

# Compilation

Hype for Types

March 11, 2023

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## Main Idea

A *compiler* is simply a translator from one programming language to another.

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Rather than going straight to Assembly, we'll want to use *intermediate languages*, composing smaller compiler *phases*.



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## Front End

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- 1 Parsing
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## Front End

- 1 Parsing
- 2 Elaboration (de-sugaring)
- 3 Typechecking (disallow malformed programs)

# How to compile?

Middle/Back End

④ CPS Conversion

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<sup>1</sup>For more information, take 15-411 (only covers 1-3, 8-10)

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## Middle/Back End

- 4 CPS Conversion
- 5 Hoisting
- 6 Memory Allocation
- 8 Analysis/Optimizations

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# Middle End

# Middle End - Hoisting

- ④ CPS Conversion
- ⑤ **Hoisting**
- ⑥ Memory Allocation

Move local functions to top level. But what to do with local variables?

```
let outer (x : int) =  
  let inner (y : int) = x + y in  
  inner
```

Multiple approaches!



# Middle End - Hoisting

```
let outer (x : int) : int -> int =  
  let inner (y : int) = x + y  
  inner
```

Straightforward solution: Partial Application + Lambda Lifting

- 1 Turn local variables into function variables
- 2 Introduce "partial application" structure for functions

```
let inner (x : int) (y : int) = x + y  
  
let outer (x : int) = pApp (inner, x)
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let inner (x : int) (y : int) = x + y  
  
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```

```
pApp (pApp (inner, 5), 6) ==>* inner 5 6
```

# Middle End - Memory Allocation

- ④ CPS Conversion
- ⑤ Hoisting
- ⑥ **Memory Allocation**

Create memory representations of program values:

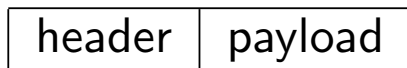
- Primitives (ex. `int`)
- Functions (are values!)
- Datatypes

# Memory Allocation - Background

**Stack:** primitives, small program values

**Heap:** larger, more complicated values (ex. non-constant constructors, closures, records)

When we store something on the heap, the memory often looks something like this:



# Memory Allocation - ADTs

## Problem

How are Algebraic Datatypes in OCaml represented in memory?

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type t = Apple | Orange | Pear | Kiwi
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Just represent each constructor as an integer!

Apple	0
Orange	1
Pear	2
Kiwi	3

# Memory Allocation - ADTs

## Problem

How are ADTs in OCaml *with arguments* represented in memory?

```
type t = Apple | Orange of int | Pear of string | Kiwi
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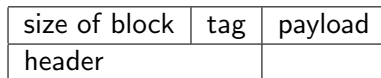
# Memory Allocation - ADTs

## Problem

How are ADTs in OCaml *with arguments* represented in memory?

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```

The arguments could be large, so let's allocate these on the heap:



The non-parameterized constructors will remain integers, while the parameterized constructors will be pointers to memory on the heap.

# Memory Allocation - ADTs

Sidenote: in OCaml the numbering for parameterized constructors is separate from non-parameterized constructors:

<b>Tags</b>	
Apple	0
Orange	0
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## Question

Why would it make sense to have separate numberings?

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## Question

Why would it make sense to have separate numberings?

Answer: idk ask the developers (probably some optimization scheme)

# Memory Allocation - Lists

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let mylist = Cons (1, Cons (2, Cons (3, Nil)))
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A linked-list!

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A linked-list! Although this may be inefficient, so we can “unroll” to put multiple elements at one node in the linked-list.



# Memory Allocation - Lists

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```

## Question

How would mylist be represented in memory?

A linked-list! Although this may be inefficient, so we can “unroll” to put multiple elements at one node in the linked-list.

At a high level it looks something like this:

```
type list =
  Nil
| One   of int
| Two   of int * int
| Rest  of int * int * int * list
```

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## Question

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Function constants = function pointers

Closures = struct with function pointer & partial application arguments  
(or environment map)

# Middle End - CPS

## ④ CPS Conversion

## ⑤ Hoisting

## ⑥ Memory Allocation

*(deep breath)* Buckle up

# CPS Conversion

# Why CPS?

CPS conversion rewrites functions to ensure every function call is a tail call

## Main Idea

CPS makes control flow explicit - everything is represented as a jump to the next continuation.

Bonus: Save stack space! Every function is tail-recursive, so no “stack overflow”. (There’s no “stack”!)

# Remember continuations?

```
signature CONT =  
sig  
  type 'a cont  
  val letcc : ('a cont -> 'a) -> 'a  
  val throw : 'a cont -> 'a -> 'b  
  val catch : ('a -> void) -> 'a cont  
end
```



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$$\frac{\Gamma, k : \tau \text{ cont} \vdash e : \tau}{\Gamma \vdash \text{letcc } k \text{ in } e : \tau}$$

$$\frac{\Gamma \vdash k : \tau \text{ cont} \quad \Gamma \vdash e : \tau}{\Gamma \vdash \text{throw } k \ e : \tau'}$$

# CPS Translation

## Function Translation

$\tau_1 \rightarrow \tau_2$  becomes  $(\tau_1 \times (\tau_2 \text{ cont})) \text{ cont}$

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add : int * int -> int
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Translates to:

```
val f = catch (fn (x, k)=> throw addCPS ((x, x), k)) where  
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```

# CPS Translation

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```

To call f:

```
letcc (fn res => throw f (5, res))
```

# Conclusion

# Summary

- Compilers are “language translators”, and often compositions of smaller “language translators”.
- Types guide our thinking when we implement the translations!
  - ▶ Each language is “real”, complete with types and an evaluation strategy for all well-typed programs.
  - ▶ Bonus: we can do optimization at any point without worrying about special “invariants”!
  - ▶ Easier to debug, too. If output code doesn’t typecheck, it’s a bug.
- By thinking compositionally, we slowly transform high-level code into assembly.

# There's Plenty More!

Writing a compiler is very hard, but rewarding (because compilers are useful, unlike most PL theory).

If this lecture seems cool, consider taking 15-411 - Compiler Design. Also beg Karl to teach 15-417 - HOT Compilation!