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
  - Available in Racket, OCaml, Haskell, ...

- Very elegant and under-appreciated

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

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

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:

\[
\text{let } \text{sendNow} \text{ ch a } = \text{sync} \left( \text{send ch a} \right) (* \text{ block } *) \\
\text{let } \text{recvNow} \text{ ch } = \text{sync} \left( \text{receive ch} \right) (* \text{ block } *)
\]

“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 OCaml’s Event library.
  - In SML, the CML book, etc.:
    
    \[
    \text{send } \leadsto \text{sendEvt} \quad \text{sendNow } \leadsto \text{send} \\
    \text{receive } \leadsto \text{recvEvt} \quad \text{recvNow } \leadsto \text{recv}
    \]
**Bank Account Example**

See `lec21code.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
Another pattern/concept easy to code up in CML is a *stream*

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

Example in `lec21code.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: `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 -> 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
- 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 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)
▶ OCaml: Not cheap, unfortunately

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