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Desperately Seeking CML

A search for a highly-efficient implementation of Concurrent ML

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Outline

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Motivation

- Looking at Belief Propagation in Stereo Matching
- Belief Propagation is described in terms of message passing
- Implementations are usually nothing like that, though
- Seemed like a perfect fit with Concurrent ML
- No evidence combination of the two ever investigated
- (NB: BP no longer state-of-the-art in Stereo Matching)

Challenge

- Stereo Matching involves images
- Output is a new image – many pixels
- With BP, each pixel can be a messenger
- Umpteen messages to exchange
- Therefore, need *extremely* efficient CML
- Thus, assess the options out there

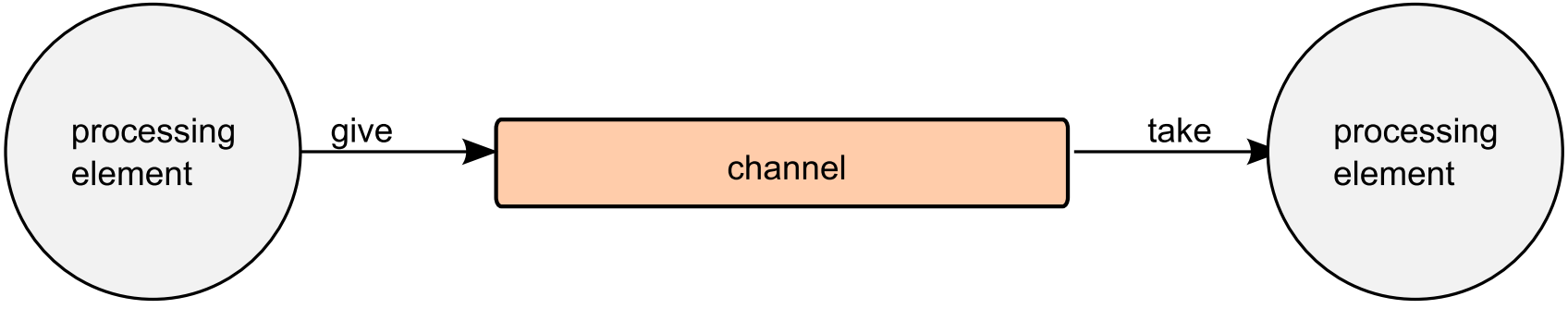
Outline

Concurrent 'Meta Language'

- Concurrency via lightweight communicating threads
- Shared-memory only
- First implemented in Standard ML of New Jersey
- Initially for concurrent but not parallel programming
- Separate processing elements communicate via channels
- Sadly, mostly forgotten now[1]

[1] But see "Concurrent ML - The One That Got Away" talk by Michael Sperber at Code Mesh 2017 (on YouTube)

Concurrent ML Diagramatically



Outline

Selected CML/host implementation requirements

- Parallel CML – aiming for 'real-time' stereo matching
- Ahead-of-time compilation/fast standalone executables
- Available for common Linux distributions
- Pre-existing support for image file IO
- Well documented
- Still maintained

Possibilities

The ready-to-use options which meet all criteria:

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Photo by Andrea Piacquadio from Pexels

https://www.pexels.com/photo/woman-in-white-shirt-showing-frustration-3807738/

Possibilities

- *No* language with CML support that meets all criteria

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- SML/NJ seems to be single-core only
- A number of languages come close, including: Go; Clojure with Core.Async library; Rust with Crossbeam crate (maybe others); Crystal; Julia; Kotlin; C++ with various old libraries; .NET with Tasks; could go on...
- All of these seem to stop at a less advanced approach
- Not necessarily parallel, either
- Many also fail to meet at least one other criterion

Possibilities with CML support I

If one relaxes criteria:

- F# with Hopac library (`https://github.com/Hopac/Hopac`)
- Haskell with Control.Concurrent.CML [2] or Transactional Events [4]
- Guile Scheme (`https://www.gnu.org/software/guile/`) with Fibers library (`https://github.com/wingo/fibers`)
- Manticore [7]
- MLton [12]

Possibilities with CML support II

- OCaml with Events module
  (`https://caml.inria.fr/pub/docs/manual-ocaml/libref/Event.html`)
  (see also [5])
- Racket [6]

Hopac

- Tried out Hopac earlier
- Compared CML with simple imperative approach for median filter [3]
- Results were underwhelming, at best
- 20+ times slower than naïve imperative version
- Turns out, *maybe* a memory leak (issues #192 & #201 at `https://github.com/Hopac/Hopac`)
- Not really maintained anymore, anyway

Elimination

- Hopac has issues
- Haskell's libraries are old and unmaintained; research prototypes only
- Guile doesn't do standalone executables
- Manticore seems to be similar to MLton, but has drawbacks
- MLton – selected
- OCaml – single-core-only
- Racket – selected

MLton

- Somewhat-maintained, largely-stable SML variant
- Includes a near-complete port of CML
- Haphazardly documented
- Some rough edges
- Few extra libraries

Racket

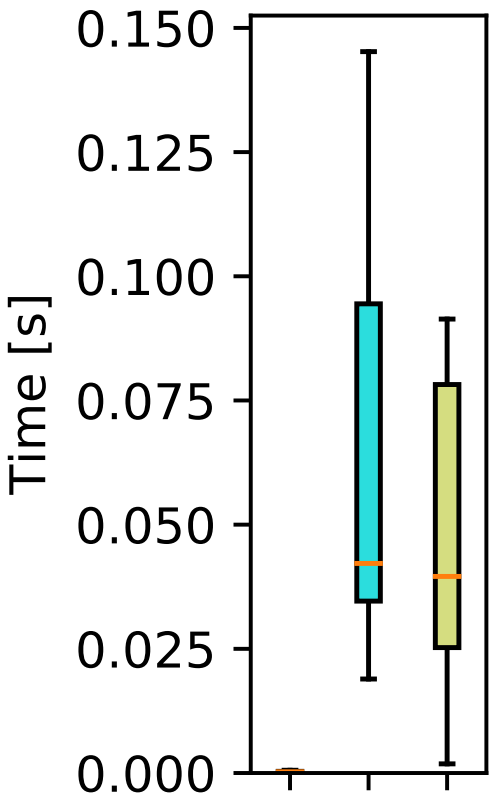
- Scheme LISP implementation – untyped & typed
- *Mostly* re-implements CML in its `sync` library
- Generally well-documented
- Active and friendly community
- Wide array of libraries available
- Doesn't *really* do standalone executables

Outline

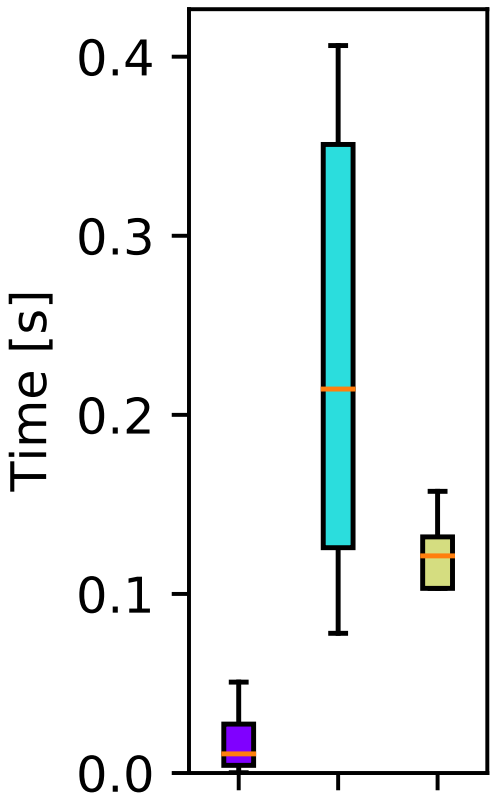
Comparative Benchmarks

- Assess running times, determine ‘fastest’ ‘language’
- Tested MLton and both Typed & Untyped Racket
- Implemented six exemplar test programs (See `https://github.com/jcoo092/CML_benchmarks`):
  - Linear Algebra
  - Monte Carlo Pi
  - Communications Time
  - Selection Time
  - Spawn
  - Whispers

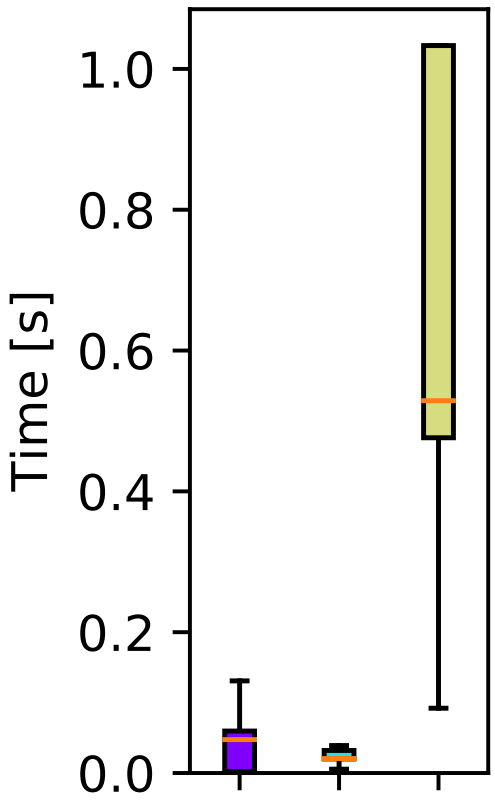
Results: Box & Whisker Plots of Running Times 1



Commstime

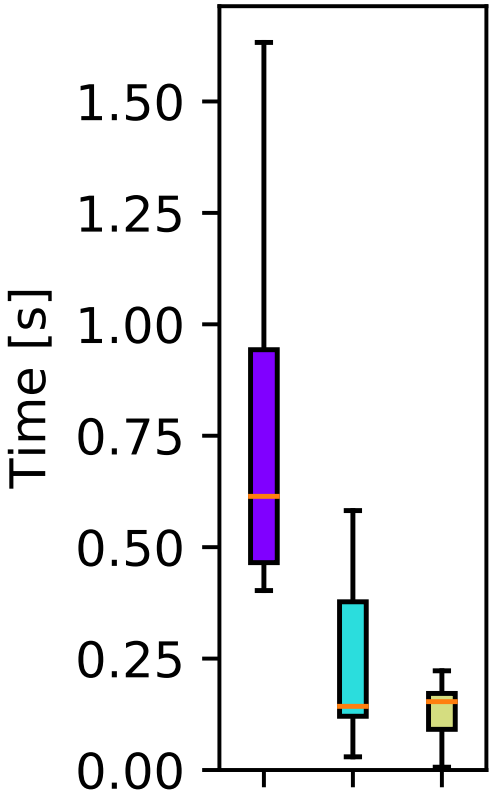


Linear Algebra (Matrix)

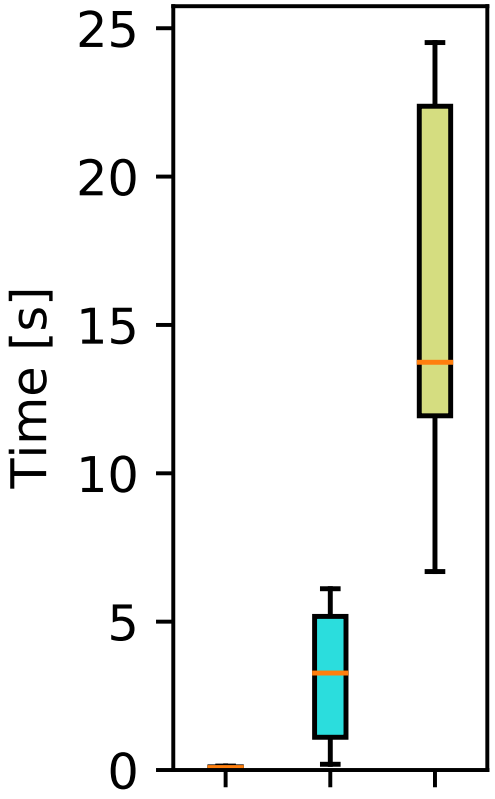


Monte Carlo Pi

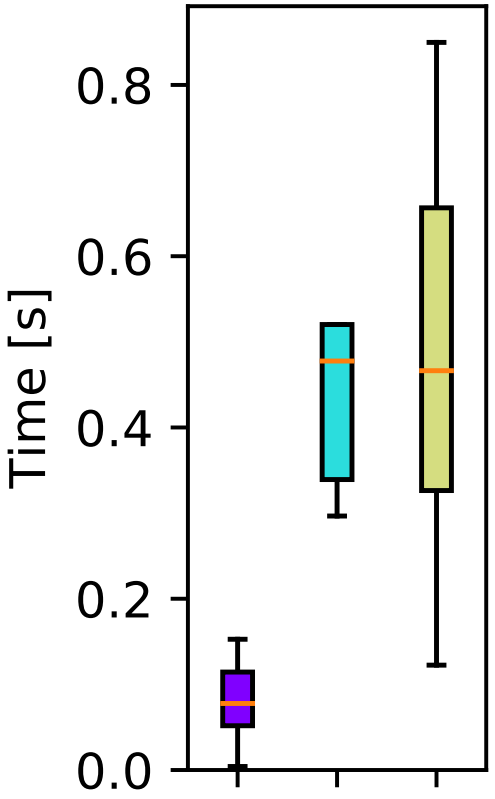
Results: Box & Whisker Plots of Running Times 2



Selection Time



Spawn



Whispers (Ring)

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- MLton outperforms Racket (both typed and untyped) on all but two benchmarks: Selection Time and Monte Carlo Pi

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- MCP tests parallelism capabilities of the language
- MCP tests showed the MLton program is very fast, but gets slower the more threads are used in the program – even with 2
- Turns out MLton is single-core-only.
- MultiMLton [10] – now dead and buried

Outline

Where to Now?

- MLton is a fairly good implementation of SML
- Lack of multithreading made it out-of-scope for this work
- Manticore is (roughly) another SML implementation
- Manticore comes with parallel CML built-in
- Obvious next choice
- *Probably* not even too hard to port MLton to Manticore

Manticore

- Research language created in late 2000s
- Standard ML-esque
- Explicitly for testing parallelism designs
- Creators implemented just enough for research goals

Sting in Manticore's Tail

- Porting from MLton proved more difficult than anticipated
- No ready-to-run installer, build from source instead
- Needed to adapt a Dockerfile from one of the researchers
- Missing parts of SML Basis (aka standard) library
- Almost no documentation – relied on reading source, plus some exemplar benchmark programs and trial & error

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- Almost no documentation – relied on reading source, plus some exemplar benchmark programs and trial & error
- Turned out to be lacking core parts of CML!

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Conclusion I

- Belief Propagation based on message-passing concepts
- Concurrent ML seems like a clear theoretical fit to BP
- Investigated CML options
- Turns out there are few usable ones out there now
- No ‘ideal’ candidate
- Had tried F# + Hopac earlier – poor performance
- Tested out MLton and Racket

Conclusion II

- MLton much faster than Racket, but actually not parallel
- Changed focus to Manticore
- Manticore now missing CML bits...
- Too many problems, redirected research focus
- Hope to re-visit in future

Acknowledgements

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Thank you to all of you!

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Message Passing

- CML builds upon Communicating Sequential Processes [8]
- Goes beyond CSP (and Go) with its 'events'
- "Higher-order concurrent programming" (per Reppy)
- Events make synchronisation a first-class value
- Event combinators permit specification of abstracted protocols

Beyond Go?

- Go has channels, and selection over channels
- Channels fixed at compile time (modulo reflection)
- CML has selection over dynamic list of channels
- Go only has (blocking) send and receive
- Send and receive events represent communication *in potentia*
- CML is arguably a ‘superset’ of CSP

Some CML Types

Blocking:

```
send: ('a chan * 'a) -> unit
recv: 'a chan -> 'a
```

Non-Blocking:

```
sendEvt: ('a chan * 'a) -> unit event
recvEvt: 'a chan -> 'a event
```

Blocking:

```
sync: 'a event -> 'a
```

Event Combinators

- `wrap`: Resolve input event, and then execute a supplied function on the result
- `guard`: Immediately prior to input event's resolution, run another supplied function and use result for resolving the event
- `withNack`: Provide a second function for cancellation/if an event is *not* selected
- `choose`: Create a new event that represents the first event from a list to become available
- `select`: `sync` $\circ$ `choose`

Why not X?

- More message passing models/libs/langs than just CML
- CSP-derived – usually limited vs. CML
- Actors – asynchronous, unbounded max memory
- Reagents [11] – Join Calculus-based
- Rendezvous (e.g. Ada, Eiffel's SCOOP) – not channel-based message passing (maybe splitting hairs)
- All good future work targets (probably)

Comparative Benchmarks I

- Assess running times, determine ‘fastest’ ‘language’
- Tested MLton and both Typed & Untyped Racket
- Implemented six exemplar test programs (See `https://github.com/jcoo092/CML_benchmarks`):
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Comparative Benchmarks II

- Inspiration for some of them was taken from [1] (see also `https://github.com/kevin-chalmers/cpa-lang-shootout`) and [9]
- Linear algebra tests matrix/vector addition and multiplication – Linear Algebra is used heavily in Computer Vision.
- Monte Carlo Pi tests parallelism/multithreading effectiveness
- Other four test aspects of the CML implementation [1]
- Communications Time measures speed at enumerating natural numbers via four threads in a specific arrangement

Comparative Benchmarks III

- Selection Time measures the time taken to 'select' over a list of channels, when one side blocks awaiting communication before the other offers on a randomly-selected channel
- Spawn measures the time taken to create CML threads
- Whispers measures message passing speed sans other computation, using different communication topologies

Whispers I

- Measures message passing speed using different communication topologies
- Independently conceived, but done in the past
- Intent was for three styles:
  - Ring – all threads arranged such that they receive from one thread, and send to another, forming a logical ring
  - Grid – Threads are arranged in a logical grid, and exchange messages with their 'neighbours' above, below and to the left and right
  - K_n (aka all-to-all) – all threads send and receive to every other thread, as on a complete graph

Whispers II

- Racket's `Places` make this awkward to implement
- Only implemented Ring in Racket, so only tested Ring on both Racket and MLton
- Other two are certainly possible, but were expected at the time to be overly lengthy to program

Experimental Process

- Assumption of long-running program. E.g. robot running stereo matching continuously as part of vision system
- Run in a virtual machine
- Automated with a Makefile
- Input & output on command line
- Timings collected using `hyperfine`[2]
- Vary number of iterations to perform, and problem size
- Hyperfine stores results in files for later analysis

[2] `https://github.com/sharkdp/hyperfine`

Threats to Validity

- Take results with pinch of salt
- Unfamiliar with tested languages before start of this work
- Not necessarily representative of the capabilities of each language for an expert
- Does provide a test of how easy it is to get fast programs from each language when previously unfamiliar with it
- First execution usually slower than others (?)
- (Even though three warm up runs were used at the beginning of each test)