# CSE 331

## Software Design & Implementation

### Topic: Generics; Event-driven Programming

**Discussion:** What can you do to make a team work smoothly?

# Reminders

- If you don't know where to start, read answers-hw6.txt!
- Don't add generics to HW6

# Upcoming Deadlines

- HW6 due Thursday (7/28)

## Last Time…

- Intro to Generics
- Generic Methods
- Generics and Subtyping
- Arrays
- Type Bounds

## Today's Agenda

- Wildcards
- Type Erasure
- Event-driven Programming

# Recall: Varieties of abstraction

Abstraction over *computation*: procedures (methods)

```
int x1, y1, x2, y2;
Math.sqrt(x1*x1 + y1*y1);
Math.sqrt(x2*x2 + y2*y2);
```

Abstraction over *data*: ADTs (classes, interfaces)

```
Point p1, p2;
```

Abstraction over *types*: polymorphism (generics)

```
Point<Integer>, Point<Double>
```

# Recall: Type Parameters

```
interface Map {
  Object put(Object key, Object value);
  …
}

interface Map<K, V> {
  V put(K key, V value);
  …
}
```

- Generics always make the client code easier to read and safer
- Generics usually clarify the *implementation*
  - (but sometimes uglify: wildcards, arrays, instantiation)

# Recall: Generic Methods

```
class Utils {
  public static <T extends Number> double sumList(List<T> lst) {
      double result = 0.0;
      for (T n : lst) { // T also works
        result += n.doubleValue();
      }
      return result;
  }
  public static <T> T choose(List<T> lst) {
      int i = … // random number < lst.size
      return lst.get(i);
  }
}
```

# Recall: Generics + Subtyping

If **`A`** and **`B`** are different, then **`GenericClass<A>`** is *not* a subtype of **`GenericClass<B>`**

For example, **`List<Integer>`** and **`List<Number>`** are not subtype-related

- Example: If **`HeftyBag`** extends **`Bag`**, then
  - **`HeftyBag<Integer>`** is a subtype of **`Bag<Integer>`**
  - **`HeftyBag<Number>`** is a subtype of **`Bag<Number>`**
  - **`HeftyBag<String>`** is a subtype of **`Bag<String>`**

# Recall: Generics + Subtyping

If **`A`** and **`B`** are different, then **`GenericClass<A>`** is *not* a subtype of **`GenericClass<B>`**

For example, **`List<Integer>`** and **`List<Number>`** are not subtype-related

- Example: If **`HeftyBag`** extends **`Bag`**, then
  - **`HeftyBag<Integer>`** is a subtype of **`Bag<Integer>`**
  - **`HeftyBag<Number>`** is a subtype of **`Bag<Number>`**
  - **`HeftyBag<String>`** is a subtype of **`Bag<String>`**

If **`B`** is a subtype of **`A`**, then **`B[]`** *is* a Java subtype of **`A[]`**
However, it is not a true subtype! Java will not give you a compiler warning
  - storing a supertype into an index causes **`ArrayStoreException`** (at run time)

# Recall: Type Bounds

Instead of this:

```
<T> void copyTo(List<T> dst, List<T> src) {
    for (T t : src)
      dst.add(t);
}
```

We can now do this:

```
<T1, T2 extends T1> void copyTo(List<T1> dst, List<T2> src) {
    for (T2 t : src)
      dst.add(t);
}
```

What is the difference between these two?

# Where are we?

- basics of generic types for classes and interfaces
- basics of *bounding* generics
- generic *methods* [not just using type parameters of class]
- generics and *subtyping*
- related digression: Java's *array subtyping*
- using *bounds* for more flexible subtyping
- using *wildcards* for more convenient bounds
- Java realities: type erasure
  - unchecked casts
  - **`equals`** interactions
  - creating generic arrays

# Examples

[Compare to earlier version]

```
interface Set<E> {
    void addAll(_______ c);
}
```

- First version:
  ```
  void addAll(Collection<E> c);
  ```

- Better version:
  ```
  <T extends E> void addAll(Collection<T> c);
  ```

# Examples

[Compare to earlier version]

```
interface Set<E> {
    void addAll(_______ c);
}
```

- First version:
  ```
  void addAll(Collection<E> c);
  ```
- Better version:
  ```
  <T extends E> void addAll(Collection<T> c);
  ```
- Most idiomatic version:
  ```
  void addAll(Collection<? extends E> c);
  ```

# Wildcards

Syntax: for a type-parameter instantiation (inside the <…>), can write:

- **`? extends Type`**, some unspecified subtype of **`Type`**
- **`?`** is shorthand for **`? extends Object`**

A wildcard is essentially an ***anonymous*** *type variable*

- each **`?`** stands for some possibly-different unknown type

# `?` versus `Object`

`?` indicates a particular but unknown type

```
void printAll(List<?> lst) {…}
```

Difference between `List<?>` and `List<Object>`:

- can instantiate `?` with any type: `Object`, `String`, …
- `List<Object>` much more restrictive:
  - e.g., wouldn't take a `List<String>`

Difference between `List<Number>` and `List<? extends Number>`:

- can instantiate `?` with `Number`, `Integer`, `Double`, …
- first version is much more restrictive

# Non-example

```
<T extends Comparable<T>> T max(Collection<T> c);
```

No change because `T` used *more than once*

- must choose a name to say that two types must match

# Wildcards

Syntax: for a type-parameter instantiation (inside the <…>), can write:

- `? extends Type`, some unspecified subtype of `Type`
- `?` is shorthand for `? extends Object`

A wildcard is essentially an ***anonymous*** *type variable*

- each `?` stands for some possibly-different unknown type
- use a wildcard when you would use a type variable only once (no need to give it a name)
- communicates to readers of your code that the type's "identity" is not needed anywhere else

# Wildcards

Syntax: for a type-parameter instantiation (inside the <…>), can write:

- **`? extends Type`**, some unspecified subtype of **`Type`**
- **`?`** is shorthand for **`? extends Object`**
- **`? super Type`**, some unspecified superclass of **`Type`**

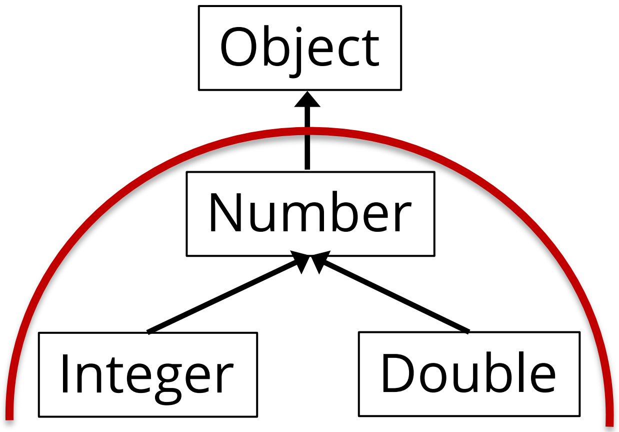
Wildcard can have lower bounds instead of upper bounds!

- says that **`?`** must be **`Type`** or a superclass of **`Type`**

# Type Bounds

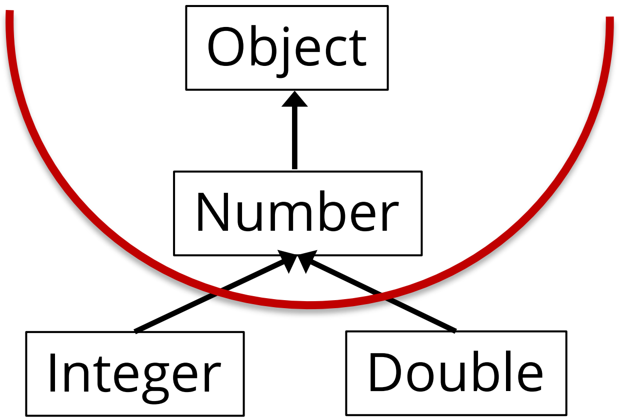
Upper Bound

`? extends Number`




Lower bound

`? super Number`



# Revisit copy method

First version:

```
<T> void copyTo(List<T> dst, List<T> src) {
    for (T t : src)
      dst.add(t);
}
```

More general version:

```
<T1, T2 extends T1> void copyTo(List<T1> dst, List<T2> src) {
    for (T2 t : src)
      dst.add(t);
}
```

# More examples

Let's rewrite this using wildcards:

```
<T> void copyTo(List<? super T> dst, List<? extends T> src) {
  for (T t : src)
        dst.add(t);
 }
```

Why this works:

- lower bound of **`T`** for where callee puts values
- upper bound of **`T`** for where callee gets values
- callers get the subtyping they want
  - Example: **`copy(numberList, integerList)`**
  - Example: **`copy(stringList, stringList)`**

# PECS: Producer Extends, Consumer Super

Should you use **`extends`** or **`super`** or neither?

- use **`? extends T`** when you *get* values (from a *producer*)
  - no problem if it's a subtype
  - (the co-variant subtyping case)
- use **`? super T`** when you *put* values (into a *consumer*)
  - no problem if it's a supertype
  - (the contra-variant subtyping case)
- use neither (just **`T`**, not **`?`**) if you both *get* and *put*
  - can't be as flexible here

```
<T> void copyTo(List<? super T> dst, List<? extends T> src);
```

# More on lower bounds

- As we've seen, lower-bound `? super T` is useful for "consumers"
- Upper-bound `? extends T` could be rewritten without wildcards, but wildcards preferred style where they suffice
- But lower-bound is *only* available for wildcards in Java
  - this does not parse:

```
<T super Foo> void m(Bar<T> x);
```

  - no good reason for Java not to support such lower bounds except designers decided it wasn't useful enough to bother
    - ¯_(ツ)_/¯

# Legal operations on wildcard types

```
Object o;
Number n;
Integer i;
PositiveInteger p;

List<? extends Integer> lei;
```

First, which of these is legal?

```
lei = new ArrayList<Object>();
lei = new ArrayList<Number>();
lei = new ArrayList<Integer>();
lei = new ArrayList<PositiveInteger>();
lei = new ArrayList<NegativeInteger>();
```

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Which of these is legal?

```
o = lei.get(0);
n = lei.get(0);
i = lei.get(0);
p = lei.get(0);
```

# Legal operations on wildcard types

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Which of these is legal?

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`i = lei.get(0);`
~~`p = lei.get(0);`~~

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```

Which of these is legal?

```
o = lei.get(0);
n = lei.get(0);
i = lei.get(0);
p = lei.get(0);
lei.add(o);
lei.add(n);
lei.add(i);
lei.add(p);
```

# Legal operations on wildcard types

```java
Object o;
Number n;
Integer i;
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~~`lei.add(n);`~~
~~`lei.add(i);`~~
~~`lei.add(p);`~~
`lei.add(null);`

# Legal operations on wildcard types

```
Object o;
Number n;
Integer i;
PositiveInteger p;

List<? super Integer> lsi;
```

First, which of these is legal?

```
lsi = new ArrayList<Object>;
lsi = new ArrayList<Number>;
lsi = new ArrayList<Integer>;
lsi = new ArrayList<PositiveInteger>;
lsi = new ArrayList<NegativeInteger>;
```

# Legal operations on wildcard types

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Which of these is legal?

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lsi.add(i);
lsi.add(p);
lsi.add(null);
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n = lsi.get(0);
i = lsi.get(0);
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Which of these is legal?

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~~lsi.add(n);~~

lsi.add(i);

lsi.add(p);

lsi.add(null);

o = lsi.get(0);

~~n = lsi.get(0);~~

~~i = lsi.get(0);~~

~~p = lsi.get(0);~~

# Where are we?

- basics of generic types for classes and interfaces
- basics of *bounding* generics
- generic *methods* [not just using type parameters of class]
- generics and *subtyping*
- related digression: Java's *array subtyping*
- using *bounds* for more flexible subtyping
- using *wildcards* for more convenient bounds
- Java realities: type erasure
  - unchecked casts
  - `equals` interactions
  - creating generic arrays

# Type erasure

All generic types become type **`Object`** once compiled

```
List<String> lst = new ArrayList<String>();
```

at runtime, becomes

```
List<Object> lst = new ArrayList<Object>();
```

Generics are purely a ***compiler*** feature!

# Type erasure example

```
import java.util.*;

public class Erasure {

  public static void foo() {
    List<String> lst = new ArrayList<String>();
    lst.add("abc");
    lst.add("def");
  }

}
```

# Type erasure example

Compile-time signature is **`add(String)`** but the bytecodes say…

```
public static void foo();
  Code:
     0: new           #7                  // class java/util/ArrayList
     3: dup
     4: invokespecial #9                  // Method java/util/ArrayList."<init>":()V
     7: astore_0
     8: aload_0
     9: ldc           #10                 // String abc
    11: invokeinterface #12,  2           // InterfaceMethod java/util/List.add:(Ljava/lang/Object;)Z
    16: pop
    17: aload_0
    18: ldc           #18                 // String def
    20: invokeinterface #12,  2           // InterfaceMethod java/util/List.add:(Ljava/lang/Object;)Z
    25: pop
    26: return
```

# Type erasure

All generic types become type **`Object`** once compiled

- gives backward compatibility (a selling point at time of adoption)
- at run-time, all generic instantiations have the same type

Cannot use **`instanceof`** to discover a type parameter

```
Collection<?> cs = new ArrayList<String>();
if (cs instanceof Collection<String>) { // illegal
  ...
}
```

# Generics and casting

Casting to generic type results in an important warning

```
List<?> lg = new ArrayList<String>();  // ok
List<String> ls = (List<String>) lg;   // warn
```

Compiler gives a warning because the runtime system *will not check for you*

Usually, if you think you need to do this, you're wrong

- a real need to do this is extremely rare

`Object` can also be cast to any generic type ☹

```
public static <T> T badCast(T t, Object o) {
  return (T) o;   // unchecked warning
}
```

# The bottom-line

- Java guarantees a **`List<String>`** variable always holds a (subtype of) the *raw type* **`List`**

- Java does not guarantee a **`List<String>`** variable always has only **`String`** elements at run-time
  - will be true if no unchecked cast warnings are shown
  - compiler inserts casts to/from **`Object`** for generics
    - if these casts fail, ***hard-to-debug errors result***:
      often far from where conceptual mistake occurred

- So, two reasons not to ignore warnings:
  1. You're violating good style/design/subtyping/generics
  2. You're risking difficult debugging

# Recall **`equals`**

```
class Node {
  …
  @Override
  public boolean equals(Object obj) {
    if (!(obj instanceof Node))  {
      return false;
    }
    Node n = (Node) obj;
    return this.data.equals(n.data);
  }
  …
}
```

# `equals` for a parameterized class

```
class Node<E> {
  …
  @Override
  public boolean equals(Object obj) {
    if (!(obj instanceof Node<E>))  {
      return false;
    }
    Node<E> n = (Node<E>) obj;
    return this.data.equals(n.data);
  }
  …
}
```

Erasure: Type arguments do not exist at runtime

# `equals` for a parameterized class

```
class Node<E> {
  …
  @Override
  public boolean equals(Object obj) {
    if (!(obj instanceof Node<E>))  {
      return false;
    }
    Node<E> n = (Node<E>) obj;
    return this.data.equals(n.data);
  }
  …
}
```

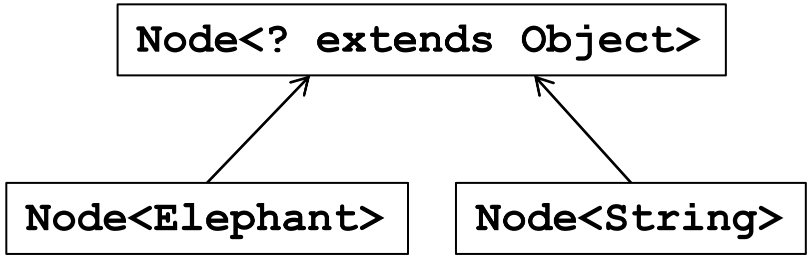
More erasure: At run time, do not know what **E** is and will not be checked, so don't indicate otherwise

# `equals` for a parameterized class

```
class Node<E> {
  …
  @Override
  public boolean equals(Object obj) {
    if (!(obj instanceof Node<?>))  {
      return false;
    }
    Node<?> n = (Node<?>) obj;
    return this.data.equals(n.data);
  }
  …
}
```

Works if the type of obj is **Node<Elephant>** or **Node<String>** or …

Leave it to here to “do the right thing” if **this** and **n** differ on element type



# Generics and arrays

```
public class Foo<T> {
    private T aField;           // ok
    private T[] anArray;        // ok

    public Foo() {
        aField  = new T();      // compile-time error
        anArray = new T[10]; // compile-time error
    }
}
```

- You cannot create objects or arrays of a parameterized type
  - type info is not available at runtime

# Necessary array cast

```
public class Foo<T> {
    private T aField;
    private T[] anArray;

    @SuppressWarnings("unchecked")
    public Foo(T param) {
        aField = param;
        anArray = (T[]) new Object[10];
    }
}
```

You *can* declare variables of type **`T`**, accept them as parameters, return them, or create arrays by casting **`Object[]`**

- casting to generic types is not type-safe (hence the warning)
- Effective Java: use **`ArrayList`** instead

# A sorting example...

Consider the following sorting method:

```
public static void sort(List<Integer> lst) {
    for (int i = 0; i != n; i++) {
        for (int j = 0; j != n - 1; j++) {
            if (lst.get(j) > lst.get(j + 1)) {
                swap(lst, j, j + 1);
            }
        }
    }
}
```

What could we improve about this?

# A sorting example...

Consider the following sorting method:

```
public static void sort(List<?> lst) {
    for (int i = 0; i != n; i++) {
        for (int j = 0; j != n - 1; j++) {
            if (lst.get(j) > lst.get(j + 1)) {
                swap(lst, j, j + 1);
            }
        }
    }
}
```

But wait - this doesn’t compile! Why?

# Achievement unlocked: Callbacks

- Even though we are the implementer, we may need the client to help us
  - previously, we have seen clients provide **data** that we can process
  - now, we will see how clients can provide **code** that can be executed

***Callback pattern***: "Code" provided by client to be used by library

- In JS etc., pass a function as an argument
- In Java, pass an object with the "code" in a method

*Synchronous* callbacks:

- Useful when library needs the callback result immediately

*Asynchronous* callbacks (i.e. event-driven programming):

- Useful for performing an action when some interesting event occurs later

# A sorting example…

First, we can define:

```
public interface Comparable<T> {
   public int compareTo(T other);
}
```

Every object that implements this interface must provide some **code** that informs us which of two objects is bigger.

- returns -1 if this is smaller than other
- returns 0 if this is equal to other
- returns 1 if this is bigger than other

# A sorting example...

```
public static <T extends Comparable<T>> void sort(List<T> lst) {
    for (int i = 0; i != n; i++) {
        for (int j = 0; j != n - 1; j++) {
            if (lst.get(j).compareTo(lst.get(j + 1)) > 0) {
                swap(lst, j, j + 1);
            }
        }
    }
}
```

Relying on client code to sort

We can use the callback pattern to ask the client how to compare to objects.

# How are callbacks used in practice?

- Clients sit around waiting for events like:
  - mouse move/drag/click, button press, button release
  - keyboard: key press or release, sometimes with modifiers like shift/control/alt/etc.
  - finger tap or drag on a touchscreen
  - window resize/minimize/restore/close
  - timer interrupt (including animations)
  - network activity or file I/O (start, done, error)
    - (we will see an example of this shortly)

# Achievement unlocked: Observers

This is the *observer pattern*

- Objects can be *observed* via *observers*/*listeners* that are *notified* via *callbacks* when an *event* (of interest) occurs
- Pattern: Something used over-and-over in software, worth recognizing when appropriate and using common terms
- Widely used in public libraries
- Useful for “visual” programs like web applications

More examples of “observers” coming later…

# Event-driven programming

An *event-driven* program is designed to wait for events:

- program initializes then enters the *event loop*
- abstractly:

```
do {
    e = getNextEvent();
    process event e;
} while (e != quit);
```

Contrast with most programs we have written so far

- they perform specified steps in order and then exit
- that style is still used, just not as frequently
  - example: computing Page Rank or other Big Data work

# Before next class…

1. Ask questions about HW6 and do answers-hw6.txt early
   - Implement your specification from HW5
   - Probably shouldn’t use generics yet (we do this in HW7)

2. Next time, we will start looking at HTML, CSS, and JS
   - HW8 and HW9 will use these instead of Java