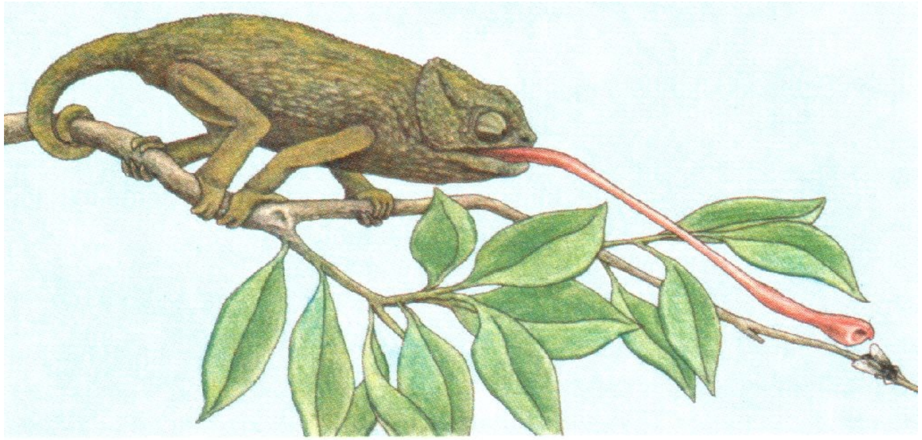
Java Generics

Th. Letschert

Fachhochschule Giessen-Friedberg, Giessen, Germany

University of Applied Sciences

Generics: Generic Classes and Methods

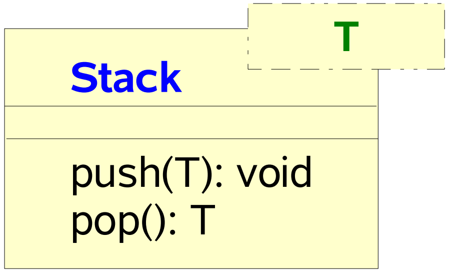


Generic Classes and Methods

Generic Class : Class with types as parameters

Form:

class C **<** *... generic parameter(s) ...* **>** .... { ... }



Generic Class in UML

```java
public class Stack<T> {
    private List<T> a = new ArrayList<T>();

    public void push( T x ) {
        a.add(x);
    }

    public T pop () {
        if ( a.isEmpty() )
            throw new IllegalStateException();
        else
            return a.remove(0);
    }
}
```

Definition

```java
Stack<String> myStack = new Stack<String>();
```

Use

Generic Method : Method with types as parameters

Form:

attributes **<** *... generic parameter(s) ...* **>** *method-definition*

```
class GenMethod
    public static <T> void swapFirstLast (T[] a) {
        T temp = a[0];
        a[0] = a[a.length-1];
        a[a.length-1] = temp;
    }
}
```

Definition

```
String[] a = { "Hello", "Java" };
swapFirstLast(a);
```

Use in same class

```
String[] a = { "Hello", "Java" };
GenMethod.swapFirstLast(a);
```

Use in different class (1)

```
String[] a = { "Hello", "Java" };
GenMethod.<String>swapFirstLast(a);
```

Use in different class (2)

Generics and Interfaces

- **Interfaces may be defined as generics**
- **Interfaces may be type parameters**

```
public interface Stack<T> {
    void push( T x );
    T pop ();
}
```

a generic interface

```
public class ListStack<T> implements Stack<T> {
    ...
}
```

imlpementation of a generic interface

```
Stack< Stack<String> > st = new ListStack< Stack<String> >();
st.push( new ListStack<String>() );
```

a Stack of Stacks of Strings

Generics: Restrictions

Instantiation

of objects with generic type: Not possible

- Instantiation of generic parameter type is not allowed

```
class C<E> {
   ... new E() ...
}
```

Static Methods

of objects with generic type: Not possible

- Static methods of objects with a generic type my not be accessed

```
class C<E> {
   ... E.m() ...
}
```

Overloading

of methods based on generics: Not possible

- Overloaded methods must differ in more than a generic type

```
void f(List<String> x) {}
void f(List<Integer> x) {}
```

```
class C<T1, T2> {
    void f(T1 x){}
    void f(T2 x){}
}
```

Generics and Arrays

do not live in complete harmony:

- arrays of generic types may not be allocated
- Solution: allocate Object-arrays and cast them

```
~~new T[10];~~
```

Type safety of generics is guaranteed by the compiler, as long as there are no casts. With casts there may be type errors at runtime – so this warning. It is suppressed because we know what we do!

```
public class ArrayStack<T> implements Stack<T> {

    @SuppressWarnings("unchecked")
    private T[] a = (T[]) new Object[10];

    private int size = 0;

    public T pop() {
        if ( size <= 0 ) throw new IllegalStateException();
    return a[--size];
    }

    public void push(T x) {
        if ( size >= 10 ) throw new IllegalStateException();
        a[++size] = x;
    }
}
```

allocation and cast with suppression of warning

Generics: Restrictions

Generics and Arrays

```java
~~new List<String>[10];~~
```

do not live in complete harmony:

- arrays of parametric instantiations may not be allocated
- Solution: allocate Object-arrays and cast them

```java
@SuppressWarnings("unchecked")
public static void main(String[] args) {
    List<String>[] a = (List<String>[]) new Object[10];
    a[0] = new ArrayList<String>();
    a[1] = new LinkedList<String>();
}
```

Kinds of Genericity

- **Java Generics ~ Parametric Polymorphism**
  Flexibility and adaption by generating definitions

```
class Cage<T> {
    void lockUp(T x) {
      ....}
    ...
};

Cage<Tiger> c1 = new Cage<Tiger>();
c.lockUp( new Tiger() );
Cage<Lion> c1 = new Cage<Lion>();
c.lockUp( new Lion() );
```

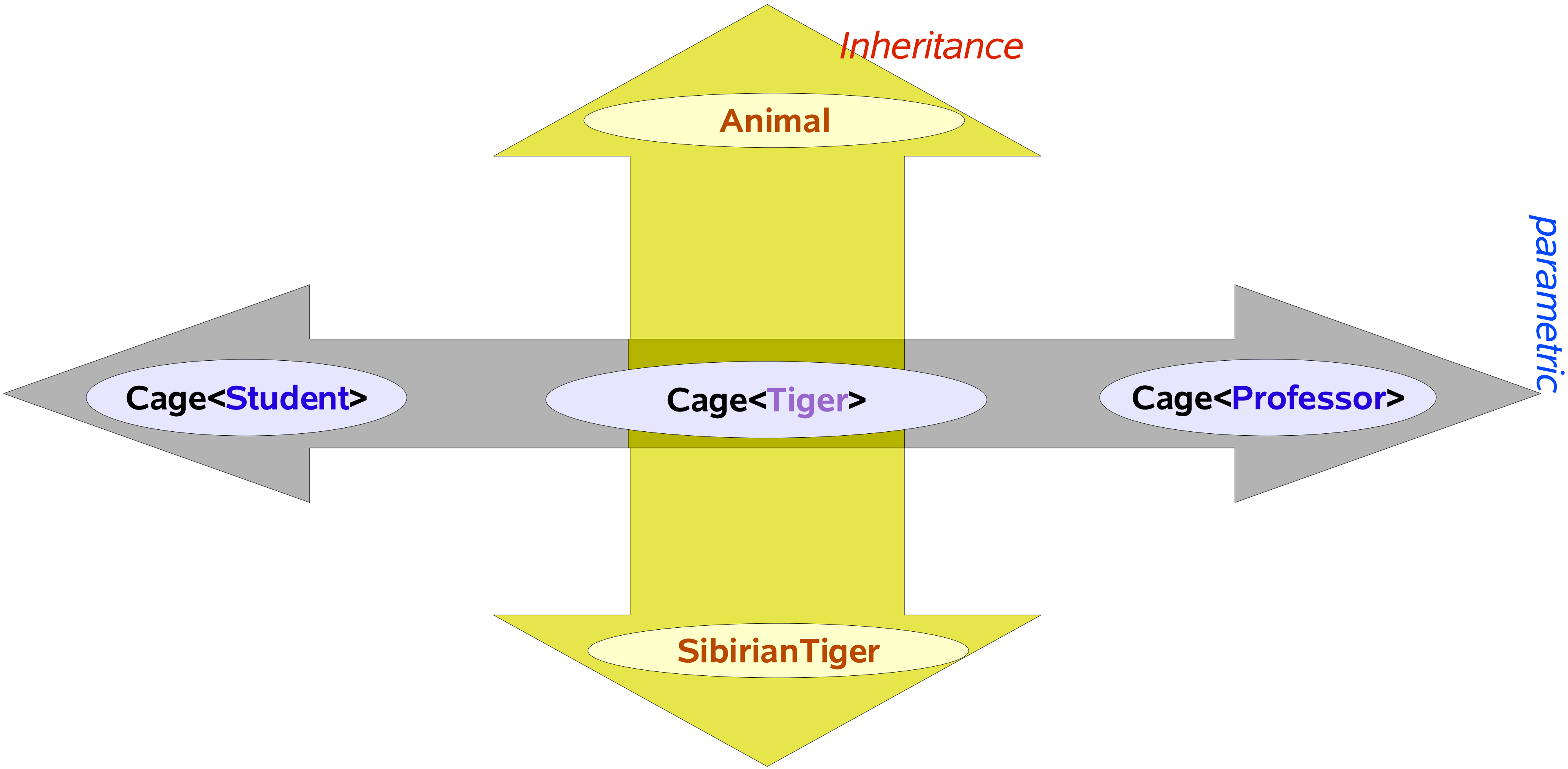
- **Genericity by Inheritance**
  Flexibility and adaption by generalization

```
class Cage {
    void lockUp(Object x) {
      ....}
    ...
};

Cage c = new Cage();
c.lockUp( new Tiger() );
c.lockUp( new Lion() );
```

The 2 Dimensions of Genericity

Inheritance : **type ~ subtype**

Parametric: **type parameter**



Implementation of Generics: type erasure

Implementation of generics by *type erasure*

- Java generics are realized by mapping parametric genericity to inheritance genericity
- The compiler removes all type parameters / arguments and replaces them by casts / base types
- ***Raw types*** (free of type parameters/arguments) appear in class files

```
class Cage<T> {
    void lockUp(T x) {....}
    T free() {....}
};

Cage<Tiger> cage = new Cage<Tiger>();
Tiger t = new Tiger();
cage.lockUp(t);
...
t = cage.free();
```

```
class Cage {
    void lockUp(Object x) {....}
    Object free() {....}
};

Cage cage = new Cage();
Tiger t = new Tiger();
cage.lockUp(t);
...
t = (Tiger)cage.free();
```

Compiler

Implementation of Generics: casts by the compiler

Type erasure and type errors

- Casts added by the compiler will never fail
- ... if it doesn't issue a waring

```
class Cage {
    void lockUp(Object x) {....}
    Object free() {....}
};
...
t = (Tiger)cage.free();
```

fail-proof cast: compiler assures success of its casts

code after type erasure

no assurance for success by the compiler

```
@SuppressWarnings("unchecked")
public static void main(String[] args) {
    List<String>[] a = (List<String>[]) new Object[10];
    a[0] = new ArrayList<String>();
    a[1] = new LinkedList<String>();
}
```

Type erasure and arrays

- Arrays carry type information at runtime
- Because: arrays are covariant in their element-type

  Cow<Animal => cow[]<Animal[],

  but this may be dangerous

```
static void f(Animal[] l){
    l[0] = new Tiger();
}

public static void main(String[] args){
        Cow[] cows = new Cow[2];
        ...
        f(cows);
}
```

ArrayStoreExeception

l is tagged with ***Cow***

Tiger is not compatible with Cow

Type erasure and arrays

- Arrays carry type information at runtime
- **... but this can only be a raw type**

```
public class Stack<T> {
    private T[] a = new T[10];
    ...
}
```

The compiler can't associate a raw type with T. Array creation is not possible

```
public static void main(String[] args) {
    List<String>[] a = new List<String>[10];
}
```

The compiler can't associate a raw type with List<String>. Array creation is not possible

Implementation of Generics: Arrays

Type erasure and arrays

- Arrays carry type information at runtime
- **... but this can only be a raw type**

```
public class ArrayStack<T> implements Stack<T> {

    private final T[] a = (T[]) new Object[10];
    private int size = 0;

    public T pop() {...}
    public void push(final T x) { ... }

    @SuppressWarnings("unchecked")
    public T[] toArray() {
        final T[] res = (T[]) new Object[size];
        for ( int i = 0; i< size; i++ ) { res[i] = a[i]; }
        return a;
    }
}
```

```
Exception in thread "main"
java.lang.ClassCastException:
[Ljava.lang.Object;
```

[*Array*
L *References*
java.lang.Object *Elements*

May not cast an array of Objects to an array of Strings

```
public static void main(String[] args) {
    ArrayStack<Integer> stack = new ArrayStack<Integer>();
    stack.push(5);
    Integer[] ar = stack.toArray(); // ClassCastException !
}
```

Bounded Type Parameters

Bounded Parameters

Bounded parameters:

A generic parameter may be restricted

```
public class Stable<T extends Animal> {

    @SuppressWarnings("unchecked")
    T[] box = (T[]) new Object[10];

    public void insert(T t, int i) {
        box[i] = t;
    }
    ...
}
```

Example: stables of different types

```
public static <T extends Comparable<T>>
T max(T x, T y) {
    return x.compareTo(y) > 0 ? x : y;
}
```

Example: generic maximum

Bounded Parameters

Bounded parameters:

A generic parameter may be restricted

```
public class Stable<T extends Animal> {

    @SuppressWarnings("unchecked")
    T[] box = (T[]) new Object[10];

    public void insert(T t, int i) {
        box[i] = t;
    }
    ...
}
```

Example: stables of different types

```
public static <T extends Comparable<T>>
T max(T x, T y) {
    return x.compareTo(y) > 0 ? x : y;
}
```

Example: generic maximum

Bounded Parameters

```
public interface PriorityQueue<E extends Comparable<E>>
    extends Iterable<E> {
        public void enqueue (E e);
        public E dequeue() throws QueueEmptyException;
}
```

Example: Generic Interface with bounded parameter that implements a generic interface

- The bounded type (E) appears in its bound (Comparable<E>) (F-bound genericity)
- The bounded type appears in the implementation clause

Bounded Parameters

Bounded parameters : &

A generic parameter may be restricted by several bounds

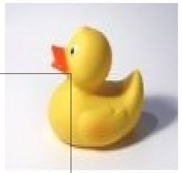
```
public static <T extends Toy & Quaker>
void goSwimming(T  t) {
    ...
}
```

Example: two bounds.
Go swimming with something that is a toy and can quake.

```
public interface Toy {
    void play();
}
```

```
public interface Quaker {
    void quake();
}
```

```
public class RubberDuck
    implements Toy, Quaker {
    public void play() {...}
    public void quake() {...}
}
```



Wildcards

Wildcard Extends

Wildcard Super

Wildcard Extend

Subtype relation

- T < T' : T-Objects may substitute T'-Objects
- T < T' : T extends / implements T'

Subtype relation and generics

- **Covariance on collection type**:

  ArrayList<E> < List<E> < Collection<E> < Iterable<E>

- **T < Object**,   for every reference type T
- **Collections take Objects of subtypes :**

  Collection<E> c;
  c.add(x)   for every **U x;** with **U < E**

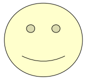
- **Generic classes: neither covariant nor contravariant on argument types:**

  T < U   ~~Collection<T> < Collection<U>~~
  ~~Collection<T> > Collection<U>~~

Wildcard Extend

$$T < U \not\Rightarrow \text{Collection}<T> \; < \; \text{Collection}<U>$$

```java
static void f(List<Animal> animals){
    animals.add( new Tiger() ); // OK (for the compiler)!
}

public static void main(String[] args){
    List<Cow> cows = new LinkedList<Cows>();
    f(cows);    // Compiler Error-Message
    ... assume f contains cows ...
}
```



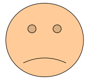
No covariance: This restrictions prevents from type errors.

however...

Wildcard Extend

$$T < U \;\; \neq\!> \;\; \mathrm{Collection}\langle T\rangle < \mathrm{Collection}\langle U\rangle$$

```
static void f(List<Animal> animals){
        for( Animal a : animals)
        a.feed(new Feed());    // OK !
}

public static void main(String[] args){
    List<Cow> cows = new LinkedList<Cows>();
    f(cows);    // Compiler Error-Message
}
```



This restrictions prevents lots of correct programs from being compiled

Wildcard Extend

What exactly might cause typing errors, if covariance were accepted ?

```
static void f (List<Animals> animals ){
    for( Animal A : animals )
        a.feed(new Feed());
    a.add( new Tiger() );
}

public static void main(String[] args){
    List<Cow> c = new LinkedList<Cow>();
    ....
    f(c);
    ... assume c contains cows ...
}
```

Reading elements from the collection and treating them as animals is OK.

Writing to the collection might cause a problem.

So: accept covariance and allow reading, prevent writing

Wildcard Extend

Wildcard Extend *<? extends T>*:

- **Accept covariance**

  T **<** U **=>** Collection<T> **<** Collection<U>

- **Accept reading operations**
- **Do not accept writing operations** (except **null**)

```
static void f (List<? extends Animal> animals ){
    for( Animal a : animals )
        a.feed(new Feed());          // OK !
    animals.add( new Tiger() );      // Compiler Error-Message
    animals.add( new Animal() );     // Compiler Error-Message
    animals.add( null );             // OK !
}

public static void main(String[] args){
    List<Cow> c = new LinkedList<Cow>();
    ....
    f(c);                        // OK !
    ... assume c contains cows ...
}
```

Lines 4 and 5 of the code (`animals.add( new Tiger() );`, `animals.add( new Animal() );`) are struck through on the page.

Wildcard Extend

Wildcard Extend ***<? extends T>*:**

– **Example 2**

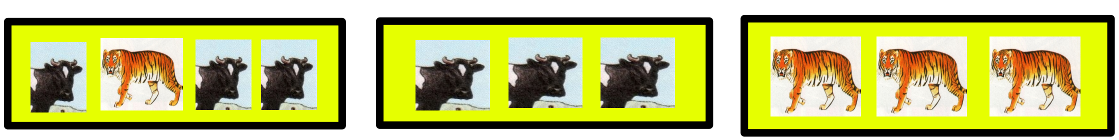
```java
public void f(Stack<? extends Animal> s) {
    s.push(new Cow());              // Compiler Error-Message
    Animal a = s.pop();             // OK !
    Cow    c = s.pop();             // Compiler Error-Message
}

public static void main(String[] args) {
    ArrayStack<Cow> stack = new ArrayStack<Cow>();
    stack.push( new Cow() );        // OK !
}
```

Wildcard Extend

The Contract of Wildcard Extend < ? extends T>

- Accept collections of subtypes of T-elements
- Will not add anythings except perhaps **null**

```
static void f(List<? extends Aninal> a) {
    tread them as animals or objects
}
```



Precondition:

Only take arguments of type List<T> with T < Animal

Postcondition:

Do not insert anything (except perhaps null) tread all elements as animals (or a superclass of Animals)

Wildcard Extend

Wildcard Extend of Object *< ? extends Object>* ≡ *< ?>*

- *<? extends Object>* has a special notation: *< ?>*
- <?>: tread elements as objects

```
static void printAll(Collection<?> c){
    for( Object o: c)
        System.out.println(o);
}

public static void main(String[] args){
    List<Cow> cows = new LinkedList<Cow>();
    cows.add( new Cow() );
    printAll(cows);
}
```

Wildcard Extend

Wildcard Extend of Object *< ? extends Object>* ***vs.*** *< Object>*

- *<? extends Object>* / *< ?>* is not the same as *<Object>*
- <?> : covariance OK, no writing (except for null)
- <Object>: treat as Objects

```
static void printAll_1( List<?> c ){
    for( Object o: c)
        System.out.println(o);
    c.add( new Tiger() );     // ERROR
    c.add(null);              // OK
}
```

```
static void printAll_2( List<Object> c ){
    for( Object o: c)
        System.out.println(o);
    c.add( new Tiger() );     // OK
    c.add(null);              // OK
}
```

```
List<Cow> cows
    = new ArrayList<Cow>();
List<Animal> animals
    = new ArrayList<Animal>();
printAll_1(cows);        // OK
printAll_1(animals);     // OK
printAll_2(cows);        // Error
printAll_2(animals);     // Error
```

Wildcard Extend

Wildcard Extend of Object < ?>

An example from the Java-API

java.util Interface Collection<E>

boolean containsAll (Collection<?> c)

Returns true if this collection contains all of the elements in the specified collection.

Checks whether all elements of a different collection are contained in this collection

```
List<Animal> animals = new LinkedList<Animal>();
List<Cow>    cows = new LinkedList<Cow>();
if ( cows.containsAll( animals ) ) {
    ....
}
```

boolean **containsAll** (Collection<?> animals)

reading access to argument animals*: OK,*
***<u>no</u> binding** E ~> Cow / Animal : all collections are accepted*

Wildcard Extend

Wildcard Extend

Example : test of containment in own collections

```
interface MyCollectionA<E> {
    ...
    public boolean contains(Object o);
    public boolean containsAll(Collection<?> c);
    ...
}
```

***Version A**:*
according to
java.util

```
interface MyCollectionB<E> {
    ...
    public boolean contains(E e);
    public boolean containsAll(Collection<? extends E> c);
    ...
}
```

***Version B**:*
better ? /
more reasonable ?

***Version A** is more liberal*
(compatible to Java 1 - 1.4)
Some errors are not recognized.

***Version B** is more restrictive*
Some correct programs are rejected..

Wildcard Extend

Wildcard Super : <? extends Animal>

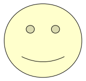
- **Reading access to the Collection: OK**
  - **Collection<? extends Animal>**
    - A collection of beings that are animals or more specific than animals
    - You can assume any feature that animals have
- **Writing access to the collection is not allowed: except for null**
  - **Collection<? extends Animal >**
    - A collection of beings that are cows or more specific than cows
    - No being should be inserted except **null.** **null** is allowed because it is of any type, even to most specific subtype of Animal. Nothing else is allowed because nothing can have all features that any subtype of animal might have. (Remember, evolution didn't stop, nature will create new species for ever.)

Wildcard Super

Wildcard Super

$$T < U \quad \neq> \quad \text{Collection}<T> \; > \; \text{Collection}<U>$$

```java
static void f(List<Cows> cows){
    Milk milk = cows.milk();    // OK (for the compiler)!
}

public static void main(String[] args){
    List<Animals> animals = new LinkedList<Animals>();
    animals.add( new Tiger() );
    f(animals);     // Compiler Error-Message
}
```



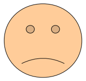
No contravariance: This restrictions prevents from type errors.

however...

Wildcard Super

$$T < U \;\; \neq> \;\; \text{Collection}<T> \; > \; \text{Collection}<U>$$

```java
static void f(List<Cows> cows){
    cows.add( new Cow() );  // OK
}

public static void main(String[] args){
    List<Animals> animals = new LinkedList<Animals>();
    ...
    f(animals);     // Compiler Error-Message
}
```



No contravariance: This prevents some legal programs from compiling.

Wildcard Super

What exactly might cause typing errors, if contravariance were accepted ?

Writing elements to the collection is OK.

reading access to the collection might cause a problem.

```
static void f(List<Cow> cows){
    cows.add( new Cow() );
    Milk milk = cows.get(0).milk();
}

public static void main(String[] args){
    List<Animals> animals = new LinkedList<Animals>();
    animals.add( new Tiger() );
    f(animals);
}
```

So: accept contravariance and allow writing, prevent reading

Wildcard Super

Wildcard Super <? super T>

- **Accept contravariance**

  T < U => Collection<T> > Collection<U>

- **Accept writing operations**
- **Do not accept reading operations** (except for type **`Object`**)

```
static void f(List<? super Cow> cows){
    cows.add( new Cow() );
    Cow cow = cows.get(0;
    Object o = cows.get(0);
}

public static void main(String[] args){
    List<Animals> animals = new LinkedList<Animals>();
    animals.add( new Tiger() );
    f(animals);
}
```

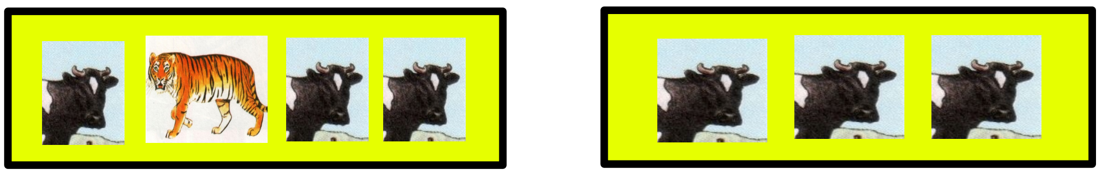
Writing elements to the collection is OK.

No reading access except for type Object

Wildcard Extend

The Contract of Wildcard Super < ? super T>

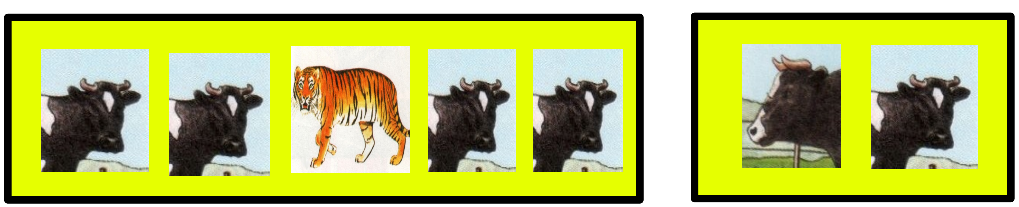
- Accept collections of supertypes of T
- Will not perform anythings except perhaps as `Object`



animal-collection

Cow-collektion

```
static void erweitere(List<? super Cow> k) {
    ....
}
```



Precondition:

Only accept lists of type List<T> with T > Cow

Postcondition:

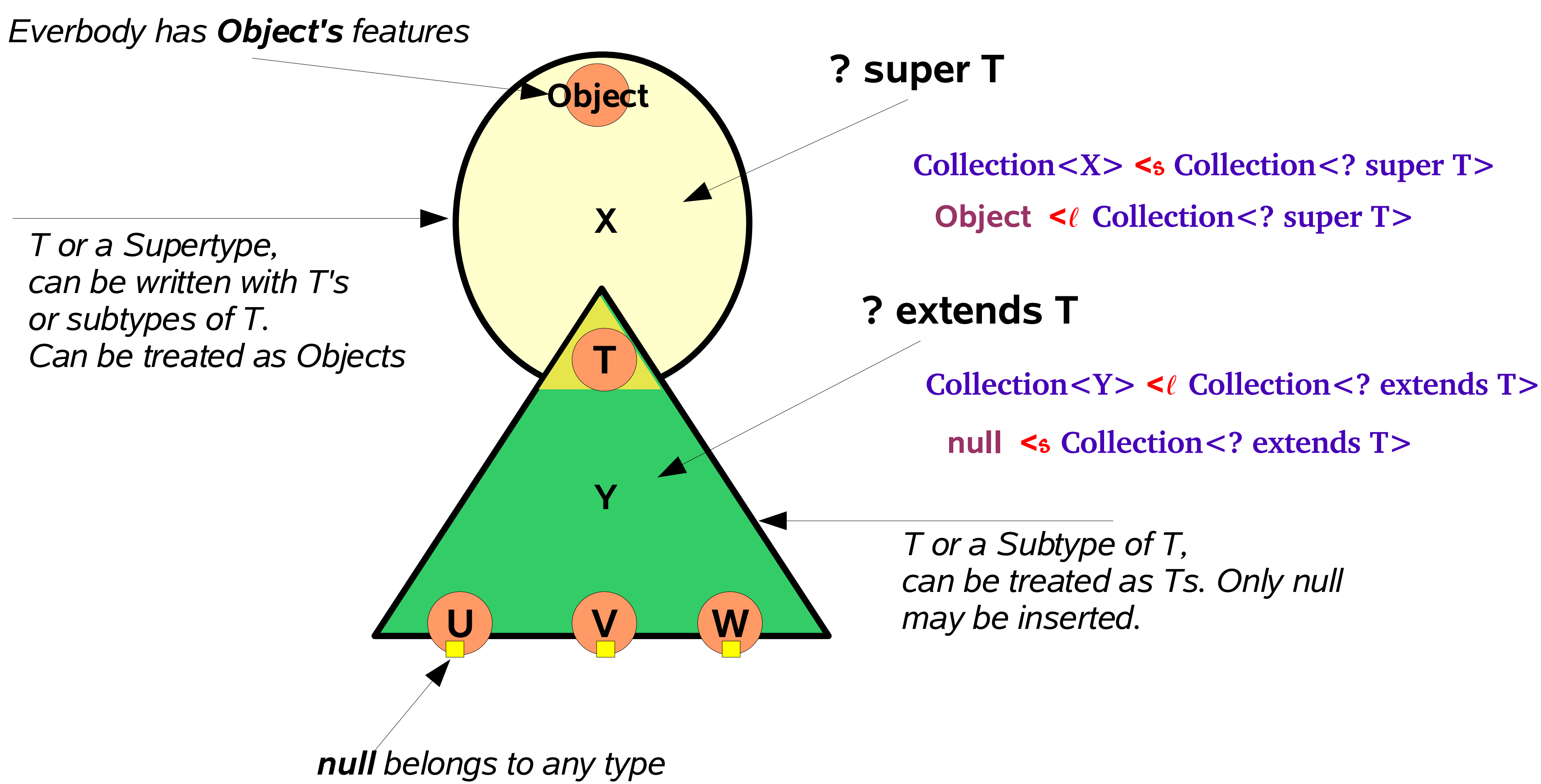
Did nothing but:
- Deletion
- Insertion of Cows or subtypes of Cow, down to `null`
- treat elements only as Objects

Wildcard Super : <? super Cow>

- **Writing access to the Collection: OK**
  - **Collection<? super Cow>**
    - A collection of beings that are cows or more general than cows
    - A cow or a subtype of Cow or null may be inserted
    - Deletions within the collections are allowed
- **Reading access to the collection is not allowed: except for treating the element that was read as an Object**
  - **Collection<? super Cow >**
    - A collection of beings that are cows or more general than cows
    - Do not assume any feature, except those that all beings (Objects) have

Wildcard Super and Wildcard Extends

- **Wildcard Extends** <? extends T> T and its super-types
- **Wildcard Super** <? super T> T and its sub-types



Wildcard Super and Wildcard Extends

Wildcard Extends and Wildcard Super

an example from the Java-API

java.util Class Collections

```
static  <T> void copy(List<? super T> dest, List<? extends T> src)
```

Copies all of the elements from one list into another.

src is read
dest is written

Wildcard or Named Type Parameter

Wildcards may replace named type parameters

```
public class Container<T> {
    T x1;
    T x2;
    ...
}
```

```
public class Containers {


    public static boolean duplicate_1(Container<?> c) {
        return c.x1.equals(c.x2);
    }

    public static <T> boolean duplicate_2(Container<T> c) {
        return c.x1.equals(c.x2);
    }

}
```

Ok!

Ok!

Wildcard or Named Type Parameter

Wildcards may replace named type parameters

but not always!

```
public class Container<T> {
    T x1;
    T x2;
    ...
}
```

```
public class Containers {

    public <T> void swap_1(Container<T> c) {
        T temp = c.x1;
        c.x1 = c.x2;
        c.x2 = temp;
    }

    public void swap_2(Container<?> c) {
        swap_1(c);
    }

    public void swap_3(Container<?> c) {
        Object temp = c.x1; //OK
        c.x1 = c.x2;  //Add cast to 'capture of ?'
        c.x2 = temp;  //Cannot convert from Object to
                      // 'capture of ?'
    }
}
```

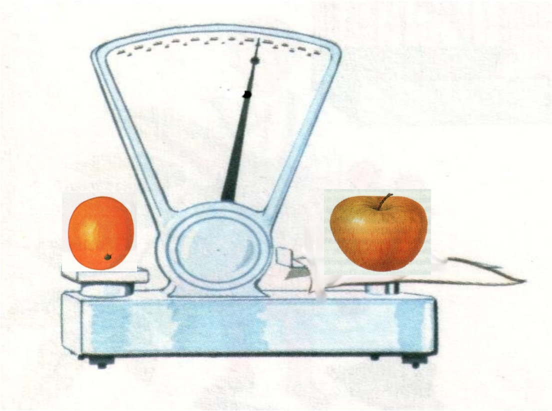
Ok: *A swap-methods that takes a container of anything.*

Ok: *A swap-methods that takes a container of anything.*

NOT Ok!

wildcard can not be "captured" !

Comparisons

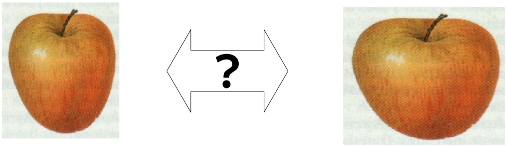


Comparisons

```java
public abstract class Fruit {
    protected int weight;

    Fruit(int weight) {
        this.weight = weight;
    }
}
```

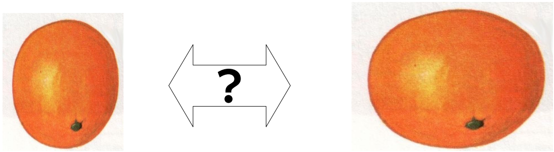
pure fruits do not exist and can't be compared

```java
public class Apple extends Fruit implements
Comparable<Apple> {
    public Apple(int weight) {
        super(weight);
    }
    public int compareTo(Apple other) {
        return this.weight < other.weight ? -1
            : this.weight == other.weight ? 0
            : 1;
    }

}
```



compare apple with apple

```java
public class Orange extends Fruit  implements
Comparable<Orange> {
    public Orange(int weight) {
        super(weight);
    }
    public int compareTo(Orange other) {
        return this.weight < other.weight ? -1
            : this.weight == other.weight ? 0
            : 1;
    }
}
```



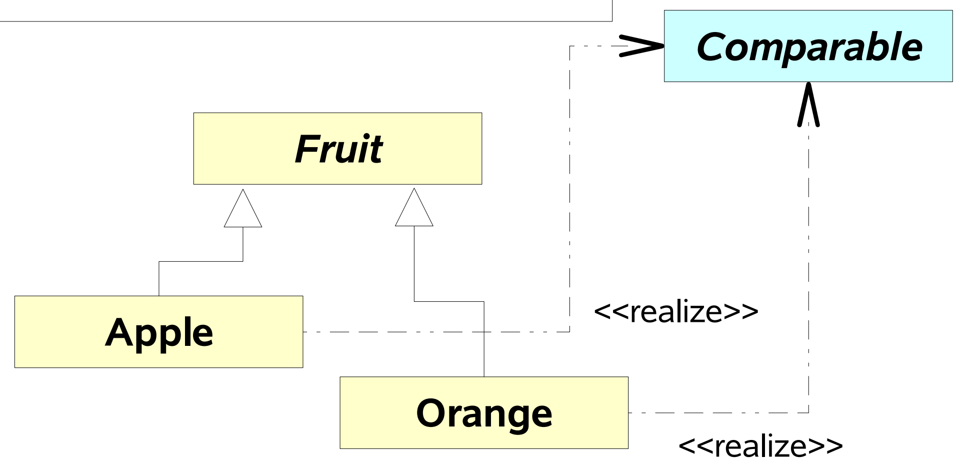
compare orange with orange

Comparisons

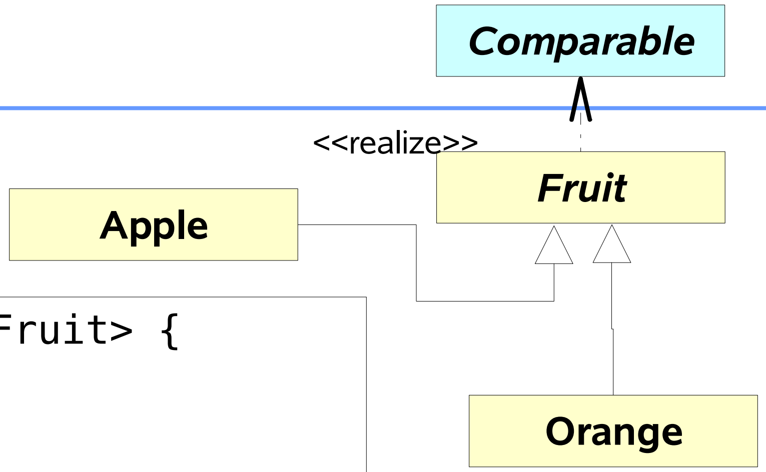
```java
public static <T extends Comparable<T> > T max (Collection<T> c) {
    if ( c.size() == 0 )
        throw new NoSuchElementException();
    T largest = null;
    for ( T x: c) {
        if ( largest == null || largest.compareTo(x) < 0)
            largest = x;
    }
    return largest;
}
```

```java
public static void main(String[] args) {
    List<Fruit> l = new LinkedList<Fruit>();
    l.add(new Apple(19));
    l.add(new Apple(20));
    System.out.println(max(l));  Type Error Bound mismatch !
}
```

Bound mismatch:
Fruit in List<Fruit>
does not match the bound
<T extends Comparable<T>>



Comparisons



Solution: make all fruits comparable

```java
abstract public class Fruit  implements Comparable<Fruit> {
    private int weight;

    Fruit(int weight) {
        this.weight = weight;
    }

    public int compareTo(Fruit other) {
        return this.weight < other.weight ? -1
            : this.weight == other.weight ? 0
            : 1;
    }
}
```

```java
public class Apple extends Fruit{
    ...
    public Apple(int weight) { super(weight); }
}
```

```java
public class Orange extends Fruit {
    ...
    public Orange(int weight) { super(weight); }
}
```

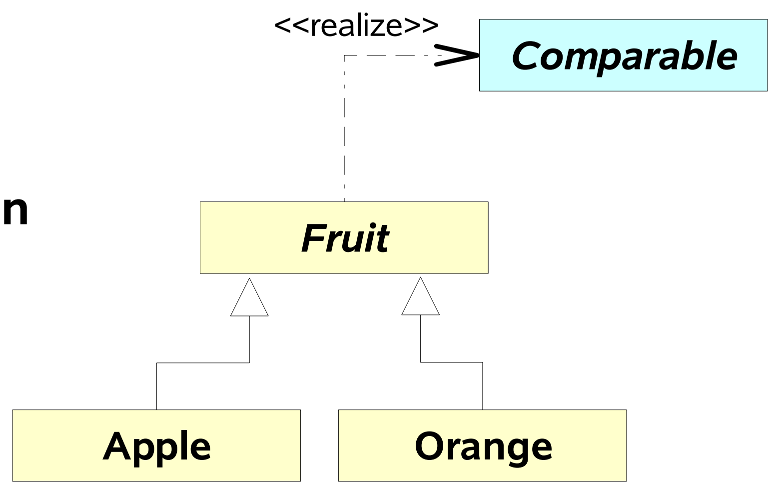
Comparisons

```java
public static <T extends Comparable<T> > T
max (Collection<T> c) {
    ...
}
```

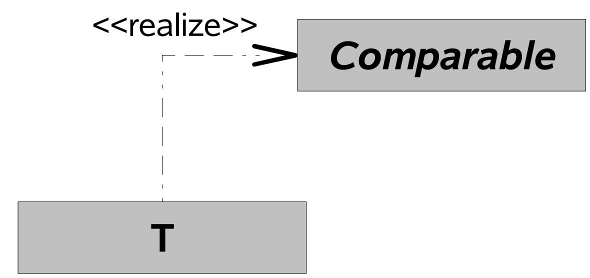
However

```java
List<Fruit> lf = new LinkedList<Fruit>();
lf.add(new Apple(19));
lf.add(new Orange(20));
System.out.println(max(lf)); // OK

List<Apple> la = new LinkedList<Apple>();
la.add(new Apple(21));
la.add(new Apple(22));
System.out.println(max(la)); Type Error Bound mismatch !
```

Apple in



does not match

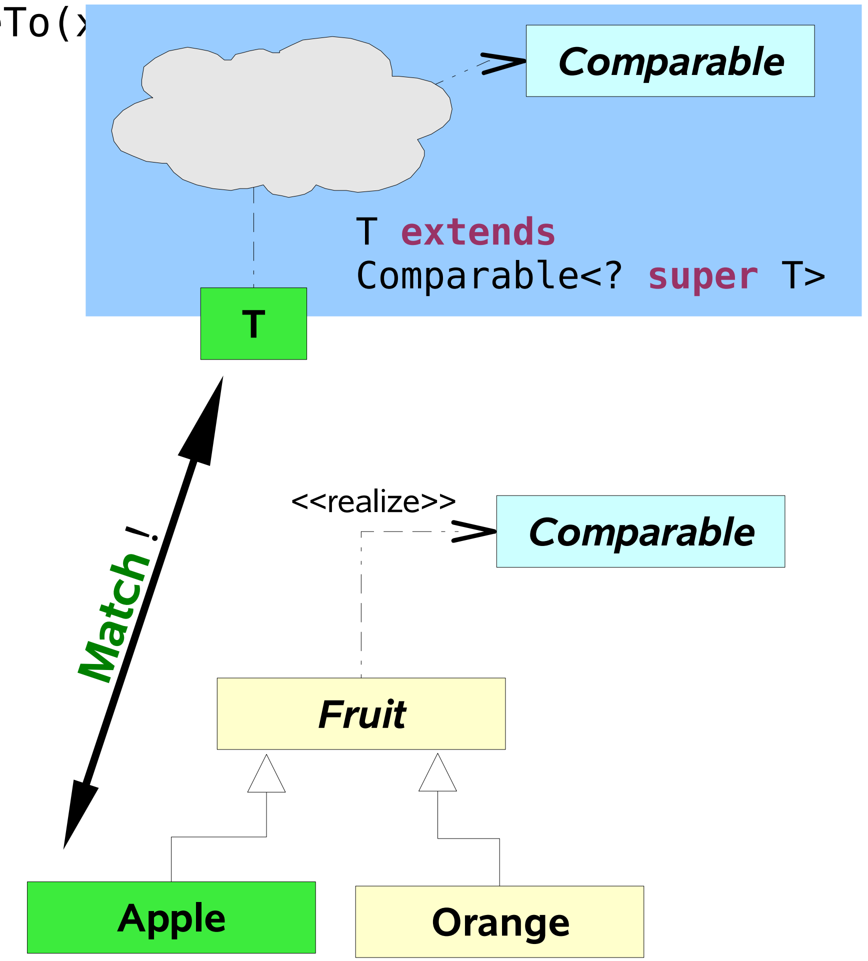



```java
<T extends Comparable<T> >
```

Comparisons

Solution completion

```java
public static <T extends Comparable<? super T> > T max (Collection<T> c) {
    if ( c.size() == 0 ) throw new NoSuchElementException();
    T largest = null;
    for ( T x: c) {
        if ( largest == null || largest.compareTo(x
            largest = x;
    }
    return largest;
}

public static void main(String[] args) {
    List<Fruit> lf = new LinkedList<Fruit>();
    lf.add(new Apple(19));
    lf.add(new Orange(20));
    System.out.println(max(lf));

    List<Apple> la = new LinkedList<Apple>();
    la.add(new Apple(21));
    la.add(new Apple(22));
    System.out.println(max(la));
}
```



Apple now matches the bound
`<T extends Comparable<? super T> >`

Example from the Java-API

java.util Class Collections

static <T extends Comparable<? super T>> void sort(List<T> list)

Sorts the specified list into ascending order, according to the natural ordering of its elements.

sort Lists

<T extends Comparable<? super T>>:

T extends ... : Take a list of comparable elements,
extends: we want to read and use compareTo

... Comparable<? super T> : compareTo may be defined in a super-class

in order to be able to sort
T must support compareTo
compareTo must be defined in T
or in a super class of T

Example: Quicksort 1

```java
class Record<K,V> {
    K key;
    V value;
}
```

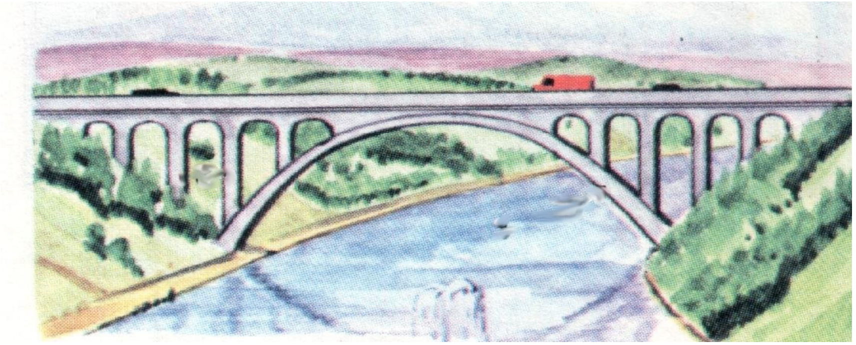
```java
/*
 * Quicksort Arrays of Records with Key that are comparable
 */
public static <Key extends Comparable<? super Key>, Value>
void quickSortRecordArray(
    Record<Key, Value>[] a, int li, int re) {
    int i = li, j = re;
    if (li >= re) return;
    Record<Key, Value> pivot = a[(li + re) >> 1];
    while (i <= j) {
        while ((a[i].key).compareTo(pivot.key) < 0) i++;
        while ((a[j].key).compareTo(pivot.key) > 0) j--;
        if (i <= j) { swap(a, i, j); i++; j--; }
    }
    quickSortRecordArray(a, li, j);
    quickSortRecordArray(a, i, re);
}
```

Example: Quicksort 2

```
/*
 * Quicksort Arrays with Elements without natural order
 *  (compare with Comparator)
 */
public static <Eintry>
void quickSortArrayUnNatural (  Eintry[] a, int li, int re,
                                Comparator<? super Eintrag> c) {
    int i = li, j = re;
    if (li >= re) return;
    Eintry pivot = a[(li + re) >> 1];
    while (i <= j) {
        while (c.compare(a[i], pivot) < 0) i++;
        while ( c.compare(a[j], pivot) > 0) j--;
        if (i <= j) { swap(a, i, j); i++; j--; }
    }
    quickSortArrayUnNatural(a, li, j, c);
    quickSortArrayUnNatural(a, i, re, c);
}
```

```
quickSortArrayUnNatural( a,  0, a.length-1,
                new Comparator<Integer>(){
                        public int compare(Integer arg0, Integer arg1) {
                            return arg0.compareTo(arg1);
                        }
                }
        );
```

Bridges



Bridges

```
public abstract class Fruit  implements Comparable<Fruit> {
    protected int weight;
    ...
    public int compareTo(Fruit other) {
        return this.weight < other.weight ? -1
                  : this.weight == other.weight ? 0 : 1;

    }
}
```

From this the compiler generates something like

```
public abstract class Fruit  implements Comparable {
    protected int weight;
    ...
    public int compareTo(Object o) {
        compareTo((Fruit)o);
    }
    public int compareTo(Fruit other) {
        return this.weight < other.weight ? -1
                  : this.weight == other.weight ? 0 : 1;

    }
}
```

Bridge method
(no variations in parameters of redefined methods!)

Cast will always succeed because the compiler checks compatibility with Comparable<Fruit>

Bridges

```java
public class Apple extends Fruit implements Comparable<Apple> {
    private int redness;
    ....
    public int compareTo(Apple other) {
        return this.redness < other.redness ? -1
            : this.redness == other.redness ? 0 : 1; }

}
```

***ERROR**: The interface can not be implemented more than once with different arguments*

From this the compiler refuses to generate something like

```java
public abstract class Fruit  implements Comparable {
    protected int redness;
    ...
    public int compareTo(Object o) {
        compareTo((Apple)o);
    }
    public int compareTo(Apple other) {
        return this.redness < other.redness ? -1
                : this.redness == other.redness ? 0 : 1;

    }
}
```

Bridge method
redefined version.
May lead to a ClassCastExceptions.
This is not acceptable for generics.
(Comparison with a Fruit)

Bridges

```java
public class Apple extends Fruit  {
    public Apple(int weight) {
        super(weight);
    }
    private int redness;

    public int compareTo(Fruit other) {
        if ( other instanceof Apple)
            return compareTo((Apple)other);
        else
            return super.compareTo(other);
    }

    public int compareTo(Apple other) {
        return this.redness < other.redness ? -1
                : this.redness == other.redness ? 0 : 1;
    }

}
```

Solution: Use the traditional way to define a special version of compareTo