Generics

Form **W-9**
(Rev. October 2007)
Department of the Treasury
Internal Revenue Service

Request for Taxpayer Identification Number and Certification

Give form to the requester. Do not send to the IRS.

Print or type
See Specific Instructions on page 2.

Name (as shown on your income tax return)

Business name, if different from above

Check appropriate box: ☐ Individual/Sole proprietor ☐ Corporation ☐ Partnership
☐ Limited liability company. Enter the tax classification (D=disregarded entity, C=corporation, P=partnership) ▶ -------
☐ Other (see instructions) ▶

☐ Exempt payee

Address (number, street, and apt. or suite no.)

Requester's name and address (optional)

City, state, and ZIP code

List account number(s) here (optional)

Part I **Taxpayer Identification Number (TIN)**

Enter your TIN in the appropriate box. The TIN provided must match the name given on Line 1 to avoid backup withholding. For individuals, this is your social security number (SSN). However, for a resident alien, sole proprietor, or disregarded entity, see the Part I instructions on page 3. For other entities, it is your employer identification number (EIN). If you do not have a number, see *How to get a TIN* on page 3.

Note. If the account is in more than one name, see the chart on page 4 for guidelines on whose number to enter.

Social security number

or

Employer identification number

Part II **Certification**

Under penalties of perjury, I certify that:

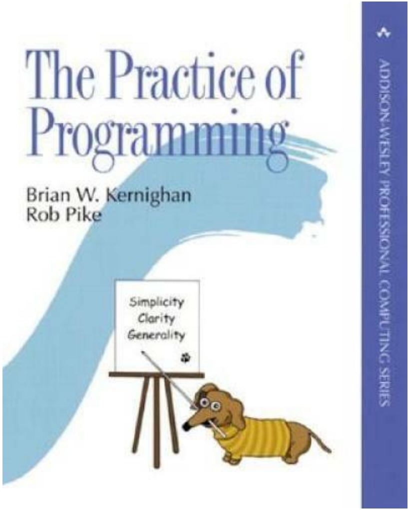
1. The number shown on this form is my correct taxpayer identification number (or I am waiting for a number to be issued to me), and
2. I am not subject to backup withholding because: (a) I am exempt from backup withholding, or (b) I have not been notified by the Internal Revenue Service (IRS) that I am subject to backup withholding as a result of a failure to report all interest or dividends, or (c) the IRS has notified me that I am no longer subject to backup withholding, and
3. I am a U.S. citizen or other U.S. person (defined below).

Certification instructions. You must cross out item 2 above if you have been notified by the IRS that you are currently subject to backup withholding because you have failed to report all interest and dividends on your tax return. For real estate transactions, item 2 does not apply. For mortgage interest paid, acquisition or abandonment of secured property, cancellation of debt, contributions to an individual retirement arrangement (IRA), and generally, payments other than interest and dividends, you are not required to sign the Certification, but you must provide your correct TIN. See the instructions on page 4.

Sign Here **Signature of U.S. person** ▶ **Date** ▶

IRS W-9 Form

Generics



- Simplify, don't repeat yourself (DRY)
- Clarify, express clearly to reader
- Generalize, abstract

Common sense comes from extensive experience, learning from the masters is a short cut. See also *Effective Java* by Block. Knowing all Java constructs is important, but good programming is about *effective* use of the language.

Generics (parametric polymorphism) is HUGE! (but simple and natural)

Computer science is about "bookkeeping." Some of the bookkeeping has been captured in standard libraries—all of it *generic*, ready to be applied to your application. Much remains to be tweaked or even invented for other problems, so designing generic data structures is important.

In Java, one type is a subtype of antoher if the are related by the extends or implments clause.

`Integer`	is a subtype of	`Number`
`Double`	is a subtype of	`Number`
`ArrayList<E>`	is a subtype of	`List<E>`
`List<E>`	is a subtype of	`Collection<E>`
`Collection<E>`	is a subtype of	`Iterable<E>`

THe subtypign relation is transitive, meaning that if one type is a subtype of a second, and the second is a subtype of a third, then the first is a subtype of the third.

Syntax

Non-parameterized class:

```
<class declaration> ::=
   "class" <identifier>
   ["extends" <type>]
   ["implements" <type list>]
   "{" <class body> "}"
```

Generic class

```
<class declaration> ::=
   "class" <identifier> [<type parameter list>]
   ["extends" <type>]
   ["implements" <type list>]
   "{" <class body> "}"
```

Syntax

Non-parametrized method

```
<method declaration> ::=
    <type> <identifier>
    "(" [<formal parameters list>] ")"
    ["throws" <qualified identifier list>]
    "{" <method body> "}"
```

Generic method

```
<method declaration> ::=
    [<type parameter list>] <type> <identifier>
    "(" [<formal parameters list>] ")"
    ["throws" <qualified identifier list>]
    "{" <method body> "}"
```

Syntax

Generic type parameters

```
<type parameter list> ::=
    "<" <type parameter> {"," <type parameter>} ">"
<type parameter> ::=
    <identifier> [ "extends" <bound> ]
<bound> ::= <type> { "&" <type> }

<type argument list> ::=
    "<" <type argument> {"," <type argument>} ">"
<type argument> ::= <type>
                  | "?" ["extends" <type>]
                  | "?" ["super" <type>]
```

Syntax

```
<type> ::= <identifier> [<type argument list>]
    {"." <identifier> [<type argument list>]}
    {"[" "]"}
          | <primitive type>
```

Already we have used ArrayList and LinkedList.

```
List<BigDecimal> list1 = new ArrayList<>();
list1.add (new BigDecimal ("123"));
list1.add (new BigDecimal ("4567"));
System.out.println (list1);

List<String> list2 = new LinkedList<String>();
list2.add ("How");
list2.add ("now");
list2.add ("brown");
list2.add ("cow");
System.out.println (list2);
```

Consider building a class to hold two values.

```
class Pair {
  int first, second;
}
```

Not very flexible. So we try using subtype polymorphism (object-oriented programming). We take advantage of the fact that every object is a subclass of `Object`.

```
class Pair {
  Object first,second;
  void setFirst (Object first) { this.first=first;}
  Object getFirst () { return first; }
}
```

Not very flexible. So we try using subtype polymorphism (object-oriented programming). We take advantage of the fact that every object is a subclass of `Object`.

```
class Pair {
  Object first,second;
  void setFirst (Object first) { this.first=first;}
  Object getFirst () { return first; }
}

Pair p = new Pair();
p.setFirst (new Object());
p.setFirst ("hello");
p.setFirst (new Integer (5));
System.out.println (p.getFirst());
```

Why Not Subtype?

Subtype polymorphism here is unsafe. The type of the objects is "laundered." We can put it in; but we can't take it out as the same type of thing we put in.

```
class Pair {
  Object first,second;
  void setFirst (Object first) { this.first=first;}
  Object getFirst () { return first; }
}
```

Why Not Subtype?

Subtype polymorphism here is unsafe. The type of the objects is “laundered.” We can put it in; but we can’t take it out as the same type of thing we put in.

```
class Pair {
  Object first,second;
  void setFirst (Object first) { this.first=first;}
  Object getFirst () { return first; }
}

Pair p = new Pair();
p.setFirst ("Hello, World!");
char leadingChar = p.getFirst().charAt(0); // Error
```

Why Not Subtype?

Subtype polymorphism here is unsafe. The type of the objects is "laundered." We can thwart the compiler, but this is not wise. The class can be abused and this is not discovered until runtime.

```java
class Pair {
  Object first,second;
  void setFirst (Object first) { this.first=first;}
  Object getFirst () { return first; }
}

Pair p = new Pair();
p.setFirst (new Integer (5));

// Trust me!
Integer i = (Integer) p.getFirst();  // narrowing
```

Why Generics?

Generic classes (universal polymorphism) is the perfect solution. The compiler checks that the class is used correctly.

```
class Pair <T> {
  public final T first, second;
  Pair (T first, T second) {
     this.first=first; this.second=second;
  }
  T getFirst () { return first; }
}
```

Pairs of integers, pairs of strings, pairs of pairs . . . there are possible and natural.

```
Pair<Integer> p =
   new Pair<Integer>(new Integer(5), new Integer(8));
Integer i = p.getFirst();

Pair<String> q = new Pair<String>("abc","xyz");
String s = q.getFirst();

Pair<Pair<String>> r = new Pair<Pair<String>> (
  new Pair<String>("a","b"), new Pair<String>("c","d"));
```

Why Generics?

Generic classes (universal polymorphism) is the perfect solution. The compiler checks that the class is used correctly.

```
record Pair<T> (T first, T second) {}

Pair<String> q = new Pair<String> ("abc","xyz");
String s = q.first();

Pair<Pair<String>> r = new Pair<Pair<String>> (
  new Pair<String>("a","b"), new Pair<String>("c","d"));
String t = r.second().first();
```

Use the static factory method—not the deprecated constructor `new Integer(3)`

```
Pair<Integer> p =
      new Pair<Integer> (
            Integer.valueOf(3), Integer.valueOf(8));
```

Or better …

Wrapper Classes

Generics class can be instantiated only with classes (not primitive types).

However, autoboxing and unboxing of primitive types make generics act as if they were applicable to primitive types. This is hugely useful.

The duplication of the type can be avoid by *type inference*

```
Pair<Integer> p = new Pair<>(5, 8);
Pair<Character> q = new Pair<>('a', 'b');
int i = p.getFirst();
char c = q.getFirst();
```

```java
class Pair <T,U> {
  public final T first;
  public final U second;
  Pair (T first, U second) {
     this.first=first; this.second=second;
  }
  T getFirst () { return first; }
  U getSecond() { return second; }
}
```

Autoboxing and unboxing.

```java
Pair<Integer,String> p = new Pair<>(5, "hello");
int i = p.getFirst();
String s = p.getSecond();
```

```java
record Pair <T,U> (T first, U second) {}
```

Autoboxing and unboxing.

```java
Pair<Integer,String> p = new Pair<>(5, "hello");
int i = p.first();
String s = p.second();
```

Generic method

A method can be generic even if the class it is in is not generic.

```java
public <T> T pick (T... choices) {
    if (choices.length==0) return null;
    final int i = new Random().nextInt(choices.length);
    return choices[i];
}
```

Using Generic Methods

AdjMain.java

Bounds

This does not work:

```java
public <T> T max (T t1, T t2) {
    if (t1>t2) {
        return t1;
    } else {
        return t2;
    }
}
```

Bounds

This does not work:

```
public <T> T max (T t1, T t2) {
    if (t1>t2) {
        return t1;
    } else {
        return t2;
    }
}
```

Nor does this:

```
public <T> T max (Comparable<T> t1, T t2) {
    if (t1.compareTo(t2) > 0) {
        return t1; // Not necessarily of type T!
    } else {
        return t2;
    }
}
```

Bounds

This does not work:

```
public <T> T max (T t1, T t2) {
    if (t1>t2) {
        return t1;
    } else {
        return t2;
    }
}
```

Bounds

This does not work:

```java
public <T> T max (T t1, T t2) {
    if (t1>t2) {
        return t1;
    } else {
        return t2;
    }
}
```

A type bound works!

```java
public <T extends Comparable<T>> T max (T t1, T t2) {
    if (t1.compareTo(t2) > 0) {
        return t1;
    } else {
        return t2;
    }
}
```

Three important Java generic interfaces:

1. `Iterator`
2. `Comparable`
3. `Comparator`

are often used in conjunction with Java collections.
Also important is:

1. `AutoCloseable`

Java 8 Functional Interfaces (Skip)

Table 2-1. Important functional interfaces in Java

Interface name	Arguments	Returns	Example
`Predicate<T>`	`T`	`boolean`	Has this album been released yet?
`Consumer<T>`	`T`	`void`	Printing out a value
`Function<T,R>`	`T`	`R`	Get the name from an `Artist` object
`Supplier<T>`	None	`T`	A factory method
`UnaryOperator<T>`	`T`	`T`	Logical not (`!`)
`BinaryOperator<T>`	`(T, T)`	`T`	Multiplying two numbers (`*`)

AutoCloseable

The try-with-resources statement is a try statement that declares one or more resources. A resource is an object that should be closed after the program is finished with it. The try-with-resources statement ensures that each resource is closed at the end of the statement. Any object that implements java.lang.AutoCloseable, which includes all objects which implement java.io.Closeable, can be used as a resource.

An object that may hold resources (such as file or socket handles) until it is closed. The close() method of an AutoCloseable object is called automatically when exiting a try-with-resources block for which the object has been declared in the resource specification header. This construction ensures prompt release, avoiding resource exhaustion exceptions and errors that may otherwise occur.

Iterator

The interface `java.lang.Iterator<E>` has methods (i.a.):

```
boolean hasNext()
E next()
```

The interface `java.util.Collection` has method (i.a.):

```
Iterator<E> iterator()
```

```
public static void main (String[] args) {
    final List<Integer>list=new ArrayList<>();
    final Iterator<Integer> it=list.iterator();
    while (it.hasNext() {
        // NB. auto unboxing, no narrowing
        final int x = it.next();
        // Do something with "x"
    }
}
```

Iterator

I tend to use the `for` loop.

```
public static void main (String[] args) {
   final List<Integer>list=new ArrayList<>();
   for (final Iterator<Integer> it=list.iterator();
         it.hasNext();
         /**/) {
      final int x = it.next();  // auto-unboxing
      // Do something with "x"
   }
}
```

(Interesting use of final in a for loop. `Iterator` is a mutable class.)

The "for each" loop is better:

```java
public static void main (String[] args) {
   final List<Integer>list=new ArrayList<>();
   for (final int x: list) {
      // Do something with "x"
   }
}
```

No narrowing necessary, and static type checking possible!

The interface `java.lang.Comparable<T>` has just one method.

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

The interface is used to give a class a "natural" ordering — an ordering the Java API's (especially the collection API's) uses by default.
It *should* be a total ordering consistent with equals: for every `e1` and `e2` of the class `T`, `e1.compareTo(e2)==0` iff `e1.equals(e2)`.

```
// Give X a "natural" ordering
class X implements Comparable<X> {
   /*  ...  */
   int compareTo (X other) {
      /*  compare 'this' and 'other'  */
      if (/* 'this' is greater than 'other' */) {
         return +1;
      } if (/* 'this' is less than 'other' */) {
         return -1;
      } else {
         /* Should be consistent with ``equals()'' */
         return 0;
      }
   }
}
```

```java
class Person implements Comparable<Person> {
    final String name;
    final int idNumber;
    /* Warning:  This method is *not* consistent with
       equals; use for sorting only and not hashing. */
    @java.lang.Override
    int compareTo (final Person other) {
        if (this.idNumber > other.idNumber) {
            return +1;
        } else if (this.idNumber < other.idNumber) {
            return -1;
        } else {
            return this.name.compareTo (other.name);
        }
    }
}
```

Comparator

The interface `java.util.Comparator<T>` has two methods.

```
interface Comparator <T> {
   int compare (T o1, T o2)
   boolean equals (Object obj);  // equal comparing classes
}
```

(We rarely create more than one instance of a particular comparator, so `equals` is hardly ever overridden.)
A comparator allows us to describe an ordering of objects without a natural ordering, or with a completely different ordering. This ordering is completely independent from the class.

Comparator

An example program which compares 2D points in threes ways.
[Need a better example without double.] `Main.java`

Comparable

> *By implementing `Comparable`, you allow your class to interoperate with all of the many genereic algorithms and collection implementations that depend on this interface. You gain a tremendous amount of power of a small amount of effort. Virtually all of the value classes [data structures] in the Java platform libraries, as well as all enum types, implement `Comparable`. If you are writing a value class with an obvious natural ordering, such as alphabetical order, numerical order, or chronological order, you should implement the `Comparable` interface:*
>
> ```
> public interface Comparable<T>
>     int compareTo(T t);
> ```

Block, *Effective Java*, third edition, "Item 14: Consider Implementing `Comparable`," 2018, page 66

Comparator

The generic procedure `reserveOrder()` has some really advanced code ultimately relying on a unsafe cast to do the work. The code is something like this:

```
class Collections {
  // ...
  private static final class RevComp<T>
    implements Comparator<T> {
    private static final RevComp<Object> INSTANCE
      = new RevComp<Object>();

    public int compare (Comparable<Object> o1, T o2) {
      // 'o2' better know how to compare type 'T'
      final Comparable<T> c2 = (Comparable<T>) o2;
      return c2.compare(o1);  // swap places
    }
  }
  public static <T> Comparator<T> reverseOrder() {
    return (Comparator<T>) RevComp.INSTANCE;
  }
}
```

Example Reverse Order

Reverse the natural order.

```
List<Event> track = new LinkedList<Event> ();
Collections.sort (track, Collections.reverseOrder ());
```

Equality

Consistent with Equals.
Usually, we require that two objects are equal if and only if they compare as the same:
x.equals(y) if and only if x.compareTo(y) $==$ 0
It is recommended that when designing a class you choose a natural ordering that is consistent with equals.
Failure to do so will cause problems with hash sets and maps which will be difficult to diagnose.

Type of `max` Function *

```
// WRONG.  A collection of things S that implement Comparable<T>
// do not have to be things of type T.
<T> T max(Collection<Comparable<T>> coll)


<T extends Comparable<T>> T max(Collection<T> coll)  // OK

// Why not be more flexible?
<T extends Comparable<? super T>>
   T max(Collection<? extends T> coll)

// Multiple bounds for backward compatibility
<T extends Object & Comparable<? super T>>
   T max(Collection<? extends T> coll)
```

See Fruity example by Naftalin and Wadler. Oranges and apples ordered by name (kind of fruit) and size.

Collection Classes

Many predefined classes in Java are generic. Generics make these classes useful in more situations. The Java package `java.util` is filled with generic, "utility" classes — classes that are used to solve a wide variety of problems types.

Many of these classes are container or collection classes — classes the hold many individual sub-pieces (like arrays do). These classes are organized in a rich system known as the collection classes.

Collections classes share two important characteristics:

1. the individual items have arbitrary type
2. it is common to iterate over all the individual items of the collection

Most prominently: lists, stacks, queues, sets, and maps.

Collection Classes

- `java.util.Collections` uninstaniable, utility class. Many static facilities for the collection classes
- `java.util.Collection<E>` generic interface. Root interface for the collection classes.

List

What is a list?
A list is an ordered collection of elements, like a chain.

There is a first element, a second element, and so on. There is a last element as well. Sometimes this structure is called a sequence.
The same value may occur more than once (unlike a set).

List

What is a list? It is the first and simplest of the data structures.
It is a polymorphic (generic), recursive structure with two constructors.

```
data List a = Nil | Cons a (List a)
```

List Essence

Operations:

- Constructor of polymorphic empty list “nil”
- Constructor of non-empty list “cons”
- Recognizer “null?”
- Destructor of the non-empty list “head” and “tail”

Rules:

- `head(cons(e,_)=e`
- `tail(cons(_,l)=l`

Implementation and performance are other matters.

List versus Array

The advantage of an array is that it is fairly cheap to allocate a big fixed amount of storage at once. But it wastes storage if a lot of elements are requested, but few are needed. Also, removing an element in the middle of an array is expensive because one has to move a lot of elements.

A list allocates exactly what is needed as it is needed— no space is wasted. Removing an element in the middle can be cheaper than with an array. On the other hand, random access to all elements is lost and more bookkeeping is required. Access to the first and last elements of a list may be cheap.

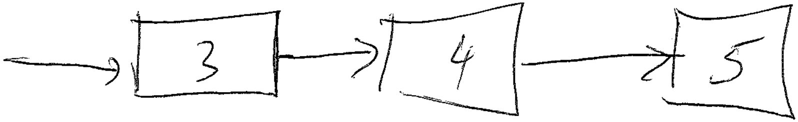
`ArrayList` in an attempted compromise. How does it handle changes in the number of elements?

List

The Java API has already implemented the `LinkedList` class. Let us implement our own simple version.

Implementing our own lists:
`IntList.java`
`GenericList.java`

But first a mental picture of the approach:



Abstract representation of a list

List

See Sedwick and Wayne section 4.3 for a array-based stack, and a linked-list with header implementation.

List

The simple version

- `IntList.java`
- `GenericList.java`

does not have an empty list–a major defect.

- `ImmutableList.java` interface
- `ImmutableLinkedList.java` generic class

The Java API has already implemented the `LinkedList` class, which like the `ArrayList` class, implements the generic `List` interface.

We can put static factory methods in an interface to increase cohesion.

> *As of Java 8, the restriction that interfaces cannot contain static methods was eliminated, so there is typically little reason to provide a noninstantiable companion class for an interface [Effective Java, 3rd edition].*

List Interface in the Collection Classes

```
interface java.util.List<E> implements Collection <E>

  E        get (int index)
  E        set (int index, E element)    returns previous elem, if any
 void      add (int index, E element)
  E        remove (int index)

  int      size()   number of elements in the list
  void     clear()  removes all the elements

  boolean  contains (Object o)   search
  int      indexOf  (Object o)   index of the first occurrence

  Iterator<E> iterator ()
```

List Interface in the Collection Classes

The Java API has two implementations of the list interface with different performance characteristics.

ArrayList in the Collection Classes

```
java.util.ArrayList<E> implements List<E>

  ArrayList()
  ArrayList (int initialCapacity)

  void ensureCapacity (int minCapacity)
  void trimToSize     ()
```

LinkedList in the Collection Classes

```
java.util.LinkedList<E> implements List<E>, Deque<E>

  LinkedList()

  E         getFirst ()   same as element()
  E         getLast  ()
  void      addFirst ()   same as push()
  void      addLast  ()
  E         removeFirst () same as pop(), remove()
  E         removeLast  ()
```

Lists

If you have to save space, then use a linked list, If you have to have fast access (set/get) to random elements, then use a list implemented as an array.
If you have to remove and add elements in the middle of the list, use a linked list. See the Josephus problem.

List methods:	get	add	contains	next	remove(0)	iterator.remove
ArrayList	chp	chp	exp	chp	exp	exp
LinkedList	exp	chp	exp	chp	chp	chp

List methods:	get	add	contains	next	remove(0)	iterator.remove
ArrayList	O(1)	O(1)	O(n)	O(1)	O(n)	O(n)
LinkedList	O(n)	O(1)	O(n)	O(1)	O(1)	O(1)

Deque methods:	get	add	contains	next	remove(0)	iterator.remove
ArrayList	O(1)	O(1)	O(n)	O(1)	O(n)	O(n)
LinkedList	O(n)	O(1)	O(n)	O(1)	O(1)	O(1)

Collection Classes

Not be be confused with the generic *interface* `Collection<T>` is the utility class

`java.util.Collections`

```
static <T>   int      binarySearch(List<...> list,T key)
static <T>   List<T>  emptyList()
static <T>   List<T>  singletonList(T o)
static <T ...>  T max (Collection<? extends T> coll)
static <T ...>  T      min (Collection<? extends T> coll)
static       int      frequency (Collection<?> coll, Object o)
static       void     shuffle (List<?> list)
static <T ...> void    sort (List<T> list)
static <T>   List<T>  synchronizedList (List<T> list)
static <T>   List<T>  unmodifiableList (List<T> list)
```

Also Useful

Also in `java.util.Arrays`

```
static <T>   List<T> asList (T... a)
```

```
List<Integer> list = Arrays.asList (1,2,3,4,5,6);
```

I never can remember where this very useful static method is found.

Avoid

Do not use `StringBuffer`, `Stack`, `Vector`, or `Hashtable`, unless you need synchronization.
Use `StringBuilder`, `ArrayDeque`, `ArrayList`, or `HashMap`, instead.

The class `java.util.Collections` has methods (i.a.):

```java
static void sort (List list);
static void sort (List list, Comparator c);
```

Notice the use of the `interface List`.

```java
class Main {
   // For some class X implementing Comparable<X>
   public static void main (String[] args) {
      final List<X> list = new ArrayList<X> ();
      add (new X());
      add (new X());
      Collections.sort (list);
      Collections.sort (list,
        Collections<X>.reverseOrder());
   }
}
```

Lists: Stack, Queue, Deque

Linear lists in which insertions, deletions, and accesses to values occur almost always at the first or the last node are very frequently encountered, and we give them special names:

A *stack* is a linear list for which all insertions and deletions (and usually all accesses) are made at one end of the list.

A *queue* is a linear list for which all insertions are made at one end of the list; all deletions (and usually all accesses) are made at the other end.

A *deque* ("double-ended queue") is a linear list for which all insertions and deletions (and usually all accesses) are made at the ends of the list.

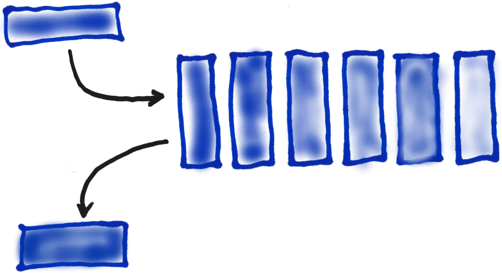
A deque is therefore more general than a stack or a queue; it has some properties in common with a deck of cards, and it is pronounced the same way. We also distinguish *output-restricted* or *input-restricted* deques, in which deletions or insertions, respectively, are allowed to take place at only one end.

From Knuth, volume I, page 235. The term deque was coined by E. J. Schweppe.

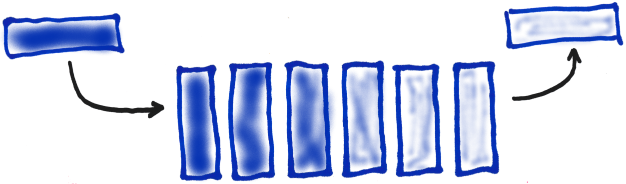
Lists: Stack, Queue, Deque

```
stack (LIFO):  push() = addFirst();  pop() = removeFirst()
queue (FIFO):  add()=addLast() (enqueue); remoe=removeFirst() (dequeue)
deque:  addFirst(); addLast(); removeFirst(); removeLast()
```

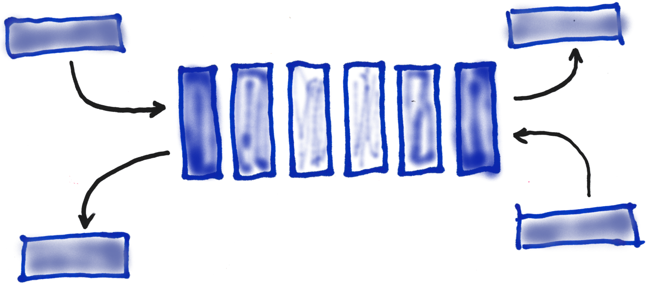
`push()=addFirst()`, `pop()=remove()=removeFirst()`; top is first or front.



`add()=addLast()`, `remove()=removeFirst()`; first is front; back is last



`addFirst(), removeFirst(), addList(), removeLast()`



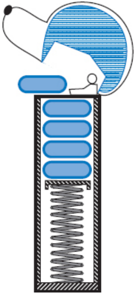
Stack, Queue in Java

If you want a stack, a queue, or a deque in Java.

```
Deque<Integer> stack = new ArrayDeque<Integer> ();
Deque<String>  queue = new ArrayDeque<String> ();
Deque<Integer> deque = new ArrayDeque<Integer> ();
```

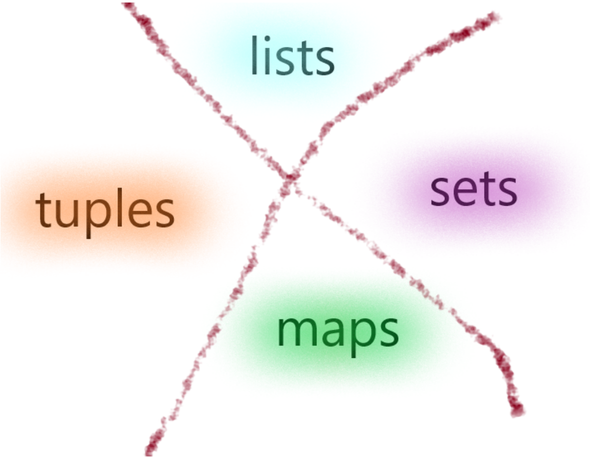
The `LinkedList` class also implements the interface `Deque`. It is preferred only when it that data is treated as an ordered sequence in which it is necessary to insert elements.

Stack



1. `Main.java` stack convert to binary
2. `Examples.java` sundary examples of maps

Important Data Structures



Sets

A set is more complicated data structure philosphically that a list, because it required a notion of equality.

Yet since is the common in mathematics, its "essence" is generally more familiar.

Concrete implementation in Java of the interface `Set` including the `HashSet` and the `TressSet` which are fascinating implementations to be studied in data structures classes. Also to be mentioned is the class BitSet. One of many things there is not time to discuss presently.

Sets

Using (mutable!) sets are easy in Java.

```java
Set<Integer> set = new HashSet<> ();
```

Maps/Dictionaries

Maps are key/value pairs. They are finite functions like arrays.
For example, keyword–definition:

> BODKIN instrument for making holes
>
> CENSORIOUS severly critical
>
> DICTIONARY book that lists words

A word is the *key* and its defintion is its *value*.

Maps/Dictionaries

Maps are key/value pairs. They are finite functions like arrays. So they have two type parameters: one for the type of keys and one for the type of values.
Using (mutable!) maps are easy in Java.

```
Map<String,List<Integer>> set = new HashMap<> ();
```

1. `Main.java` stack convert to binary
2. `Examples.java` sundary examples of maps

Immutable Maps

```java
// this works for up to 10 elements:
import java.util.Map;
Map<String, Integer> test1 = Map.of (
    "a", 101,
    "b", 327,
);

// this works for any number of elements:
import static java.util.Map.entry;
Map<String, Integer> test2 = Map.ofEntries(
    entry("a", 101),
    entry("b", 327)
);
```

Maps/Dictionaries

The tools (the data structures) lists, sets, and map solve many problems.

What is missing are the algorithms, the performance analyses, the implementation choices to solve problems efficiently.