

# **Konzepte objektorientierter Programmierung – Lecture 6 –**

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# Information Hiding

## ■ Definition

*Information hiding is a technique for reducing the dependencies between modules:*

- *The intended client is provided with all the information needed to use the module **correctly**, and **with nothing more***
- *The client uses only the (publicly) available information*

# Exchanging Implementations

- Observable behavior must be preserved
- Exported attributes limit modifications severely
  - Use getter and setter methods instead
  - Uniform access in Eiffel
- Modifications are critical
  - Fragile baseclass problem
  - **Object structures**

```
class Coordinate {  
    private float x,y;  
    ...  
    public float distOrigin( )  
        { return Math.sqrt( x*x + y*y ); }  
}
```

```
class Coordinate {  
    private float radius, angle;  
    ...  
    public float distOrigin( )  
        { return radius; }  
}
```

# Encapsulation

- Definition

*Encapsulation is a technique for structuring the state space of executed programs. Its objective is to guarantee data and structural consistency by establishing capsules with clearly defined interfaces.*

# Levels of Encapsulation

- Capsules can be
  - **Individual objects**
  - Object structures
  - **A class (with all of its objects)**
  - All classes of a subtype hierarchy
  - A package (with all of its classes and their objects)
  - Several packages
- Encapsulation requires a definition of the boundary of a capsule and the interfaces at the boundary

# Invariants for Java (Simple Solution)

- Assumption: The invariants of object X may only refer to **private attributes** of X
  
- For each invariant, we have to show
  - That all exported method **and constructors of class T** preserve the invariants **of all objects of T and T's subclasses**
  - That all constructors **in addition** establish the invariants of the new object

# Agenda for Today

## 6. Object Structures and Aliasing

6.1 Object Structures

6.2 Aliasing

6.3 Problems of Aliasing

6.4 Encapsulation of Object Structures

## Objectives

- Aliasing
- Encapsulation of object structures

# 6. Object Structures and Aliasing

## 6.1 Object Structures

## 6.2 Aliasing

## 6.3 Problems of Aliasing

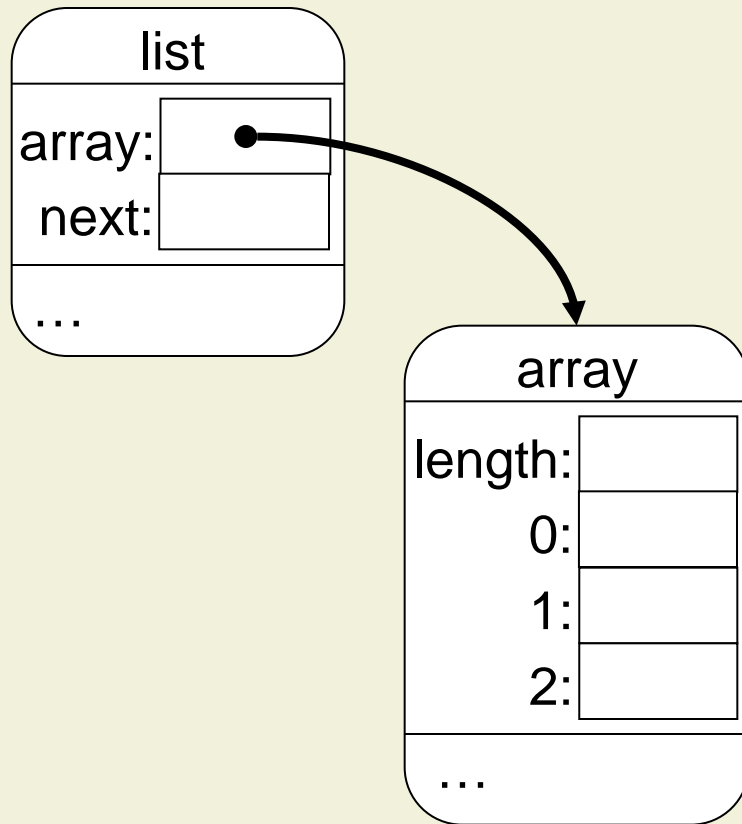
## 6.4 Encapsulation of Object Structures



# Object Structures

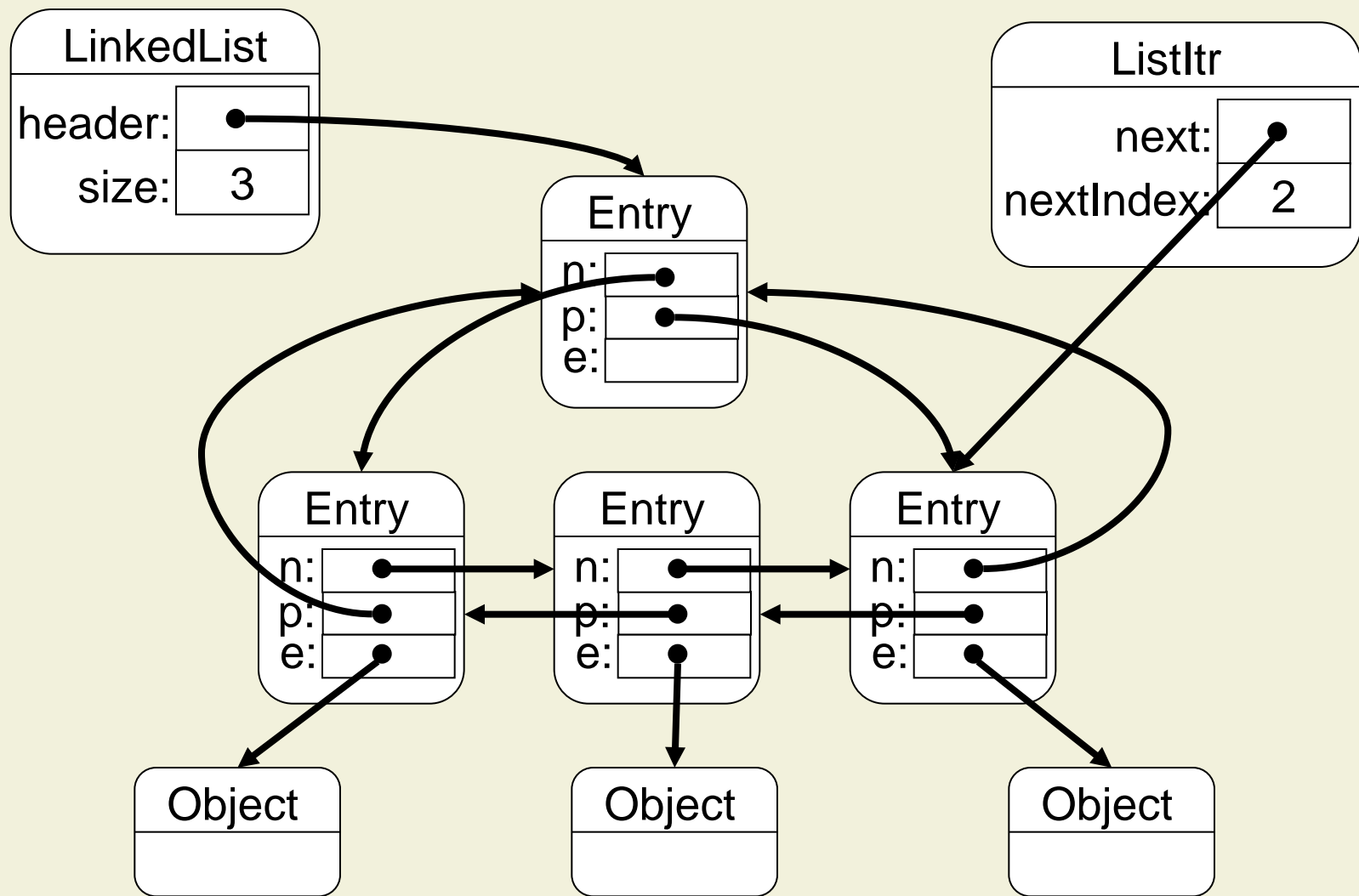
- Objects are the building blocks of object-oriented programming
- However, interesting abstractions are almost always provided by sets of cooperating objects
- Definition:  
*An object structure is a set of objects that are connected via references*

# Example 1: Array-Based Lists



```
class ArrayList {  
    private int[ ] array;  
    private int next;  
  
    public void add( int i ) {  
        if (next==array.length) resize( );  
        array[ next ] = i;  
        next++;  
    }  
  
    public void addElems( int[ ] ia )  
        { ... }  
  
    ...  
}
```

# Example 2: Doubly-Linked Lists



# 6. Object Structures and Aliasing

6.1 Object Structures

**6.2 Aliasing**

6.3 Problems of Aliasing

6.4 Encapsulation of Object Structures

# Alias

- Definition:

*A name that has been assumed temporarily*

[WordNet, Princeton University]

# Aliasing in Procedural Programming

- var-parameters are passed **by reference** (call by name)
- Modification of a var-parameter is observable by caller
- Aliasing: **Several variables** (here: p, q) refer to **same memory cell**
- Aliasing can lead to **unexpected side-effects**

```
program aliasTest
  procedure assign( var p: int, var q: int );
  begin
    { p = 1  $\wedge$  q = 1 }
    p := 25;
    { p = 25  $\wedge$  q = 25 }
  end;
  begin
    var x: int := 1;
    assign( x, x );
    { x = 25 }
  end
end.
```

# Aliasing in Object-Oriented Programming

- Definition:

*An object  $X$  is aliased if two or more variables hold references to  $X$ .*

- Variables can be

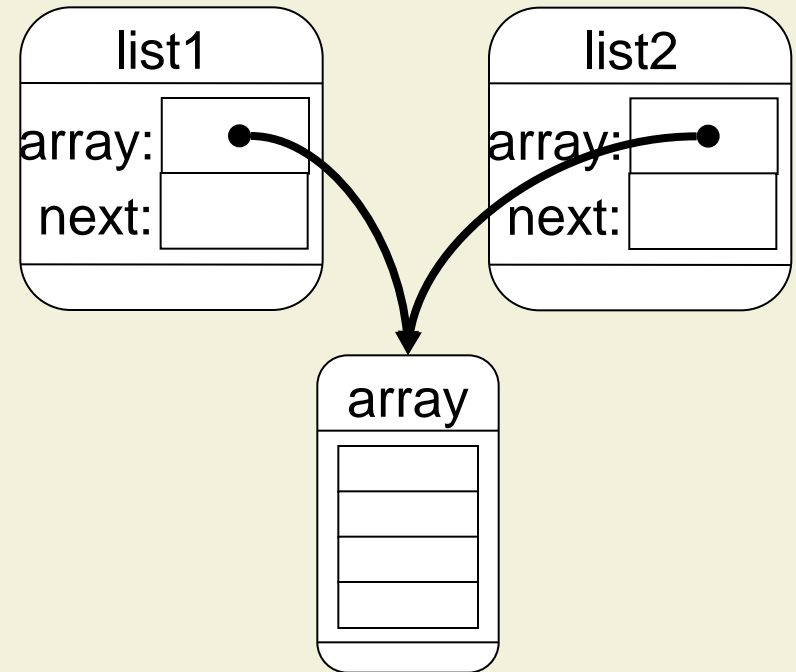
- Fields of objects (instance variables)
- Static fields (global variables)
- Local variables of method executions, including **this**
- Formal parameters of method executions
- Results of method invocations or other expressions

# Static Aliasing

- Definition:

*An alias is static if all involved variables are fields of objects or static fields.*

- Static aliasing occurs in the heap memory

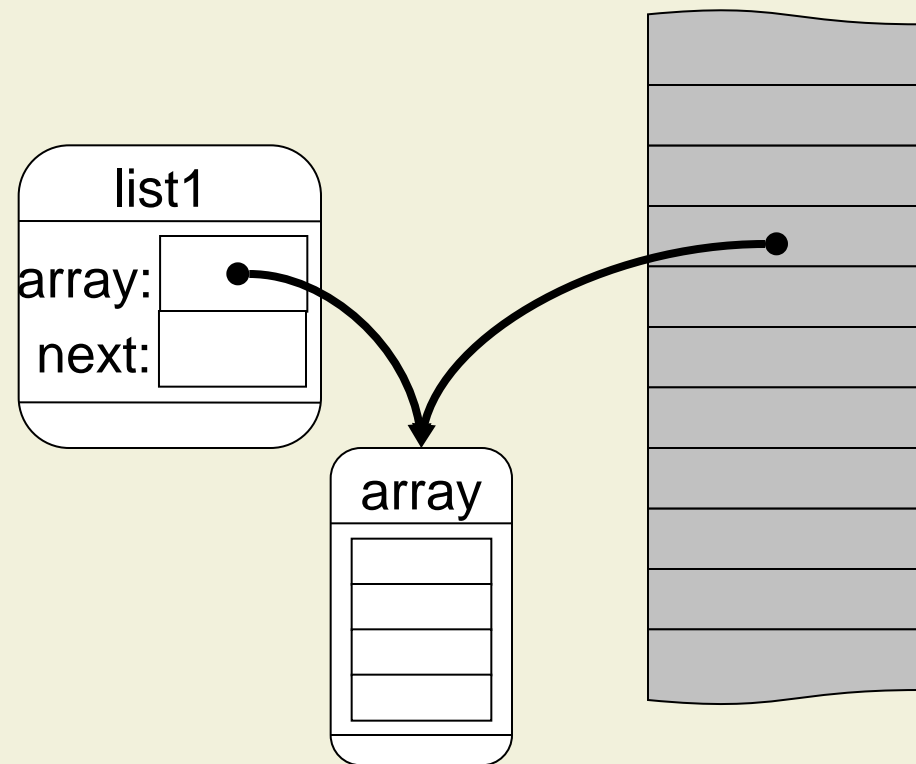


```
list1.array[ 0 ] = 1;
list2.array[ 0 ] = -1;
System.out.println( list1.array[ 0 ] );
```



# Dynamic Aliasing

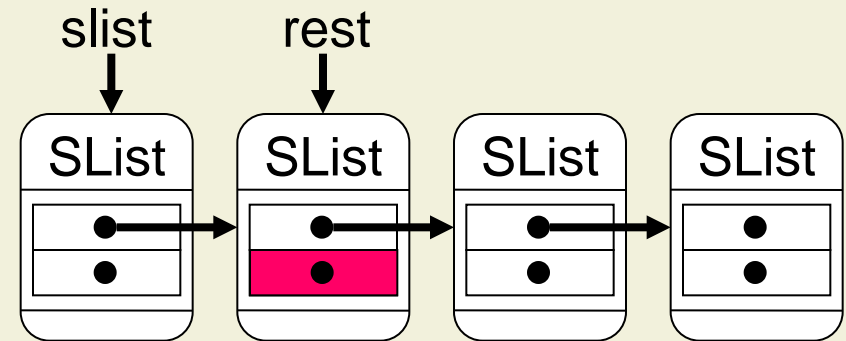
- Definition:  
*An alias is dynamic if it is not static.*
- Dynamic aliasing involves stack-allocated variables



```
int[ ] ia = list1.array;  
list1.array[ 0 ] = 1;  
ia[ 0 ] = -1;  
System.out.println( list1.array[ 0 ] );
```

# Intended Aliasing: Efficiency

- In OO-programming, data structures are usually **not copied** when passed or modified
- Aliasing and **destructive updates** make OO-programming efficient

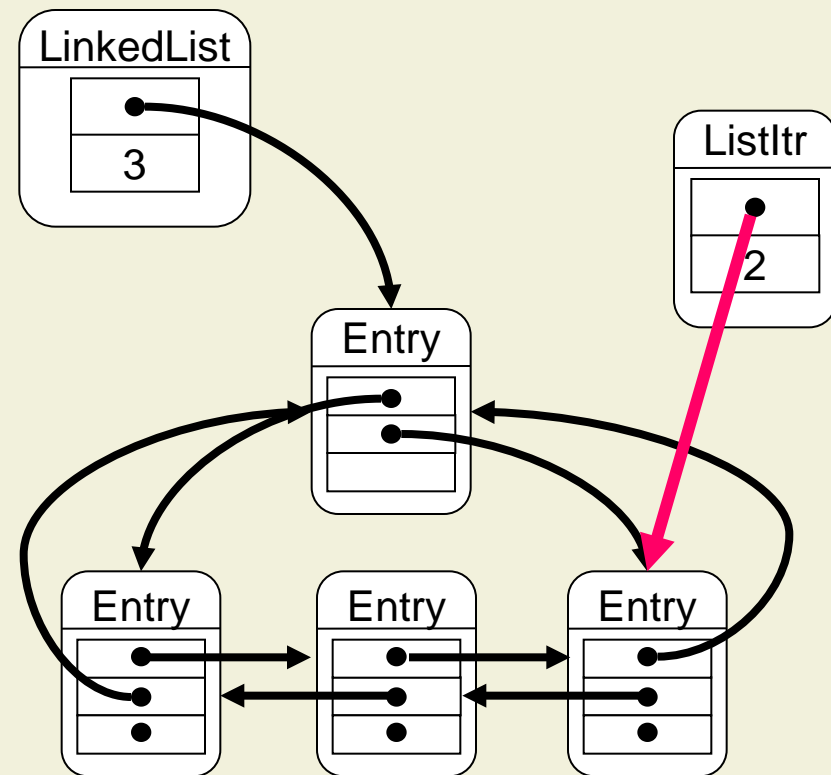


```
class SList {  
    SList next;  
    Object elem;  
    void rest( ) { return next; }  
    void set( Object e ) { elem = e; }  
}
```

```
void foo( SList slist ) {  
    SList rest = slist.rest( );  
    rest.set( "Hello" );  
}
```

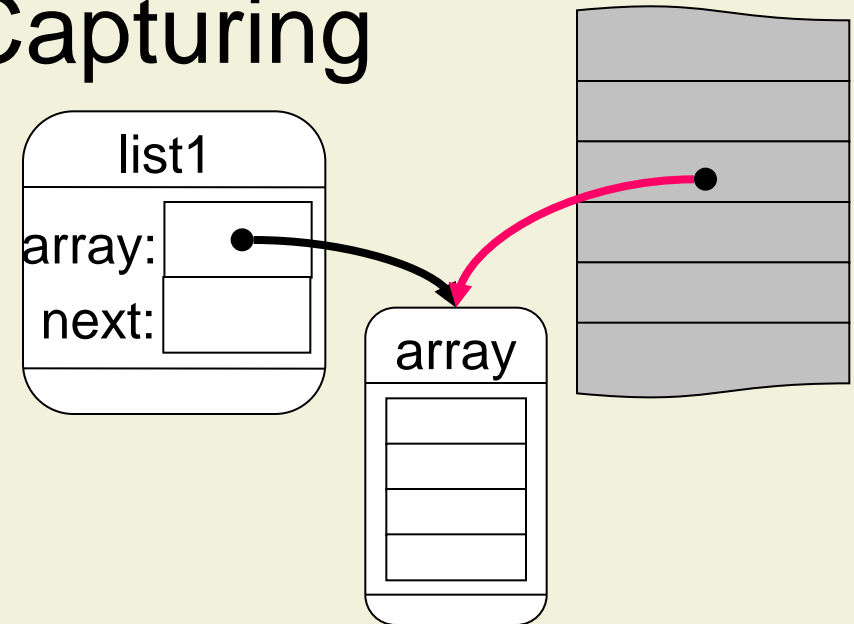
# Intended Aliasing: Sharing

- Aliasing is a direct **consequence of object identity**
- Objects have **state** that can be modified
- Objects have to be **shared** to make modifications of state effective



# Unintended Aliasing: Capturing

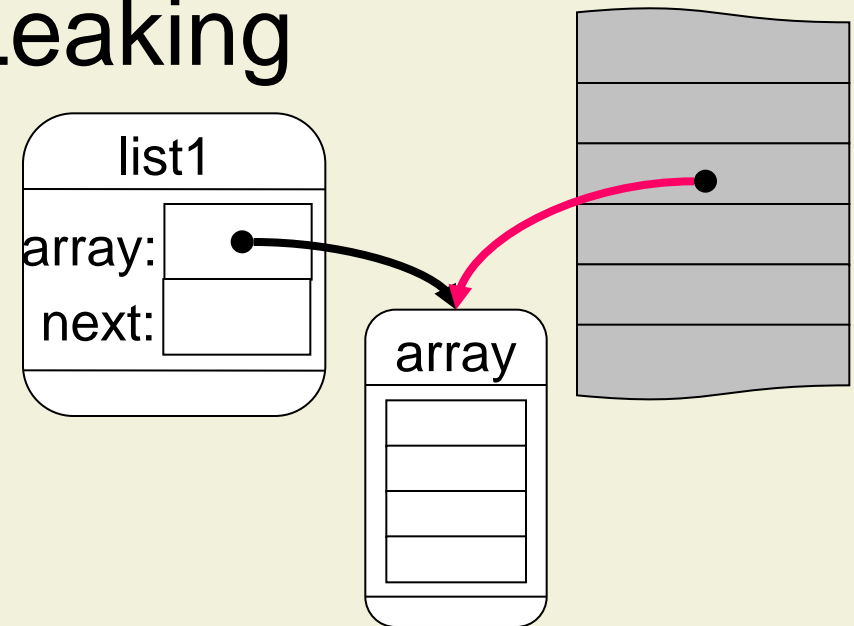
- Capturing occurs when objects are **passed to a data structure and then stored** by the data structure
- Capturing often occurs **in constructors** (e.g., streams in Java)
- Problem: Alias can be used to **by-pass interface** of data structure



```
class ArrayList {  
    private int[ ] array;  
    private int next;  
    public void addElems( int[ ] ia )  
        { array = ia; next = ia.length; }  
    ...  
}
```

# Unintended Aliasing: Leaking

- Leaking occurs when data structure **pass a reference** to an object, which is **supposed to be internal** to the outside
- Leaking **often** happens **by mistake**
- Problem: Alias can be used to **by-pass interface** of data structure



```
class ArrayList {  
    private int[ ] array;  
    private int next;  
    public int[ ] getElems( )  
    { return array; }  
    ...  
}
```

# 6. Object Structures and Aliasing

6.1 Object Structures

6.2 Aliasing

**6.3 Problems of Aliasing**

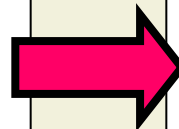
6.4 Encapsulation of Object Structures

# Observation

- Many **well-established techniques** of object-oriented programming work for individual objects, but **not for object structures in the presence of aliasing**
- Examples
  - Information hiding and exchanging implementations
  - Encapsulation and consistency

# Exchanging Implementations

```
class ArrayList {  
  private int[ ] array;  
  private int next;  
  
  // requires ia != null  
  // ensures  $\forall i. 0 \leq i < \text{ia.length}:$   
  //           isElem( old( ia[ i ] ) )  
  public void addElems( int[ ] ia )  
    { array = ia; next = ia.length; }  
  
  ...  
}
```



```
class ArrayList {  
  private Entry header;  
  
  // requires ia != null  
  // ensures  $\forall i. 0 \leq i < \text{ia.length}:$   
  //           isElem( old( ia[ i ] ) )  
  public void addElems( int[ ] ia )  
    { ... /* create Entry for each  
        element */ }  
  
  ...  
}
```

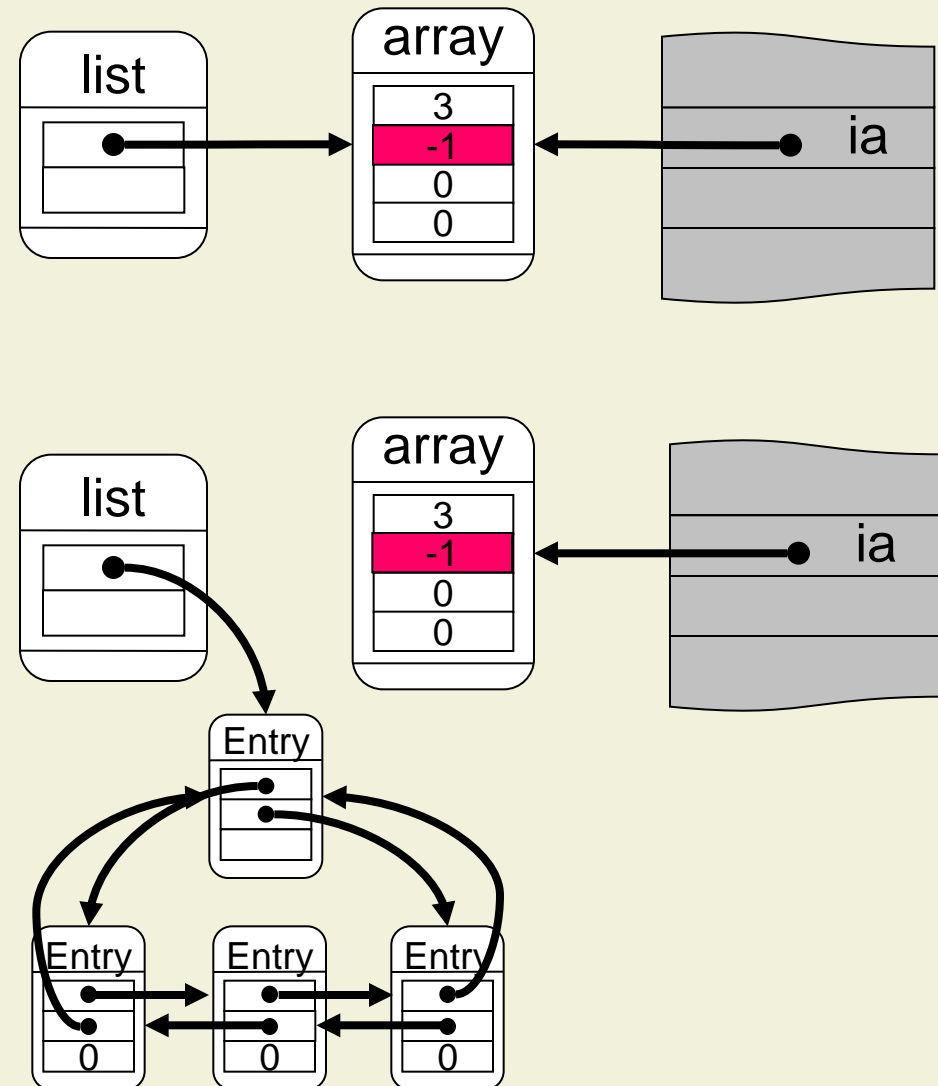
- Interface including contract remains unchanged



# Exchanging Implementations (cont'd)

```
int foo( ArrayList list ) {  
    int[ ] ia = new int[ 3 ];  
    list.addElems( ia );  
    ia[ 0 ] = -1;  
    return list.getFirst( );  
}
```

- Aliases can be used to by-pass interface
- **Observable behavior is changed!**



# Consistency of Object Structures

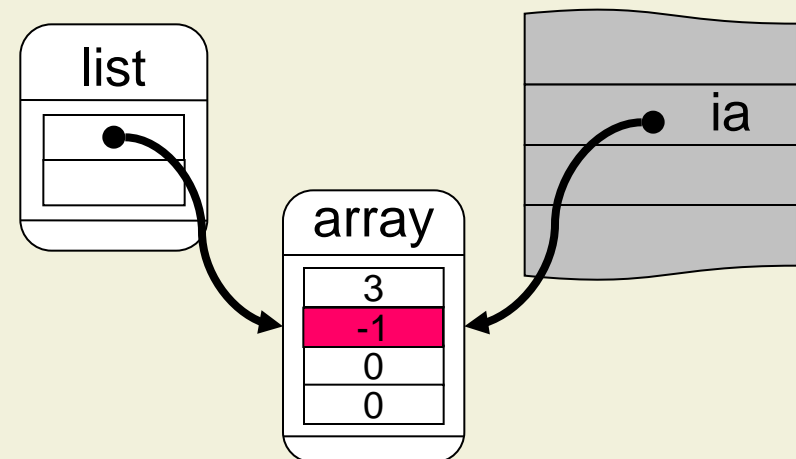
- Consistency of object structures depends on **fields of several objects**
- **Invariants** are usually specified as part of the contract **of those objects** that represent the **interface of the object structure**

```
class ArrayList {  
    private int[ ] array;  
    private int next;  
  
    // invariant array != null    &&  
    //  0<=next<=array.length  &&  
    //   $\forall i. 0 \leq i < \text{next}: \text{array}[i] \geq 0$   
  
    public void add( int i )    { ... }  
    public void addElems( int[ ] ia )  
        { ... }  
  
    ...  
}
```

# Consistency of Object Structures (cont'd)

```
int foo( ArrayList list ) {           // invariant of list holds
    int[ ] ia = new int[ 3 ];
    list.addElems( ia );              // invariant of list holds
    ia[ 0 ] = -1;                     // invariant of list violated
}
```

- **Aliases can be used to violate invariant**
- Making all attributes private is not sufficient to encapsulate internal state



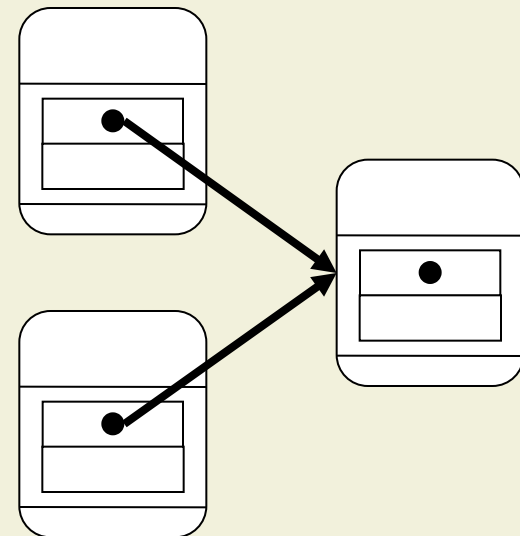
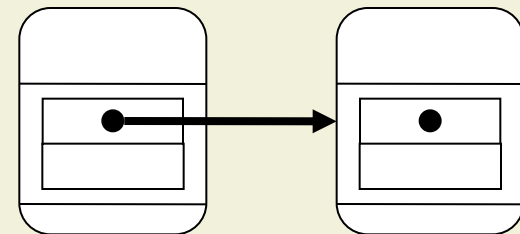
# Security Breach in Java JDK 1.1.1

- Each Class-object stores array of signers
- Only trusted signers get extended access rights to the host system
- Through leaking, a malicious applet can modify the list of signers to get extended rights
- Again, access modifiers cannot prevent the problem because arrays are mutable

```
private Identity[ ] signers;  
  
...  
public Identity[ ] getSigners( ) {  
    return signers;  
}
```

# Other Problems with Aliasing

- Synchronization in concurrent programs
  - Monitor of each individual object has to be locked to ensure mutual exclusion
- Distributed programming
  - For instance, parameter passing for remote method invocation
- Optimizations
  - For instance, object inlining is not possible for aliased objects



# 6. Object Structures and Aliasing

6.1 Object Structures

6.2 Aliasing

6.3 Problems of Aliasing

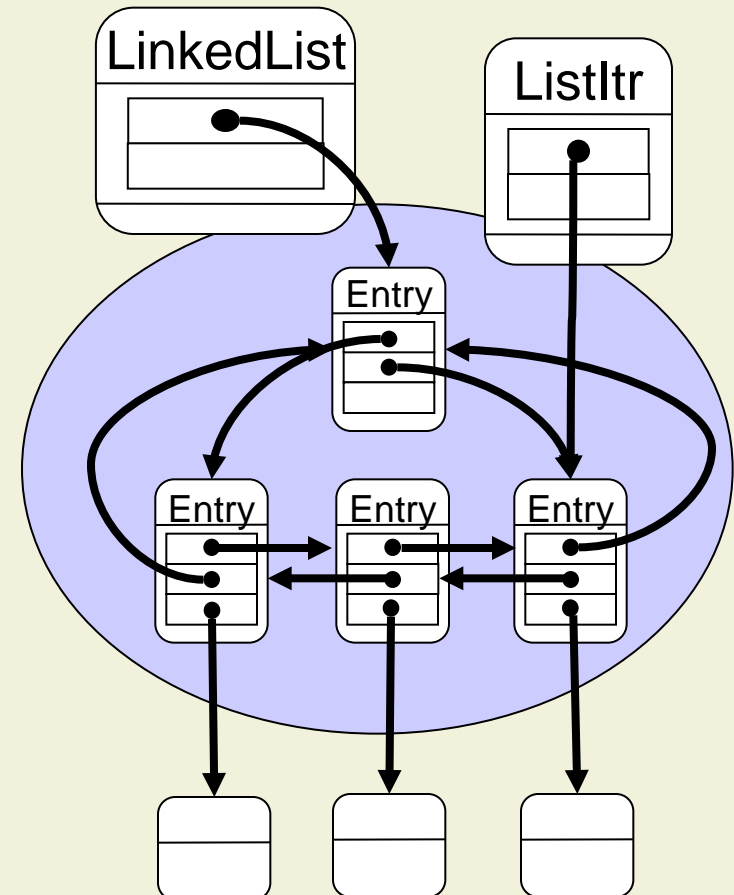
**6.4 Encapsulation of Object Structures**

# Alias Modes

- We need **better control** over the objects in an object structure to avoid the problems with aliasing
- Approach
  1. Define **roles** of objects in object structures
  2. Assign a tag (**alias mode**) to every expression to indicate the role of the referenced object
  3. Impose **programming rules** to guarantee that objects are only used according to their alias modes

# Roles in Object Structures

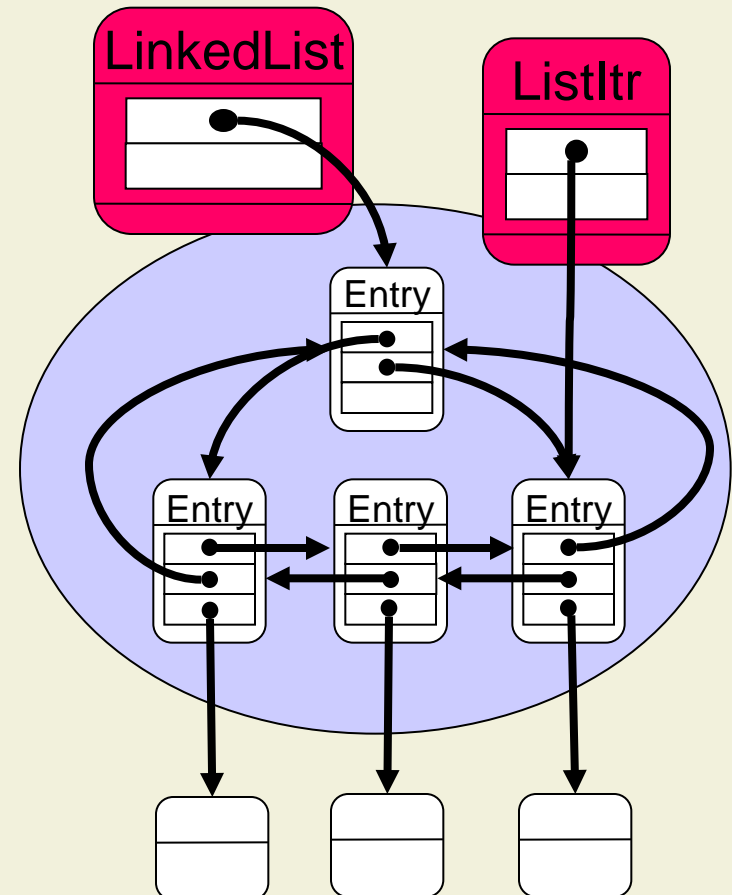
- **Interface objects** that are used to access the structure
- **Internal representation** of the object structure
- **Arguments** of the object structure





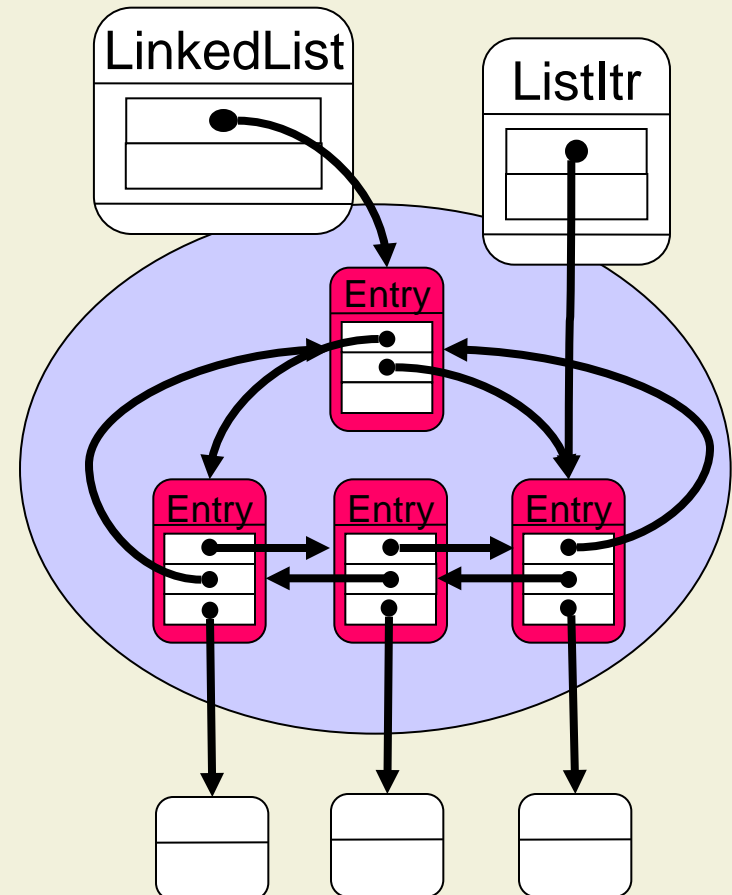
# Interface Objects (default Mode)

- Interface objects are used to **access the structure**
- Interface objects can be **used in any way** objects are usually used (passed around, changed, etc.)



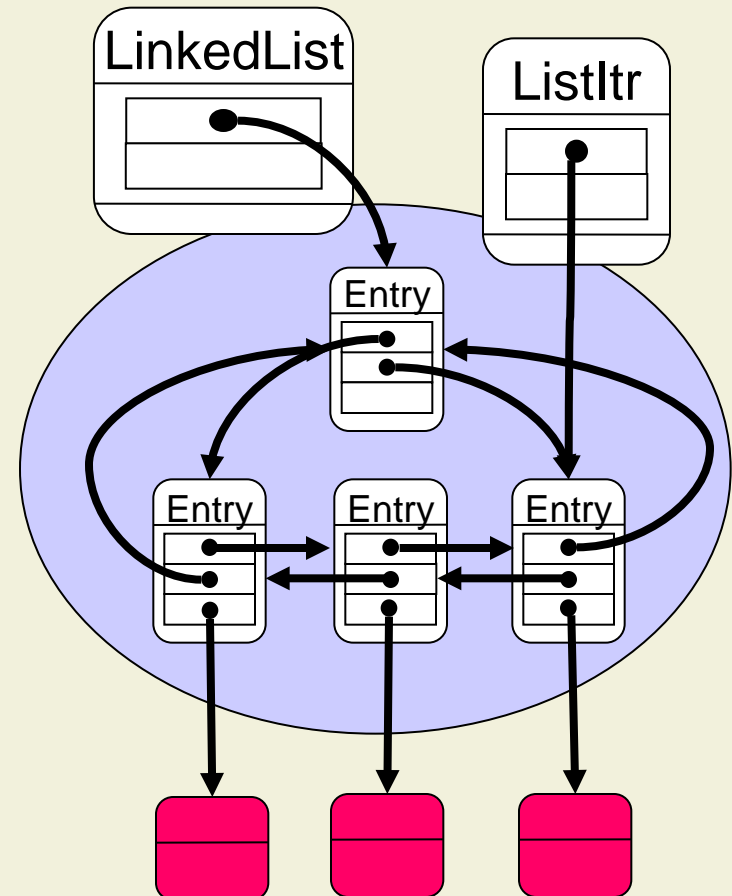
# Representations (rep Mode)

- Expressions with mode “rep” hold references to the **representation** of the object structure
- Objects referenced by rep-expressions can **be changed**
- Rep-objects **must not be exported** from the object structure



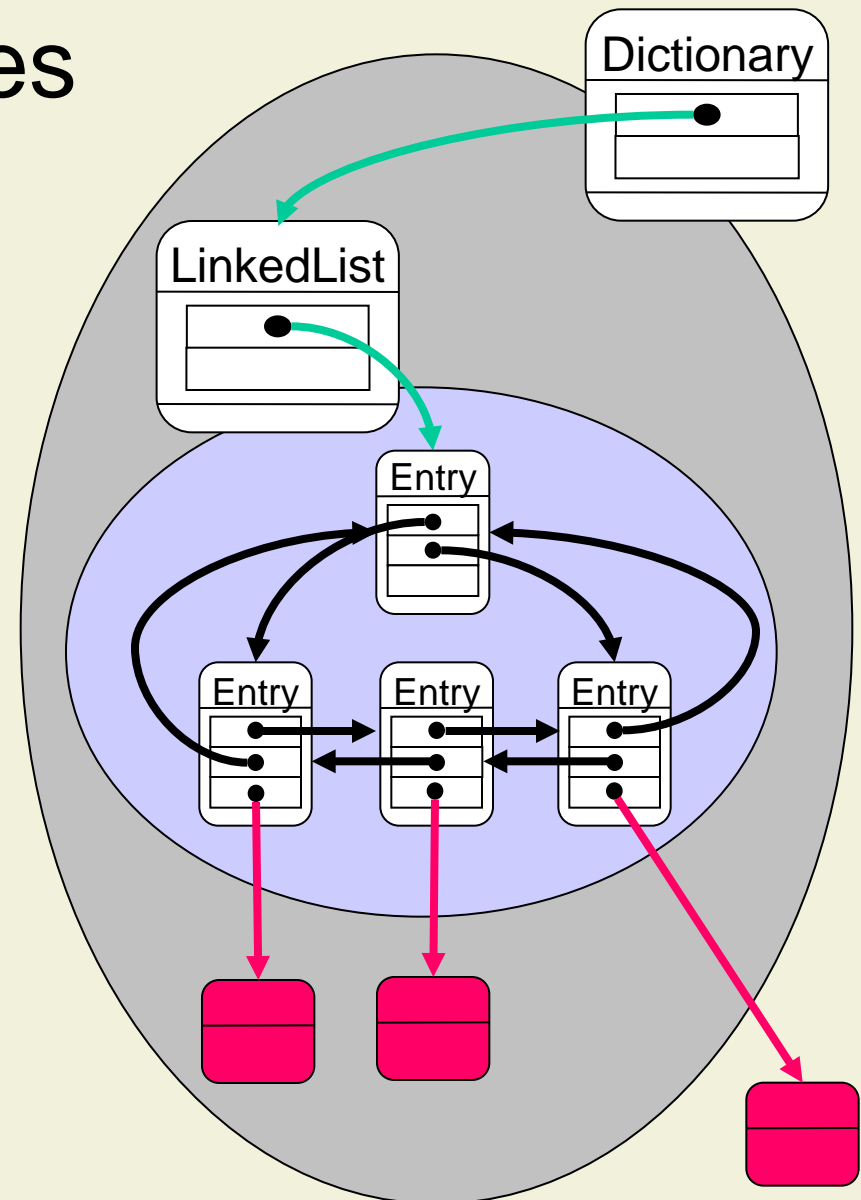
# Arguments (arg Mode)

- Expressions with mode “arg” hold references to **arguments** of the object structure
- Objects **must not be changed** through arg-references
- Arg-objects can be **passed around** and aliased freely



# Meaning of Alias Modes

- Alias modes describe the role of an object relative to an interface object
- Informally: References
  - With **default mode** stay in the same context
  - With **rep-mode** go from an interface object into its context
  - With **arg-mode** may go to any context



# (Simplified) Programming Discipline

## ■ Rule 1: No Role Confusion

- Expression with one alias mode must not be assigned to variables with another mode

## ■ Rule 2: No Representation Exposure

- rep-mode must not occur in an object's interface
- Methods must not take or return rep-objects
- Fields with rep-mode may only be accessed on **this**

## ■ Rule 3: No Argument Dependence

- Implementations must not depend on the state of argument objects

# Example 1: LinkedList with Alias Modes

```
class LinkedList {  
    private /* rep */ Entry header;  
    private int size;  
  
    public void add( /* arg */ Object o ) {  
        /* rep */ Entry newE = new /* rep */ Entry( o, header, header.previous );  
        ... }  
}
```

```
class Entry {  
    private /* arg */ Object element;  
    private Entry previous, next;  
  
    public Entry( /* arg */ Object o, Entry p, Entry n ) { ... }  
}
```

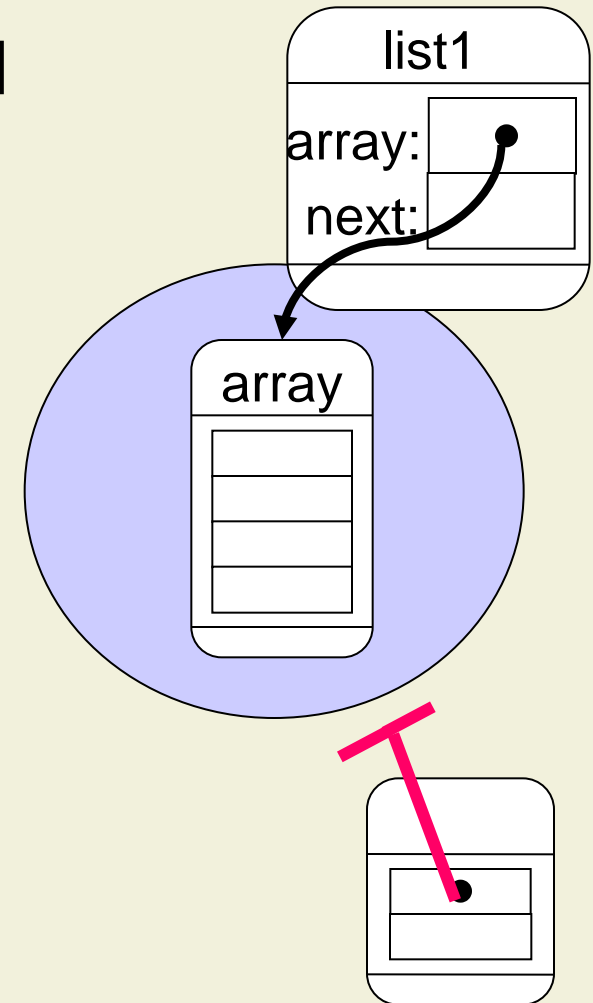
## Example 2: ArrayList with Alias Modes

- Array is **internal representation** of the list
- Method addElems **confuses alias modes**
- Clean solution requires **array copy**

```
class ArrayList {  
    private /* rep */ int[ ] array;  
    private int next;  
  
    public void addElems( int[ ] ia ) {  
        array = new /* rep */ int[ ia.length ];  
        System.arraycopy  
            (ia, 0, array, 0, ia.length );  
        next = ia.length;  
    }  
    ...  
}
```

# No Representation Exposure

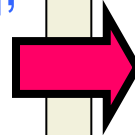
- rep-objects can only be referenced
  - By their interface objects
  - By other rep-objects of the same object structure
- rep-objects can only be modified
  - By methods executed on their interface objects
  - By methods executed on rep-objects of the same object structure
- Rep-objects are **encapsulated** inside the **object structure**





# Implementation Exchange Revisited

```
class ArrayList {  
    private /* rep */ int[ ] array;  
    private int next;  
    public void addElems( int[ ] ia ) {  
        array = new /* rep */ int[ ia.length ];  
        System.arraycopy  
            (ia, 0, array, 0, ia.length );  
        next = ia.length;  
    }  
    ...  
}
```



```
class ArrayList {  
    private /* rep */ Entry header;  
  
    public void addElems( int[ ] ia )  
    { ... /* create Entry for each  
        element */ }  
    ...  
}
```

- **Observable behavior remains unchanged!**

# Invariants for Object Structures

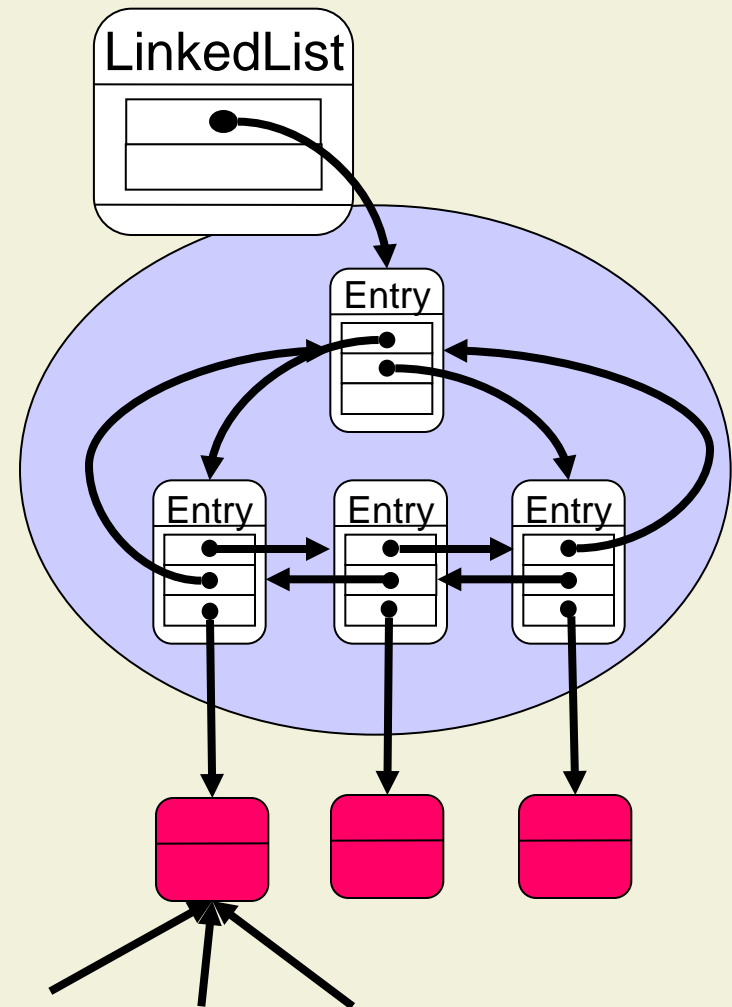
- The invariant of object X **may depend on**
  - Encapsulated fields of X
  - Fields of objects X references through references
- Interface objects have **full control** over their rep-objects

```
class ArrayList {  
    private /* rep */ int[ ] array;  
    private int next;  
  
    // invariant array != null    &&  
    //  0<=next<=array.length  &&  
    //   $\forall i. 0 \leq i < \text{next}: \text{array}[i] \geq 0$   
  
    public void add( int i )    { ... }  
    public void addElems( int[ ] ia )  
        { ... }  
  
    ...  
}
```

# No Argument Dependence

- Objects referenced through arg-references may be **freely aliased**
- Object structures have **no control over** the **state** of their argument objects
- Invariants **must not depend** on fields of argument objects, but can depend on their identity

```
private /* arg */ T v, w;  
// invariant v != w           -- legal  
// invariant v.f != w.f       -- illegal
```



# Alias Control in Modular Programs

- Rules for rep-mode can in general **not** be **checked modularly**
- **Subclasses** can add new methods or override methods
- In Java, rep exposure can be prevented by
  - Access modifiers
  - Final
  - Inner Classes

```
class ArrayList {  
    protected /* rep */ int[ ] array;  
    private int next;  
    ...  
}
```

```
class MyList extends ArrayList {  
    public int[ ] leak( ) {  
        return array;  
    }  
}
```

# Alias Control in Java: LinkedList

- All **fields** are **private**
- Entry is a **private inner class** of LinkedList
  - References are not passed out
  - Subclasses cannot manipulate or leak Entry-objects
- Listltr is a **private inner class** of LinkedList
  - Interface Listlterator provides controlled access to Listltr-objects
  - Listltr-objects are passed out, but in a controlled fashion
  - Subclasses cannot manipulate or leak Listltr-objects
- **Subclassing is severely restricted**

# Alias Control in Java: String

- All **fields** are **private**
- References to internal character-array are not passed out (no representation exposure)
- **Subclassing is prohibited** (final)

