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, OCaml, 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:

```
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 OCaml’s Event library.
  - In SML, the CML book, etc.: send ~ sendEvt sendNow ~ send receive ~ recvEvt 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

See lec17code.ml
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

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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

Choosing and Wrapping

- 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

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 passed to sync
- Provide events in interfaces so other libraries can compose larger abstractions

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

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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)