Konzepte objektorientierter Programmierung
– Lecture 6 –

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Chair of Programming Methodology

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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

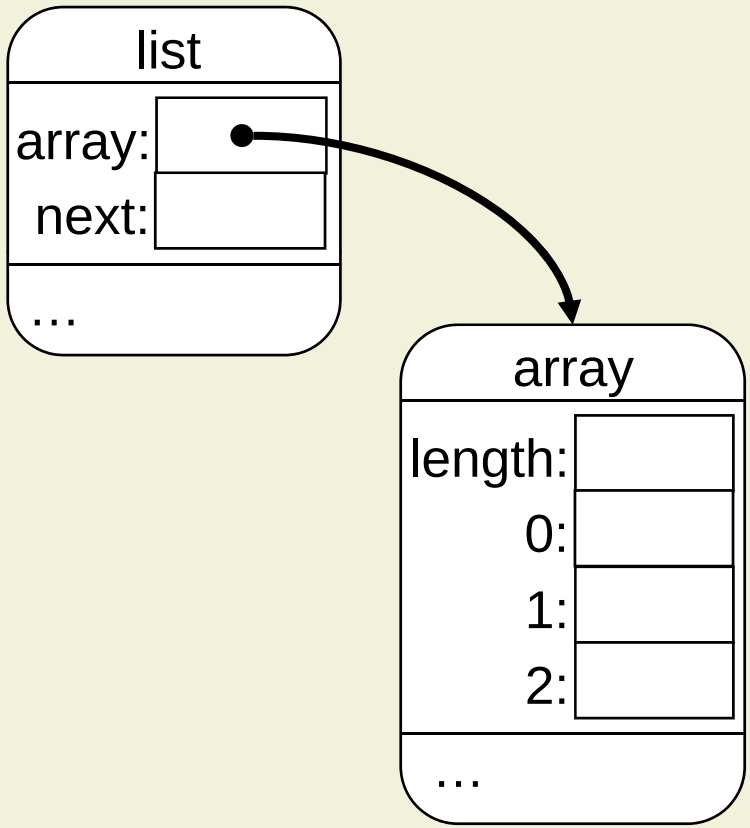
6. Object Structures and Aliasing

Object Structures

- Objects are the building blocks of object-oriented programming
- However, interesting abstractions are almost always provided by sets of cooperating objects

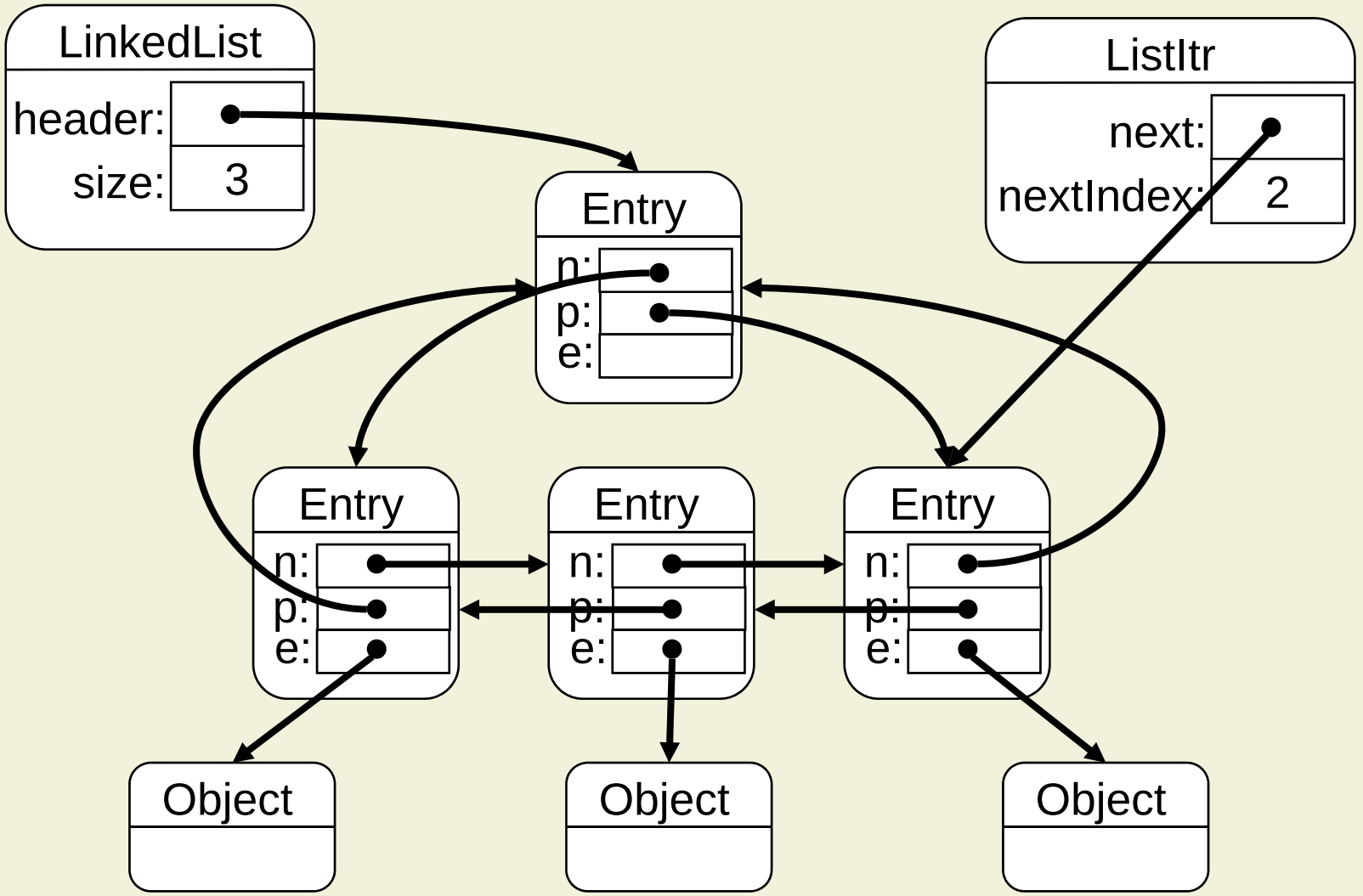
- Definition:
  An object structure is a set of objects that are connected via references

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

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 ∧ q = 1 }
  p := 25;
  { p = 25 ∧ q = 25 }
end;
  begin
    var x: int := 1;
    assign( x, x );
    { x = 25 }
  end
end.
```

Aliasing in Object-Oriented Programming

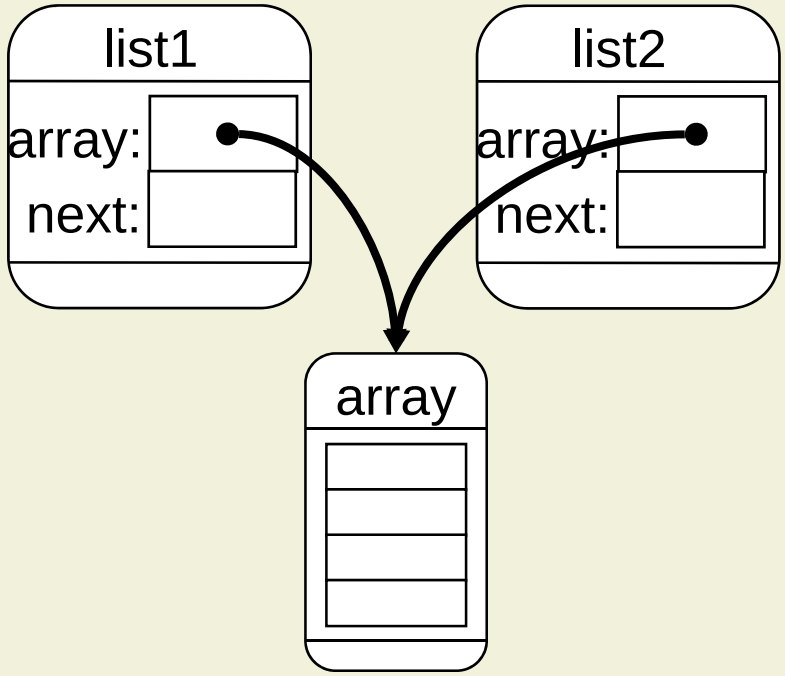
- Definition:
  An object X is aliased if two or more variables hold references to X.

- 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

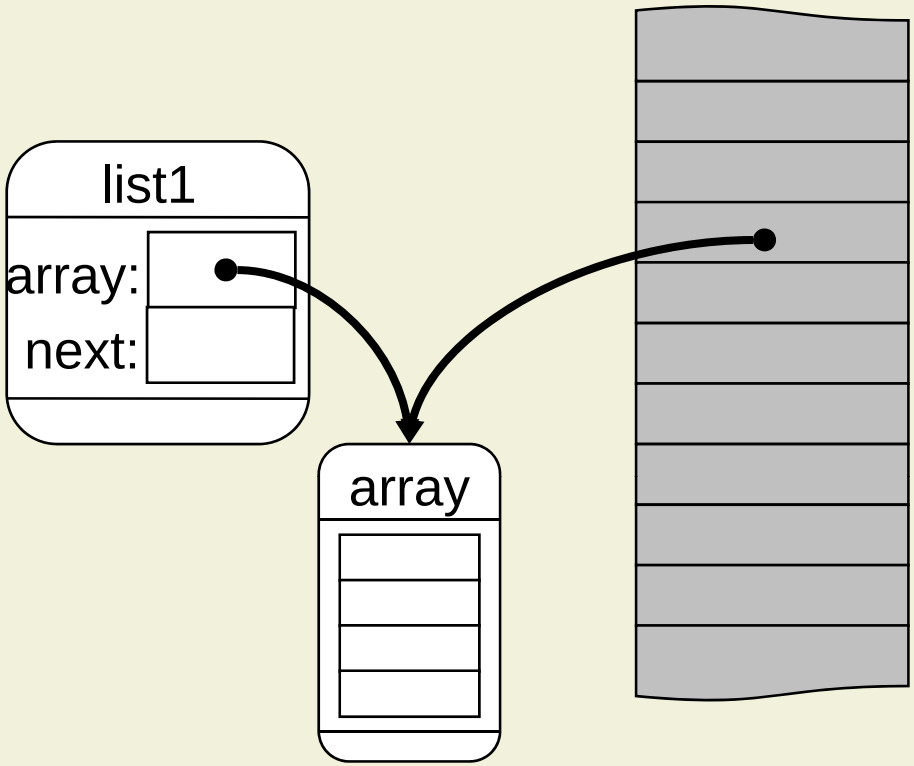



```
list1.array[ 0 ] = 1;
list2.array[ 0 ] = -1;
System.out.println( list1.array[ 0 ] );
```

Dynamic Aliasing

- Definition:
  An alias is dynamic if it is not static.

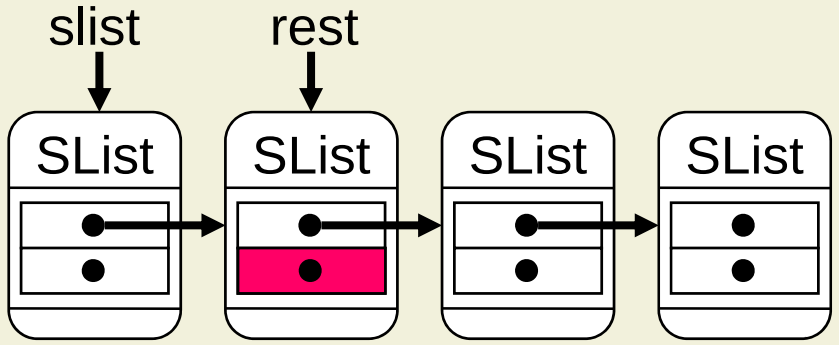
- Dynamic aliasing involves stack-allocated variables




```
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

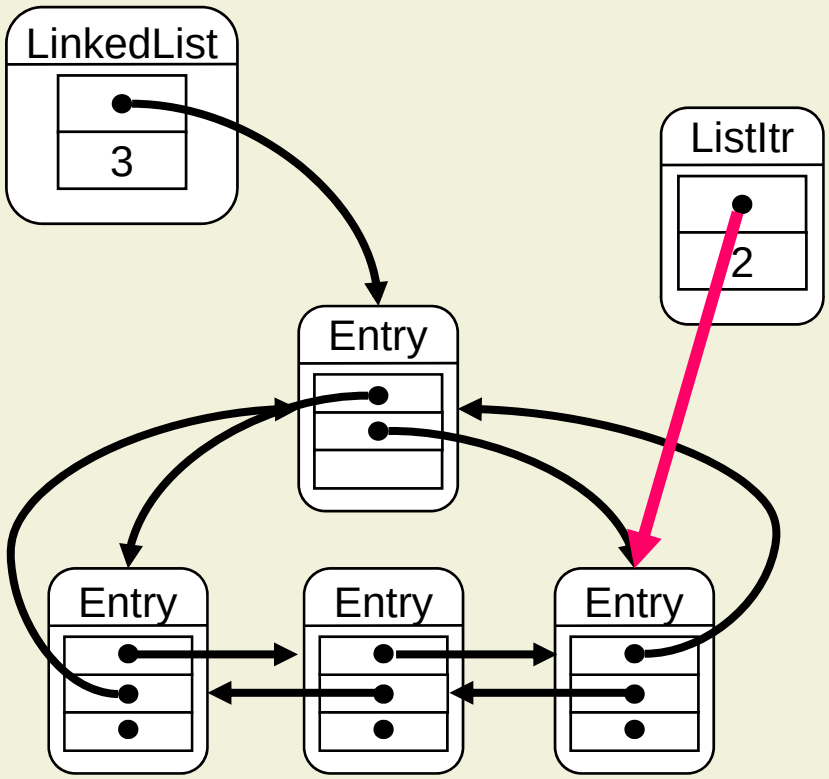



```
class SList {
  SList next;
  Object elem;
  void rest( ) { return next; }
  void set( Object e ) { elem = e; }
}
```

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

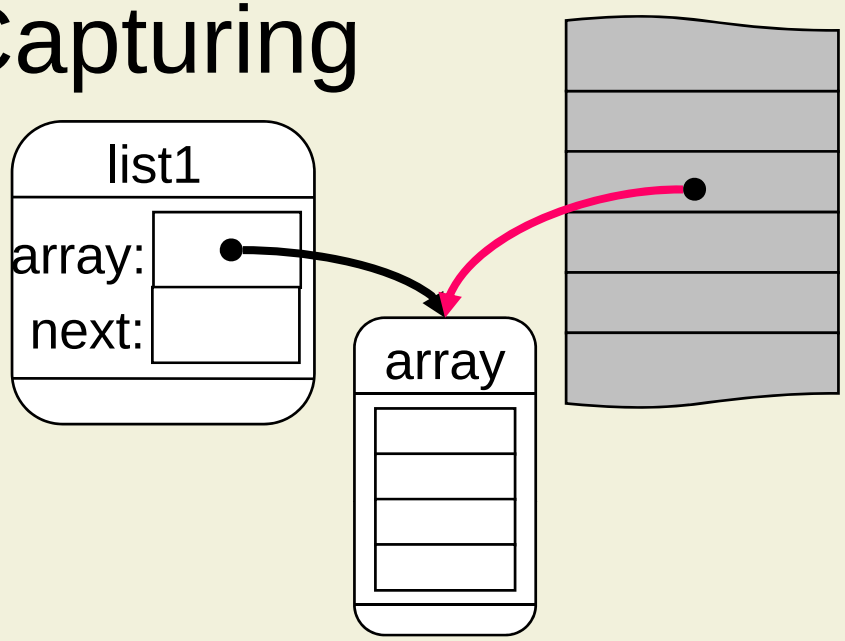
Intended Aliasing: Sharing

- 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

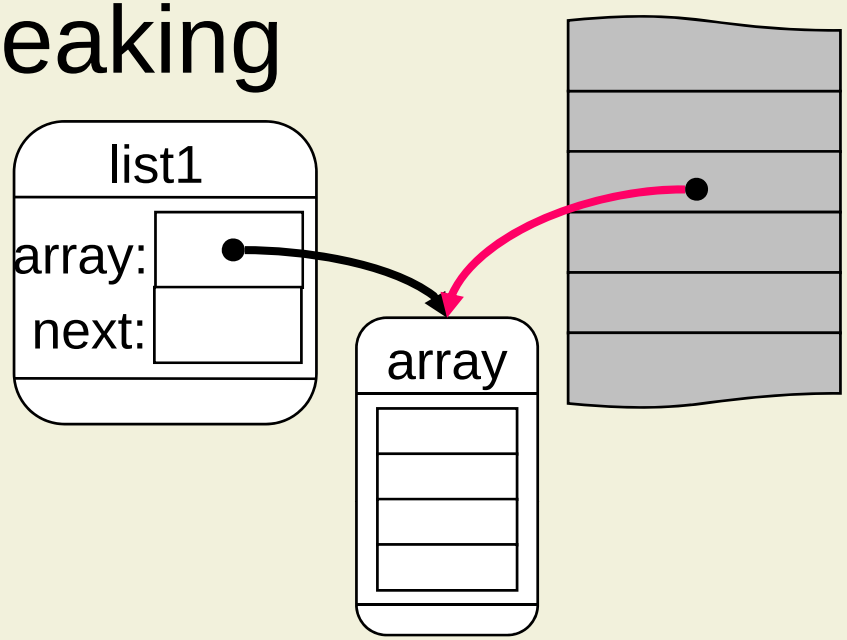
- Capturing occurs when objects are **passed to a data structure and then stored** by the data structure
- Capturing often occurs **in constructors** (e.g., streams in Java)
- Problem: Alias can be used to **by-pass interface** of data structure




```
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

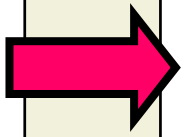
Observation

- 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 ∀i. 0<=i<ia.length:
  //                isElem( old( ia[ i ] ) )
  public void addElems( int[ ] ia )
    { array = ia; next = ia.length; }

  …
}
```

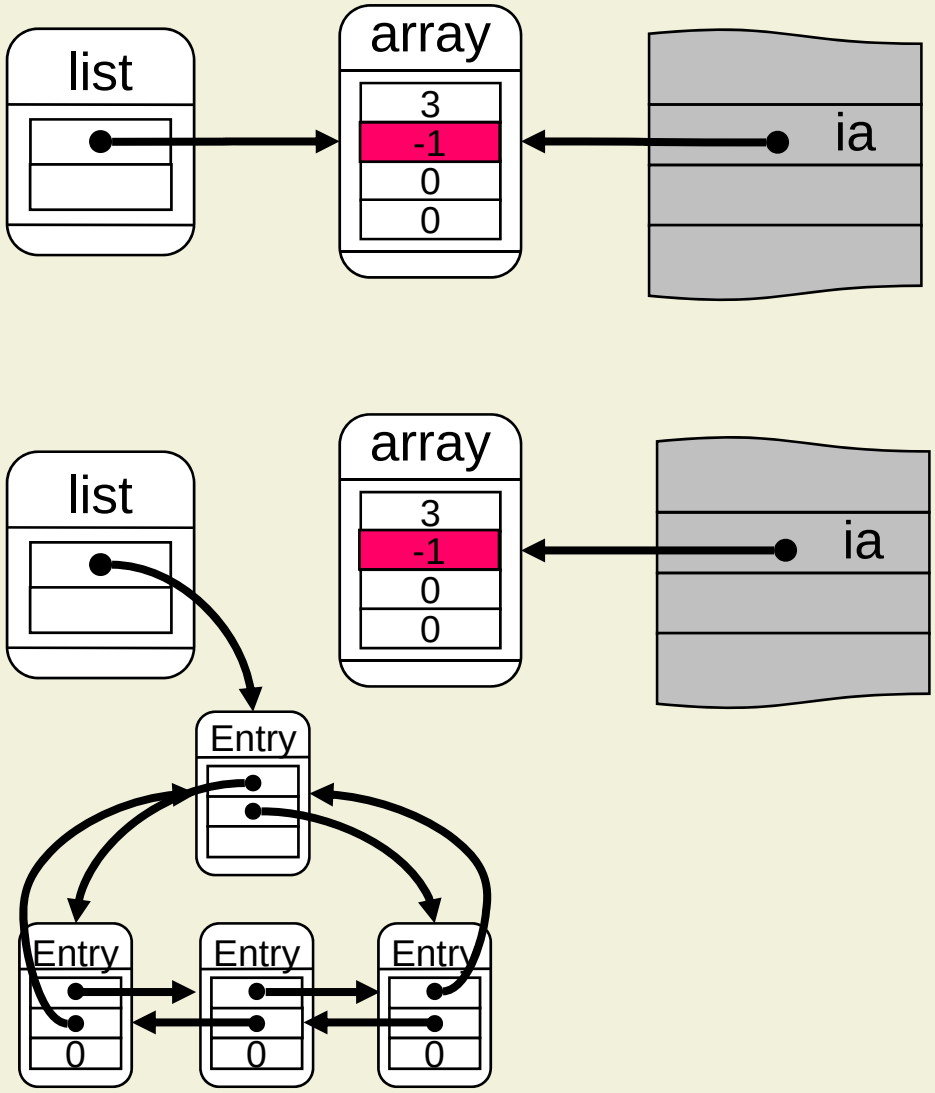


```
class ArrayList {
  private Entry header;

  // requires ia != null
  // ensures ∀i. 0<=i<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

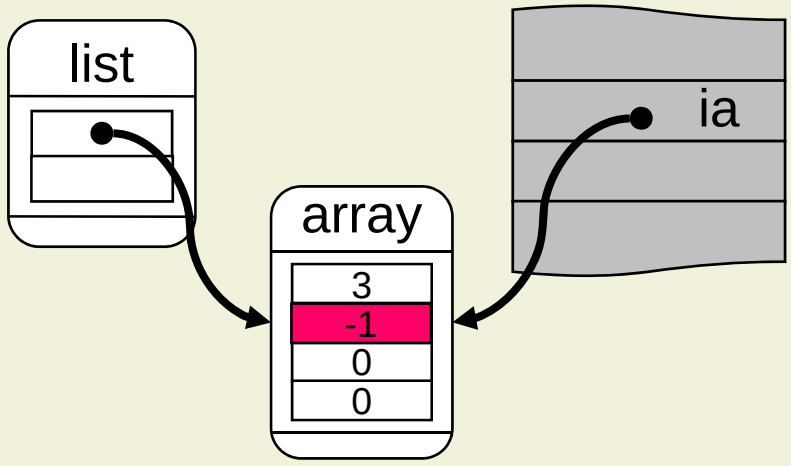
- Consistency of object structures depends on **fields of several objects**
- **Invariants** are usually specified as part of the contract **of those objects** that represent the **interface of the object structure**

```
class ArrayList {
  private int[ ] array;
  private int next;

  // invariant array != null        &&
  //    0<=next<=array.length   &&
  //    ∀i.0<=i<next: array[ i ] >= 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
}
```

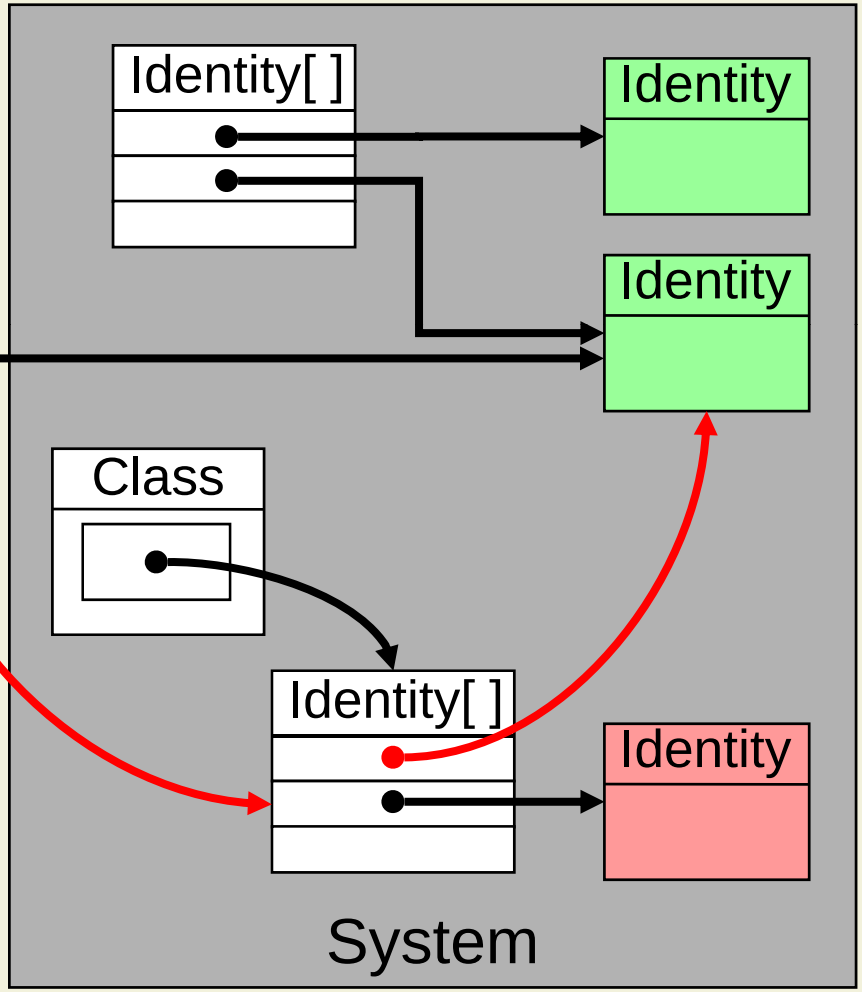
- **Aliases can be used to violate invariant**
- Making all attributes private is not sufficient to encapsulate internal state



Security Breach in Java 1.1.1

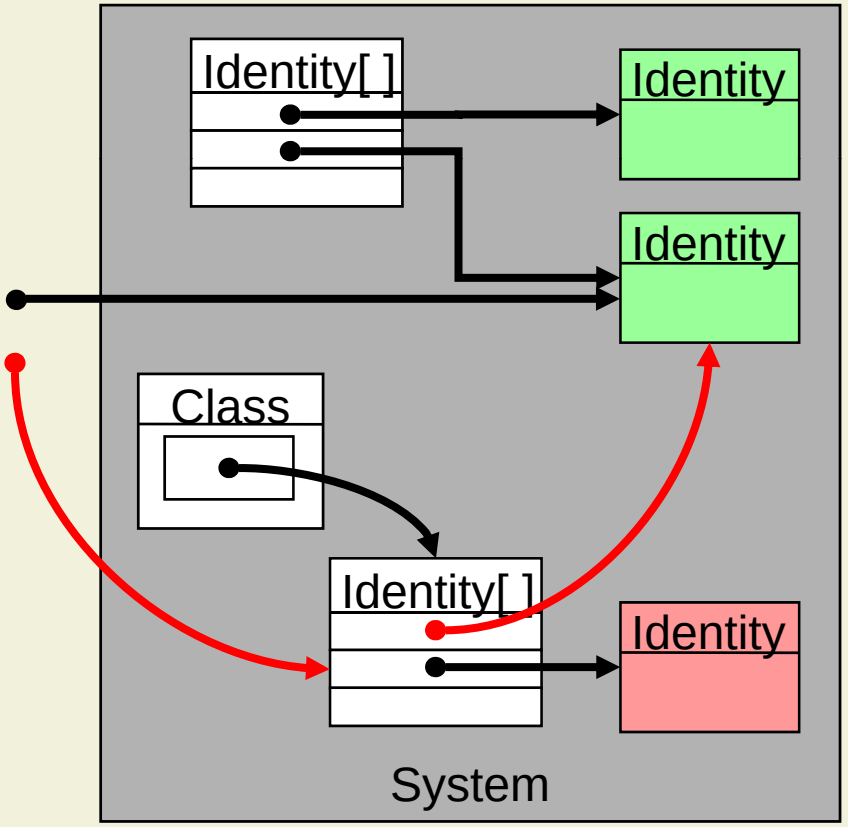
```
class Malicious  {

 void bad( ) {
  Identity[ ] s;
  Identity trusted = java.Security…;
  s = Malicious.class.getSigners( );
  s[ 0 ] = trusted;
  /* abuse privilege */
 }

}
```

Identity[ ] getSigners( )
{ return signers; }



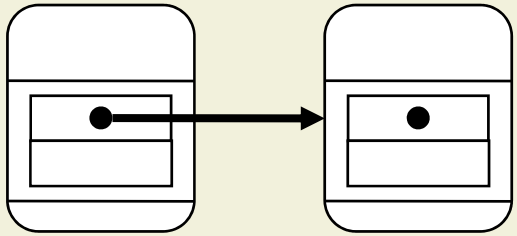
Problem Analysis

- 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
  - Runtime checks: too expensive

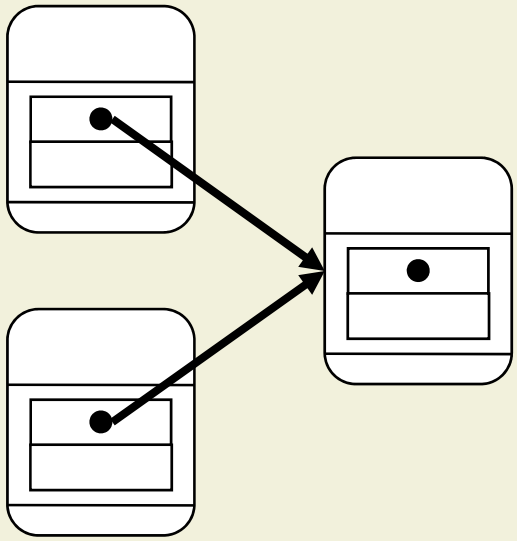


Other Problems with Aliasing

- 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



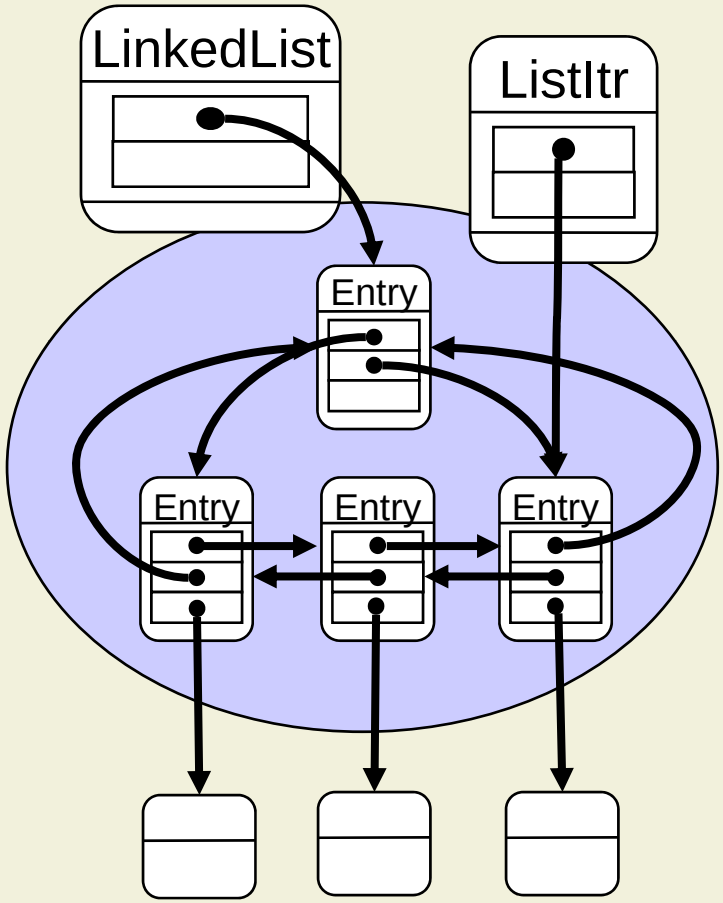
6. Object Structures and Aliasing

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

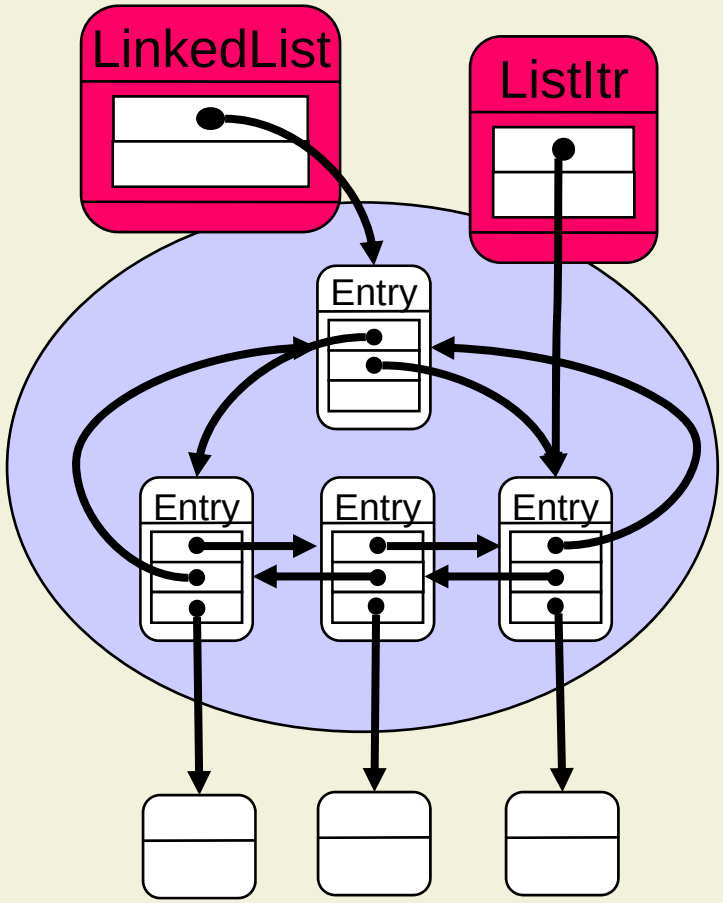
Roles in Object Structures

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



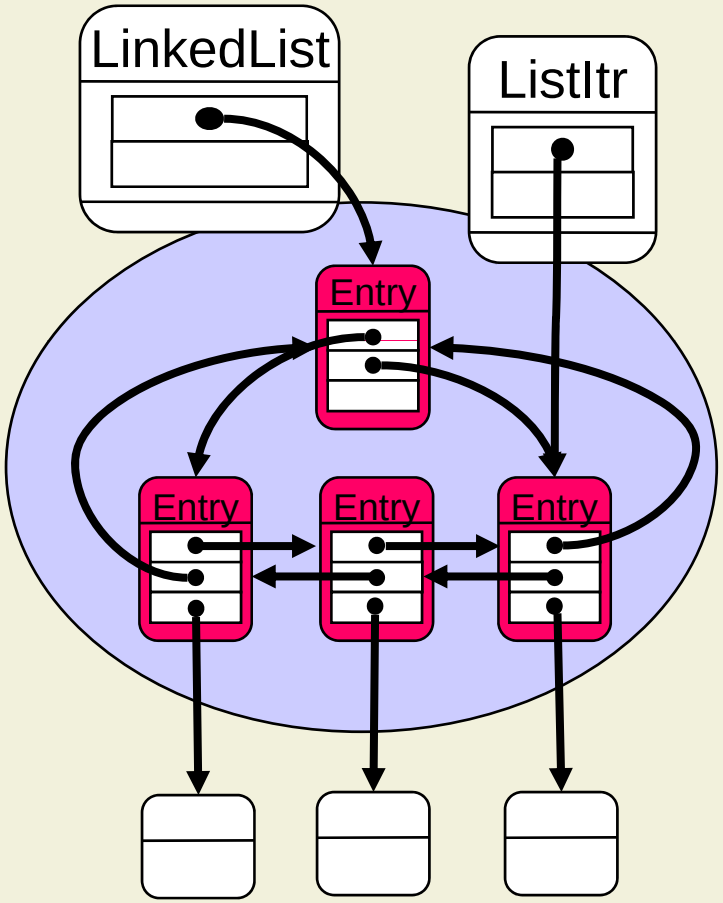
Interface Objects (peer Mode)

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



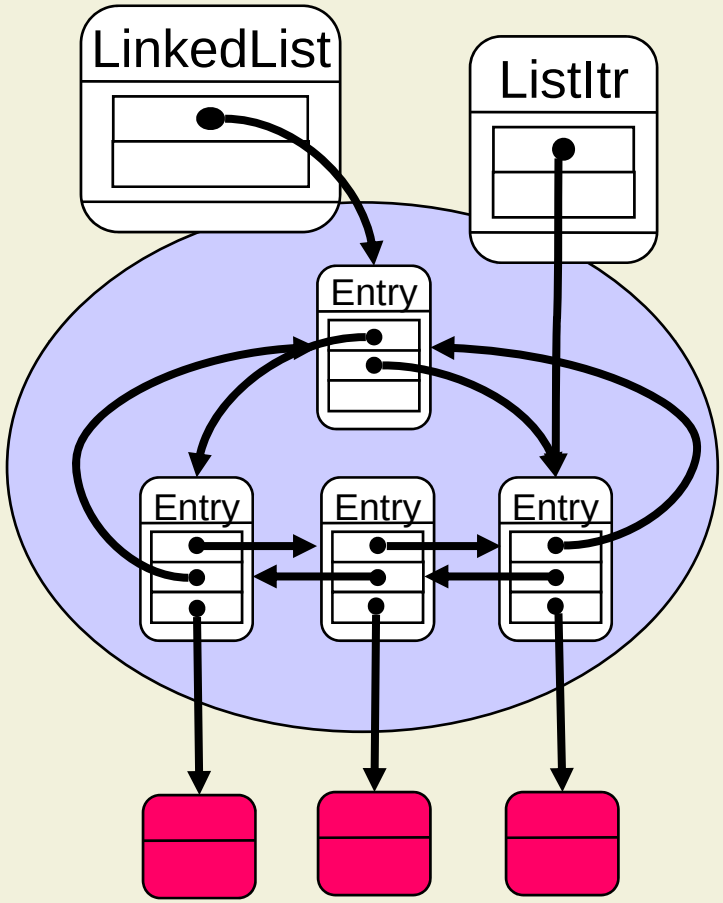
Representations (rep Mode)

- 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



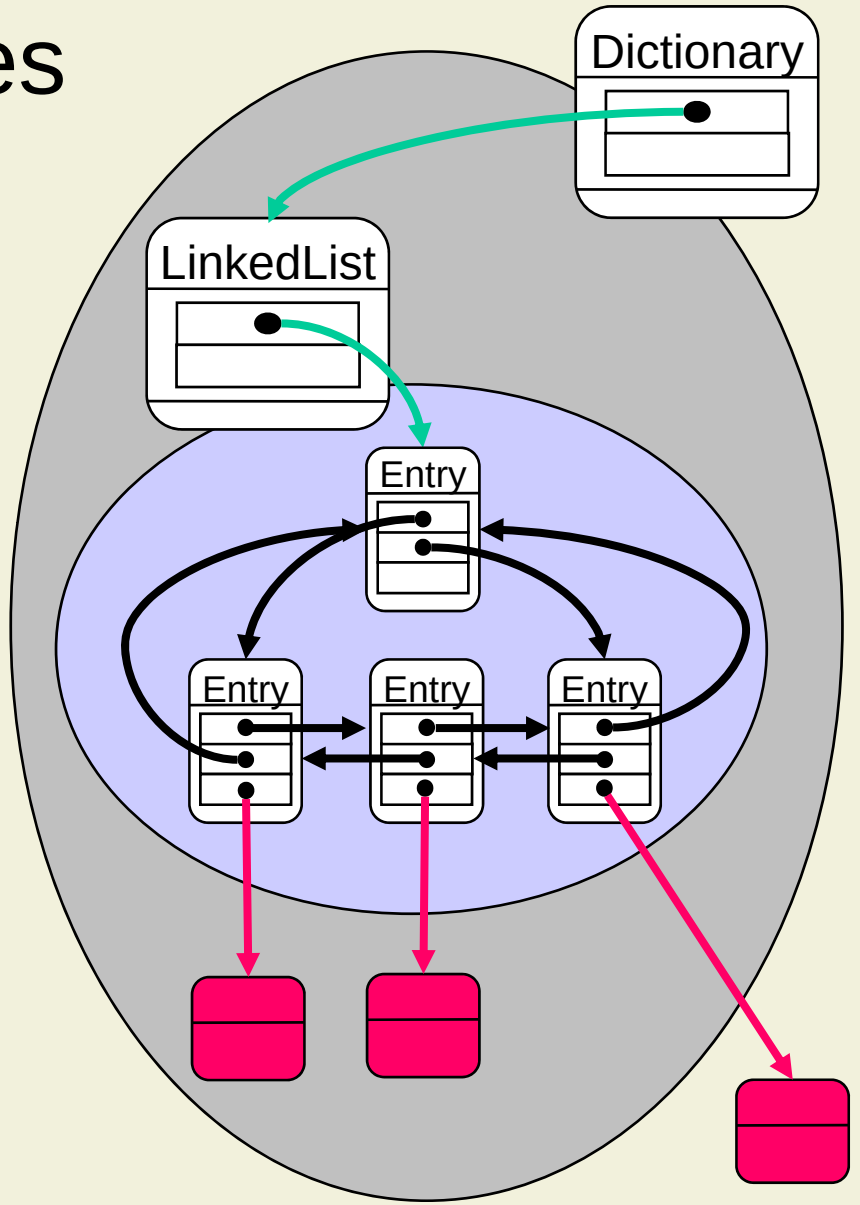
Arguments (arg Mode)

- 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 **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
- **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 ) { … }
}
```

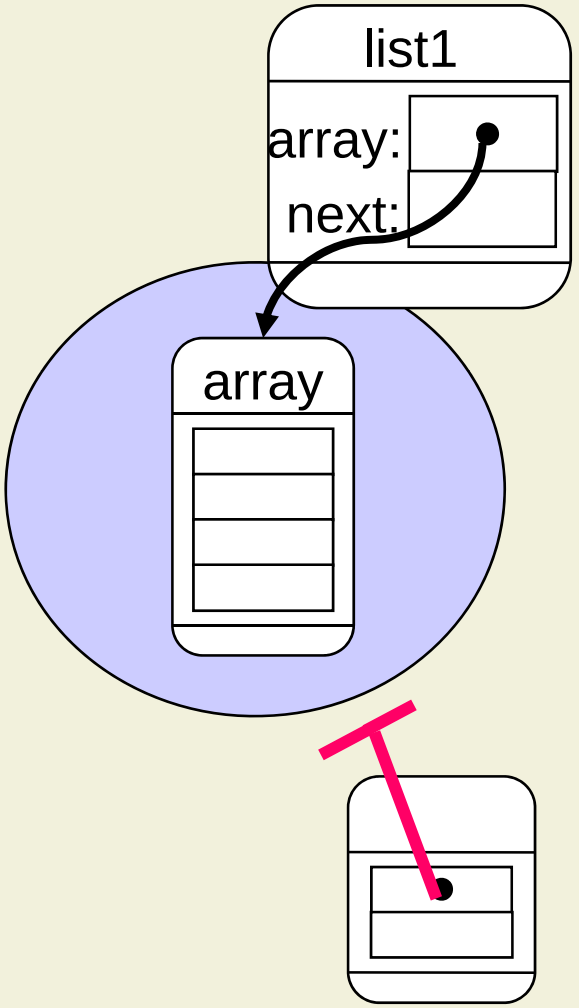
Example 2: ArrayList with Alias Modes

- Array is **internal representation** of the list
- Method addElems **confuses alias modes**
- 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;
  }
  …
}
```

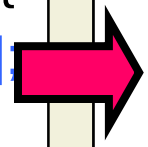
No Representation Exposure

- rep-objects can 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
                    ( /* 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

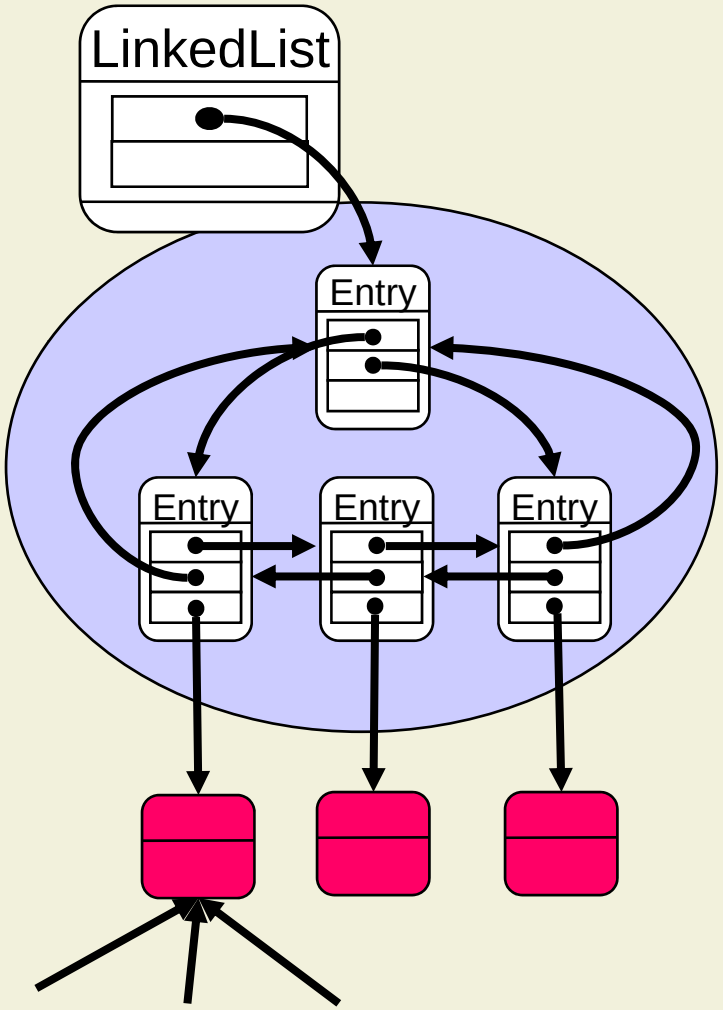
- The invariant of object X **may depend on**
  - Encapsulated fields of X
  - Fields of objects X references through rep-references
- Interface objects have **full control** over their rep-objects

```
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 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
- ListItr is a **private inner class** of LinkedList
  - Interface ListIterator provides controlled access to ListItr-objects
  - ListItr-objects are passed out, but in a controlled fashion
  - Subclasses cannot manipulate or leak ListItr-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)