

Lecture 9, 5 February 2026  
Java: callbacks, iterators, generics

Madhavan Mukund, S P Suresh

Programming Language Concepts  
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- An interface is a purely abstract class
  - All methods are abstract
- A class **implements** an interface
  - Provide concrete code for each abstract function
- Classes can implement multiple interfaces
  - Abstract functions, so no contradictory inheritance
- Interfaces describe relevant aspects of a class
  - Abstract functions describe a specific "slice" of capabilities
  - Another class only needs to know about these capabilities

# Interfaces express relevant capabilities

- Generic `quicksort` for any datatype that supports comparisons
- Express this capability by making the argument type `Comparable[]`
  - **Only** information that `quicksort` needs about the underlying type
  - All other aspects are irrelevant
- Describe the relevant functions supported by `Comparable` objects through an interface
- However, we **cannot** express the intended behaviour of `cmp` explicitly

```
public class SortFunctions{
    public static void quicksort(Comparable[] a){
        ...
        // Usual code for quicksort, except that
        // to compare a[i] and a[j] we use
        // a[i].cmp(a[j])
    }
}
```

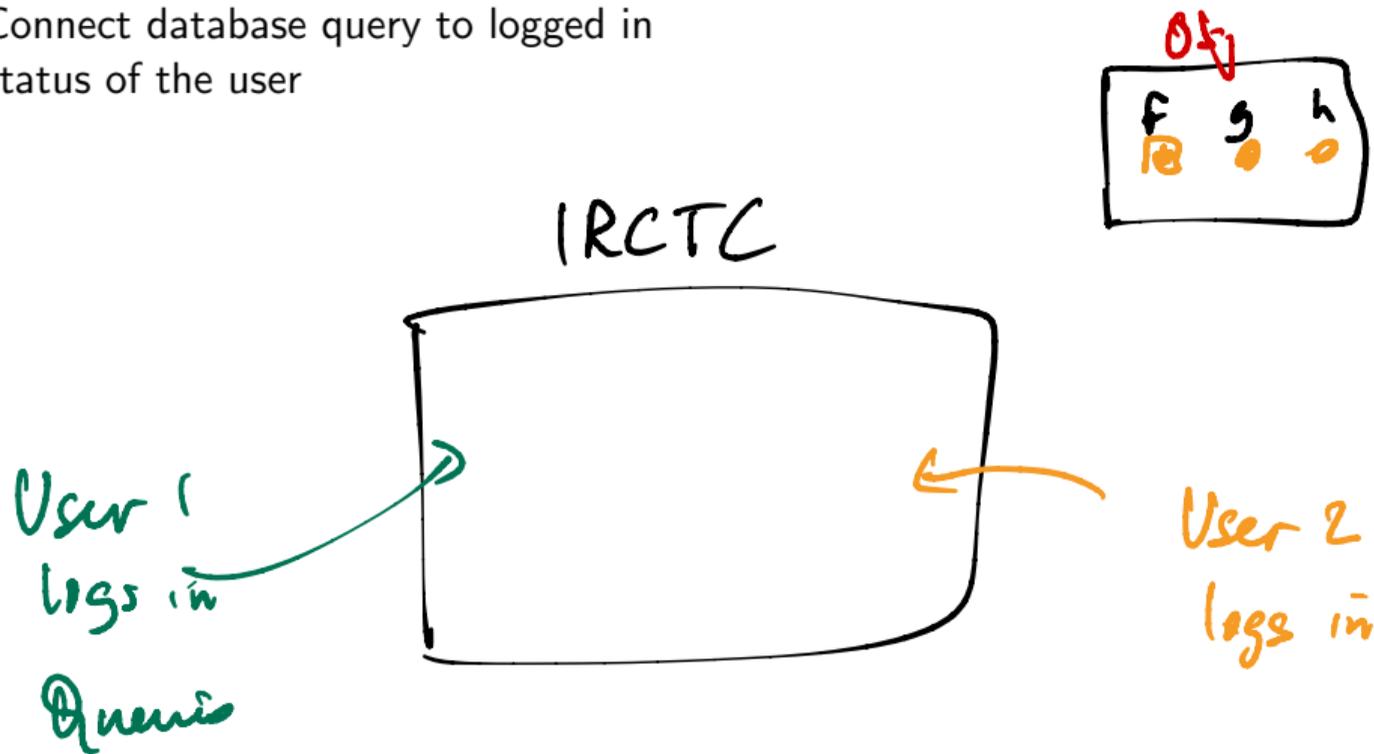
*Only signature*

```
public interface Comparable{
    public abstract int cmp(Comparable s);
    // return -1 if this < s,
    //           0 if this == s,
    //           +1 if this > s
}
```



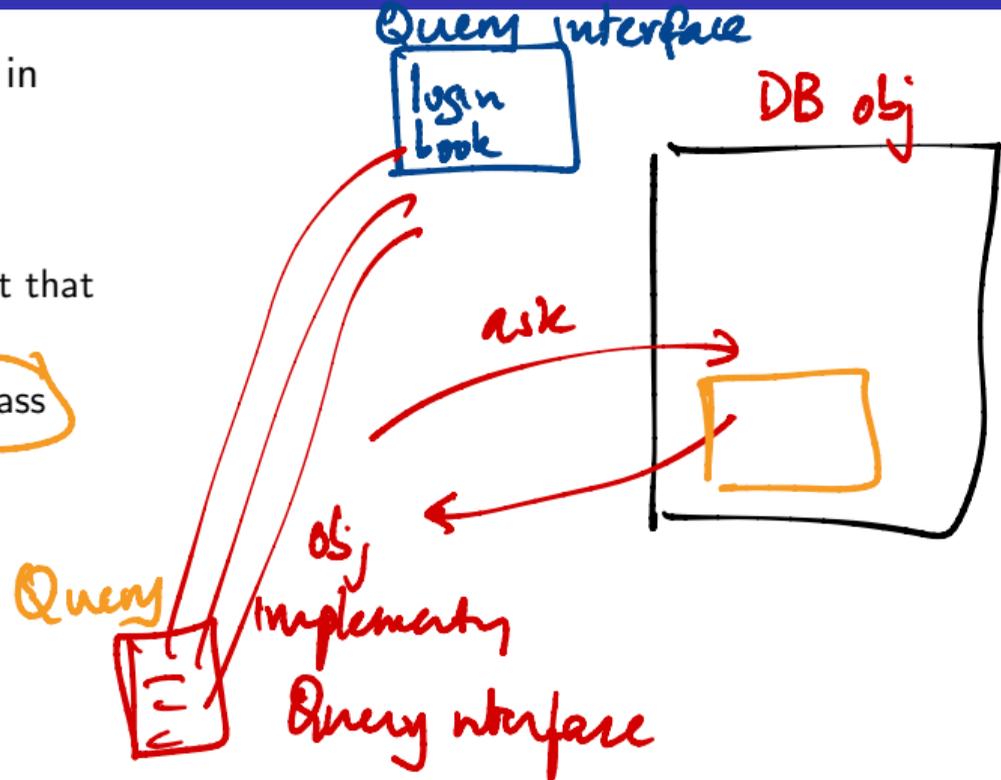
# Interactions with state

- Connect database query to logged in status of the user



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- Use objects!
  - On log in, user receives an object that can make a query
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- Connect database query to logged in status of the user
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  - On log in, user receives an object that can make a query
  - Object is created from private class that can look up `railwaydb`
- How does user know the capabilities of private class `QueryObject`?

# Interactions with state

- Connect database query to logged in status of the user
- Use objects!
  - On log in, user receives an object that can make a query
  - Object is created from private class that can look up `railwaydb`
- How does user know the capabilities of private class `QueryObject`?
- Use an interface!
  - Interface describes the capability of the object returned on login

```
public interface QIF{
    public abstract int
        getStatus(int trainno, Date d);
}

public class RailwayBooking {
    private BookingDB railwaydb;
    public QIF login(String u, String p){
        QueryObject qobj;
        if (valid_login(u,p)) {
            qobj = new QueryObject();
            return(qobj);
        }
    }
}

private class QueryObject implements QIF {
    public int getStatus(int trainno, Date d){
        ...
    }
}
}
```

*Query interface*

```
class Date {
```

```
    private day, month, year
```

```
    equals (Date d)
```

```
        this.day == d.day
```

```
}
```

# Interactions with state ...

- Query object allows unlimited number of queries
- Limit the number of queries per login?
- Maintain a counter
  - Add instance variables to object returned on login
  - Query object can remember the **state** of the interaction

```
public class RailwayBooking {
    private BookingDB railwaydb;
    → public QIF login(String u, String p){
        QueryObject qobj;
        if (valid_login(u,p)) {
            qobj = new QueryObject(); ←
            return(qobj);
        }
    }
    private class QueryObject implements QIF {
        private int numqueries;
        private static int QLIM; ||

        public int getStatus(int trainno, Date d){
            if (numqueries < QLIM){
                // respond, increment numqueries
            }
        }
    }
}
```

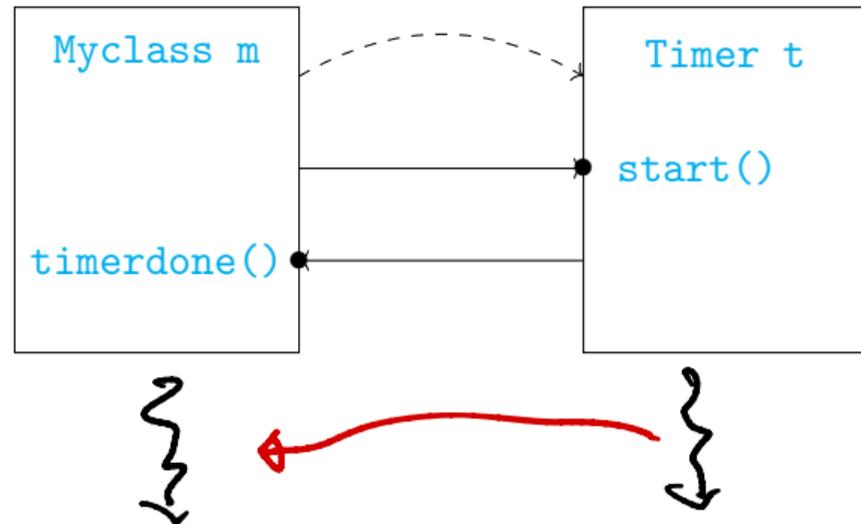
?

QIF

myqobj = DB.login( - - , )  
myqobj.getStatus( - )

# Implementing a call-back facility

- `Myclass m` creates a `Timer t`
- Start `t` to run in parallel
  - `Myclass m` continues to run
  - Will see later how to invoke parallel execution in Java!
- `Timer t` notifies `Myclass m` when the time limit expires
  - Assume `Myclass m` has a function `timerdone()`



# Implementing callbacks

## ■ Code for `Myclass`

```
public class Myclass{  
  
    public void f(){  
        ..  
        Timer t =  
            new Timer(this);  
            // this object  
            // created t  
        ...  
        t.start(); // Start t in parallel  
        ...  
    }  
  
    public void timerdone(){...}  
}
```

# Implementing callbacks

- Code for `Myclass`
- `Timer t` should know whom to notify
  - `Myclass m` passes its identity when it creates `Timer t`
- Code for `Timer`
  - Interface `Runnable` indicates that `Timer` can run in parallel

```
public class Myclass {
    public void f(){
        ..
        Timer t =
            new Timer(this);
        // this object
        // created t
        ...
        t.start(); // Start t
        ...
    }

    public void timerdone(){...}
}

public class Timer
    implements Runnable{
    // Timer can be
    // invoked in parallel
    private Myclass owner;

    public Timer(Myclass o){
        owner = o; // My creator
    }

    public void start(){
        ..
        owner.timerdone();
        // I'm done
    }
}
```

# Implementing callbacks

- Code for `Myclass`
- `Timer t` should know whom to notify
  - `Myclass m` passes its identity when it creates `Timer t`
- Code for `Timer`
  - Interface `Runnable` indicates that `Timer` can run in parallel
- `Timer` specific to `Myclass`
- Create a generic `Timer`?

```
public class Myclass{  
  
    public void f(){  
        ..  
        Timer t =  
            new Timer(this);  
            // this object  
            // created t  
        ...  
        t.start(); // Start t  
        ...  
    }  
  
    public void timerdone(){...}  
}
```

```
public class Timer  
    implements Runnable{  
    // Timer can be  
    // invoked in parallel  
  
    private Myclass owner;  
  
    public Timer(Myclass o){  
        owner = o; // My creator  
    }  
  
    public void start(){  
        ...  
        owner.timerdone();  
        // I'm done  
    }  
}
```

# Generic timer — use interfaces

- Define an interface for callback

```
public interface
    Timerowner{

    public abstract
        void timerdone();
}
```

# Generic timer — use interfaces

- Define an interface for callback

```
public interface  
    Timerowner{  
  
    public abstract  
        void timerdone();  
}
```

- Modify `Myclass` to implement `Timerowner`

```
public class Myclass  
    implements Timerowner{  
  
    public void f(){  
        ..  
        Timer t =  
            new Timer(this);  
        // this object  
        // created t  
        ...  
        t.start(); // Start t  
        ...  
    }  
  
    public void timerdone(){...}  
}
```

# Generic timer — use interfaces

- Define an interface for callback

```
public interface Timerowner{  
    public abstract  
    void timerdone();  
}
```

- Modify `Myclass` to implement `Timerowner`

- Modify `Timer` so that `owner` is compatible with `Timerowner`

```
public class Myclass  
    implements Timerowner{  
    public void f(){  
        ..  
        Timer t =  
            new Timer(this);  
        // this object  
        // created t  
        ...  
        t.start(); // Start t  
        ...  
    }  
    public void timerdone(){...}  
}
```

```
public class Timer  
    implements Runnable{  
    // Timer can be  
    // invoked in parallel  
    private Timerowner owner;  
    public Timer(Timerowner o){  
        owner = o; // My creator  
    }  
    public void start(){  
        ...  
        owner.timerdone();  
        // I'm done  
    }  
}
```

- A generic linear list of objects

# Linear list

- A generic linear list of objects
- Internal implementation may vary

# Linear list

- A generic linear list of objects
- Internal implementation may vary
- An array implementation

```
public class Linearlist {  
    // Array implementation  
    private int limit = 100;  
    private Object[] data = new Object[limit];  
    private int size; // Current size  
  
    public Linearlist(){ size = 0; }  
  
    public void append(Object o){  
        data[size] = o;  
        size++;  
        ...  
    }  
    ...  
}
```

# Linear list

- A generic linear list of objects
- Internal implementation may vary
- An array implementation
- A linked list implementation

for (i=0; i < n; i++) {  
    l[i]  
}

```
public class Linearlist {  
    private Node head;  
    private int size;  
  
    public Linearlist(){ size = 0; }  
  
    public void append(Object o){  
        Node m;  
  
        for (m = head; m.next != null; m = m.next){  
            Node n = new Node(o);  
            m.next = n;  
  
            size++;  
        }  
        ...  
    private class Node (...}  
}
```

# Iteration

- Want a loop to run through all values in a linear list

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- Want a loop to run through all values in a linear list
- If the list is an array with public access, we write this

```
int i;  
for (i = 0; i < data.length; i++){  
    ... // do something with data[i]  
}
```

# Iteration

- Want a loop to run through all values in a linear list
- If the list is an array with public access, we write this
- For a linked list with public access, we could write this

```
int i;  
for (i = 0; i < data.length; i++){  
    ... // do something with data[i]  
}
```

```
Node m;  
for (m = head; m != null; m = m.next){  
    ... // do something with m.data  
}
```

# Iteration

- Want a loop to run through all values in a linear list
- If the list is an array with public access, we write this
- For a linked list with public access, we could write this
- We don't have public access ...

```
int i;  
for (i = 0; i < data.length; i++){  
    ... // do something with data[i]  
}
```

```
Node m;  
for (m = head; m != null; m = m.next){  
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}
```

# Iteration

- Want a loop to run through all values in a linear list
- If the list is an array with public access, we write this
- For a linked list with public access, we could write this
- We don't have public access ...
- ... and we don't know which implementation is in use!

```
int i;  
for (i = 0; i < data.length; i++){  
    ... // do something with data[i]  
}
```

```
Node m;  
for (m = head; m != null; m = m.next){  
    ... // do something with m.data  
}
```

- Need the following abstraction

```
Start at the beginning of the list;
while (there is a next element){
    get the next element;
    do something with it
}
```

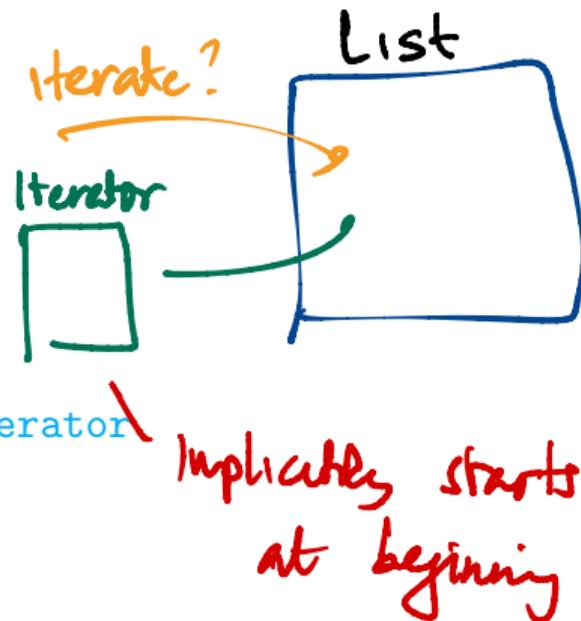
# Iterators

- Need the following abstraction

```
Start at the beginning of the list;  
while (there is a next element){  
    get the next element;  
    do something with it  
}
```

- Encapsulate this functionality in an interface called `Iterator`

```
public interface Iterator{  
    public abstract boolean has_next();  
    public abstract Object get_next();  
}
```



- How do we implement `Iterator` in `Linearlist`?

# Iterators

- How do we implement `Iterator` in `Linearlist`?
- Need a “pointer” to remember position of the iterator

```
private class I  
    implements  
    Iterator {  
    int position = 0;  
    has-next { . }  
    get-next { . }  
}
```

- How do we implement `Iterator` in `Linearlist`?
- Need a “pointer” to remember position of the iterator
- How do we handle nested loops?

```
for (i = 0; i < data.length; i++){  
    for (j = 0; j < data.length; j++){  
        ... // do something with data[i] and data[j]  
    }  
}
```

# Iterators

- Solution: Create an `Iterator` object and export it!

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```
public class Linearlist{  
  
    private class Iter implements Iterator{  
        private Node position;  
        public Iter(){...}    // Constructor  
        public boolean has_next(){...}  
        public Object get_next(){...}  
    }  
  
    // Export a fresh iterator  
    public Iterator get_iterator(){  
        Iter it = new Iter();  
        return(it);  
    }  
}
```

- Solution: Create an `Iterator` object and export it!

```
public class Linearlist{  
  
    private class Iter implements Iterator{  
        private Node position; ←  
        public Iter(){...} // Constructor  
        public boolean has_next(){...} —  
        public Object get_next(){...} —  
    }  
  
    // Export a fresh iterator  
    public Iterator get_iterator(){  
        Iter it = new Iter();  
        return(it);  
    }  
}
```

- Definition of `Iter` depends on linear list

- Now, we can traverse the list externally as follows:

```
Linearlist l = new Linearlist();
...
Object o;
Iterator i = l.get_iterator();

while (i.has_next()){
    o = i.get_next();
    ...    // do something with o
}
```

# Iterators

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while (i.has_next()){
    o = i.get_next();
    ... // do something with o
}
```

- For nested loops, acquire multiple iterators!

```
Linearlist l = new Linearlist();
...
Object oi,oj;
Iterator i,j;
```

```
i = l.get_iterator();
while (i.has_next()){
    oi = i.get_next();
    j = l.get_iterator();
    while (j.has_next()){
        oj = j.get_next();
        ... // do something with oi, oj
    }
}
...
```

# Iterators

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```

- The new Java `for` over lists implicitly constructs and uses an iterator

```
for (type x : a)
    do something with x;
}
```

- For nested loops, acquire multiple iterators!

```
Linearlist l = new Linearlist();
...
Object oi,oj;
Iterator i,j;

i = l.get_iterator();
while (i.has_next()){
    oi = i.get_next();
    j = l.get_iterator();
    while (j.has_next()){
        oj = j.get_next();
        ... // do something with oi, oj
    }
}
...
```

# Polymorphism – “Run time”

- In object-oriented programming, **polymorphism** usually refers to the effect of dynamic dispatch
  - **S** is a subclass of **T**
  - **S** overrides a method **f()** defined in **T**
  - Variable **v** of type **T** is assigned to an object of type **S**
  - **v.f()** uses the definition of **f()** from **S** rather than **T**

`T var = new S();`

T  
|  
S

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- More generally, polymorphism refers to behaviour that depends only a specific capabilities
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  - Search for an element in an array/list
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- Every object “knows” what it needs to do
- More generally, polymorphism refers to behaviour that depends only a specific capabilities — **structural polymorphism**
  - Reverse an array/list (**should work for any type**)
  - Search for an element in an array/list (**need equality check**)
  - Sort an array/list (**need to compare values**)

# Structural polymorphism

- Use the Java class hierarchy to simulate this

# Structural polymorphism

- Use the Java class hierarchy to simulate this
- Polymorphic `reverse`

```
public void reverse (Object[] objarr){  
    Object tempobj;  
    int len = objarr.length;  
    for (i = 0; i < n/2; i++){  
        tempobj = objarr[i];  
        objarr[i] = objarr[(n-1)-i];  
        objarr[(n-1)-i] = tempobj;  
    }  
}
```

# Structural polymorphism

- Use the Java class hierarchy to simulate this
- Polymorphic `reverse`
- Polymorphic `find`
  - `==` translates to `Object.equals()`

```
public int find (Object[] objarr, Object o){  
    int i;  
    for (i = 0; i < objarr.length; i++){  
        if (objarr[i] == o) {return i};  
    }  
    return (-1);  
}
```

# Structural polymorphism

- Use the Java class hierarchy to simulate this
- Polymorphic `reverse`
- Polymorphic `find`
  - `==` translates to `Object.equals()`
- Polymorphic `sort`
  - Use interfaces to capture capabilities

```
public interface Comparable{
    public abstract int cmp(Comparable s);
}

public class SortFunctions{
    public static void quicksort(Comparable[] a){
        ...
        // Usual code for quicksort, except that
        // to compare a[i] and a[j] we use
        // a[i].cmp(a[j])
    }
}
```

# Type consistency

- Polymorphic function to copy an array

```
public static void arraycopy (Object[] src,
                              Object[] tgt){
    int i,limit;
    limit = Math.min(src.length,tgt.length);
    for (i = 0; i < limit; i++){
        tgt[i] = src[i]; ✓
    }
}
```

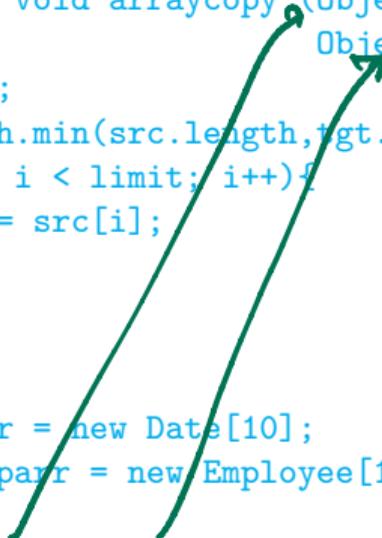
# Type consistency

- Polymorphic function to copy an array
- Need to ensure that target array is type compatible with source array
  - Type errors should be flagged at compile time

```
public static void arraycopy(Object[] src,
                             Object[] tgt){
    int i,limit;
    limit = Math.min(src.length,tgt.length);
    for (i = 0; i < limit; i++){
        tgt[i] = src[i];
    }
}

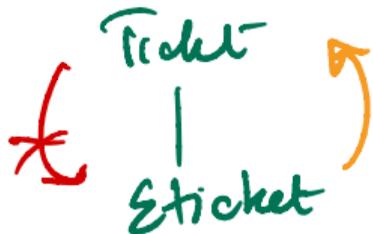
Date[] datearr = new Date[10];
Employee[] emparr = new Employee[10];

arraycopy(datearr,emparr); // Run-time error
```



# Type consistency

- Polymorphic function to copy an array
- Need to ensure that target array is type compatible with source array
  - Type errors should be flagged at compile time
- More generally source array can be a subtype of the target array



```
public static void arraycopy (Object[] src,
                              Object[] tgt){
    int i,limit;
    limit = Math.min(src.length,tgt.length);
    for (i = 0; i < limit; i++){
        tgt[i] = src[i];
    }
}
```

```
public class Ticket {...}
public class ETicket extends Ticket{...}
```

```
Ticket[] tktarr = new Ticket[10];
ETicket[] etktarr = new ETicket[10];
```

```
arraycopy(etktarr,tktarr); // Allowed
```

# Type consistency

- Polymorphic function to copy an array
- Need to ensure that target array is type compatible with source array
  - Type errors should be flagged at compile time
- More generally source array can be a subtype of the target array
- But the converse is illegal

```
public static void arraycopy (Object[] src,
                              Object[] tgt){
    int i,limit;
    limit = Math.min(src.length,tgt.length);
    for (i = 0; i < limit; i++){
        tgt[i] = src[i];
    }
}
```

```
public class Ticket {...}
public class ETicket extends Ticket{...}

Ticket[] tktarr = new Ticket[10];
ETicket[] etktarr = new ETicket[10];

arraycopy(tktarr,etktarr); // Illegal
```

# Polymorphic data structures

- Arrays, lists, ... should allow arbitrary elements

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- Arrays, lists, ... should allow arbitrary elements
- A polymorphic list stores values of type `Object`

```
public class LinkedList{
    private int size;
    private Node first;

    public Object head(){
        Object returnval;
        ...
        return(returnval);
    }

    public void insert(Object newdata){...}

    private class Node {
        private Object data;
        private Node next;
        ...
    }
}
```

# Polymorphic data structures

- Arrays, lists, ... should allow arbitrary elements
- A polymorphic list stores values of type `Object`
- Two problems

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public class LinkedList{
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}
```

# Polymorphic data structures

- Arrays, lists, ... should allow arbitrary elements
- A polymorphic list stores values of type `Object`
- Two problems
  - Type information is lost, need casts

```
public class LinkedList{
    private int size;
    private Node first;

    public Object head(){ ... }

    public void insert(Object newdata){...}

    private class Node {...}
}
```

```
LinkedList list = new LinkedList();
Ticket t1,t2;
```

```
t1 = new Ticket();
list.insert(t1);
t2 = (Ticket)(list.head());
// head() returns an Object
```

# Polymorphic data structures

- Arrays, lists, ... should allow arbitrary elements
- A polymorphic list stores values of type `Object`
- Two problems
  - Type information is lost, need casts
  - List need not be homogenous!

```
public class LinkedList{
    private int size;
    private Node first;

    public Object head(){ ... }

    public void insert(Object newdata){...}

    private class Node {...}
}
```

```
LinkedList list = new LinkedList();
Ticket t = new Ticket();
Date d = new Date();
list.insert(t);
list.insert(d);
...
```

- Use type variables

# Java Generics

- Use type variables
- Polymorphic `reverse` in Java
  - Type **quantifier** before return type
  - “For every type `T ...`”

**VT** **return value**

```
public <T> void reverse (T[] objarr){  
    T tempobj;  
    int len = objarr.length;  
    for (i = 0; i < n/2; i++){  
        tempobj = objarr[i];  
        objarr[i] = objarr[(n-1)-i];  
        objarr[(n-1)-i] = tempobj;  
    }  
}
```

Handwritten annotations: A red circle around the type variable `T` in the return type `<T>` is labeled "VT". A green circle around the parameter type `T` in `(T[])` is labeled "return value". A green line connects the "return value" label to the `T` in the parameter list.

- Use type variables
- Polymorphic `reverse` in Java
  - Type `quantifier` before return type
  - “For every type `T ...`”
- Polymorphic `find` in Java
  - Searching for a value of incompatible type is now a compile-time error

```
public <T> int find (T[] objarr, T o){  
    int i;  
    for (i = 0; i < objarr.length; i++){  
        if (objarr[i] == o) {return i};  
    }  
    return (-1);  
}
```

*Handwritten annotations:* A red circle around the angle brackets in the generic declaration `<T>` with the text `forall` written above it. A green underline under the parameter `T o`.

- Use type variables
- Polymorphic `reverse` in Java
  - Type **quantifier** before return type
  - “For every type `T ...`”
- Polymorphic `find` in Java
  - Searching for a value of incompatible type is now a compile-time error
- Polymorphic `arraycopy`
  - Source and target types must be identical

```
public static <T> void arraycopy (T[] src,  
                                T[] tgt){  
    int i,limit;  
    limit = Math.min(src.length,tgt.length);  
    for (i = 0; i < limit; i++){  
        tgt[i] = src[i];  
    }  
}
```

T  
|  
S

- Use type variables
- Polymorphic `reverse` in Java
  - Type **quantifier** before return type
  - “For every type `T ...`”
- Polymorphic `find` in Java
  - Searching for a value of incompatible type is now a compile-time error
- Polymorphic `arraycopy`
  - Source and target types must be identical
- A more generous `arraycopy`
  - Source and target types may be different
  - Source type **must** extend target type

```
public static <S extends T,T>
    void arraycopy (S[] src,
                   T[] tgt){
    int i,limit;
    limit = Math.min(src.length,tgt.length);
    for (i = 0; i < limit; i++){
        tgt[i] = src[i];
    }
}
```

# Polymorphic data structures

- A polymorphic list

```
public class LinkedList<T>{  
    private int size;  
    private Node first;  
  
    public T head(){  
        T returnval;  
        ...  
        return(returnval);  
    }  
  
    public void insert(T newdata){...}  
  
    private class Node {  
        private T data;  
        private Node next;  
        ...  
    }  
}
```

# Polymorphic data structures

- A polymorphic list
- The type parameter `T` applies to the class as a whole

```
public class LinkedList<T>{  
    private int size;  
    private Node first;  
  
    public T head(){  
        T returnval;  
        ...  
        return(returnval);  
    }  
  
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    private class Node {  
        private T data;  
        private Node next;  
        ...  
    }  
}
```

# Polymorphic data structures

- A polymorphic list
- The type parameter `T` applies to the class as a whole
- Internally, the `T` in `Node` is the same `T`

```
public class LinkedList<T>{
    private int size;
    private Node first;

    public T head(){
        T returnval;
        ...
        return(returnval);
    }

    public void insert(T newdata){...}

    private class Node {
        private T data;
        private Node next;
        ...
    }
}
```

# Polymorphic data structures

- A polymorphic list
- The type parameter `T` applies to the class as a whole
- Internally, the `T` in `Node` is the same `T`
- Also the return value of `head()` and the argument of `insert()`

```
public class LinkedList<T>{
    private int size;
    private Node first;

    public T head(){
        T returnval;
        ...
        return(returnval);
    }

    public void insert(T newdata){...}

    private class Node {
        private T data;
        private Node next;
        ...
    }
}
```

# Polymorphic data structures

- A polymorphic list
- The type parameter `T` applies to the class as a whole
- Internally, the `T` in `Node` is the same `T`
- Also the return value of `head()` and the argument of `insert()`
- Instantiate generic classes using concrete type

```
public class LinkedList<T>{  
    ...  
}  
  
LinkedList<Ticket> ticketlist =  
    new LinkedList<Ticket>();  
LinkedList<Date> datelist =  
    new LinkedList<Date>();  
  
Ticket t = new Ticket();  
Date d = new Date();  
  
ticketlist.insert(t);  
datelist.insert(d);
```

# Polymorphic data structures

- Be careful not to accidentally hide a type variable

```
public <T> void  
    insert(T newdata){...}
```

*fn - (fn - )*

```
public class LinkedList<T>{  
    private int size;  
    private Node first;  
  
    public T head(){  
        T returnval;  
        ...  
        return(returnval);  
    }  
  
    public <T> void insert(T newdata){...}  
  
    private class Node {  
        private T data;  
        private Node next;  
        ...  
    }  
}
```



# Polymorphic data structures

- Be careful not to accidentally hide a type variable

```
public <T> void  
    insert(T newdata){...}
```

- **T** in the argument of `insert()` is a **new T**

```
public class LinkedList<T>{  
    private int size;  
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    public T head(){  
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        ...  
        return(returnval);  
    }  
  
    public <T> void insert(T newdata){...}  
  
    private class Node {  
        private T data;  
        private Node next;  
        ...  
    }  
}
```

# Polymorphic data structures

- Be careful not to accidentally hide a type variable

```
public <T> void
    insert(T newdata){...}
```

- `T` in the argument of `insert()` is a `new T`

- Quantifier `<T>` masks the type parameter `T` of `LinkedList`

```
public class LinkedList<T>{
    private int size;
    private Node first;

    public T head(){
        T returnval;
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        return(returnval);
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    private class Node {
        private T data;
        private Node next;
        ...
    }
}
```

# Polymorphic data structures

- Be careful not to accidentally hide a type variable

```
public <T> void
    insert(T newdata){...}
```

- `T` in the argument of `insert()` is a **new** `T`

- Quantifier `<T>` masks the type parameter `T` of `LinkedList`

- Contrast with

```
public <T> static void
    arraycopy (T[] src, T[] tgt){...}
```

```
public class LinkedList<T>{
    private int size;
    private Node first;

    public T head(){
        T returnval;
        ...
        return(returnval);
    }

    public <T> void insert(T newdata){...}

    private class Node {
        private T data;
        private Node next;
        ...
    }
}
```

# Extending subtyping in contexts

- If  $S$  is compatible with  $T$ ,  $S[]$  is compatible with  $T[]$

```
ETicket[] elecarr = new ETicket[10];  
Ticket[] ticketarr = elecarr;  
// OK. ETicket[] is a subtype of Ticket[]
```

T  
|  
S

# Extending subtyping in contexts

- If `S` is compatible with `T`, `S[]` is compatible with `T[]`

```
ETicket[] elecarr = new ETicket[10];  
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// OK. ETicket[] is a subtype of Ticket[]
```

- But ...

```
...  
ticketarr[5] = new Ticket();  
// Not OK. ticketarr[5] refers to an ETicket!
```

# Extending subtyping in contexts

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- A type error at run time!

# Extending subtyping in contexts

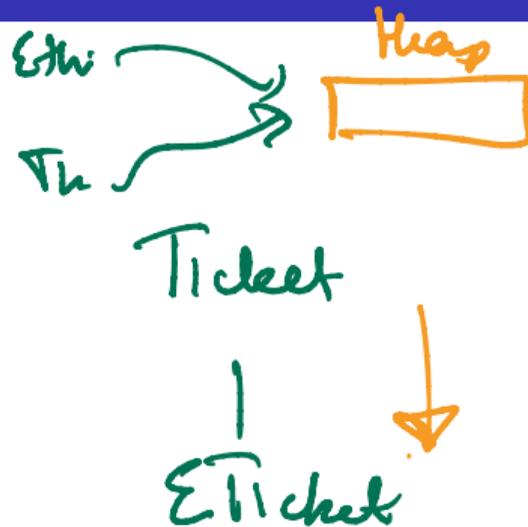
- If `S` is compatible with `T`, `S[]` is compatible with `T[]`

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ETicket[] elecarr = new ETicket[10];  
Ticket[] ticketarr = elecarr;  
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```

- But ...

```
...  
ticketarr[5] = new Ticket();  
// Not OK. ticketarr[5] refers to an ETicket!
```

- A type error at run time!
- Java array typing is **covariant**
  - If `S` extends `T` then `S[]` extends `T[]`



*Ticket var = new ETicket();*

# Generics and subtypes

- Generic classes are not covariant
  - `LinkedList<String>` is not compatible with `LinkedList<Object>`

`LinkedList<T>`

# Generics and subtypes

- Generic classes are not covariant
  - `LinkedList<String>` is not compatible with `LinkedList<Object>`
- The following will not work to print out an arbitrary `LinkedList`

```
public class LinkedList<T>{...}

public static void printlist(LinkedList<Object> l){
    Object o;
    Iterator i = l.get_iterator();
    while (i.has_next()){
        o = i.get_next();
        System.out.println(o);
    }
}
```

# Generics and subtypes

- Generic classes are not covariant
  - `LinkedList<String>` is not compatible with `LinkedList<Object>`
- The following will not work to print out an arbitrary `LinkedList`

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public class LinkedList<T>{...}

public static void printlist(LinkedList<Object> l){
    Object o;
    Iterator i = l.get_iterator();
    while (i.has_next()){
        o = i.get_next();
        System.out.println(o);
    }
}
```

- How can we get around this limitation?

# Generic methods

- As we have seen, we can make the method generic by introducing a type variable

```
public class LinkedList<T>{...}
```

```
public static <T> void printlist(LinkedList<T> l){  
    Object o;  
    Iterator i = l.get_iterator();  
    while (i.has_next()){  
        o = i.get_next();  
        System.out.println(o);  
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}
```

# Generic methods

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    Object o;  
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```

- `<T>` is a type quantifier: *For every type T, ...*

# Generic methods

- As we have seen, we can make the method generic by introducing a type variable

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public class LinkedList<T>{...}  
  
public static <T> void printlist(LinkedList<T> l){  
    Object o;  
    Iterator i = l.get_iterator();  
    while (i.has_next()){  
        o = i.get_next();  
        System.out.println(o);  
    }  
}
```

- `<T>` is a type quantifier: *For every type T, ...*
- Note that `T` is not actually used inside the function
  - We use `Object o` as a generic variable to cycle through the list