More idioms

We know the rule for lexical scope and function closures
- Now what is it good for

A partial but wide-ranging list:
- Pass functions with private data to iterators: Done
- Combine functions (e.g., composition)
- Currying (multi-arg functions and partial application)
- Callbacks (e.g., in reactive programming)
- Implementing an ADT with a record of functions (optional)

Combine functions

Canonical example is function composition:

```ml
fun compose (f, g) = fn x => f (g x)
```

- Creates a closure that “remembers” what f and g are bound to
- Type ('b -> 'c) * ('a -> 'b) -> ('a -> 'c)
- Type ('b -> 'c) * ('a -> 'b) -> ('a -> 'c)
- but the REPL prints something equivalent

- ML standard library provides this as infix operator o
- Example (third version best):

```ml
val sqrt_of_abs = Math.sqrt o Real.fromInt o abs
```

Left-to-right or right-to-left

As in math, function composition is “right to left”
- “take absolute value, convert to real, and take square root”
- “square root of the conversion to real of absolute value”
- “Pipelines” of functions are common in functional programming and many programmers prefer left-to-right
- Can define our own infix operator
- This one is very popular (and predefined) in F#

```fsharp
infix |>
fun x |> f  =  f x
fun sqrt_of_abs i = i |> abs |> Real.fromInt |> Math.sqrt
```

Another example

“Backup function”

```ml
fun backup1 (f, g) = fn x => case f x of
  NONE => g x
| SOME y => y
```

- As is often the case with higher-order functions, the types hint at
what the function does
- (‘a -> ‘b option) * (‘a -> ‘b) -> ‘a -> ‘b

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### Currying

- Recall every ML function takes exactly one argument
- Previously encoded \( n \) arguments via one \( n \)-tuple
- Another way: Take one argument and return a function that takes another argument and...
  - Called “currying” after famous logician Haskell Curry

```
val sorted3 = fn x => fn y => fn z =>
  z >= y andalso y >= x
val t1 = ((sorted3 7) 9) 11
```

```
fun fold f acc xs =
  case xs of
    [] => acc
  | x::xs' => fold f (f(acc,x)) xs'
fun sum xs = fold (fn (x,y) => x+y) 0 xs
```

### Example

```
val sorted3 = fn x => fn y => fn z =>
  z >= y andalso y >= x
val t1 = ((sorted3 7) 9) 11
```

- Calling \((\text{sorted3} \ 7)\) returns a closure with:
  - Code \(\text{fn } y \Rightarrow \text{fn } z \Rightarrow \ z \geq y \text{ andalso } y \geq x\)
  - Environment maps \(x\) to 7
- Calling \(\text{that}\) closure with 9 returns a closure with:
  - Code \(\text{fn } z \Rightarrow \ z \geq y \text{ andalso } y \geq x\)
  - Environment maps \(x\) to 7, \(y\) to 9
- Calling \(\text{that}\) closure with 11 returns \text{true}

### Syntactic sugar, part 1

```
val sorted3 = fn x => fn y => fn z =>
  z >= y andalso y >= x
val t1 = ((sorted3 7) 9) 11
```

- In general, \(e_1 \ e_2 \ e_3 \ e_4 \ldots\), means \(\ldots(e_1 \ e_2) \ e_3 \ e_4\)
- So instead of \(((\text{sorted3} \ 7) \ 9)\) 11, can just write \text{sorted3 7 9 11}
- Callers can just think “multi-argument function with spaces instead of a tuple expression”
  - Different than tupling; caller and callee must use same technique

### Syntactic sugar, part 2

```
val sorted3 = fn x => fn y => fn z =>
  z >= y andalso y >= x
val t1 = ((sorted3 7) 9) 11
```

- In general, \(\text{fun } f \ p_1 \ p_2 \ p_3 \ldots = e\), means \(\text{fun } f \ p_1 = \text{fn } p_2 \Rightarrow \text{fn } p_3 \Rightarrow \ldots \Rightarrow e\)
- So instead of \(\text{val sorted3} = \text{fn } x \Rightarrow \text{fn } y \Rightarrow \text{fn } z \Rightarrow \ldots\)
  or \(\text{fun sorted3} \ x = \text{fn } y \Rightarrow \text{fn } z \Rightarrow \ldots\)
  can just write \(\text{fun sorted3} \ x \ y \ z = x \Rightarrow \text{y andalso y } \Rightarrow x\)
- Callees can just think “multi-argument function with spaces instead of a tuple pattern”
  - Different than tupling; caller and callee must use same technique

### Final version

```
fun sorted3 x y z = z >= y andalso y >= x
val t1 = sorted3 7 9 11
```

As elegant syntactic sugar (even fewer characters than tupling) for:

```
val sorted3 = fn x => fn y => fn z =>
  z >= y andalso y >= x
val t1 = ((sorted3 7) 9) 11
```

### Curried fold

A more useful example and a call to it
  - Will improve call next

```
fun fold f acc xs =
  case xs of
    [] => acc
  | x::xs' => fold f (f(acc,x)) xs'
fun sum xs = fold (fn (x,y) => x+y) 0 xs
```

Note: \text{foldl} in ML standard-library has \(f\) take arguments in opposite order
“Too Few Arguments”

- Previously used currying to simulate multiple arguments
- But if caller provides “too few” arguments, we get back a closure “waiting for the remaining arguments”
  - Called partial application
  - Convenient and useful
  - Can be done with any curried function
- No new semantics here: a pleasant idiom

Example

```
fun fold f acc xs =
  case xs of
    []    => acc
  | x::xs' => fold f (f(acc,x)) xs'
```

```
fun sum_inferior xs = fold (fn (x,y) => x+y) 0 xs
val sum = fold (fn (x,y) => x+y) 0
```

As we already know, `fold (fn (x,y) => x+y) 0` evaluates to a closure that given `xs`, evaluates the case-expression with `f` bound to `fold (fn (x,y) => x+y)` and `acc` bound to `0`.

Unnecessary function wrapping

```
fun sum_inferior xs = fold (fn (x,y) => x+y) 0 xs
val sum = fold (fn (x,y) => x+y) 0
```

- Previously learned not to write `fun f x = g x` when we can write `val f = g`
- This is the same thing, with `fold (fn (x,y) => x+y) 0` in place of `g`

Iterators

- Partial application is particularly nice for iterator-like functions
- Example:

```
fun exists predicate xs =
  case xs of
    []    => false
  | x::xs' => predicate x
          orelse exists predicate xs'
val no = exists (fn x => x=7) [4,11,23]
val hasZero = exists (fn x => x=0)
```

- For this reason, ML library functions of this form usually curried
  - Examples: `List.map`, `List.filter`, `List.foldl`

The Value Restriction Appears 😞

If you use partial application to create a polymorphic function, it may not work due to the value restriction
- Warning about “type vars not generalized”
  - And won’t let you call the function
- This should surprise you; you did nothing wrong 😞 but you still must change your code
- See the code for workarounds
- Can discuss a bit more when discussing type inference

More combining functions

- What if you want to curry a tupled function or vice-versa?
- What if a function’s arguments are in the wrong order for the partial application you want?

Naturally, it is easy to write higher-order wrapper functions
- And their types are neat logical formulas

```
fun other_curry1 f = fn x => fn y => f y x
fun other_curry2 f x y = f y x
fun curry f x y = f (x,y)
fun uncurry f (x,y) = f x y
```
### Efficiency

So which is faster: tupling or currying multiple-arguments?

- They are both constant-time operations, so it doesn’t matter in most of your code – “plenty fast”
  - Don’t program against an implementation until it matters!
- For the small (zero?) part where efficiency matters:
  - It turns out SML/NJ compiles tuples more efficiently
  - But many other functional-language implementations do better with currying (OCaml, F#, Haskell)
- So currying is the “normal thing” and programmers read $t_1 \rightarrow t_2 \rightarrow t_3 \rightarrow t_4$ as a 3-argument function that also allows partial application

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### ML has (separate) mutation

- Mutable data structures are okay in some situations
  - When “update to state of world” is appropriate model
  - But want most language constructs truly immutable
- ML does this with a separate construct: references
- Introducing now because will use them for next closure idiom
- Do not use references on your homework
  - You need practice with mutation-free programming
  - They will lead to less elegant solutions

### References

- New types: $t$ ref where $t$ is a type
- New expressions:
  - `ref e` to create a reference with initial contents $e$
  - $e_1 := e_2$ to update contents
  - `!e` to retrieve contents (not negation)

### References example

```plaintext
val x = ref 42
val y = ref 42
val z = x
val _ = x := 43
val w = (!y) + (!z) (* 85 *) (* x + 1 does not type-check *)
```

- A variable bound to a reference (e.g., $x$) is still immutable: it will always refer to the same reference
- But the contents of the reference may change via $:=$
- And there may be aliases to the reference, which matter a lot
- References are first-class values
- Like a one-field mutable object, so $:=$ and $!$ don’t specify the field

### Callbacks

A common idiom: Library takes functions to apply later, when an event occurs – examples:

- When a key is pressed, mouse moves, data arrives
- When the program enters some state (e.g., turns in a game)

A library may accept multiple callbacks

- Different callbacks may need different private data with different types
- Fortunately, a function’s type does not include the types of bindings in its environment
- (In OOP, objects and private fields are used similarly, e.g., Java Swing’s event-listeners)
Mutable state

While it's not absolutely necessary, mutable state is reasonably appropriate here
– We really do want the “callbacks registered” to change when a function to register a callback is called

Example call-back library

Library maintains mutable state for “what callbacks are there” and provides a function for accepting new ones
– A real library would also support removing them, etc.
– In example, callbacks have type \(\text{int} \rightarrow \text{unit}\)

So the entire public library interface would be the function for registering new callbacks:

```plaintext
val onKeyEvent : (int -> unit) -> unit
```

(Because callbacks are executed for side-effect, they may also need mutable state)

Library implementation

```plaintext
val cbs : (int -> unit) list ref = ref []
fun onKeyEvent f = cbs := f :: (!cbs)
fun onEvent i = let fun loop fs =
    case fs of
        [] => ()
    | f::fs' => (f i; loop fs')
in loop (!cbs) end
```

Clients

Can only register an \(\text{int} \rightarrow \text{unit}\), so if any other data is needed, must be in closure’s environment
– And if need to “remember” something, need mutable state

Examples:

```plaintext
val timesPressed = ref 0
val _ = onKeyEvent (fn _ =>
    timesPressed := (!timesPressed) + 1)
fun printIfPressed i =
onKeyEvent (fn j =>
    if i=j
    then print ("pressed " ^ Int.toString i)
    else ()
```

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Optional: Implementing an ADT

As our last idiom, closures can implement abstract data types
– Can put multiple functions in a record
– The functions can share the same private data
– Private data can be mutable or immutable
– Feels a lot like objects, emphasizing that OOP and functional programming have some deep similarities

See code for an implementation of immutable integer sets with operations \text{insert}, \text{member}, and \text{size}

The actual code is advanced/clever/tricky, but has no new features
– Combines lexical scope, datatypes, records, closures, etc.
– Client use is not so tricky