• Values are numbers, booleans, and pointers. Values never change.

$3 \ 'a' \ \text{true}$

• Simple containers contain values:

$x: 3 \ L: \emptyset \ p: \emptyset$

Examples: variables, fields, individual array elements, parameters.

• Structured containers contain (0 or more) other containers:

<table>
<thead>
<tr>
<th>Class Object</th>
<th>Array Object</th>
<th>Empty Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>h: 3</td>
<td>0 1 2</td>
<td>0 42 17 9</td>
</tr>
<tr>
<td>t: 7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Alternative Notation:

| h: 3         | 0 42         |
| t: 17        | 2 9          |

• Containers may be named or anonymous.

• In Java, all simple containers are named, all structured containers are anonymous, and pointers point only to structured containers. (Therefore, structured containers contain only simple containers.)

named simple containers (fields) within structured containers

$p: 3 \ h: t \ 7$

simple container (local variable) structured containers (anonymous)

• In Java, assignment copies values into simple containers.

• Exactly like Scheme!
Defining New Types of Object

- Class declarations introduce new types of objects.
- Example: list of integers:

```java
class IntList {
    // Constructor function
    // (used to initialize new object)
    // ** List cell containing (HEAD, TAIL). */
    public IntList(int head, IntList tail) {
        this.head = head; this.tail = tail;
    }

    // Names of simple containers (fields)
    public int head;
    public IntList tail;
}
```

Primitive Operations

```java
IntList Q, L;
L = new IntList(3, null);
Q = L;

Q = new IntList(42, null);
L.tail = Q;

L.tail.head += 1;
// Now Q.head == 43
// and L.tail.head == 43
```

Side Excursion: Another Way to View Pointers

- Some folks find the idea of "copying an arrow" somewhat odd.
- Alternative view: think of a pointer as a label, like a street address.
- Each object has a permanent label on it, like the address plaque on a house.
- Then a variable containing a pointer is like a scrap of paper with a street address written on it.
- One view:

```
last:  
result: 5 45
```

- Alternative view:

```
last: #7
result: #7 5 45
```

Another Way to View Pointers (II)

- Assigning a pointer to a variable looks just like assigning an integer to a variable.
- So, after executing "last = last.tail;" we have

```
last:  
result: 5 45
```

- Alternative view:

```
last: #3
result: #7 5 #3 45
```

- Under alternative view, you might be less inclined to think that assignment would change object #7 itself, rather than just "last".
- BEWARE! Internally, pointers really are just numbers, but Java treats them as more than that: they have types, and you can't just change integers into pointers.
Destructive vs. Non-destructive

**Problem:** Given a (pointer to a) list of integers, \( L \), and an integer increment \( n \), return a list created by incrementing all elements of the list by \( n \).

```java
/** List of all items in P incremented by n. Does not modify existing IntLists. */
static IntList incrList(IntList P, int n) {
    return /*( P, with each element incremented by n )*/
}
```

We say `incrList` is non-destructive, because it leaves the input objects unchanged, as shown on the left. A destructive method may modify the input objects, so that the original data is no longer available, as shown on the right:

<table>
<thead>
<tr>
<th>L</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>43</td>
</tr>
<tr>
<td>5</td>
<td>45</td>
</tr>
</tbody>
</table>

After \( Q = \text{incrList}(L, 2) \):

<table>
<thead>
<tr>
<th>L</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>45</td>
</tr>
</tbody>
</table>

After \( Q = \text{dincrList}(L, 2) \) (destructive):

<table>
<thead>
<tr>
<th>L</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>45</td>
</tr>
</tbody>
</table>

An Iterative Version

An iterative `incrList` is tricky, because it is not tail recursive. Easier to build things first-to-last, unlike recursive version:

```java
static IntList incrList(IntList P, int n) {
    if (P == null)
        return null;
    IntList result, last;result = last = new IntList(P.head+n, null);
    while (P.tail != null) {
        P = P.tail;last.tail = new IntList(P.head+n, null);
        last = last.tail;
    }
    return result;
}
```

Nondestructive IncrList: Recursive

```java
/** List of all items in P incremented by n. */
static IntList incrList(IntList P, int n) {
    if (P == null)
        return null;
    else return new IntList(P.head+n, incrList(P.tail, n));
}
```

- Why does `incrList` have to return its result, rather than just setting \( P \)?
- In the call `incrList(P, 2)`, where \( P \) contains 3 and 43, which `IntList` object gets created first?