CSCI 334: Principles of Programming Languages

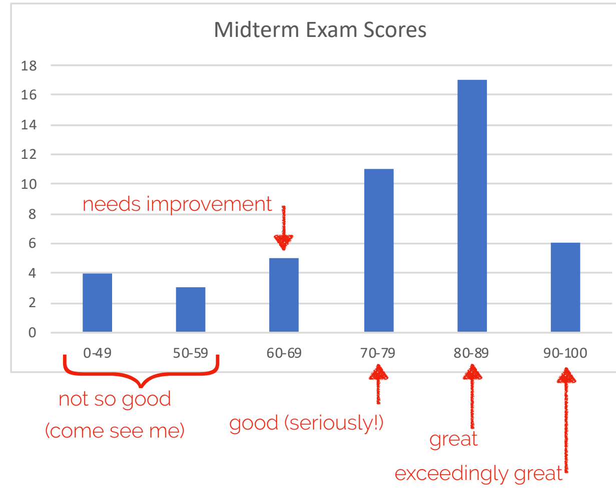
Lecture 13: Exceptions

Instructor: Dan Barowy

Williams

Midterm Exam

Note: This was a challenging exam.



Midterm Exam

Midterm exam grades are not necessarily a reflection of your final grade; homework is more important!

If you are worried, come see me!

Announcements

HW5 solutions

Announcements

HW6 out today, due next Wednesday, April 11.

Announcements

Typo on HW6: if you want a new partner, notify me (via email) by Wed, April 4 with your partner's name

Announcements

Grades for HW3 programming portion, HW4, HW5 will be back soon.

Refresher: First-class functions

- A language with *first-class functions* treats functions no differently than any other value:
- You can assign functions to variables:

```
val f = fn x => x + 1
```

- You can pass functions as arguments:

```
fun g h = h 3
g f
```

- You can return functions:

```
fun k x = fn () => x + 3
```

- First-class function support complicates *implementation* of lexical scope.

First Class Functions

- To implement support for first class functions, we need two additional data structures:
  - Access links
  - Closures
- The implementation difficulty of maintaining lexical scope for first class function is called the *funarg problem*.

Access link

- An *access link* is a pointer from the current activation record to the activation record of the closest lexical scope.
- In other words, the access link in the activation frame for a function f points to where f was defined.
- Why do we need access links? So that the language can determine the values of free variables in a function.

Closure

- A *closure* is a tuple that represents a function value. One tuple value points to a function's code and the other value points to the activation record of the point of definition of the function (i.e., closest lexical scope).

Example

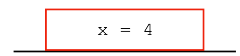
```
val x = 4
fun f y = x * y
fun g h = let val x = 7 in (h 3) + x
g f
```

Desugared Example

```
let val x = 4 in
  let f = fn y => x * 4 in
    let g =
      fn h => let val x = 7 in (h 3) + x in
        g f
    end
  end
end
```

Blocks Define Activation Records

```
val x = 4
fun f y = x * y
fun g h = let val x = 7 in (h 3) + x
g f
```



call stack

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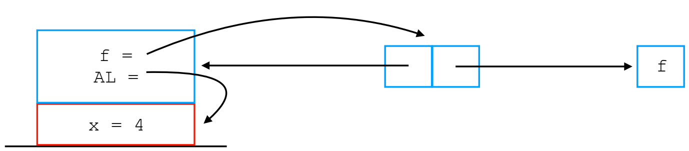

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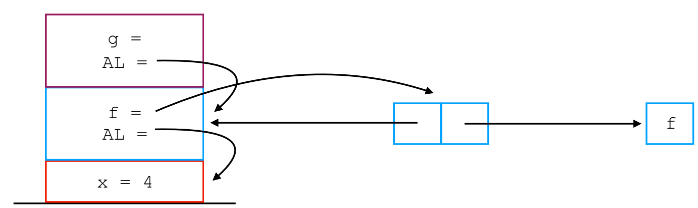

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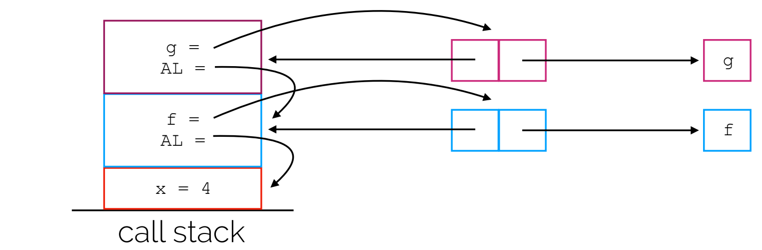

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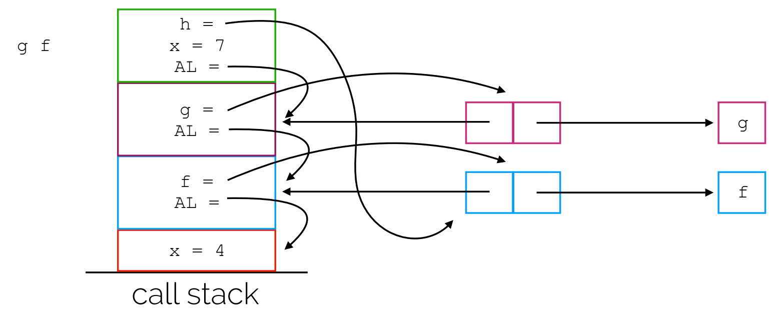

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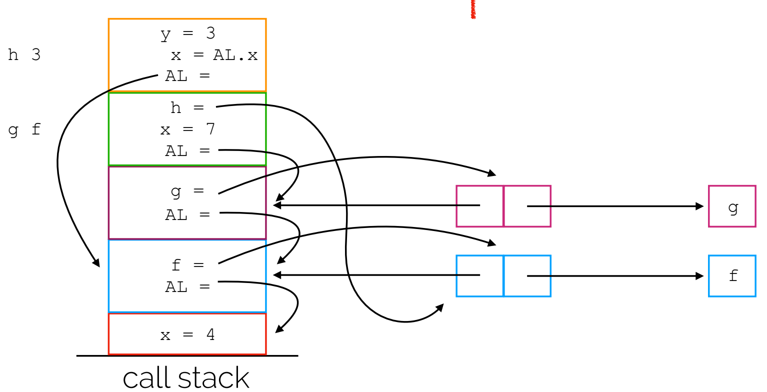

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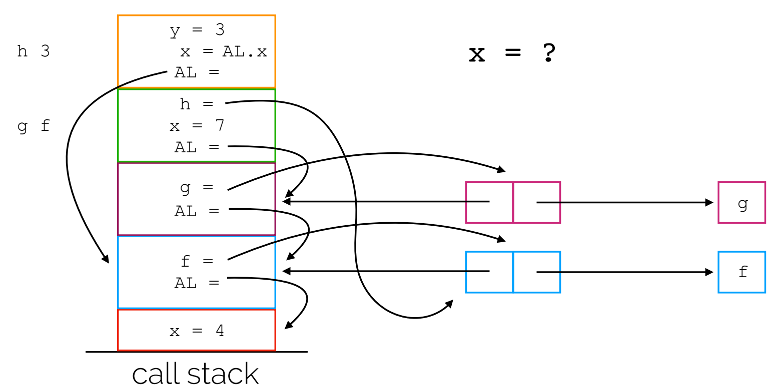

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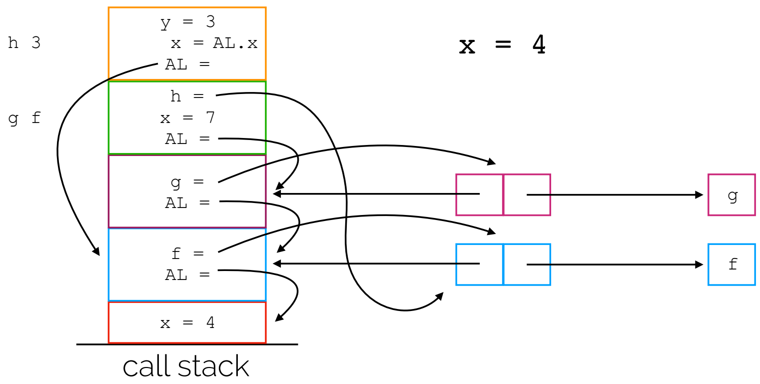


Activation Records in Functional Langs

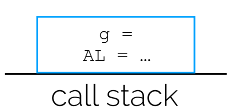
```
let val g =
  let
    val x = 1
    fun f () = x + 1
  in
    f
  end
in
  g()
end
```

How is this function evaluated? Do we have a problem when we call `g()`?

Upward funargs

```
let val g =
  let val x = 1
      fun f () = x + 1
  in f end
in g() end
```

1. Push `let` block for `g` onto call stack. We don't yet know `g`'s value.



Upward funargs

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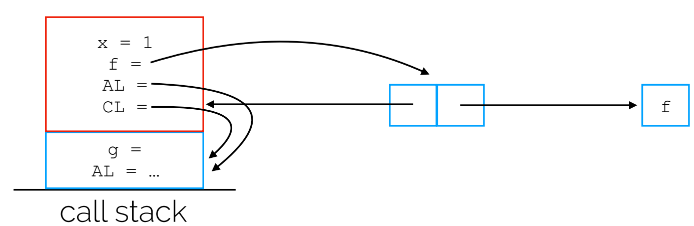
1. Push `let` block for `g` onto call stack. We don't yet know `g`'s value.
2. Push let block for x and f.



Upward funargs

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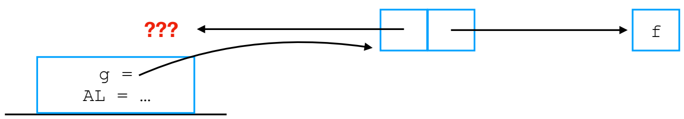
2. Push let block for x and f.
3. Return `f`. We have a problem!



call stack

Upward funargs

```
let val g =
 let val x = 1
     fun f () = x + 1
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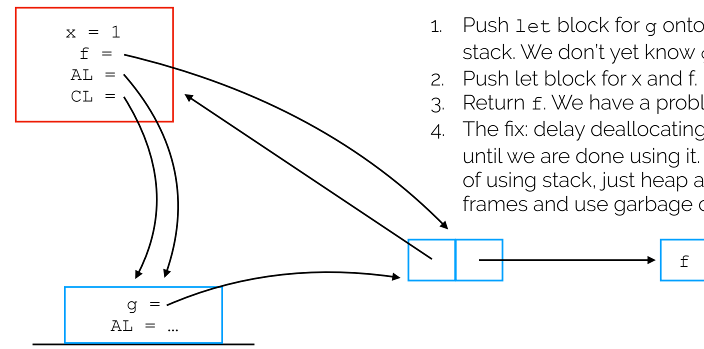
 in g() end
```

1. Push `let` block for `g` onto call stack. We don't yet know `g`'s value.
2. Push let block for x and f.
3. Return `f`. We have a problem!
4. The fix: delay deallocating record until we are done using it. Instead of using stack, just heap allocate frames and use garbage collector!



heap-allocated records

Upward funargs

```
let val g =
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1. Push `let` block for `g` onto call stack. We don't yet know `g`'s value.
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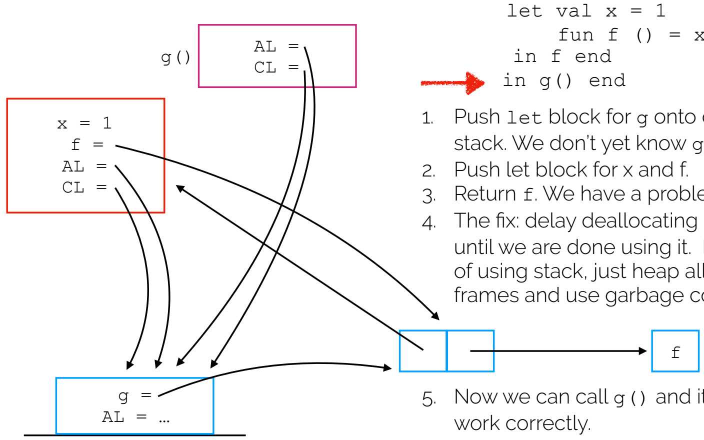


5. Now we can call `g()` and it will work correctly.

heap-allocated records

Safety

- SML is a "safe" language.
- What does that mean?
- It means that execution behavior is determined solely by the program, not:

  a. the implementation of the language, or

  b. the design of the hardware

Safety

- How is safety achieved?
- Type checking rules out manifestly incorrect constructs.

```
"hello" - "world"
```

- However, type checking cannot rule out all errors.

```
fun sum (xs: int list) =
  foldl (fn (x,acc) => x + acc) 0 xs
fun mean (xs: int list) =
  (sum xs) div (List.length xs)
```

- For these kinds of errors, we use "exceptions."

Exceptions

- In ML (and in Java), exceptions have three parts:

a. Exception declaration:

```
exception MyException of string
```

b. Exception use:

```
raise MyException "Don't send me back to school!"
```

c. Exception handling:

```
handle MyException msg => msg ^ "? Fine. Here's
your tuition bill. Pay it yourself."
```

Exceptions

- More generally…

a. Exception declaration:

```
exception <exception name> [of <type>]
```

b. Exception use:

```
raise <exception name> [expr]
```

c.Exception handling:

```
handle <pattern>
```

A real example

```
fun sum (xs: int list) =
  foldl (fn (x,acc) => x + acc) 0 xs
fun mean (xs: int list) =
  (sum xs) div (List.length xs)
```

```
- mean [] handle Div => 0;
val it = 0 : int
```

A real example

```
exception ZeroLength
fun sum (xs: int list) =
  foldl (fn (x,acc) => x + acc) 0 xs
fun mean (xs: int list) =
  if List.length xs = 0 then
    raise ZeroLength
  else (sum xs) div (List.length xs)
```

```
- mean [] handle
    Div => 0
  | ZeroLength => 1 (* … for fun *)
  val it = 1 : int
```

Exceptions aren't just for errors

- Exceptions are actually a special form of `goto`.
- You can use them to return data to any calling function on the stack.

Exceptions for efficiency

```
datatype tree =
  Leaf of int
| Node of tree * tree

fun prod (Leaf x) = x
 |  prod (Node(x,y)) = prod x * prod y

val t = Node(Node(Leaf 1, Leaf 2), Leaf 3)
```

```
- prod t;
val it = 6 : int
```

Exceptions for efficiency

- What if …

```
val t = Node(Node(Leaf 0, Leaf 2), Leaf 3)
- prod t;
val it = 0 : int
```

- Somewhat inefficient, isn't it?

Exceptions for efficiency

```
exception Zero

fun prod (Leaf x) =
  if x = 0 then raise Zero else x
 |  prod (Node(x,y)) = prod x * prod y

val t = Node(Node(Leaf 0, Leaf 2), Leaf 3)
```

```
- prod t handle Zero => 0;
val it = 0 : int
```

Exceptions are dynamically scoped

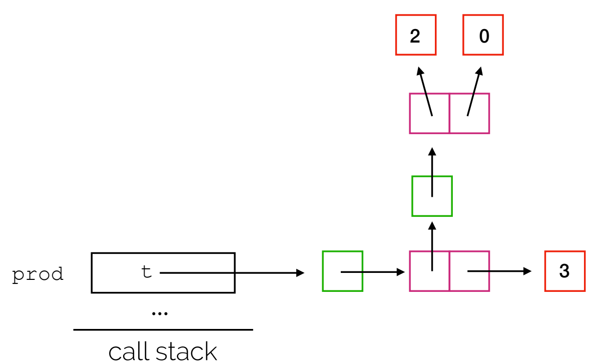
- Remember: variable bindings are statically (lexically) scoped.
- Exceptions are *dynamically scoped*.

```
fun prod (Leaf x) =
  if x = 0 then raise Zero else x
 |  prod (Node(x,y)) = prod x * prod y
```

- Remember that I said `raise` is like `goto`?
- Where would this raise "go to"? We haven't even used `prod` yet!

Exceptions are dynamically scoped

```
val t = Node(Node(Leaf 2, Leaf 0), Leaf 3)
prod t handle Zero => 0;
```



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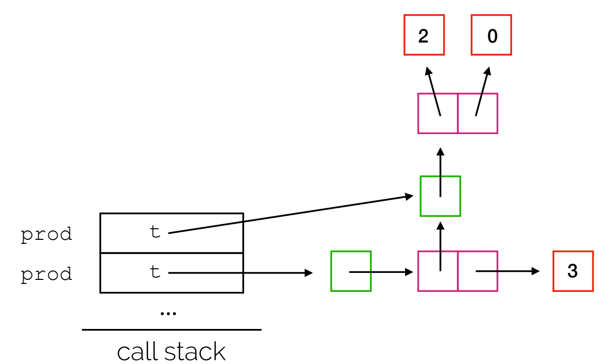

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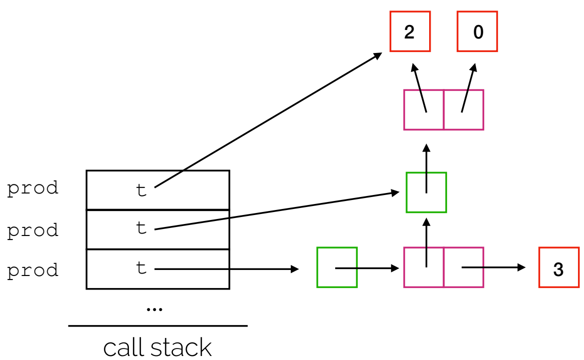

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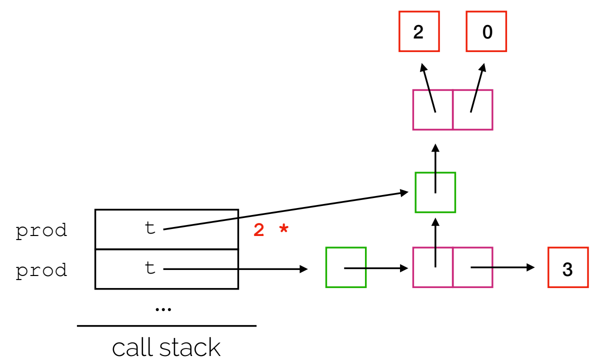

Exceptions are dynamically scoped

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val t = Node(Node(Leaf 2, Leaf 0), Leaf 3)
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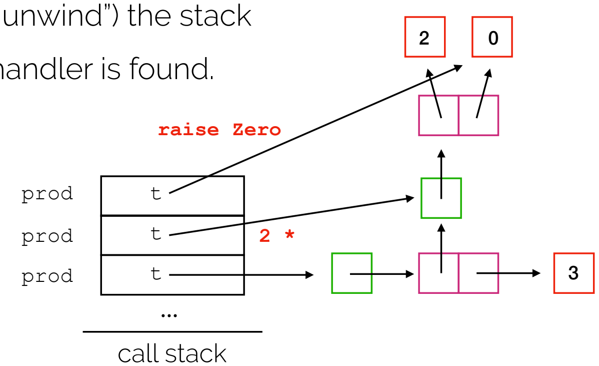
- Pop ("unwind") the stack until handler is found.



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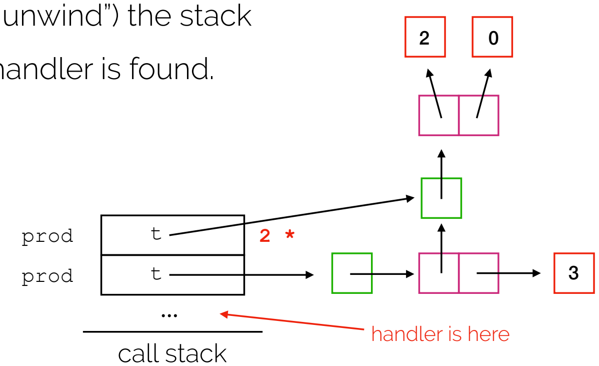

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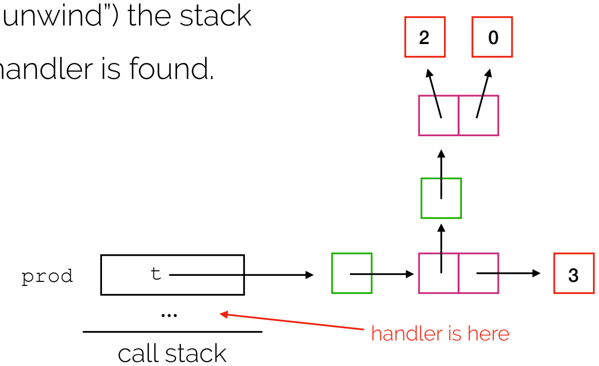

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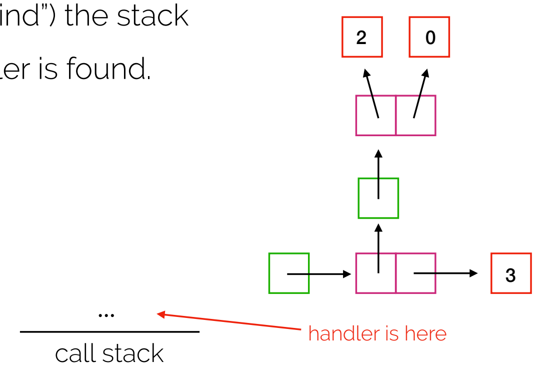

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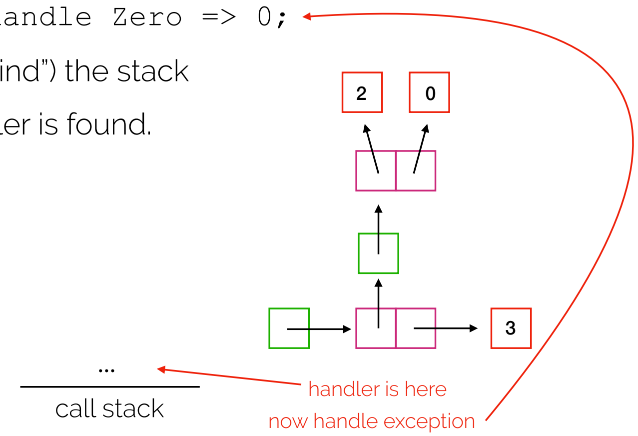

Activity

What is the value of the following expression?

```
exception X
(let fun f(y) = raise X
 and g(h) = h(1) handle X => 2 in
   g(f) handle X => 4 end)
handle X => 6
```