CSE 341:
Programming Languages

Spring 2007

Lecture 6 — More on Tail Recursion & Accumulators

More on Bindings & Immutability

What does this do?

```
val x = 1;
val x = 2;
```

First binding to x is *hidden* by 2nd, but not overwritten, changed or erased.

You could still see it if you wanted, e.g.:

```
val x = 1;
fun oldx() = x;
val x = 2;
oldx();
```

Bindings are *immutable*. (Deleting inaccessible ones, e.g. the 1st x in the 1st example, is a performance issue, not a correctness issue.)

More...

A more subtle example:

```
val x = [3];
val y = 2 :: x;
val z = 1 :: y;
(* What's z? *)
val x = [42];
(* What's z now? *)
```

Or this:

```
val x = [1,2,3,4,...,999];
val y = 42 :: tl(x);
```

Did that allocate 1000 mem cells, or 2000?

Implementing lists

Want: null, hd, tl, ::

How: Arrays? Pointers? Other?

Costs: memory, time, code

Using Lists (Java)

Consider a linked list of integers, implemented in Java.

- What data structure (if you build it from scratch)?

How would you implement functions for:

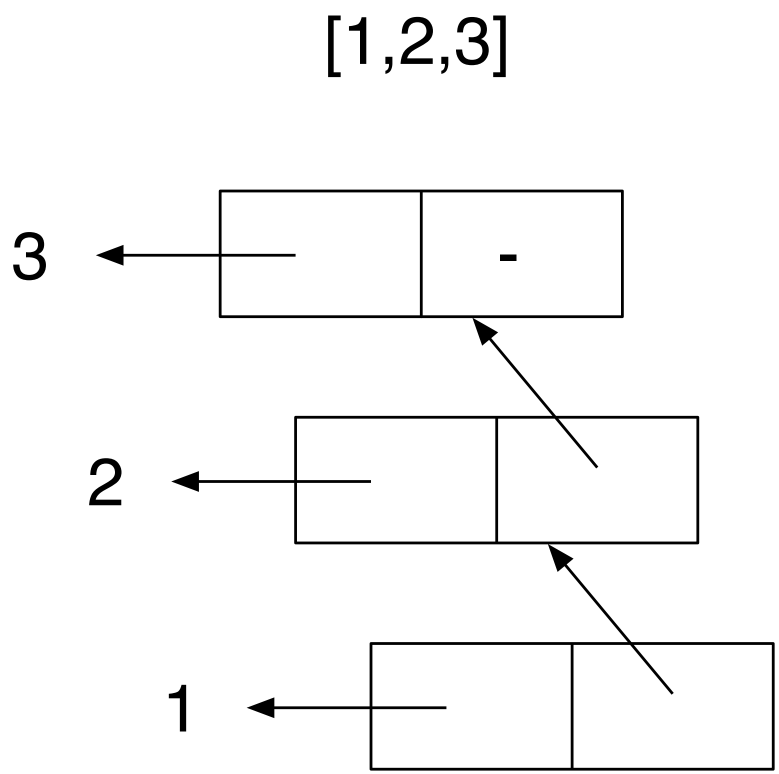
- Test if a list is empty? (How fast?)
- Extract the hd of a lst? (How fast?)
- Extract the tl of a lst? (How fast?)
- Implement ::? (How fast? Semantics?)
- Find the *last element* of a list? (How fast? How much memory?)
- Find the *length* of a list? (How fast? How much memory?)

Implementing lists

Want: null, hd, tl, ::

How: Arrays? Pointers? Other?

Costs: memory, time, code



Using Lists (ML)

Consider

```
fun len []       = 0
|   len (x::xs) = 1 + len xs;

val theLength = len [1,2,3,4,5];
```

Q: How do you implement function call?

A: “Activation Records” and a “Call Stack”

Activation Records

What:

- Info about each activation of each procedure
- Dynamically created on call, destroyed (usually) on return
- Values of local variables
- Where was I called from/Where do I return to?
- (Housekeeping info: save state, registers, temp variables, partially evaluated exprs, etc. across function calls)

Activation Records (cont.)

Why:

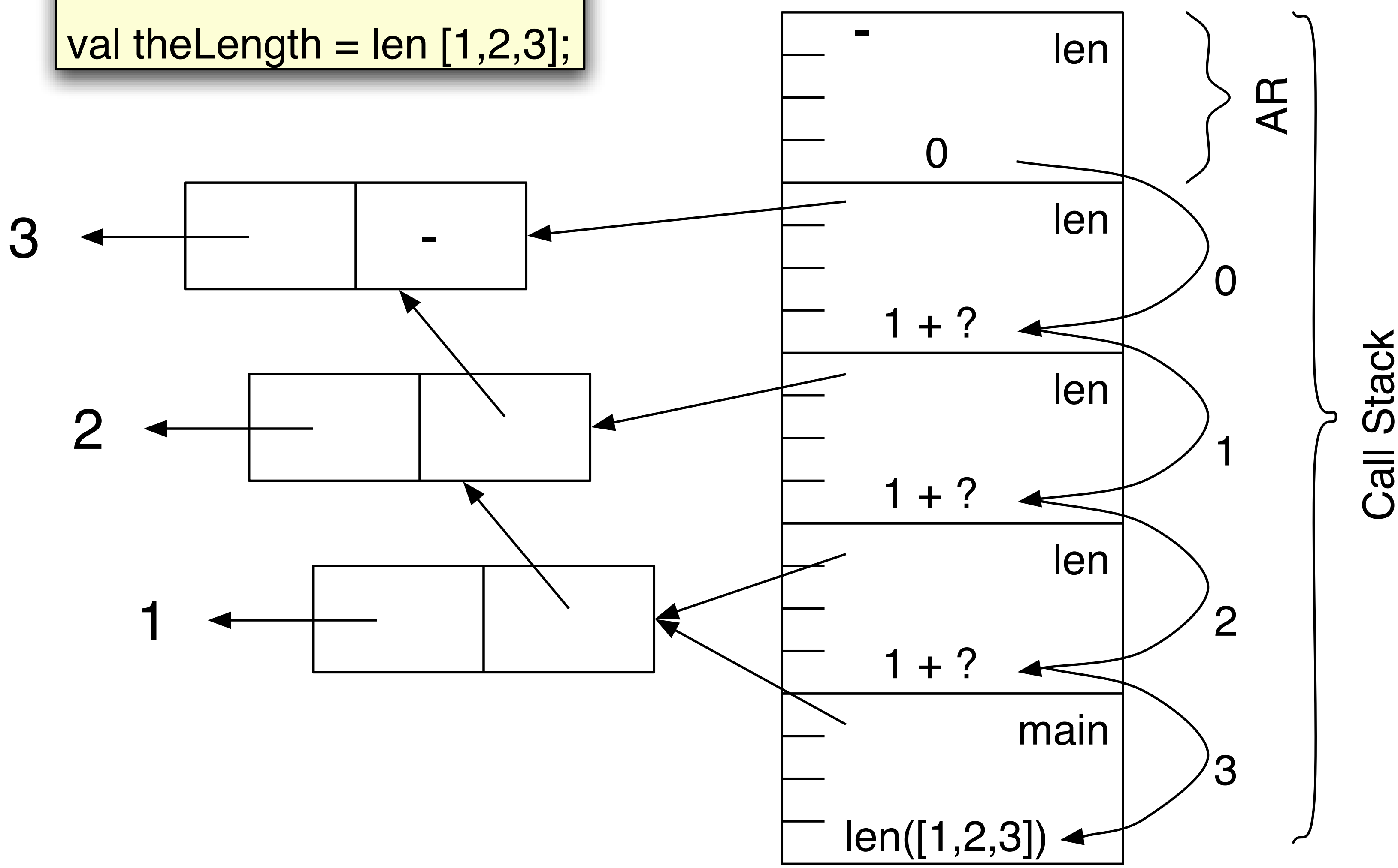
- Esp. with recursion, there may be *many* simultaneous activations of a given procedure, each with *different* values for local vars, *different* return addresses, etc.
- The AR is a simple implementation trick to keep it all straight

Downsides:

- The main source of “function call overhead”, both space & time.

```
fun len []       = 0
  |   len (x::xs) = 1 + len xs;

val theLength = len [1,2,3];
```



Implementing calls

Consider

```
fun len []       = 0
|   len (x::xs) = 1 + len xs;

val theLength = len [1,2,3,4,5];
```

Compare:

```
fun last  [x]   = x
|   last(x::xs) = last xs;

val theLast = last [1,2,3,4,5];
```

Tail calls

A call `f(x)` is called a *tail call* if it appears at the "tail end" of g, and the value of `f(x)` is returned as the value of g without change.

Why care? Because they can be optimized! The usual call mechanism:

- Suspend activation of g
- Build AR for `f`, then run `f`
- Destroy AR for `f`, passing value of `f(x)` back to g
- Destroy AR for g, passing value of `g(-) = f(x)` back to g's caller

Can be streamlined to:

- *Reuse* g's AR for `f`
- Don't "call" `f`, just jump to start of its code
- When `f` returns, return its value directly g's caller

A key special case: direct tail-recursion turns into a loop!

Accumulators: can turn non-tail calls into tail calls

```
fun len []       = 0
|   len (x::xs) = 1 + len xs;
```

Becomes:

```
fun len2 lst =
    let lenaux([],    acc) = acc
    |   lenaux(x::xs,acc) = lenaux(xs, acc+1);
in
    lenaux(lst,0)
end;
```

The standard trick: Do ops on way in, not way out. Instead of operating on recursive *result*, move operation into the recursive *call*.

Tail calls: definition

If the result of `f(x)` is the result of the enclosing function body, then `f(x)` is a *tail call*.

More precisely, a tail call is a call in *tail position*:

- In `fun f(x) = e`, `e` is in tail position.
- If `if e1 then e2 else e3` is in tail position, then `e2` and `e3` are in tail position (not `e1`). (Similar for case).
- If `let b1 ... bn in e end` is in tail position, then `e` is in tail position (not any binding expressions).
- Function arguments are not in tail position.
- ...