Concurrency and Message Passing
Message Passing

- Threads communicate via *send* and *receive* along *channels* instead of *read* and *write* of references.

- Not so different? (trivially inter-implementable)

- *Synchronous* message-passing
  - *Block* until communication takes place
  - Encode asynchronous by “spawn someone who blocks”
Concurrent ML

- CML is synchronous message-passing with \textit{first-class} synchronization events
  - Can wrap synchronization abstractions to make new ones
  - At run-time

- Originally done for ML and fits well with lambdas, type-system, and implementation techniques, but more widely applicable
  - Available in DrScheme, Caml, Haskell, ...

- In my opinion, very elegant and under-appreciated.
The Basics

type 'a channel (* messages passed on channels *)
val new_channel : unit -> 'a channel

type 'a event (* when sync'ed on, get an 'a *)
val send : 'a channel -> 'a -> unit event
val receive : 'a channel -> 'a event
val sync : 'a event -> 'a

- Send and receive return “events” immediately
- Sync blocks until “the event happens”
- Separating these is key in a few slides
Simple version

Can define helper functions by trivial composition:

let sendNow ch a = sync (send ch a) (* block *)
let recvNow ch = sync (receive ch) (* block *)

Terminology note:

• I am using the function names in Caml’s Event library.

• In SML, the CML book, etc.:
  send  ~→  sendEvt
  recv  ~→  recvEvt
  sendNow  ~→  send
  recvNow  ~→  recv
Bank Account Example

• First version: In/out channels are only access to private reference
  – In channel of type action channel
  – Out channel of type float channel

• Second version: Makes functional programmers smile
  – State can be argument to a recursive function
  – “Loop-carried”
  – Hints at deep connection between references and channels
    * Can implement the reference abstraction in CML
The Interface

The real point of the example is that you can abstract all the threading and communication away from clients:

```haskell
type acct
val mkAcct : unit -> acct
val get : acct->float->float
val put : acct->float->float

Hidden thread communication:

- mkAcct makes a thread (the “this account server”)
- get and put make the server go around the loop once

Races naturally avoided: the server handles one request at a time.

- CML implementation has queues for waiting communications.
```
Streams

Another pattern/concept easy to code up in CML is a \textit{stream}

- An infinite sequence of values, produced lazily ("on demand")

Example in \texttt{lec15.ml}: square numbers

Standard more complicated example: A network of streams for producing prime numbers. One approach:

- First stream generates 2, 3, 4, ...

- When the last stream generates a number \( p \), return it and \textit{dynamically} add a stream as the new last stream
  - Draws input from old last stream but outputs only those that are not divisible by \( p \)

Streams also have deep connections to \textit{circuits}. 
Wanting choice

- So far just used sendNow and recvNow, hidden behind simple interfaces.

- But these *block* until the *rendezvous*, which is insufficient for many important communication patterns.

- Example: add : int channel -> int channel -> int
  - Must choose which to receive first; hurting performance if other provider ready earlier

- Example: or : bool channel -> bool channel -> int
  - Cannot short-circuit

*This* is why we split out *sync* and have other primitives.
Choose and Wrap

type 'a event (* when sync’ed on, get an 'a *)
val send : 'a channel -> 'a -> unit event
val receive : 'a channel -> 'a event
val sync : 'a event -> 'a

val choose : 'a event list -> 'a event
val wrap : 'a event -> ('a -> 'b) -> 'b event

• choose: when synchornized on, block until one of the event happens (cf. UNIX select, but much more useful because sync is separate)

• wrap: an event with the function as post-processing
  – Can wrap as many times as you want

Note: Skipping a couple other important primitives (e.g., wrap_abort
for timeouts)
Circuits

To an electrical engineer:

- send and receive are ends of a gate
- wrap is combinational logic connected to a gate
- choose is a multiplexer
What can’t you do

CML is by-design for point-to-point communication

- Provably impossible to do things like 3-way swap (without busy-waiting or higher-level protocols)
- Related to issues of common-knowledge, especially in a distributed setting
- Metamoral: Being a broad computer scientist is really useful
A note on implementation and paradigms

CML encourages using *lots* of threads

- Example: X Window library with one thread per widget

Threads should be cheap to support this paradigm

- SML N/J: about as expensive as making a closure! (See hw3)
- Caml: Not cheap

A thread responding to channels is a lot like an *asynchronous object* (cf. *actors*).

And OOP is next.