inheritance: Extends
- Encapsulation
- Casting
- Higher Order Functions in Java

Implementation Inheritance: Extends

The Extends Keyword

When a class is a hyponym of an interface, we used **implements.**

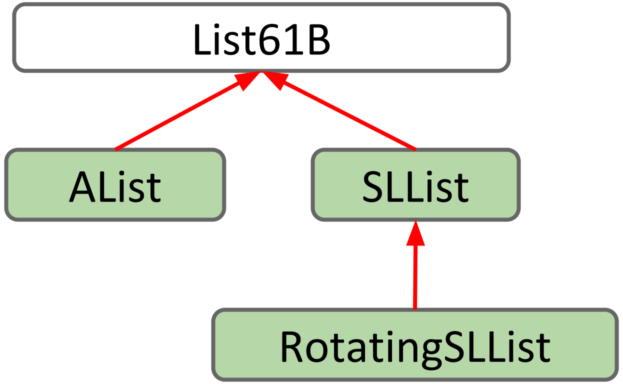
- Example: `SLList<Blorp> implements List61B<Blorp>`

instead of an interface

If you want one class to be a hyponym of another *class*, you use **extends.**

We'd like to build RotatingSLList that can perform any SLList operation as well as:

- rotateRight(): Moves back item the front.



Example: Suppose we have [5, 9, 15, 22].

- After rotateRight: [22, 5, 9, 15]

RotatingSLList

```java
public class RotatingSLList<Blorp> extends SLList<Blorp>{
    public void rotateRight() {
        Blorp oldBack = removeLast();
        insertFront(oldBack);
    }
}
```

Because of **extends**, `RotatingSLList` inherits all members of `SLList`:

- All instance and static variables.
- All methods.
- All nested classes.

… but members may be private and thus inaccessible! More after midterm.

Constructors are not inherited.

Another Example: VengefulSLList

Suppose we want to build an SLList that:

- Remembers all Items that have been destroyed by `removeLast`.
- Has an additional method `printLostItems()`, which prints all deleted items.

```
public static void main(String[] args) {
    VengefulSLList<Integer> vs1 = new VengefulSLList<Integer>();
    vs1.addLast(1);
    vs1.addLast(5);
    vs1.addLast(10);
    vs1.addLast(13);      /* [1, 5, 10, 13] */
    vs1.removeLast();     /* 13 gets deleted. */
    vs1.removeLast();     /* 10 gets deleted. */
    System.out.print("The fallen are: ");
    vs1.printLostItems(); /* Should print 10 and 13. */
}
```

Another Example: VengefulSLList

```
public class VengefulSLList<Item> extends SLList<Item> {
    private SLList<Item> deletedItems;
    public VengefulSLList() {
       deletedItems = new SLList<Item>();
    }

    @Override
    public Item removeLast() {
        Item oldBack = super.removeLast();
        deletedItems.addLast(oldBack);
        return oldBack;
    }

    public void printLostItems() {
        deletedItems.print();
    }
}
```

calls Superclass's version of removeLast()

Note: Java syntax disallows super.super. For a nice description of why, see [this link].

Constructor Behavior Is Slightly Weird

Constructors are not inherited. However, the rules of Java say that **all constructors must start with a call to one of the super class's constructors [Link].**

- Idea: If every VengefulSLList is-an SLList, every VengefulSLList must be set up like an SLList.
  - If you didn't call SLList constructor, sentinel would be null. Very bad.
- You can explicitly call the constructor with the keyword super (no dot).
- If you don't explicitly call the constructor, Java will automatically do it for you.

```java
public VengefulSLList() {
   deletedItems = new SLList<Item>();
}
```

```java
public VengefulSLList() {
   super();  // must come first!
   deletedItems = new SLList<Item>();
}
```

These constructors are exactly equivalent.

Calling Other Constructors

If you want to use a super constructor other than the no-argument constructor, can give parameters to super.

```
public VengefulSLList(Item x) {
    super(x);
    deletedItems = new SLList<Item>();
}
```

calls SLList(Item x)

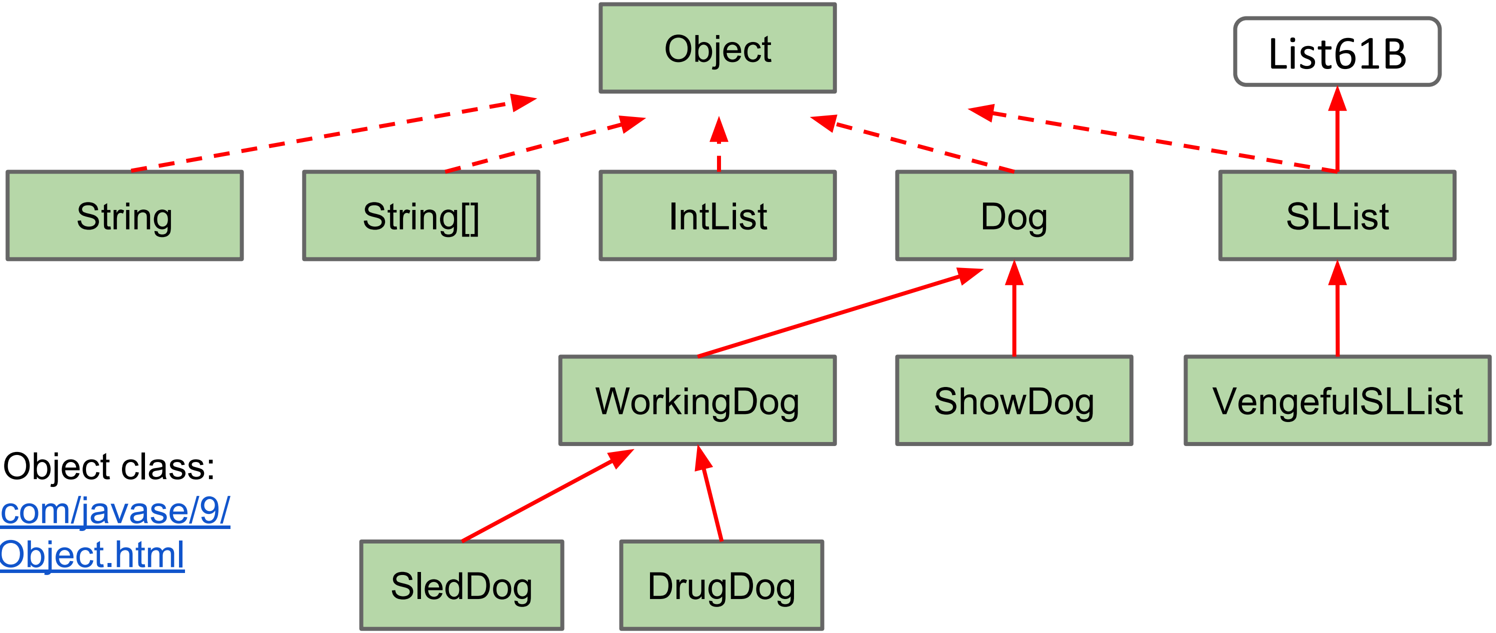
Not equivalent! Code to the right makes implicit call to super(), not super(x).

```
public VengefulSLList(Item x) {
    deletedItems = new SLList<Item>();
}
```

The Object Class

As it happens, every type in Java is a descendant of the Object class.

- VengefulSLList extends SLList.
- SLList extends Object (implicitly).



Documentation for Object class:
https://docs.oracle.com/javase/9/docs/api/java/lang/Object.html

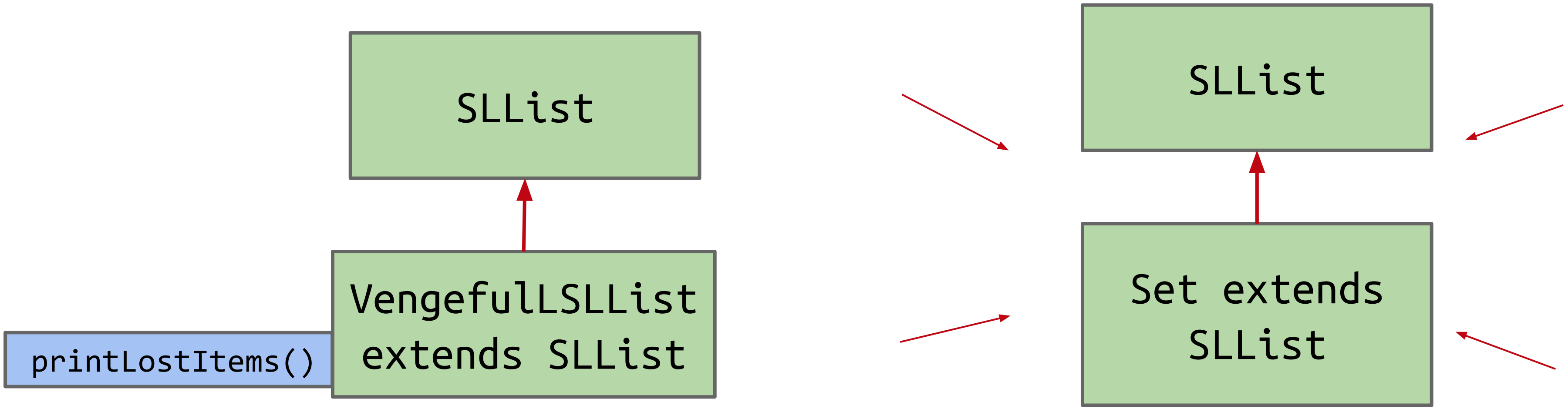
Interfaces don't extend Object:
http://docs.oracle.com/javase/specs/jls/se7/html/jls-9.html#jls-9.2

Is-a vs. Has-A

Important Note: extends should only be used for **is-a** (hypernymic) relationships!

Common mistake is to use it for "**has-a**" relationships. (a.k.a. meronymic).

- Possible to subclass SLList to build a Set, but conceptually weird, e.g. get(i) doesn't make sense, because sets are not ordered.



This is an abomination.

Encapsulation

Complexity: The Enemy

When building large programs, our enemy is complexity.

Some tools for managing complexity:

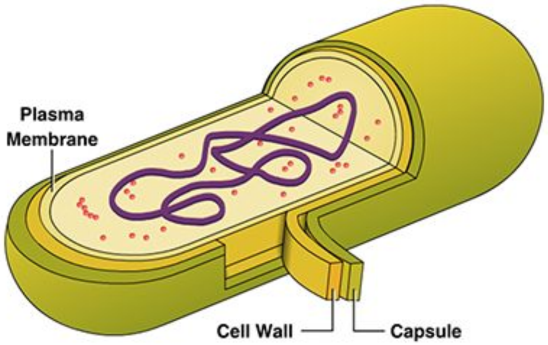
- Hierarchical abstraction.
  - Create **layers of abstraction**, with clear abstraction barriers!
- “Design for change” (D. Parnas)
  - Organize program around objects.
  - Let objects decide how things are done.
  - **Hide information** others don’t need.

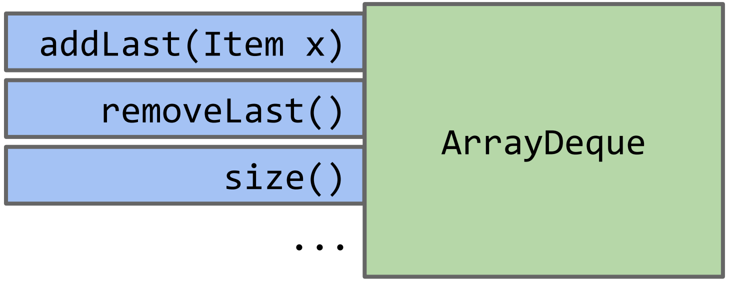
Managing complexity supremely important for large projects (e.g. project 2).

Modules and Encapsulation [Shewchuk]

Module: A set of methods that work together as a whole to perform some task or set of related tasks.

A module is said to be ***encapsulated*** if its implementation is completely hidden, and it can be accessed only through a documented interface.





A Cautionary Tale

Interesting Piazza questions from proj1gold from 2016.

How can we check the length of StudentArrayDeque?

I am trying to find a bug about resizing method, but i don't know how to see the length of the studentArrayDeque.

StudentArrayDeque.length( ) nor StudentArrayDeque.length is not working..... so i don't know how to check whether the Array can expend to double of its capacity or not.

Private access in given classes

I wanted to test whether the resizing and downsizing is working properly, but when I try to call array.items.length, the compiler yells at me, saying items is a private variable. Is there any way around this, or should we just not test this?

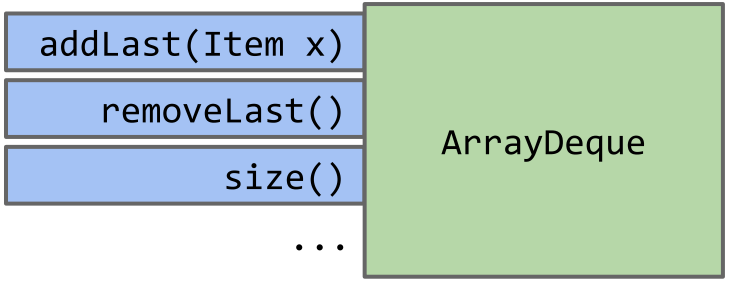
Can we assume these things about studentarraydeque?

Can we assume the studentarraydeque implementation uses nextfront = 4 nextlast =5, and starting size array 8?

Abstraction Barriers

As the user of an ArrayDeque, you cannot observe its internals.

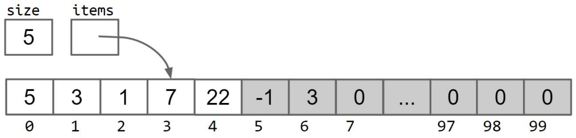
- Even when writing tests, you don't (usually) want to peer inside.



Java is a great language for enforcing abstraction barriers with syntax.

{5, 3, 1, 7, 22}

Implementation

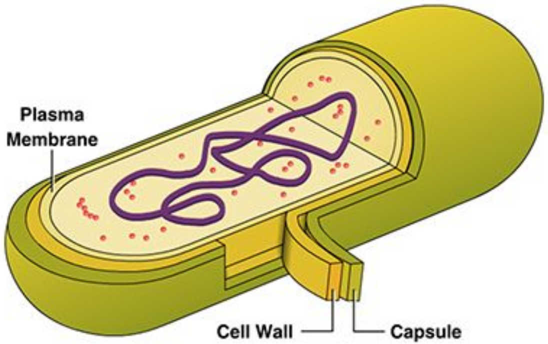


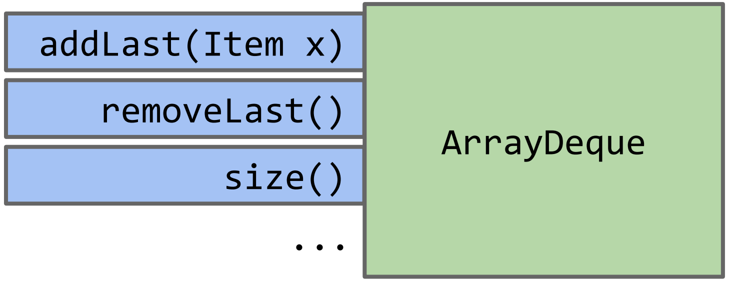
Modules and Encapsulation [Shewchuk]

Module: A set of methods that work together as a whole to perform some task or set of related tasks.

A module is said to be ***encapsulated*** if its implementation is completely hidden, and it can be accessed only through a documented interface.

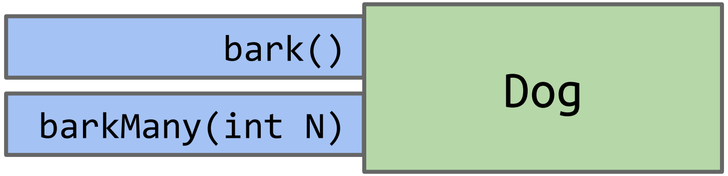
- Instance variables private. Methods like `resize` private.
- As we'll see: Implementation inheritance (e.g. extends) breaks encapsulation!





Implementation Inheritance Breaks Encapsulation

Suppose we have a Dog class with the two methods shown.



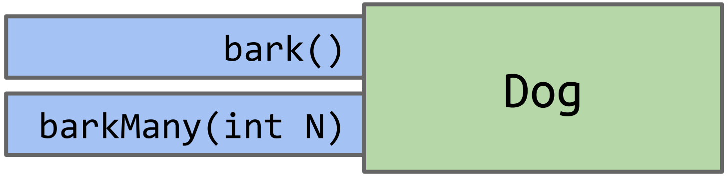

```java
public void bark() {
   System.out.println("bark");
}

public void barkMany(int N) {
    for (int i = 0; i < N; i += 1) {
        bark();
    }
}
```

Implementation Inheritance Breaks Encapsulation

We could just as easily have implemented methods as shown below.

- From the outside, functionality is exactly the same, it's just a question of aesthetics.




```
public void bark() {
   barkMany(1);
}

public void barkMany(int N) {
    for (int i = 0; i < N; i += 1) {
        System.out.println("bark");
    }
}
```

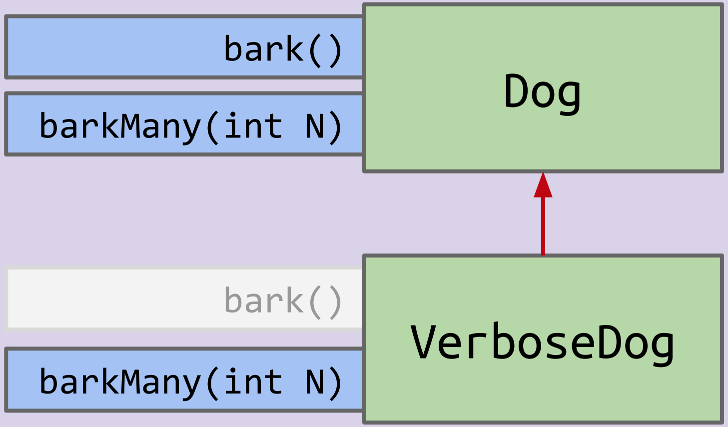
http://yellkey.com/explain

What would vd.barkMany(3) output?

a. As a dog, I say: bark bark bark
b. bark bark bark
c. Something else.

(assuming vd is a Verbose Dog)

```
public void bark() {
   System.out.println("bark");
}
public void barkMany(int N) {
    for (int i = 0; i < N; i += 1) {
        bark();
    }
}
```



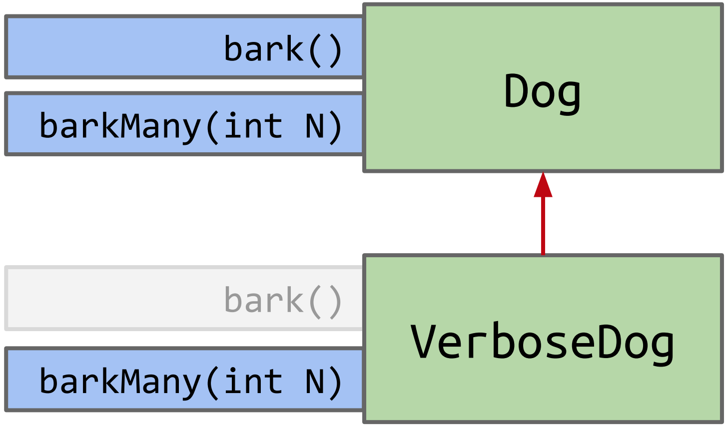

```
@Override
public void barkMany(int N) {
    System.out.println("As a dog, I say: ");
    for (int i = 0; i < N; i += 1) {
        bark();  ←  calls inherited bark method
    }
}
```

Implementation Inheritance Breaks Encapsulation

What would vd.barkMany(3) output?

a. **As a dog, I say: bark bark bark**
b. bark bark bark
c. Something else.

(assuming vd is a Verbose Dog)




```
public void bark() {
   System.out.println("bark");
}
public void barkMany(int N) {
    for (int i = 0; i < N; i += 1) {
        bark();
    }
}
```

```
@Override
public void barkMany(int N) {
    System.out.println("As a dog, I say: ");
    for (int i = 0; i < N; i += 1) {
        bark();      calls inherited bark method
    }
}
```

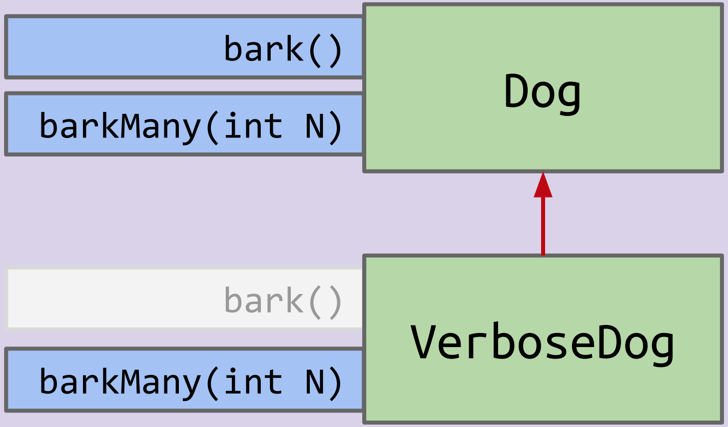
http://yellkey.com/without

What would vd.barkMany(3) output?

a. As a dog, I say: bark bark bark
b. bark bark bark
c. Something else.

(assuming vd is a Verbose Dog)

```java
public void bark() {
    barkMany(1);
}
public void barkMany(int N) {
    for (int i = 0; i < N; i += 1) {
        System.out.println("bark");
    }
}
```




```java
@Override
public void barkMany(int N) {
    System.out.println("As a dog, I say: ");
    for (int i = 0; i < N; i += 1) {
        bark();  ← calls inherited bark method
    }
}
```

Implementation Inheritance Breaks Encapsulation

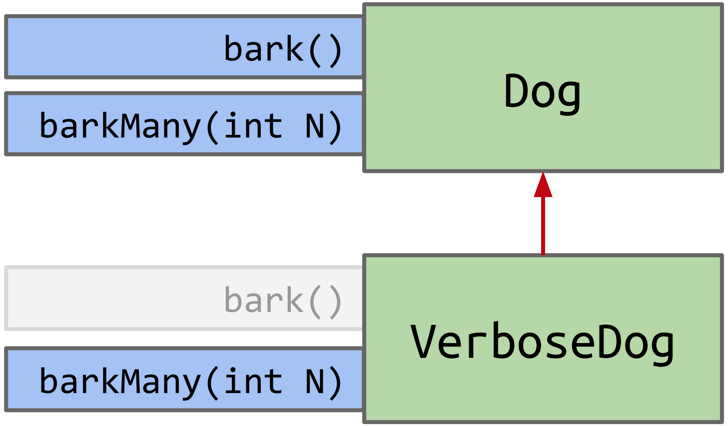
What would vd.barkMany(3) output?

c. **Something else.**

- Gets caught in an infinite loop!

(assuming vd is a Verbose Dog)

```java
public void bark() {
    barkMany(1);
}
public void barkMany(int N) {
    for (int i = 0; i < N; i += 1) {
        System.out.println("bark");
    }
}
```



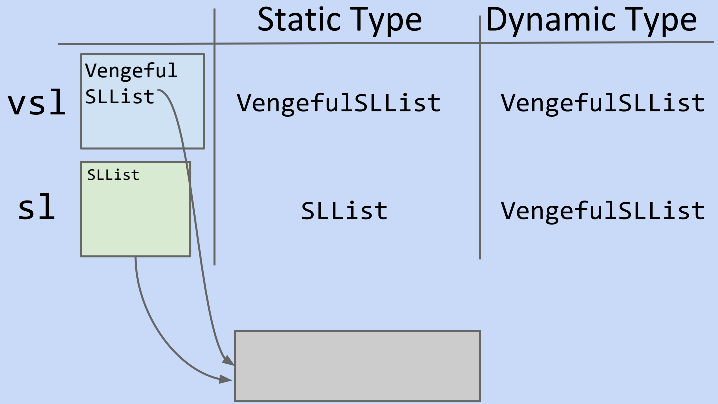

```java
@Override
public void barkMany(int N) {
    System.out.println("As a dog, I say: ");
    for (int i = 0; i < N; i += 1) {
        bark();   ← calls inherited bark method
    }
}
```

Type Checking and Casting

Dynamic Method Selection and Type Checking Puzzle

For each line of code, determine:

- Does that line cause a compilation error?
- Which method does dynamic method selection use?




```
public static void main(String[] args) {
    VengefulSLList<Integer> vsl =
          new VengefulSLList<Integer>(9);
    SLList<Integer> sl = vsl;

    sl.addLast(50);
    sl.removeLast();

    sl.printLostItems();
    VengefulSLList<Integer> vsl2 = sl;
}
```

Reminder: VengefulSLList overrides removeLast and provides a new method called printLostItems.

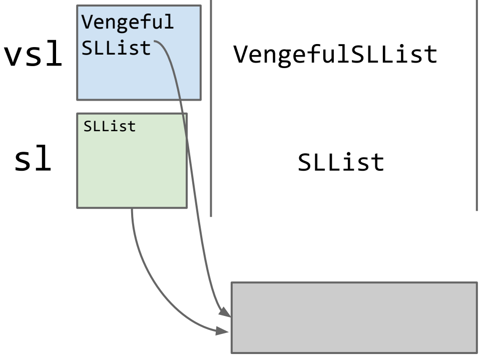
Reminder: Dynamic Method Selection

Also called dynamic type.

If <u>overridden</u>, decide which method to call based on **run-time** type of variable.

- sl's runtime type: VengefulSLList.

	Static Type	Dynamic Type
vsl	VengefulSLList	VengefulSLList
sl	SLList	VengefulSLList




```java
public static void main(String[] args) {
    VengefulSLList<Integer> vsl =
            new VengefulSLList<Integer>(9);
    SLList<Integer> sl = vsl;

    sl.addLast(50);
    sl.removeLast();
}
```

VengefulSLList doesn't override, uses SLList's.

Uses VengefulSLList's.

Reminder: VengefulSLList overrides removeLast and provides a new method called printLostItems.

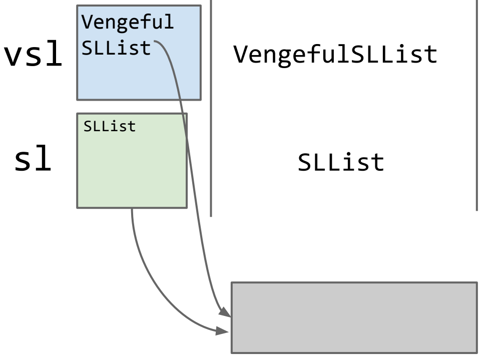
Compile-Time Type Checking

Also called static type.

Compiler allows method calls based on **compile-time** type of variable.

- sl's runtime type: VengefulSLList.
- But cannot call printLostItems.

	Static Type	Dynamic Type
vsl	VengefulSLList	VengefulSLList
sl	SLList	VengefulSLList




```java
public static void main(String[] args) {
    VengefulSLList<Integer> vsl =
          new VengefulSLList<Integer>(9);
    SLList<Integer> sl = vsl;

    sl.addLast(50);
    sl.removeLast();

    sl.printLostItems();
}
```

Compilation error!

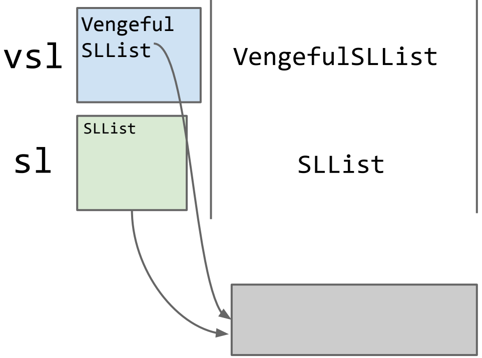
Reminder: VengefulSLList overrides removeLast and provides a new method called printLostItems.

Compile-Time Type Checking

Also called static type.

Compiler allows method calls based on **compile-time** type of variable.

- sl's runtime type: VengefulSLList.
- But cannot call printLostItems.



	Static Type	Dynamic Type
vsl	VengefulSLList	VengefulSLList
sl	SLList	VengefulSLList

```
public static void main(String[] args) {
    VengefulSLList<Integer> vsl =
         new VengefulSLList<Integer>(9);
    SLList<Integer> sl = vsl;

    sl.addLast(50);
    sl.removeLast();

    sl.printLostItems();
    VengefulSLList<Integer> vsl2 = sl;
}
```

Compilation errors!

Compiler also allows assignments based on compile-time types.

- Even though sl's runtime-type is VengefulSLList, cannot assign to vsl2.
- Compiler plays it as safe as possible with type checking.

Compile-Time Types and Expressions

Expressions have compile-time types:

- An expression using the new keyword has the specified compile-time type.

```
SLList<Integer> sl = new VengefulSLList<Integer>();
```

- Compile-time type of right hand side (RHS) expression is VengefulSLList.
- A VengefulSLList is-an SLList, so assignment is allowed.

```
VengefulSLList<Integer> vsl = new SLList<Integer>();
```

Compilation error!

- Compile-time type of RHS expression is SLList.
- An SLList is not necessarily a VengefulSLList, so compilation error results.

Compile-Time Types and Expressions

Expressions have compile-time types:

- Method calls have compile-time type equal to their declared type.

```
public static Dog maxDog(Dog d1, Dog d2) { … }
```

- **Any call to maxDog will have compile-time type Dog!**

Example:

```
Poodle frank  = new Poodle("Frank", 5);
Poodle frankJr = new Poodle("Frank Jr.", 15);

Dog largerDog = maxDog(frank, frankJr);
Poodle largerPoodle = maxDog(frank, frankJr);
```

Compilation error!

RHS has compile-time type Dog.

Casting

Java has a special syntax for specifying the compile-time type of any expression.

- Put desired type in parenthesis before the expression.
- Examples:
  - Compile-time type Dog:

```
maxDog(frank, frankJr);
```

  - Compile-time type Poodle:

```
(Poodle) maxDog(frank, frankJr);
```

Tells compiler to pretend it sees a particular type.

Compilation OK!
RHS has compile-time type Poodle.

```
Poodle frank  = new Poodle("Frank", 5);
Poodle frankJr = new Poodle("Frank Jr.", 15);
Dog largerDog = maxDog(frank, frankJr);
Poodle largerPoodle = (Poodle) maxDog(frank, frankJr);
```

Casting

Casting is a powerful but dangerous tool.

- Tells Java to treat an expression as having a different compile-time type.
- In example below, effectively tells the compiler to ignore its type checking duties.
- Does not actually change anything: sunglasses don't make the world dark.

```
Poodle frank  = new Poodle("Frank", 5);
Malamute frankSr = new Malamute("Frank Sr.", 100);

Poodle largerPoodle = (Poodle) maxDog(frank, frankSr);
```

If we run the code above, we get a ClassCastException at runtime.

- So much for .class files being verifiably type checked...

Dynamic Method Selection and Casting Puzzle

Is it Overriding? Overloading?

```java
public class Bird {
    public void gulgate(Bird b) {
        System.out.println("BiGulBi"); }}
```

```java
public class Falcon extends Bird {
    public void gulgate(Falcon f) {
        System.out.println("FaGulFa");}}
```

```java
Bird bird = new Falcon();
Falcon falcon = (Falcon) bird;
bird.gulgate(falcon);
falcon.gulgate(falcon);
```

What gets printed?

a. BiGulBi BiGulBi
b. BiGulBi FaGulFa
c. FaGulFa BiGulBi
d. FaGulFa FaGulFa

Is it Overriding? Overloading?

```
public class Bird {
    public void gulgate(Bird b) {
        System.out.println("BiGulBi"); }}
```

```
public class Falcon extends Bird {
    public void gulgate(Falcon f) {
        System.out.println("FaGulFa");}}
```

Casting causes no change to the bird variable, nor to the object the bird variable points at!

```
Bird bird = new Falcon();
Falcon falcon = (Falcon) bird;
bird.gulgate(falcon);
falcon.gulgate(falcon);
```

What gets printed?

b. BiGulBi FaGulFa

Why does BiGulBi get printed first?

```java
public class Bird {
    public void gulgate(Bird b) {
        System.out.println("BiGulBi"); }}
```

```java
public class Falcon extends Bird {
    public void gulgate(Falcon f) {
        System.out.println("FaGulFa");}}
```

```java
Bird bird = new Falcon();
Falcon falcon = (Falcon) bird;
bird.gulgate(falcon);
```

Remember: The compiler chooses the most specific matching method signature from the static type of the invoking class.

- Falcon is overloading the gulgate method, not overriding.
- Compiler basically thinks “does Bird class have a gulgate method? Yes! I’ll use that”. Since there is no overloading, no dynamic method selection occurs.

Higher Order Functions (A First Look)

Higher Order Functions

Higher Order Function: A function that treats another function as data.

- e.g. takes a function as input.

Example in Python:

```
def tenX(x):
    return 10*x

def do_twice(f, x):
    return f(f(x))

print(do_twice(tenX, 2))
```

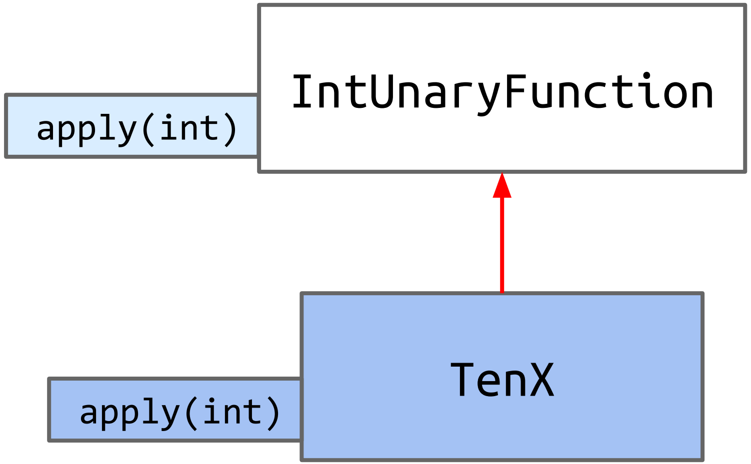
```
200
```

Higher Order Functions in Java 7

Old School (Java 7 and earlier)

- Fundamental issue: Memory boxes (variables) cannot contain pointers to functions.

Can use an interface instead. Let's try it out.




```python
def tenX(x):
    return 10*x

def do_twice(f, x):
    return f(f(x))

print(do_twice(tenX, 2))
```

Higher Order Functions in Java 7

Old School (Java 7 and earlier)

- Fundamental issue: Memory boxes (variables) cannot contain pointers to functions.

Can use an interface instead: Java code below is equivalent to given python code.

```java
public interface IntUnaryFunction {
    int apply(int x);
}
```

```java
public class TenX implements IntUnaryFunction {
    public int apply(int x) {
        return 10 * x;
    }
}
```

```python
def tenX(x):
    return 10*x
```

Example: Higher Order Functions Using Interfaces in Java

```java
public interface IntUnaryFunction {
    int apply(int x);
}
```

```java
public class TenX implements IntUnaryFunction {
    public int apply(int x) {
        return 10 * x;
    }
}
```

```python
def tenX(x):
    return 10*x

def do_twice(f, x):
    return f(f(x))

print(do_twice(tenX, 2))
```

```java
public class HoFDemo {
    public static int do_twice(IntUnaryFunction f, int x) {
        return f.apply(f.apply(x));
    }
    public static void main(String[] args) {
        System.out.println(do_twice(new TenX(), 2));
    }
}
```

Example: Higher Order Functions in Java 8 or Later

In Java 8, new types were introduced: now can can hold references to methods.

- You're welcome to use these features, but we won't teach them.
- Why? The old way is still widely used, e.g. Comparators (see next lecture).

```
public class Java8HoFDemo {
    public static int tenX(int x) {
        return 10*x;
    }
    public static int doTwice(Function<Integer, Integer> f, int x) {
        return f.apply(f.apply(x));
    }
    public static void main(String[] args) {
        int result = doTwice(Java8HoFDemo::tenX, 2);
        System.out.println(result);
    }
}
```

Implementation Inheritance Cheatsheet

VengefulSLList extends SLList means a VenglefulSLList is-an SLList. Inherits all members!

- Variables, methods, nested classes.
- Not constructors.
- Subclass constructor must invoke superclass constructor first.
- Use super to invoke overridden superclass methods and constructors.

Invocation of overridden methods follows two simple rules:

- Compiler plays it safe and only lets us do things allowed by ***static*** type.
- Compiler chooses 2
- For <u>overridden</u> methods the actual method invoked is based on **dynamic** type of invoking expression, e.g. Dog.maxDog(d1, d2).bark();
- Can use casting to overrule compiler type checking.

Does not apply to **overloaded** methods!

Extra Problem Just For Fun

Type Checking Quiz!

```
ShowDog dogC = new ShowDog("Franklin", "Malamute", 180, 6);
ShowDog dogD = new ShowDog("Gargamel", "Corgi", 44, 12);

Dog.maxDog(dogC, dogD);
```

1. What is the static type of `Dog.maxDog(dogC, dog D)`?

2. Which (if any), will compile:

```
Dog md = Dog.maxDog(dogC, dogD);
ShowDog msd = Dog.maxDog(dogC, dogD);
```

3. How many memory boxes are there in the code below? What are the dynamic types of their contents?

```
Object o = new Dog("Hammy", "Beagle", 15);
Dog d = new Dog("Ammo", "Labrador", 54);
Object stuff[] = new Object[5];
stuff[0] = o;
stuff[1] = d;
stuff[2] = null;
```

Citations

https://wikids-life.wikispaces.com/file/view/LadybirdInheritance.jpg/160451153/604x297/LadybirdInheritance.jpg

Actual truth: