

GJ:

Making Java easier to type, and easier to type

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Lists in Java and GJ

	in Java	in GJ
integer list	List	List<Integer>
string list	List	List<String>
string list list	List	List<List<String>>

Support for reuse at multiple types

- C++: templates
- Ada: generics
- Standard ML, Haskell: parametric polymorphism
- Java: ???

Collection classes in Java 1.2

- Collection
- Set (HashSet, TreeSet)
- List (ArrayList, LinkedList)
- Map (HashMap, TreeMap)
- Iterator, ListIterator
- Comparator, Comparable

The basics:

Lists in Java and GJ

Lists in Java

```
interface List {  
    public void add (Object x);  
    public Iterator iterator ();  
}  
  
interface Iterator {  
    public Object next ();  
    public boolean hasNext ();  
}
```

Lists in GJ

```
interface List<A> {  
    public void add (A x);  
    public Iterator<A> iterator ();  
}  
  
interface Iterator<A> {  
    public A next ();  
    public boolean hasNext ();  
}
```

Translating lists from GJ to Java

```
interface List {  
    public void add (Object x);  
    public Iterator iterator ();  
}  
  
interface Iterator {  
    public Object next ();  
    public boolean hasNext ();  
}
```

Accessing lists in Java

```
// integer list
```

```
List xs = new LinkedList();  xs.add(new Integer(0));
```

```
Integer x = (Integer)xs.iterator().next();
```

```
// string list list
```

```
List ys = new LinkedList();  ys.add(new "zero");
```

```
List yss = new LinkedList();  yss.add(ys);
```

```
String y = (String)((List)yss.iterator().next()).iterator().next();
```

```
// string list treated as integer list
```

```
Integer z = (Integer)ys.iterator().next();  // run-time exception
```

Accessing lists in GJ

```
// integer list
```

```
List<Integer> xs = new LinkedList<Integer>();  xs.add(new Integer(0));  
Integer x = xs.iterator().next();
```

```
// string list list
```

```
List<String> ys = new LinkedList<String>();  ys.add("zero");  
List<List<String>> yss = new LinkedList<List<String>>();  yss.add(ys);  
String y = yss.iterator().next().iterator().next();
```

```
// string list treated as integer list
```

```
Integer z = ys.iterator().next();  // compile-time error
```

Implementing lists in Java

```
class LinkedList implements List {  
    protected class Node {  
        Object elt;  Node next;  
        Node (Object e) { elt=e; next=null; }  
    }  
    protected Node h, t;  
    public LinkedList () { h=new Node(null); t=h; }  
    public void add (Object elt) { t.next=new Node(elt); t=t.next; }  
    public Iterator iterator () {  
        return new Iterator () {  
            protected Node p=h.next;  
            public boolean hasNext () { return p!=null; }  
            public Object next () { Object e=p.elt; p=p.next; return e; }  
        };  
    }  
}
```

Implementing lists in GJ

```
class LinkedList<A> implements List<A> {  
    protected class Node {  
        A elt;  Node next;  
        Node (A e) { elt=e; next=null; }  
    }  
    protected Node h, t;  
    public LinkedList () { h=new Node(null); t=h; }  
    public void add (A elt) { t.next=new Node(elt); t=t.next; }  
    public Iterator<A> iterator () {  
        return new Iterator<A> () {  
            protected Node p=h.next;  
            public boolean hasNext () { return p!=null; }  
            public A next () { A e=p.elt; p=p.next; return e; }  
        };  
    }  
}
```

Generic methods, Bridges, and Bounds

Generic methods: First in Java

```
class Lists {  
    public static Object first (List xs) {  
        return xs.iterator().next();  
    }  
}
```

```
List ys = new LinkedList();  ys.add("zero");  
List yss = new LinkedList<List<String>>();  yss.add(ys);  
String y = (String)Lists.first((List)Lists.first(yss));
```

Generic methods: First in GJ

```
class Lists {  
    public static <A> A first (List<A> xs) {  
        return xs.iterator().next();  
    }  
}
```

```
List<String> ys = new LinkedList<String>();  ys.add("zero");  
List<List<String>> yss = new LinkedList<List<String>>();  yss.add(ys);  
String y = Lists.first(Lists.first(yss));
```

Bridges: Comparing bytes in Java

```
interface Comparable {  
    public int compareTo (Object that);  
}  
  
class Byte implements Comparable {  
    private byte value;  
    public Byte (byte value) { this.value = value; }  
    public byte byteValue () { return value; }  
    public int compareTo (Byte that) { // overloading  
        return this.value - that.value;  
    }  
    public int compareTo (Object that) { // overriding - bridge  
        return this.compareTo((Byte)that);  
    }  
}
```

Bridges: Comparing bytes in GJ

```
interface Comparable<A> {  
    public int compareTo (A that);  
}  
  
class Byte implements Comparable<Byte> {  
    private byte value;  
  
    public Byte (byte value) { this.value = value; }  
  
    public byte byteValue () { return value; }  
  
    public int compareTo (Byte that) {  
        return this.value - that.value;  
    }  
}
```

Bounds: Maximum in Java

```
class Lists { ...
    public static Comparable max (List xs) {
        Iterator xi = xs.iterator();
        Comparable w = (Comparable)xi.next();
        while (xi.hasNext()) {
            Comparable x = (Comparable)xi.next();
            if (w.compareTo(x) < 0) w = x;
        }
        return w;
    }
}

List xs = new LinkedList(); xs.add(new Byte(0));
Byte x = (Byte)Lists.max(xs);

List ys = new LinkedList(); ys.add(new Boolean(false));
Boolean y = (Boolean)Lists.max(ys); // run-time exception
```

Bounds: Maximum in GJ

```
class Lists {  
    public static <A implements Comparable<A>> A max (List<A> xs) {  
        Iterator<A> xi = xs.iterator();  
        A w = xi.next();  
        while (xi.hasNext()) {  
            A x = xi.next();  
            if (w.compareTo(x) < 0) w = x;  
        }  
        return w;  
    }  
}  
  
List<Byte> xs = new LinkedList<Byte>(); xs.add(new Byte(0));  
Byte x = Lists.max(xs);  
  
List<Boolean> ys = new LinkedList<Boolean>(); ys.add(new Boolean(false));  
Boolean y = Lists.max(ys); // compile-time error
```

Retrofitting and Raw types (Evolution vs. Revolution)

Review: Old definition with old use

// old definition

```
interface List {  
    public void add (Object x);  
    public Iterator iterator (); }  
  
interface Iterator {  
    public Object next ();  
    public boolean hasNext (); }  
  
class LinkedList implements List { ...  
    public void add (Object x) { ... }  
    public Iterator iterator () { ... } }
```

// old use

```
List xs = new LinkedList();  xs.add(new Integer(0));  
Integer x = (Integer)xs.iterator().next();
```

Review: New definition with new use

// new definition

```
interface List<A> {  
    public void add (A x);  
    public Iterator<A> iterator (); }  
interface Iterator<A> {  
    public A next ();  
    public boolean hasNext (); }  
class LinkedList<A> implements List<A> { ...  
    public void add (A elt) { ... }  
    public Iterator<A> iterator () { ... } }
```

// new use

```
List<Integer> xs = new LinkedList<Integer>();  xs.add(new Integer(0));  
Integer x = xs.iterator().next();
```

Retrofitting types: Old definition with new use

```
// old definition as before
```

```
...
```

```
// retrofitting
```

```
interface List<A> {  
    public void add (A x);  
    public Iterator<A> iterator (); }
```

```
interface Iterator<A> {  
    public A next ();  
    public boolean hasNext (); }
```

```
class LinkedList<A> implements List<A> { ...  
    public void add (A elt);  
    public Iterator<A> iterator (); }
```

```
// new use
```

```
List<Integer> xs = new LinkedList<Integer>();  xs.add(new Integer(0));
```

```
Integer x = xs.iterator().next();
```

Raw types: New definition with old use

// new definition

```
interface List<A> {  
    public void add (A x);  
    public Iterator<A> iterator (); }  
interface Iterator<A> {  
    public A next ();  
    public boolean hasNext (); }  
class LinkedList<A> implements List<A> { ...  
    public void add (A elt) { ... }  
    public Iterator<A> iterator () { ... } }
```

// old use

```
List xs = new LinkedList();  xs.add(new Integer(0));  
Integer x = (Integer)xs.iterator().next();
```

Raw types: Unchecked warnings

```
public String loophole (Integer x) {  
    List<String> ys = new LinkedList<String>();  
    List xs = ys;  
    xs.add(x); // compile-time unchecked warning  
    return ys.iterator().next();  
}
```

```
// The loophole translated to Java  
public String loophole (Integer x) {  
    List ys = new LinkedList();  
    List xs = ys;  
    xs.add(x);  
    return (String)ys.iterator().next(); // run-time exception  
}
```

Raw types: Equality in Java

```
class LinkedList implements List { ...
    public boolean equals (Object that) {
        if (!that instanceof LinkedList) return false;
        Iterator xi = this.iterator();
        Iterator yi = ((LinkedList)that).iterator();
        while (xi.hasNext() && yi.hasNext()) {
            Object x = xi.next();
            Object y = yi.next();
            if (!(x == null ? y == null : x.equals(y)))
                return false;
        }
        return !xi.hasNext() && !yi.hasNext();
    }
}
```

Raw types: Equality in GJ

```
class LinkedList<A> implements List<A> { ...
    public boolean equals (Object that) {
        if (!that instanceof LinkedList) return false;
        Iterator<A> xi = this.iterator();
        Iterator yi = ((LinkedList)that).iterator();
        while (xi.hasNext() && yi.hasNext()) {
            A x = xi.next();
            Object y = yi.next();
            if (!(x == null ? y == null : x.equals(y)))
                return false;
        }
        return !xi.hasNext() && !yi.hasNext();
    }
}
```

Arrays

Arrays in Java

```
class List { ...
    public int size();
    public Object[] toArray();
}

class LinkedList implements List { ...
    public Object[] toArray() {
        Object[] xa = new Object[this.size()];
        ... // copy list into xa
        return xa;
    }
}
```

```
List ys = new LinkedList();  xs.add("zero");
String[] ya = (String[])ys.toArray();  // run-time exception
```

Arrays in GJ — the wrong way

```
class List<A> { ...
    public int size();
    public A[] toArray();
}

class LinkedList<A> implements List<A> { ...
    public A[] toArray() {
        A[] xa = new A[this.size()]; // compile-time unchecked warning
        ... // copy list into xa
        return xa;
    }
}
```

```
List<String> ys = new LinkedList<String>(); ys.add("zero");
String[] ya = ys.toArray(); // run-time exception
```

Arrays in GJ — the right way

```
class List<A> { ...
    public int size();
    public A[] toArray(A[] xa);
}

class LinkedList<A> implements List<A> { ...
    public A[] toArray(A[] xa) {
        if (xa.length < this.size())
            xa = gj.lang.Array.newInstance(xa, this.size()); // no warning
        ... // copy list into xa
        return xa;
    }
}

List<String> ys = new LinkedList<String>(); ys.add("zero");
String[] ya = ys.toArray(new String[0]); // no exception
```

A bridge too far

Iterators in GJ

```
interface Iterator<A> {  
    public boolean hasNext ();  
    public A next ();  
}  
  
class Interval implements Iterator<Integer> {  
    private int i;  
    private int n;  
    public Interval (int l, int u) { i = l; n = u; }  
    public boolean hasNext () { return i <= n; }  
    public Integer next () { return new Integer(i++); }  
}
```

Translating GJ to Java

```
interface Iterator {  
    public boolean hasNext ();  
    public Object next ();  
}  
  
class Interval implements Iterator {  
    private int i;  
    private int n;  
    public Interval (int l, int u) { i = l; n = u; }  
    public boolean hasNext () { return i <= n; }  
    public Integer next/*1*/ () { return new Integer(i++); }  
    // bridge  
    public Object next/*2*/ () { return this.next/*1*/(); }  
}
```

Conclusion

A Generic Java

- GJ supports generic types
- GJ contains Java as a subset
- GJ compiles to Java, and hence the Java Virtual Machine
- GJ works with Java libraries

Higher-order functions

Lambda calculus

$\lambda x. x + 1 : \text{int} \rightarrow \text{int}$

SML

`fn(x) => x+1 : int -> int`

GJ

```
interface Function<A,B> {  
    public B apply (A x);  
}  
  
new Function<Integer,Integer>() {  
    public Integer apply (Integer x) {  
        return new Integer(x.intValue()+1);  
    }  
}
```

Related Work

	run-time types	new def old use	old def new use
Pizza Odersky & Wadler	×	×	×
virtual types Thorup	×	×	×
class loader Agesen, Freund, & Mitchell	✓	×	×
PolyJ Myers, Bank, & Liskov	✓	×	×
NextGen Cartwright & Steele	✓	✓	×
GJ Bracha, Odersky, Stoutamire, Wadler	×	✓	✓

GJ vs. C++

	GJ	C++
Requirements on types explicit (bounds)	✓	✗
Report errors at compile-time	✓	✗
Avoid code bloat	✓	✗
Easy to in-line operators	✗	✓
Allow base types as type parameters	✗	✓

GJ is available from:

www.cs.bell-labs.com/~wadler/pizza/gj/

www.cis.unisa.edu.au/~pizza/gj/

wwwipd.ira.uka.de/~pizza/gj/

You can give Sun feedback on generic types:

[http://developer.javasoft.com/
developer/bugParade/bugs/4173702.html](http://developer.javasoft.com/developer/bugParade/bugs/4173702.html)