Varieties of abstraction

Abstraction over **computation**: procedures

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

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

```java
Point p1, p2;
```

Abstraction over **types**: polymorphism (generics)

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

Applies to both computation and data
Why we ♥ abstraction

- Hide details
  - Avoid distraction
  - Permit the details to change later
- Give a meaningful name to a concept
- Permit reuse in new contexts
  - Avoid duplication: error-prone, confusing
  - Programmers hate to repeat themselves – “lazy”
Programs include a group of abstractions

interface ListOfNumbers {
    boolean add(Number elt);
    Number get(int index);
}
interface ListOfIntegers {
    boolean add(Integer elt);
    Integer get(int index);
}
... and many, many more

interface List<E> {
    boolean add(E elt);
    E get(int index);
}

Declares a new type variable, called a type parameter

Declare a new variable, called a formal parameter

Instantiate by passing an Integer: lst.add(7); aList.add(anInt);

The type of add is Integer $\rightarrow$ boolean

The type of List is Type $\rightarrow$ Type
Using Generics (type arguments)

List<Type> name = new ArrayList<Type>();

The type that is passed is called the type parameter

    List<String> names = new ArrayList<String>();
    names.add("Boris");
    names.add("Natasha");
    String spy = names.get(0); // ok element type
    Point oops = (Point)names.get(1);
    // error -- need String not Point

Use of the “raw type” ArrayList (with no type argument) opens door for problems/errors

    Compiler will warn (can suppress if really needed)
Type variables are types

class NewSet<T> implements Set<T> {
  // rep invariant:
  //   non-null, contains no duplicates
  List<T> theRep;
}

Declaration

Use
Declaring and instantiating generics

// a parameterized (generic) class
public class Name<TypeVar,..., TypeVar> { 
    Convention: 1-letter name such as:
    T for Type, E for Element, N for Number,
    K for Key, V for Value, M for Murder

Class code refers to type parameter by name, e.g., E

To instantiate, client supplies type arguments
    e.g., String as in Name<String>

Analogous to “constructing” a specific class from the
generic definition
Restricting instantiations by clients

boolean add1(Object elt);
boolean add2(Number elt);
add1(new Date());  // OK
add2(new Date());  // compile-time error

interface List1<E extends Object> {...}
interface List2<E extends Number> {...}
List1<Date>      // OK, Date is a subtype
                 // of Object
List2<Date>      // compile-time error,
                 // Date is not a subtype
                 // of Number
Using type variables

Code can perform any operation permitted by the bound

```java
interface List1<E extends Object> {
    void m(E arg) {
        arg.asInt(); // compiler error, E might not
        // support asInt
    }
}

interface List2<E extends Number> {
    void m(E arg) {
        arg.asInt(); // OK, since Number and its
        // subtypes support asInt
    }
}
```
public class Graph<N> implements Iterable<N> { 
    private final Map<N, Set<N>> node2neighbors;
    public Graph(Set<N> nodes, Set<Tuple<N,N>> edges) {
        ...
    }
}

public interface Path<N, P extends Path<N,P>>
    extends Iterable<N>, Comparable<Path<?, ?>> {
    public Iterator<N> iterator();
}

Do **NOT** cut/paste this into your project unless it is what you want (and you understand it!)
Bounded type parameters

<Type extends SuperType>
An upper bound; accepts the given supertype or any of its subtypes
Works for multiple superclass/interfaces with &
<Type extends ClassA & InterfaceB & InterfaceC & ...>

<Type super SuperType>
A lower bound; accepts the given supertype or any of its supertypes

Example
// tree set works for any comparable type
public class TreeSet<T extends Comparable<T>> { 
   ...
}
Not all generics are for collections

Class **Utils** {
    static Number **sumList**(List<Number> **lst**) {
        Number **result** = 0;
        for (Number **n** : **lst**) {
            **result** += **n**;
        }
        return **result**;
    }
}
Signature of a generic method

Class `Utils` {
    static
    T `sumList` (Collection<T> `lst`) {
        // ... black magic within ...
    }
}
Declaring a method’s type parameter

class MyUtils {
    static <T extends Number> T sumList(Collection<T> lst) {
        // ... black magic within ...
    }
}

How to declare a type parameter of a method
public static
<T extends Comparable<T>>
void sort(List<T> list) {
    // ... use list.get() and T.compareTo(T)
}

Actually:
<T extends Comparable<? super T>>
Generic methods

```java
public static <Type> returnType name(params) {

When you want to make just a single (often static) method generic in a class, precede its return type by type parameter(s)

public class Collections {
    ...
    public static <T> void copy(List<T> dst, List<T> src) {
        for (T t : src) {
            dst.add(t);
        }
    }
}
```
Complex bounded types

<T extends Comparable<T>>
T max(Collection<T> c)
    Find max value in any collection (if the elements can be compared)

<T>
void copy(
    List<T2 super T> dst, List<T3 extends T> src)
    Copy all elements from src to dst
    dst must be able to safely store anything that could be in src
    This means that all elements of src must be of dst's element type
    or a subtype

<T extends Comparable<T2 super T>>
void sort(List<T> list)
    Sort any list whose elements can be compared to the same type or
    a broader type
Generics and subtyping

**Integer** is a subtype of **Number**  
Is **List<Integer>** a subtype of **List<Number>**?  
Use subtyping rules (stronger, weaker) to find out

![Subtyping diagram](image)
List<Number> and List<Integer>

interface List<Number> {
    boolean add(Number elt);
    Number get(int index);
}

interface List<Integer> {
    boolean add(Integer elt);
    Integer get(int index);
}

Java subtyping is **invariant** with respect to generics

i.e, not covariant, not contravariant
Invariant subtyping is restrictive
Solution: wildcards

A wildcard is essentially an anonymous type variable
Use it when you would use a type variable exactly once
It appears at the use site; nothing appears at the declaration site
Using wildcards

class HashSet<E> implements Set<E> {
    void addAll(Collection<? extends E> c) {
        // What can this code assume about c?
        // What operations can this code invoke on c?
        ...
    }
}

A wildcard is essentially an anonymous type variable
Wildcards are written at type argument uses
    Within a parameter declaration
A missing extends clause means “extends Object”
There is also “? super E”
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>;;

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

Which of these is legal?
lsi.add(o);
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);
Wildcards

? indicates a wild-card type parameter, one that can be any type

```
List<?> list = new List<?>();  // anything
```

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

? can become any particular type; `Object` is just one such type

```
List<Object>  is restrictive; wouldn't take a List<String>
```

Difference between `List<Foo>` and `List<? extends Foo>`

The latter binds to a particular `Foo` subtype and allows ONLY that

```
Ex: List<? extends Animal>  might store only Giraffes but not Zebras
```

The former allows anything that is a subtype of `Foo` in the same list

```
Ex: List<Animal>  could store both Giraffes and Zebras
```
class Node {

    ...

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

    ...
}
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());
    }
    ...
}
Equals for a parameterized class

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

Erasure again. At run time, equivalent to:
Node<Elephant> type = (Node<String>) obj;
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());
    }
    ...
}
Get/Put Principle

Should you insert wildcards everywhere, and if so, `extends` or `super` or neither?

Get/Put principle

- Use `? extends T` when you `get` values from a producer
- Use `? super T` when you `put` values into a consumer
- Use neither (just `T`, not `?`) if you do both

Example:

```java
<T> void copy(
    List<? super T> dst,
    List<? extends T> src
)
```
Arrays and subtyping

Integer is a subtype of Number

Is Integer[] a subtype of Number[]?

Use our subtyping rules to find out
(Same question as with Lists)

Same answer with respect to true subtyping

Different answer in Java!

Integer[] is a Java subtype of Number[]
Java subtyping disagrees with true subtyping
Integer[] is a Java subtype of Number[]

Number n;
Number[] na;
Integer i;
Integer[] ia;

na[0] = n;
na[1] = i;
n = na[0];
i = na[1];

ia[0] = n;
ia[1] = i;
n = ia[0];
i = ia[1];

ia = na;

Double d = 3.14;

na = ia;
na[2] = d;
i = ia[2];

Why did the Java designers do this?
Tips when writing a generic class

Start by writing a concrete instantiation
Get it correct (testing, reasoning, etc.)
Consider writing a second concrete version
Generalize it by adding type parameters
   Think about which types are the same & different
   Not all ints are the same, nor are all Strings
   The compiler will help you find errors
Eventually, it will be easier to write the code generically from the start
   but probably not yet
Parametric polymorphism

“Parametric polymorphism” means: identical code and behavior, regardless of the type of the input

- Applies to procedures and types
- One copy of the code, many instantiations
- Utilizes dynamic dispatch

Types of parametric polymorphism

- Dynamic (e.g., Lisp)
- static (e.g., ML, Haskell, Java, C#, Delphi)
- C++ templates are similar; both more and less expressive

In Java, called “generics”

- Most commonly used in Java with collections
- Also used in reflection and elsewhere

Lets you write flexible, general, type-safe code
Generics clarify your code

interface Map {
    Object put(Object key, Object value);
    equals(Object other);
}

plus casts in client code
→ possibility of run-time errors

interface Map<Key, Value> {
    Value put(Key key, Value value);
    equals(Object other);
}

Cost: More complicated
declarations and instantiations,
added compile-time checking

Generics usually clarify the implementation
sometimes ugly: wildcards, arrays, instantiation
Generics always make the client code prettier and safer
Java practicalities
Type erasure

All generic types become type `Object` once compiled
   Big reason: backward compatibility with old ancient byte code
   So, at runtime, all generic instantiations have the same type

```java
List<String> lst1 = new ArrayList<String>();
List<Integer> lst2 = new ArrayList<Integer>();
lst1.getClass() == lst2.getClass()  // true
```

You cannot use `instanceof` to discover a type parameter

```java
Collection<?> cs = new ArrayList<String>();
if (cs instanceof Collection<String>) { // illegal
}
```
Generics and casting

Casting to generic type results in a warning

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

The compiler gives an unchecked warning, since this isn't something the runtime system is going to check for you

Usually, if you think you need to do this, you're wrong
(Unless you’re implementing things like `ArrayList` – and then be sure you understand why you’re getting the warning)

The same is true of type variables:

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

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

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

You cannot create objects or arrays of a parameterized type
(Actual type info not available at runtime)
Generics/arrays: a hack

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

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

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

Casting to generic types is not type-safe, so it generates a warning
You almost surely don’t need this in common situations!
Comparing generic objects

```java
public class ArrayList<E> {
    ...
    public int indexOf(E value) {
        for (int i = 0; i < size; i++) {
            // if (elementData[i] == value) {
            if (elementData[i].equals(value)) {
                return i;
            }
        }
        return -1;
    }
}
```

When testing objects of type E for equality, must use `equals`