Message Passing

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

- Not so different? (can implement references on top of channels and channels on top of references)

- *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
  - Variants available in Racket, Caml, Haskell, ...

- Very elegant and under-appreciated

- Think of threads as *very lightweight*
  - Creation/space cost about like a function call
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:

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

“Who communicates” is up to the CML implementation
  ▶ Can be nondeterministic when there are multiple senders/receivers on the same channel
  ▶ Implementation needs collection of waiting senders xor receivers

Terminology note:
  ▶ Function names are those in Caml’s Event library.
  ▶ In SML, the CML book, etc.:
    ```ml
    send ~> sendEvt    sendNow ~> send
    receive ~> recvEvt    recvNow ~> recv
    ```
Bank Account Example

See lec17code.ml

- 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:

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 `lec17code.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*
▶ Are easy to code up in lazy languages like Haskell
▶ Are a key abstraction in real-time data processing
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: \( \text{or} : \text{bool channel} \rightarrow \text{bool channel} \rightarrow \text{bool} \)
  - 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 events happen (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
- \texttt{sync} is getting a result out

To a programming-language person:
- Build up a data structure describing a communication protocol
- Make it a first-class value that can be by passed to \texttt{sync}
- Provide events in interfaces so other libraries can compose larger abstractions
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* (100,000s) 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!
  ▶ Think “current stack” plus a few words
  ▶ Cost no time when blocked on a channel (dormant)

▶ Caml: Not cheap, unfortunately

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