

Concepts of Object-Oriented Programming

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Chair of Programming Methodology

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6. Object Structures and Aliasing

6.1 Object Structures

6.2 Aliasing

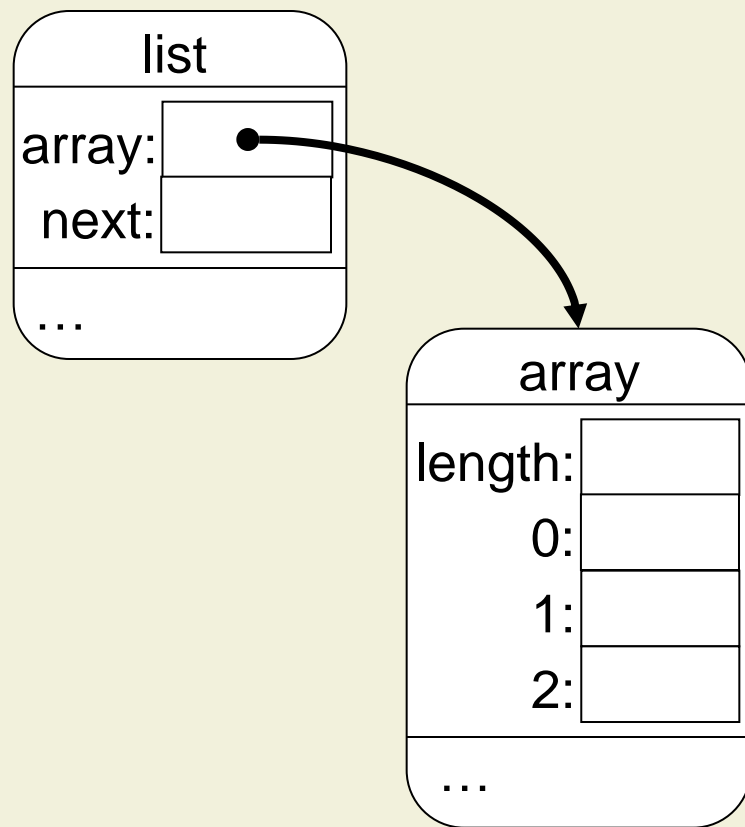
6.3 Problems of Aliasing

6.4 Encapsulation of Object Structures

Object Structures

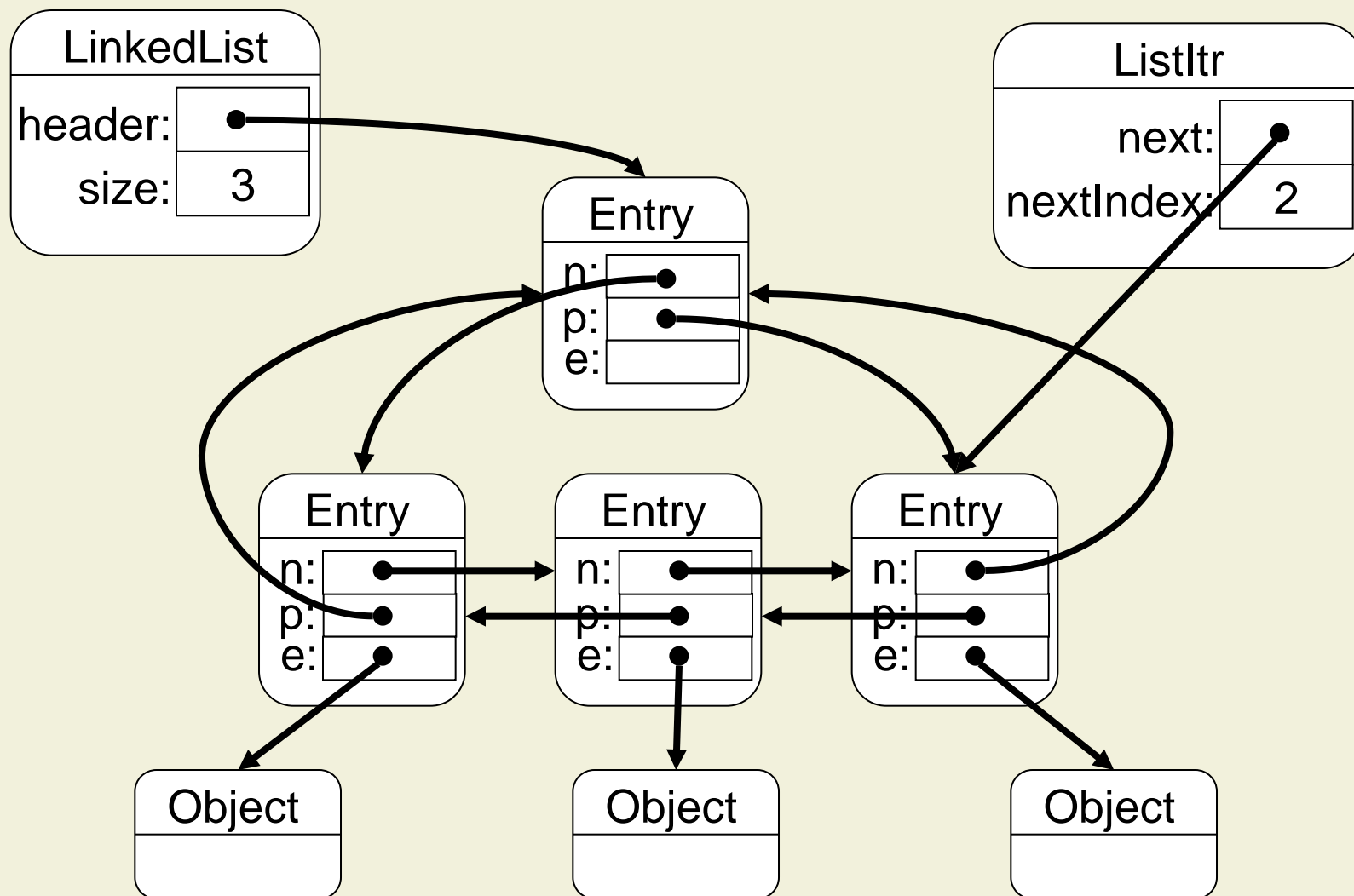
- Objects are the building blocks of object-oriented programming
- However, interesting abstractions are almost always provided by sets of cooperating objects
- Definition:
An object structure is a set of objects that are connected via references

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



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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 o is aliased if two or more variables hold references to o .

- Variables can be

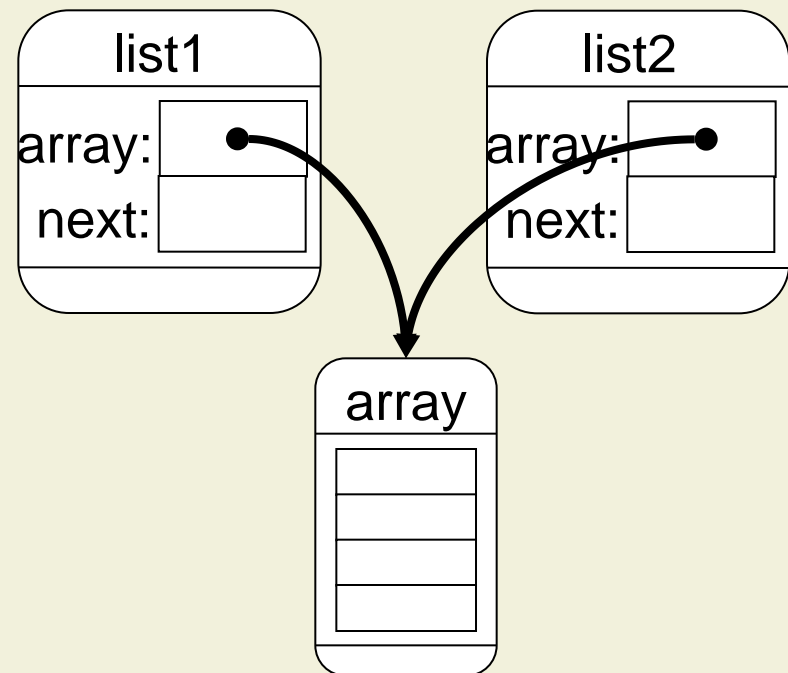
- Fields of objects (instance variables)
- Static fields (global variables)
- Local variables of method executions, including **this**
- Formal parameters of method executions
- Results of method invocations or other expressions

Static Aliasing

- Definition:

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

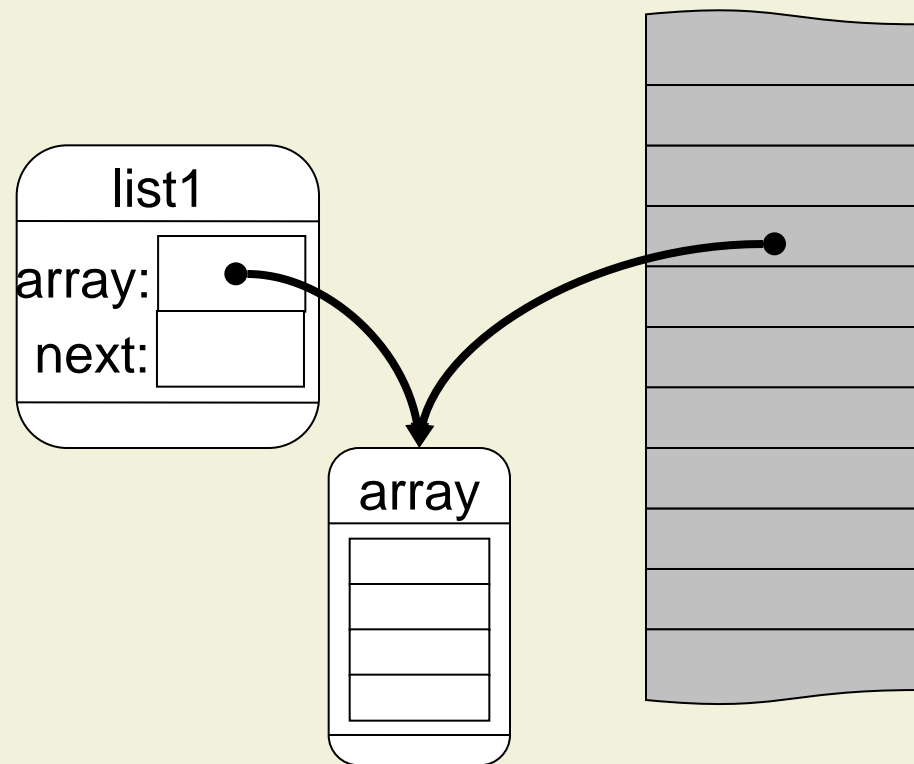
- Static aliasing occurs in the heap memory



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

Dynamic Aliasing

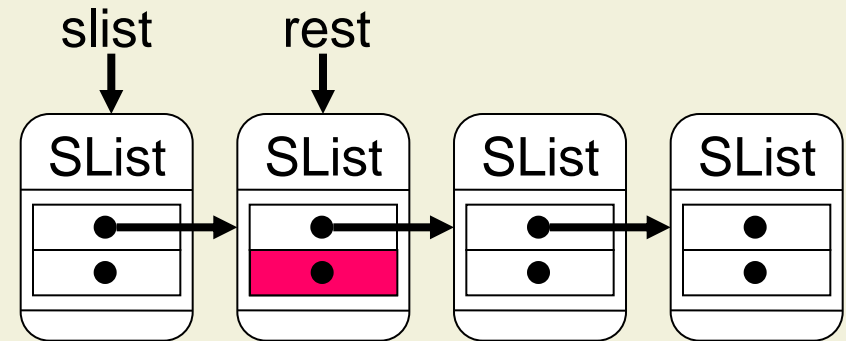
- Definition:
An alias is dynamic if it is not static.
- Dynamic aliasing involves stack-allocated variables



```
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

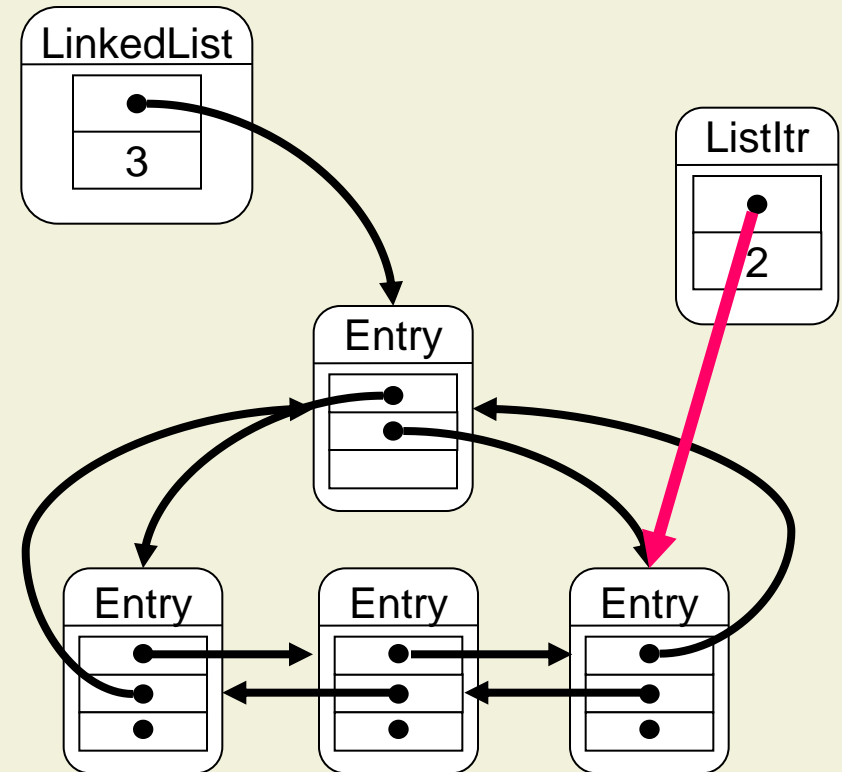


```
class SList {  
    SList next;  
    Object elem;  
    SList rest( ) { return next; }  
    void set( Object e ) { elem = e; }  
}
```

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

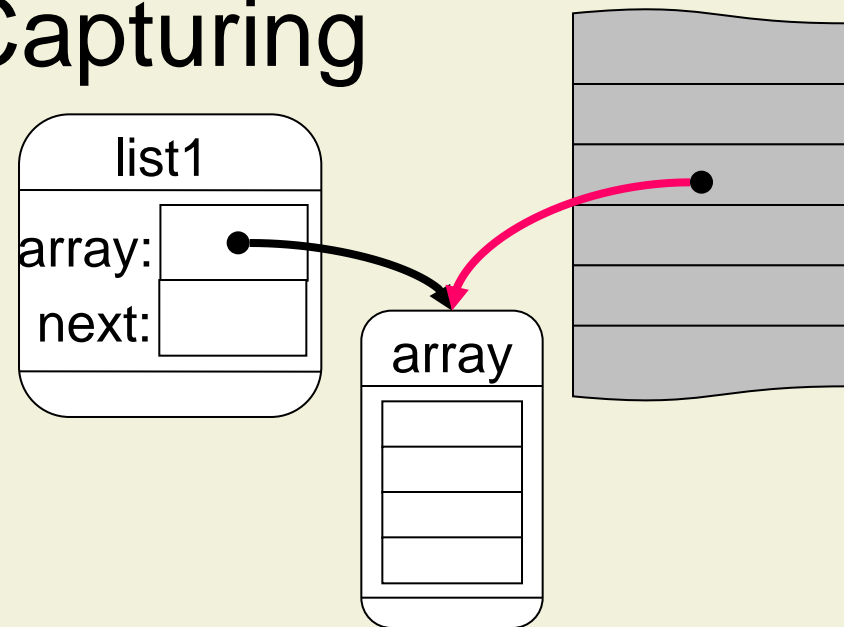
Intended Aliasing: Sharing

- 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

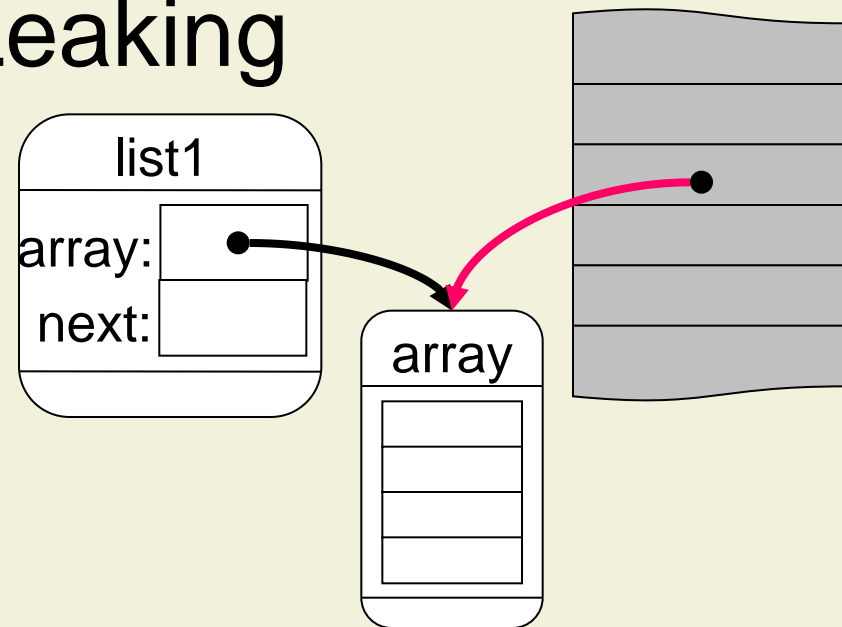
- Capturing occurs when objects are **passed to a data structure and then stored** by the data structure
- Capturing often occurs **in constructors** (e.g., streams in Java)
- Problem: Alias can be used to **by-pass interface** of data structure



```
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; }  
    ...  
}
```

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6.3 Problems of Aliasing

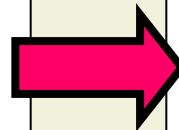
6.4 Encapsulation of Object Structures

Observation

- Many **well-established techniques** of object-oriented programming work for individual objects, but **not for object structures in the presence of aliasing**
- *“The big lie of object-oriented programming is that objects provide encapsulation”* [Hogg, 1991]
- 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; }  
  
  ...  
}
```



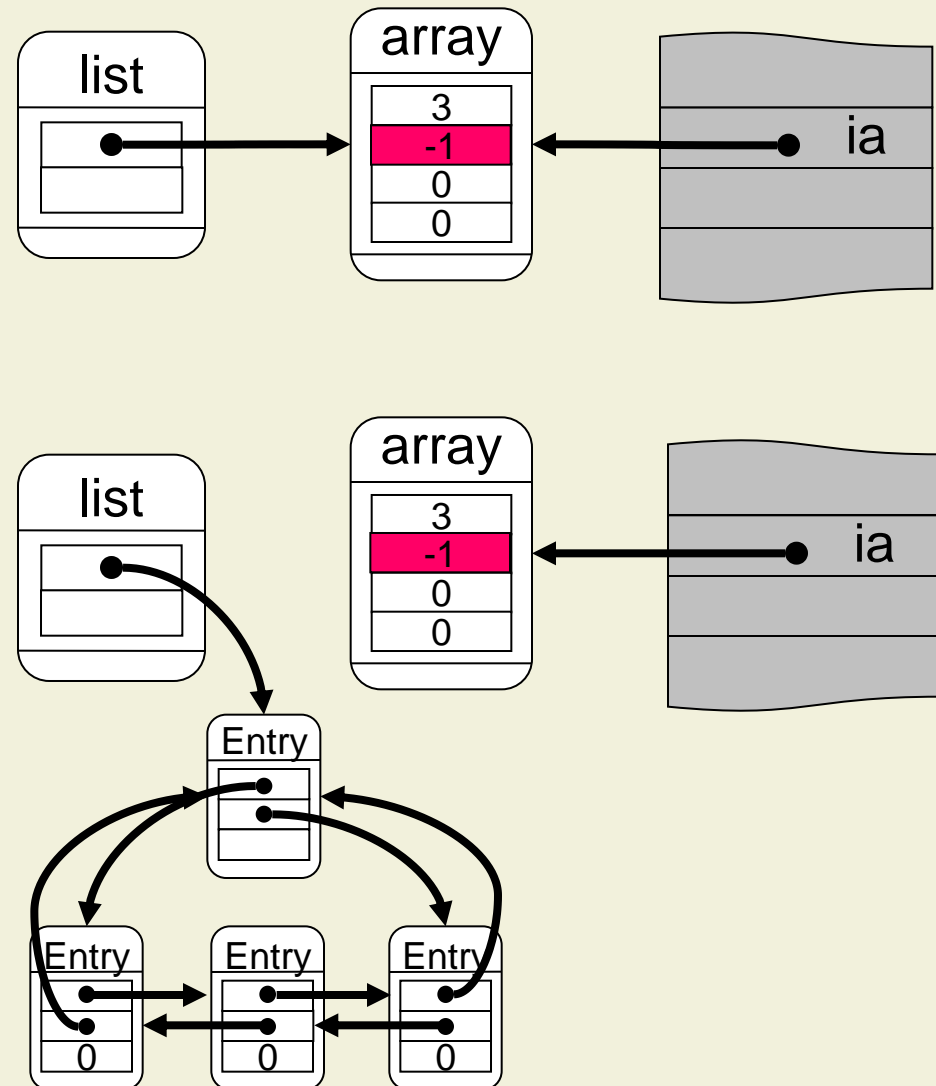
```
class ArrayList {  
  private Entry header;  
  
  // requires ia != null  
  // ensures  $\forall i. 0 \leq i < \text{ia.length}:$   
  //           isElem( old( ia[ i ] ) )  
  public void addElems( int[ ] ia )  
    { ... /* create Entry for each  
        element */ }  
  
  ...  
}
```

- 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

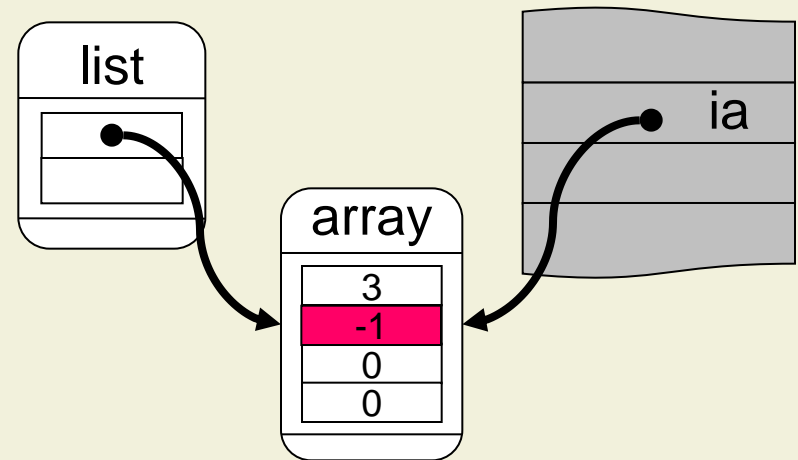
- Consistency of object structures depends on fields of several objects
- Invariants are usually specified as part of the contract of those objects that represent the interface of the object structure

```
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 fields private is not sufficient to encapsulate internal state



Security Breach in Java 1.1.1

```
class Malicious {
```

```
  void bad( ) {
```

```
    Identity[ ] s;
```

```
    Identity trusted = java.Security...;
```

```
    s = Malicious.class.getSigners( );
```

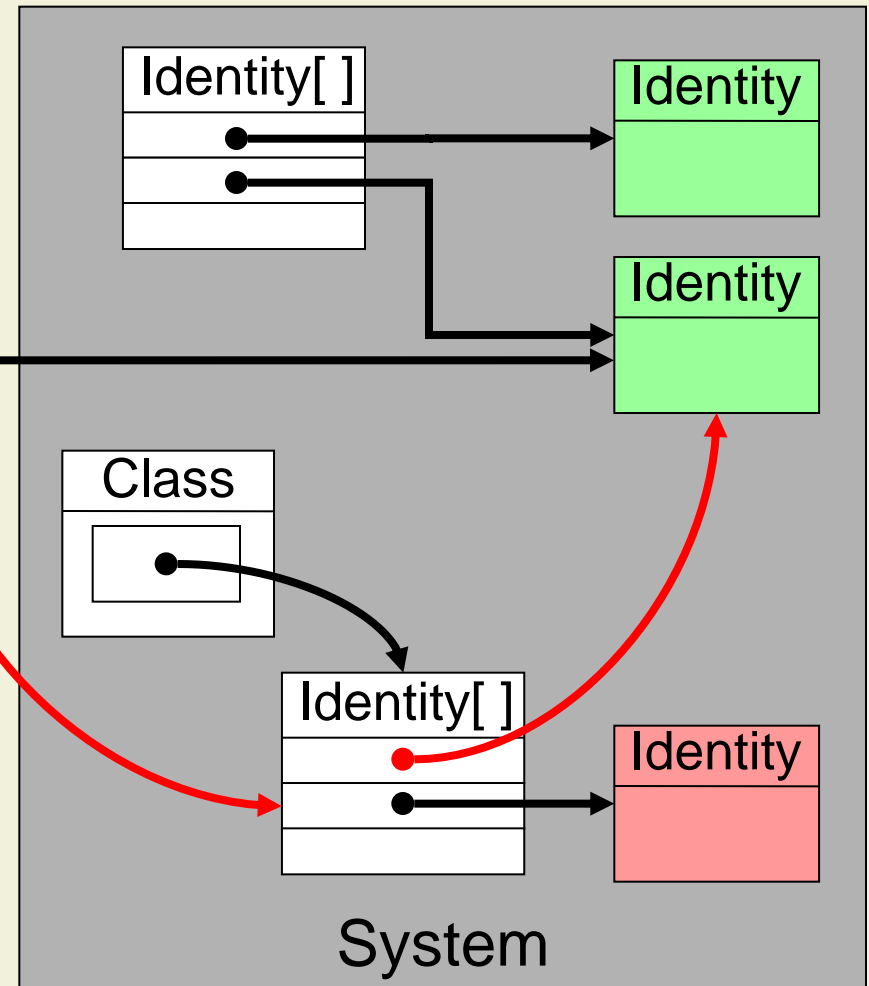
```
    s[ 0 ] = trusted;
```

```
    /* abuse privilege */
```

```
  }
```

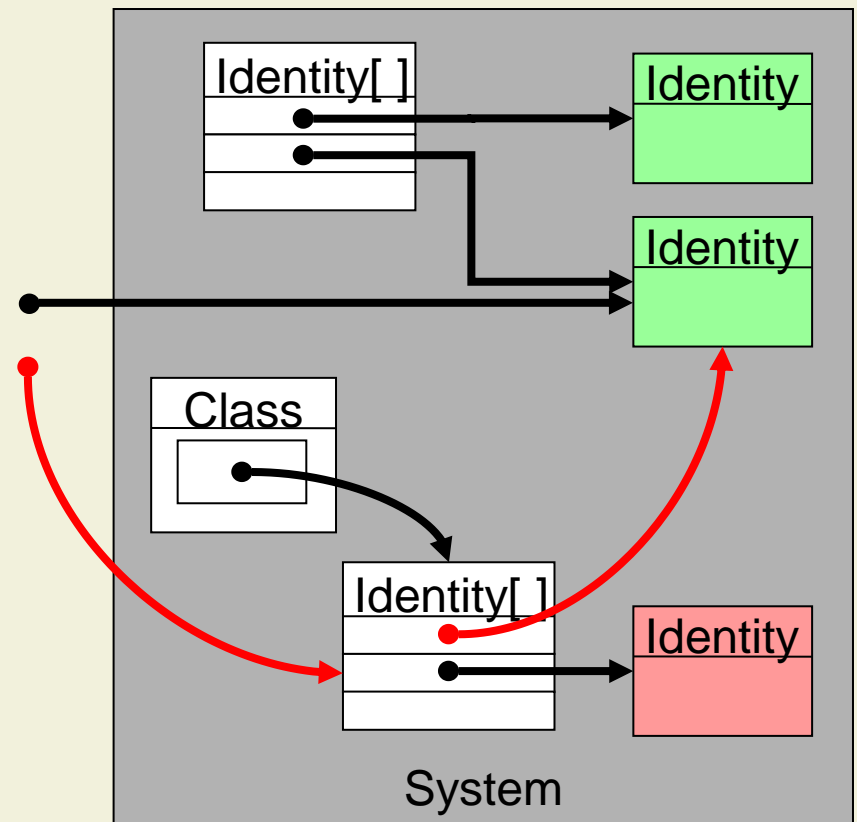
```
}
```

Identity[] getSigners()
{ **return** signers; }



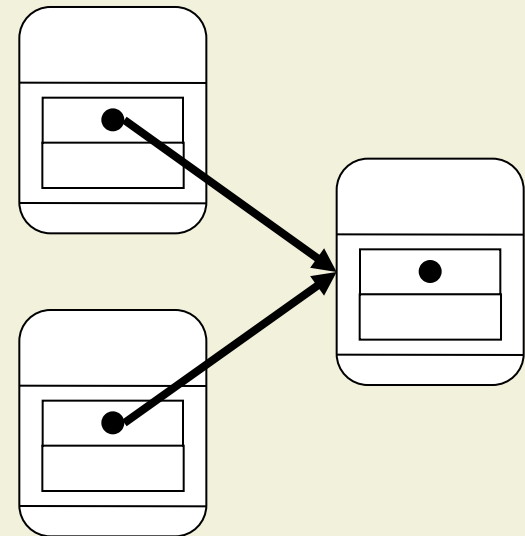
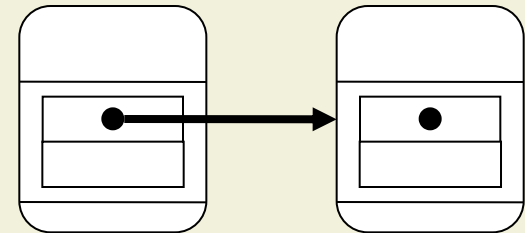
Problem Analysis

- Breach caused by unwanted alias
 - Leaking of reference
- Difficult to prevent
 - Information hiding: not applicable to arrays
 - Restriction of Identity objects: not effective
 - Secure information flow: read access permitted
 - Run-time checks: too expensive



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



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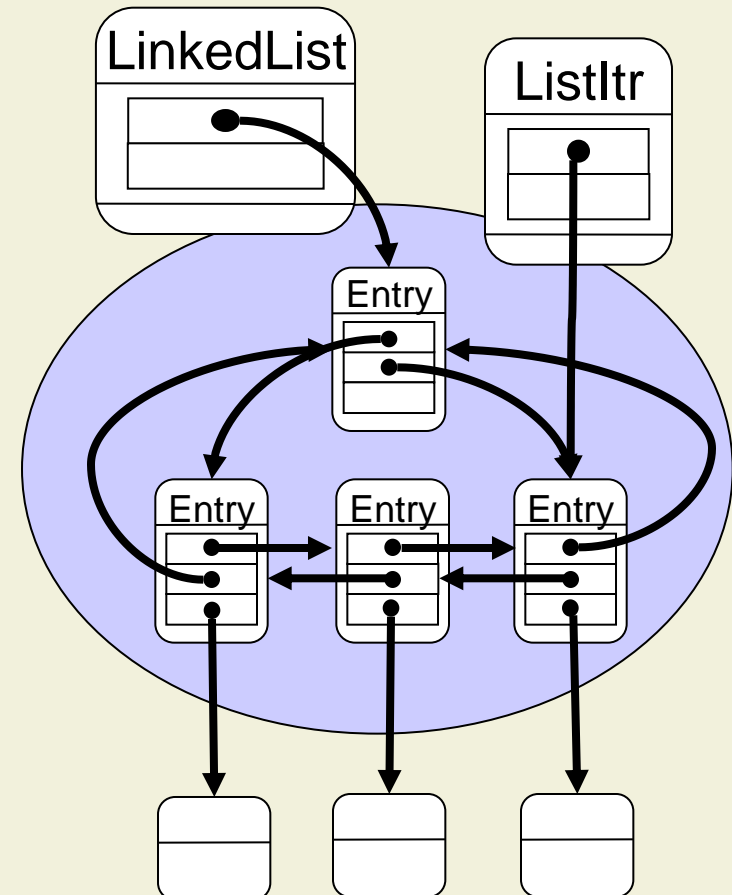
6.4 Encapsulation of Object Structures

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

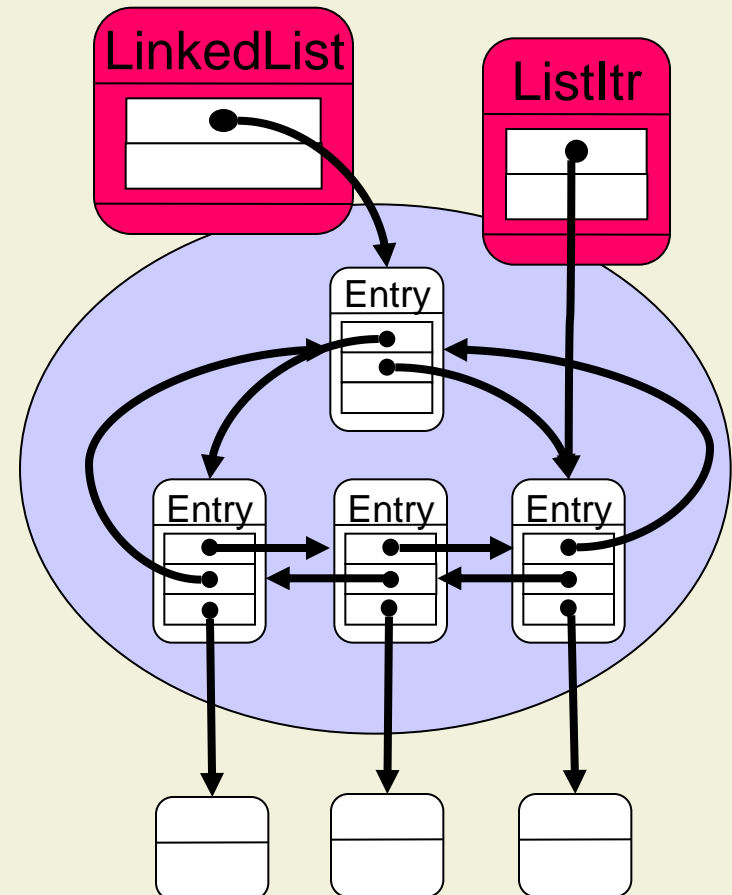
Roles in Object Structures

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



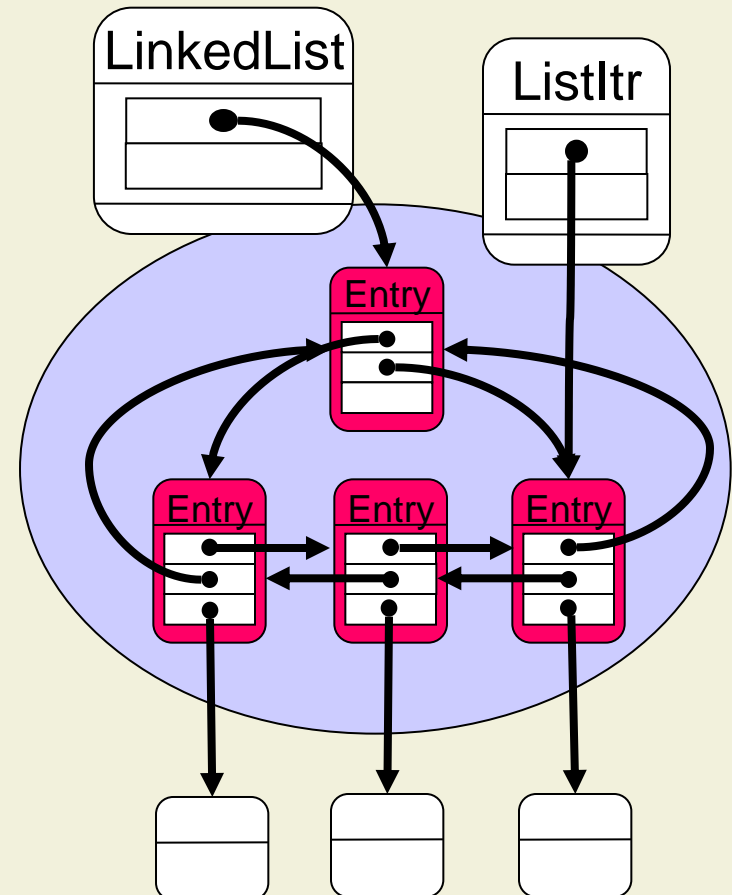
Interface Objects (peer Mode)

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



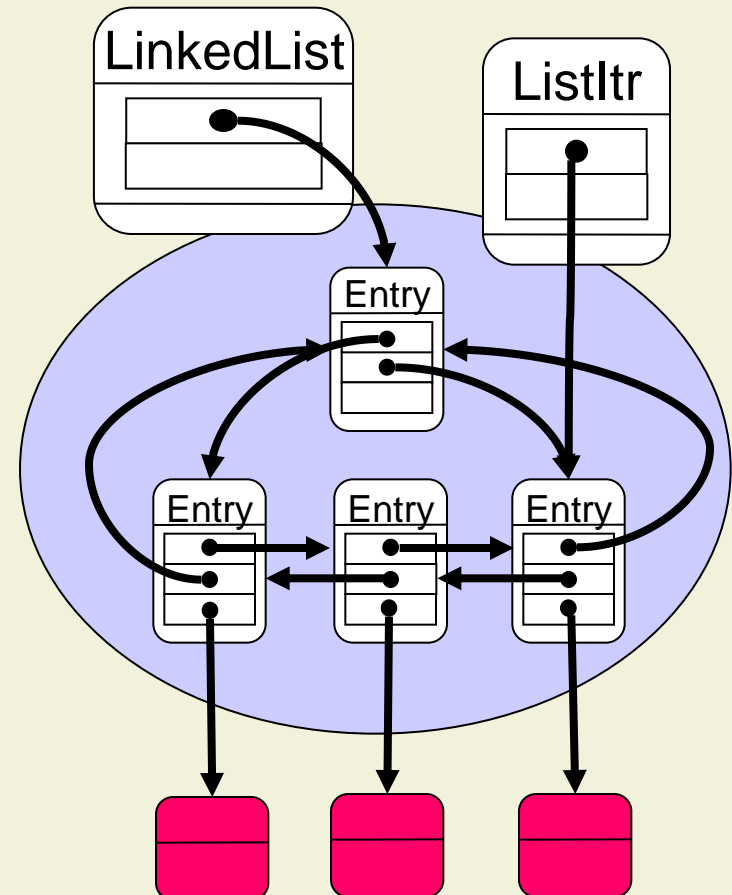
Representations (rep Mode)

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



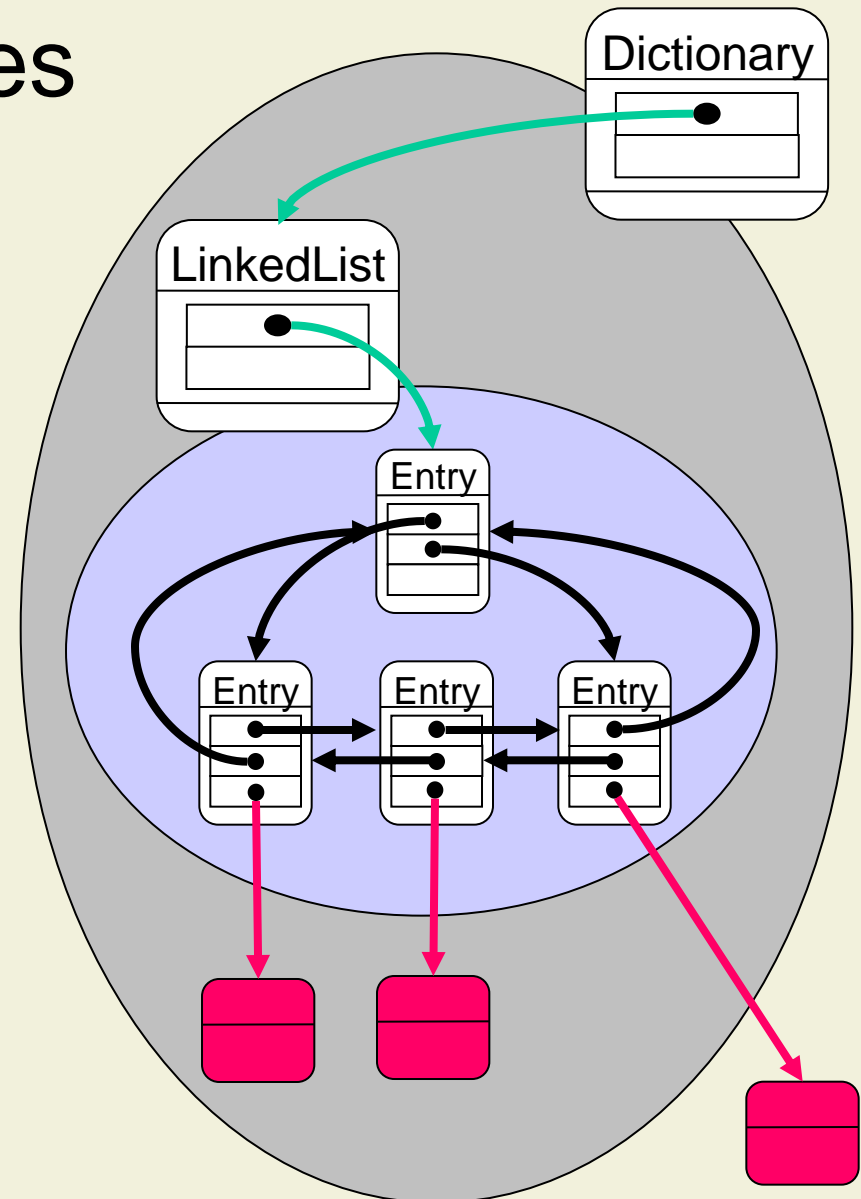
Arguments (arg Mode)

- Expressions with mode “arg” hold references to **arguments** of the object structure
- Objects **must not be modified** 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 peer-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, except to an arg-variable

■ 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 /* peer */ Entry previous, next;  
  
  public Entry( /* arg */ Object o, /* peer */ Entry p, /* peer */ Entry n ) { ... }  
}
```

Example 2: ArrayList with Alias Modes

- Array is **internal representation** of the list
- **addElems** **confuses alias modes**

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

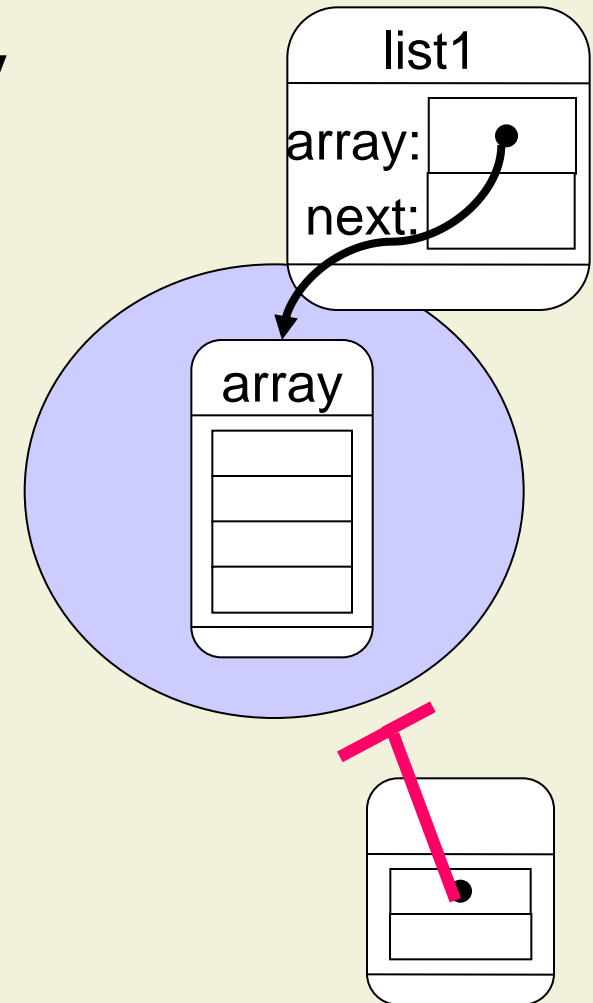
Example 2: ArrayList with Alias Modes

- Array is **internal representation** of the list
- Clean solution requires **array copy**

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

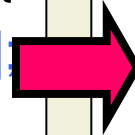
No Representation Exposure

- rep-objects can be referenced only
 - By their interface objects
 - By other rep-objects of the same object structure
 - Via arg-references
- rep-objects can be modified only
 - By methods executed on their interface objects or 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  
    ( /* peer */ 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  
    ( /* peer */ int[ ] ia )  
  { ... /* create Entry for each  
    element */ }  
  ...  
}
```

- Observable behavior remains unchanged!

Invariants for Object Structures

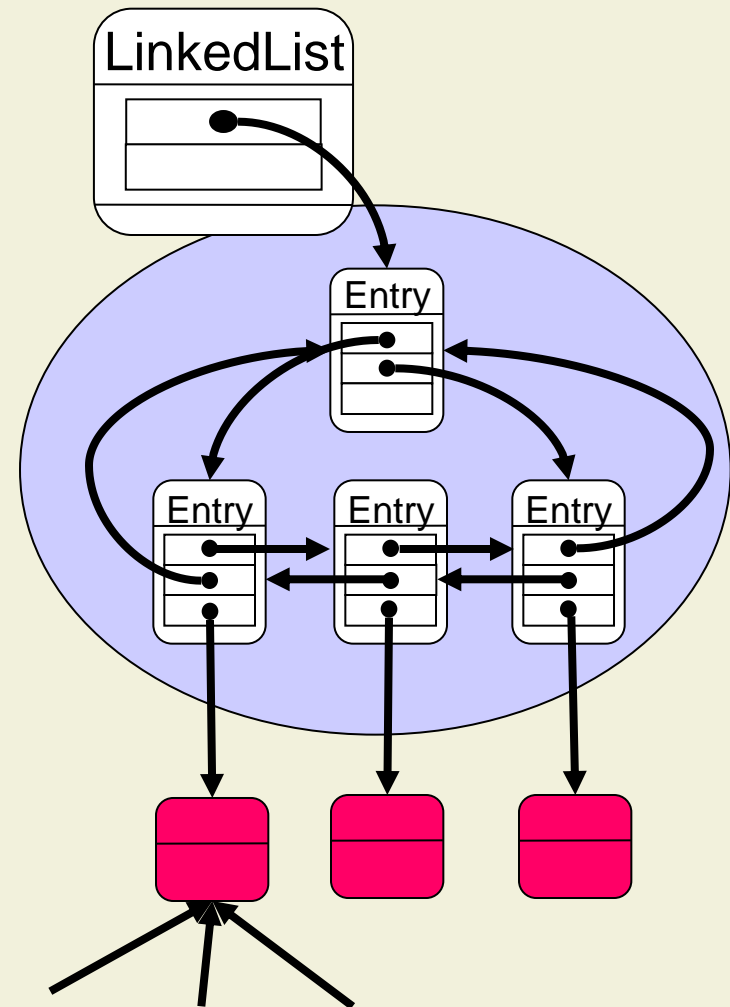
- The invariant of object o **may depend on**
 - Encapsulated fields of o
 - Fields of objects o referenced through rep-references
- Interface objects have **full control** over their rep-objects

```
class ArrayList {  
    private /* rep */ int[ ] array;  
    private int next;  
  
    // invariant array != null    &&  
    //  0<=next<=array.length    &&  
    //  ∀i.0<=i<next: array[ i ] >= 0  
  
    public void add( int i )    { ... }  
    public void addElems  
        ( /* peer */ 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 **cannot** be **checked modularly**
 - Annotations are **just comments** that may be ignored by other classes
 - **Subclasses** can add new methods or override methods
- Traditionally, rep exposure can be prevented by
 - Access modifiers
 - Final
 - Inner Classes

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

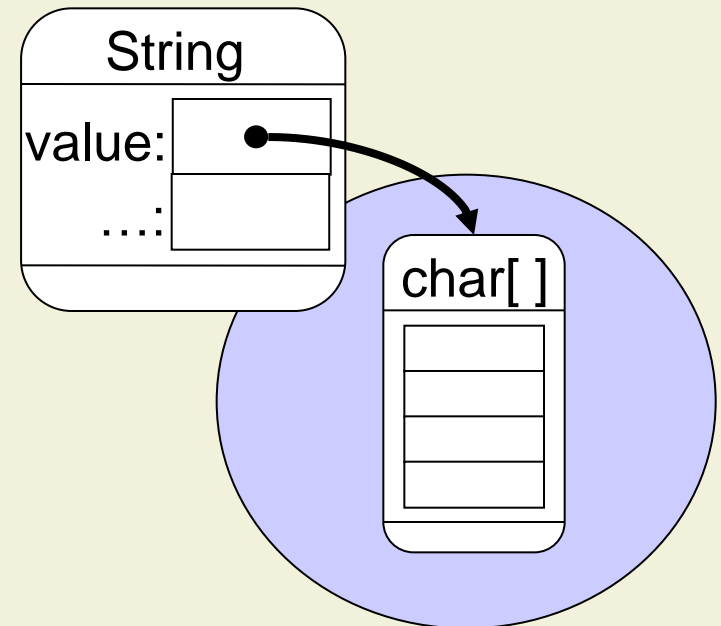
```
class MyList extends ArrayList {  
    public int[ ] leak( ) {  
        return array;  
    }  
}
```


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 Listliterator 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)



References

- James Noble, Jan Vitek, and John Potter: *Flexible Alias Protection*. ECOOP 1998