COS320: Compiling Techniques

Zak Kincaid

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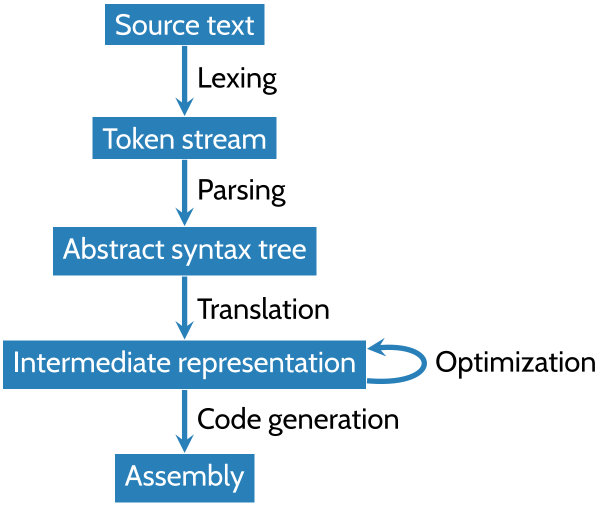
Compiler phases (simplified)



Compiling functional languages

Functional languages

- First class functions: functions are values just like any other
    - can be passed as parameters (e.g., `map`)
    - can be returned (e.g. `(+) 1`)

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- Functions that take functions as parameters or return functions are called *higher-order*
- A higher-order functional language is one with *nested functions* with *lexical scope*

Scoping

- $($**fun** x `->` $e)$ is an expression that evaluates to a function
  - x is the function's parameter
  - e is the function's body
- Occurrences of x within e are said to be *bound* in $($**fun** x `->` $e)$
  - Variables are resolved to most closely containing **fun**.
- Occurrences of variables that are not bound are called *free*

$$(\textbf{fun}\ x\ \texttt{->}\ (\textbf{fun}\ y\ \texttt{->}\ (x\ z)\ (\textbf{fun}\ x\ \texttt{->}\ x)\ y))$$

Closures

- Consider $((\textbf{fun}\ x\ \texttt{->}\ (\textbf{fun}\ y\ \texttt{->}\ x))\ 0)\ 1$
  1. Apply the function $(\textbf{fun}\ x\ \texttt{->}\ \textbf{fun}\ y\ \texttt{->}\ x)$ to the argument 0 $\rightsquigarrow (\textbf{fun}\ y\ \texttt{->}\ x)$

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     - x is free in $(\textbf{fun}\ y\ \texttt{->}\ x)$!
- In higher-order functional languages, a function value is a *closure*, which consists of a function pointer *and* an environment
  - Environment is used to interpret variables from enclosing scope

```
let compose =
  fun (f : int -> int) ->
    (fun (g : int -> int) ->
      (fun (x : int) ->
        f (g x)))
let add10 = fun (x : int) -> x + 10
let mul2 = fun (x : int) -> 2 * x
let result = compose add10 mul2 100
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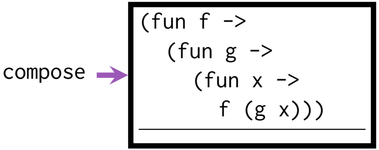

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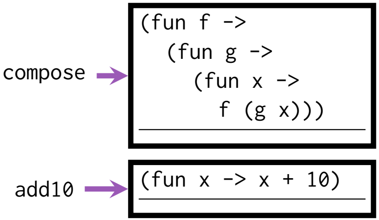

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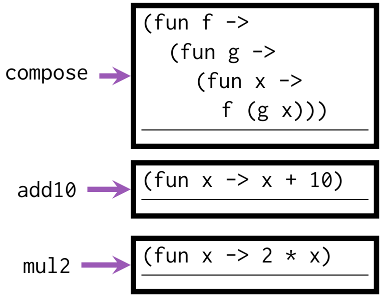

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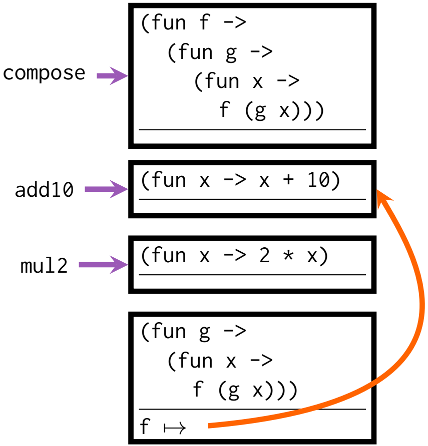

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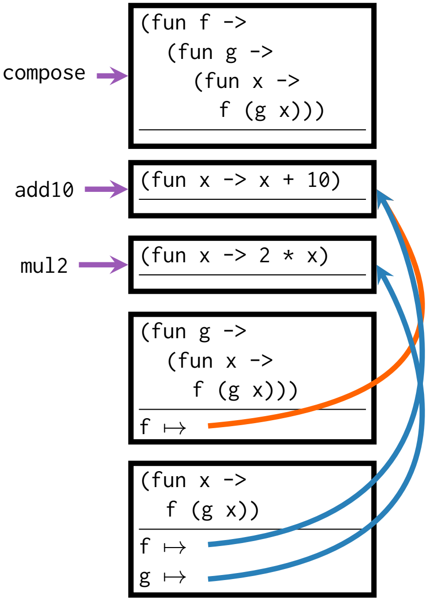

Compiling closures

- *Closure conversion* transforms a program so that no function accesses free variables
- *Hoisting* transforms a closure-converted program so that all function expressions appear at the top-level
    - Function expressions can be implemented as functions

Nameless representation

- Idea (de Bruijn): use a representation of expressions without named bound variables
  - Each variable is replaced by a number: # of enclosing scopes between occurrence & the scope it is resolved to
  - $(\textbf{fun}\ x\ \texttt{->}\ x) \rightsquigarrow (\textbf{fn}\ 0)$
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- Environments can be implemented as lists
  - Each environment has a pointer to parent environment

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Evaluation environment: index $0 \mapsto a$, other indices shifted

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  - Greater space requirement (no sharing with parent environment)
  - Can reduce space by storing only variables that are actually free

Hoisting

- After closure-conversion, every function expression is closed (no free variables)
  - No free variables $\Rightarrow$ no need for closures
  - Function expressions evaluate to function pointers
- *Hoisting*
  - Gives globally unique identifiers each function expression
  - Replaces function expressions with their identifiers
  - Places definitions for the identifiers as top-level scope

Functional optimizations

- Tail call elimination: functional languages favor recursion over loops, but loops are more efficient (need to allocate stack frame, push return address, save registers, ...)
  - Tail call elimination searches for the pattern

    ```
    %x = call foo ...; ret %x
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  - *Inlining* replaces function calls with their definitions to alleviate some of this burden
- Uncurrying: in some functional languages (e.g., OCaml), functions always take a single argument at a time
  - E.g., in `let f x y = ...`, `f` takes one argument `x`, and returns a closure which takes a second argument `y` and produces the result
  - A single OCaml-level function call may result in *several* function calls and closure allocations
  - *Uncurrying* is an optimization that determines when a function is always called with more that one paramter `(f 3 4)`, and compiles it as a multi-parameter function.