# CSE 341: Programming Languages

Winter 2005

Lecture 17— varargs and apply, implementing higher-order functions

Today:

- Some “easy” Scheme odds and ends
- Implementing higher-order functions and exceptions

## Scheme varargs

In Scheme, functions can:

- Take exactly $n$ arguments, for any $n \geq 0$
  - Examples: `cons` $(n = 2)$, `null?` $(n = 1)$
- Take $n$ *or more* arguments, for any $n \geq 0$
  - Examples: `+` $(n = 0)$, `string=?` $(n = 2)$

For user-defined functions taking 0 or more arguments:

```
(define f (lambda x e)) ; no parens on x, x is a list
(f 3 4 "hi" (list 2 4))
```

For user-defined functions taking $n > 0$ or more arguments:

```
(define g (lambda (x y . z) e)) ; note ., z is a list
(g 3 4) (g 3 4 5) (g 3 4 5 6)
```

Really just sugar: implicitly put arguments in a list.

# Implementing Languages

Mostly 341 is about language meaning, not "how can an implementation do that", but it's important to "dispel the magic".

At super high-level, there are two ways to implement a language $\boldsymbol{A}$:

- Write an *interpreter* in language $\boldsymbol{B}$ that evaluates a program in $\boldsymbol{A}$
- Write a *compiler* in langage $\boldsymbol{B}$ that translates a program in $\boldsymbol{A}$ to a program in language $\boldsymbol{C}$ (and have an implementation of $\boldsymbol{C}$)

In theory, this is just an implementation decision.

Issue: Higher-order functions and exceptions seem less straightforward.

# Implementing Higher-Order Functions

The magic: How is the “right environment” around for lexical scope (the environment from when the function was defined)?

Lack of magic: Implementation keeps it around!

Interpreter:

- An interpreter has a “current environment”
- To evaluate a function (expression), create a closure (value), a pair of the function and the environment.
- Application will now apply a closure to an argument: Interpret function body, but instead of using “current environment”, use closure’s environment extended with the argument.

Note: This is a direct “coding” of the semantics we defined several weeks ago.

# Compiling Higher-Order Functions

The key to the interpreter approach: The interpreter has an explicit environment and can "change" it to implement lexical scope.

We can also *compile* to a language without free variables:
Instead of an *implicit* environment, we pass an *explicit* environment to every function.

- As with interpreter, we build a closure to evaluate functions.
- But all functions now take one extra argument.
- Application passes a closure's code its own environment for the extra argument.
- Evaluating variables uses this extra argument.

Plus: Lots of data-structure optimizations so variable-lookup is fast (often a read from a known-size record).

# Implementing Exceptions

Implementing exceptions (e.g., `(make-handle e1 e2)`) is:

- easier: dynamically scoped
- harder: have to "immediately transfer control elsewhere"

In addition to the current environment, we have a "current handler", i.e., where to transfer control to when raising an exception.

Calling a function does *not* change the handler (dynamic scope).

Installing a nested handler changes the handler for evaluating a subexpression (e.g., `e1`).

In our example, what to do if `e1` raises an exception it doesn't handle?

- Evaluate `e2`, under environment and handler we had when we started evaluating `e1`.
- Return this result for the evaluation of `(make-handle e1 e2)`.

# Implementing exceptions, continued

The hard part: “Stop what you’re doing” and evaluate `e2`. Interpreter approaches:

- “Bubble-up”: For every subexpression, interpreter returns a one-of type “normal value” or “exception”. (Slow, cumbersome, straightforward.)
- “Control transfer”: Use the interpreter-language (e.g., Scheme) to do what you need (e.g., `let/cc`). (Elegant, unobtrusive, requires powerful interpreter-language.)

Compiler approaches the same in theory, but if target language is assembly, bubbling up can be less cumbersome: Special code can treat the call-stack as a data object and explicitly pop until reaching handler.