Message Passing

- Threads communicate via send and receive along channels instead of read and write of references.
- Not so different? (can implement one on top of the other)
- Synchronous message-passing
  - Block until communication takes place
  - Encode asynchronous by “spawn someone who blocks”
Concurrent ML

- CML is synchronous message-passing with *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.:
  
  \[
  \begin{align*}
  \text{send} & \sim \text{sendEvt} \\
  \text{recv} & \sim \text{recvEvt} \\
  \text{sendNow} & \sim \text{send} \\
  \text{recvNow} & \sim \text{recv}
  \end{align*}
  \]
Bank Account Example

- First version: In/out channels are only access to private reference
  - In channel of type \texttt{action channel}
  - Out channel of type \texttt{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:

```ocaml
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 stream

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

Example in 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 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 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: \( \text{add} : \text{int channel} \rightarrow \text{int channel} \rightarrow \text{int} \)
  - Must choose which to receive first; hurting performance if other provider ready earlier

- Example: \( \text{or} : \text{bool channel} \rightarrow \text{bool channel} \rightarrow \text{int} \)
  - 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 synchronized on, block until one of the event happens (cf. UNIX select, but more useful to have sync separate)

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

Note: Skipping a couple other key primitives (e.g., withNack 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.