CS-XXX: Graduate Programming Languages

Lecture 21 — Synchronous Message-Passing and Concurrent ML

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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

```
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 trival 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

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 communcation:

- `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 `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*)