

Compilation

Hype for Types

October 7, 2024

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Main Idea

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

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- 1 Parsing
- 2 Elaboration (de-sugaring)

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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

¹For more information, take 15-411 (only covers 1-3, 7-10)

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- 4 CPS Conversion
- 5 Hoisting
- 6 Memory Allocation
- 7 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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```
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:

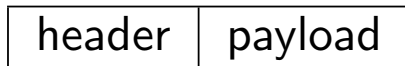
- Primitives (ex. `int`)
- Functions (are values!)
- Datatypes

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

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

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type t = Apple | Orange of int | Pear of string | Kiwi
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The arguments could be large, so let's allocate these on the heap:

size of block	tag	payload
header		

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:

Tags	
Apple	0
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Pear	1
Kiwi	1

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Why would it make sense to have separate numberings?

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Why would it make sense to have separate numberings?

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

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type list = Nil | Cons of int * list
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.

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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.

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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After lambda-lifting, all function bodies are top-level functions.

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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Logically $\tau_1 \rightarrow \tau_2$ is $\phi_1 \supset \phi_2$. Since continuation corresponds to classical logic, this is equivalent to $\neg(\phi_1 \wedge \neg\phi_2)$, which is $(\tau_1 \times (\tau_2 \text{ cont})) \text{ cont}$.

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val f : int -> int = fn x => add (x, x) where  
add : int * int -> int
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Translates to:

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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 PL theory).

If this lecture seems cool, consider taking 15-411 - Compiler Design. Also take 15-417 - HOT Compilation!²

²Frank is teaching it next semester! Yippee!