Process Cooperativity as a Feedback Metric in Concurrent Message-Passing Languages

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August 12, 2014

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- Thank Fluet, Heliotis, and Raj.
- Dedicate to parents, who are unable to be present.

1 Background
- Cooperativity
- Message Passing
- Runtime Scheduling

2 ErLam
- The Language
- Channel Implementations
- Simulation & Visualization

3 Scheduler Implementations
- Example Schedulers
- Feedback Schedulers

4 Results

5 Conclusions & Future Work
- ErLam Toolkit
- Cooperative Schedulers
- Cooperativity as a Metric

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- Break apart title = Background.
- Then simulator and test primitives (process behaviours).
- Schedulers and how comparisons are made.
- Results, Conclusions (of both simulator and cooperativity).

Current Section:

1 Background

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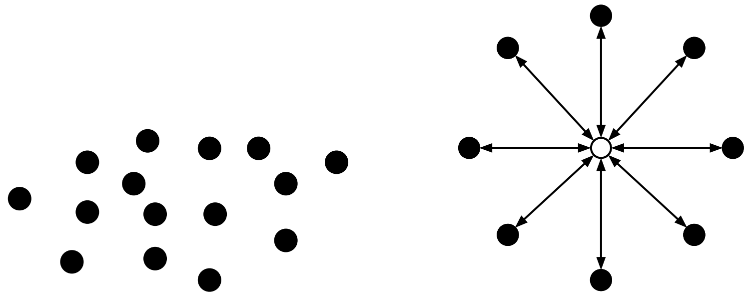
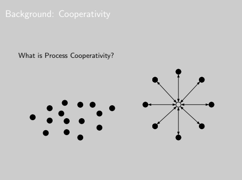
Background: Cooperativity

What is Process Cooperativity?



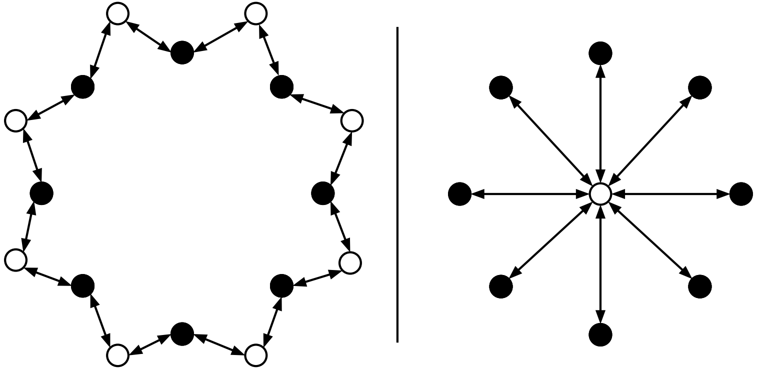


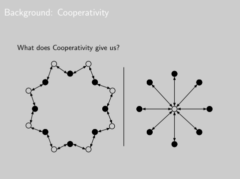
- Where white represents a channel and black represents a process.
- Channel = Source of synchronization (*i.e.* locks, abstractions, *etc.*)

- Left: Cloud of processes with no interaction.
- Right: Some sort of batch job? A bit of shared state amongst all processes these processes could all really be parallel or be competing, but in either case they cooperate.
- DEGREE OF COOPERATIVITY:
  - *of process:* flux of interaction with inter-proc comm method.
  - *of system:* rate of interaction between Ps and Cs as both flux in size.

Background: Cooperativity

What does Cooperativity give us?





Whats the difference in cooperativity in the left and right set of processes?

- Left: A Ring, the level of parallelism is nearly nil. Each process is cooperating yes, but the granularity of the application is very fine.
- Right: A Star, the level of parallelism is nearly full. Each process is cooperating, and is **not reliant on more than one** other.

Overall, what can be gained by looking at cooperativity in terms of understanding the applications behaviour? Knowing the granularity of parallelism.

Next: what is a minimal inter-proc comm method?

Background: Message Passing

We use a Symmetric, Synchronous, Message-Passing Primitive:

`swap`

- Purely captures cooperation of processes by synchronizing on the shared channel.
- Ultimately can be extended to take into account:
  - Directionality
  - Asynchrony

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- Async: while user code doesn't block, there is blocking in terms of the channel implementation. This is not indicated (in most cases) to the scheduler.
- Sync: The issue of process cooperation has been elevated to the process level for the scheduler to directly involve itself.
- Ultimately there is nothing stopping us from choosing the other types of message passing, but it would conflate the issue of process cooperativity if all we are after is whether two processes are cooperating on some task.

Next: How would we use coop as a feedback metric?
What does that mean?

Background: Runtime Scheduling

- Schedulers can be defined in a discrete manner:
  1. *Choose* a process from set
  2. *Reduce* it
  3. *Update* private scheduler state
- Statistics can be gathered at every step about process:
  - Number of channel partners,
  - Timestamp of last run,
  - Number of reductions, *etc.*
- *What statistics are neccessary for recognizing cooperativity?*

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- *What statistics are neccessary for recognizing cooperativity?*

- Choosing from set: Top Always (batching), Queue (Round-Robin)
- Reductions Return some indication: yield/blocked, unblocked, completed, nothing
- Update state based on historical data.
  - Timestamp of last run = Separate between batching/round-robin
  - Cooperativity metrics: yields, partners, thus longevity and granularity
- gets back to why we chose swap:
  - (if asymmetrical, we would have a harder time with 'partner')
  - (if async, we would have a harder time with 'yield' and noticing longevity/progress)

Current Section:

2 ErLam

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ErLam: The Language

```
<Expression> ::= <Variable>
               |  <Integer>
               |  'newchan'
               |  '(' <Expression> ')'
               |  <Expression> <Expression>
               |  'if' <Expression> <Expression> <Expression>
               |  'swap' <Expression> <Expression>
               |  'spawn' <Expression>
               |  'fun' <Variable> '.' <Expression>
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ErLam: The Language
<Expression> ::= <Variable> | <Integer> | 'newchan' | '(' <Expression> ')' | <Expression> <Expression> | 'if' <Expression> <Expression> <Expression> | 'swap' <Expression> <Expression> | 'spawn' <Expression> | 'fun' <Variable> '.' <Expression>

- Extremely simple on purpose (5 keywords).
- Issue now began to be how to build up test primitives
- Made a library which allowed for built ins.

ErLam: The Language

```
elib
    // ...
    omega = (fun x.(x x));
    // ...
    add = _erl[2]{ fun(X) when is_integer(X) ->
                        fun(Y) when is_integer(Y) ->
                            X+Y
                        end
                    end
                };
    // ...
bile
```


ErLam: The Language

- There's options for built-ins as well as macros.
- Built-ins are raw Erlang, gets wrapped up into AST, and still "reduces" the same (*i.e.* no multi-variable functions).

ErLam: The Language
Example Application: Parallel Fibonacci

```
// pfib.els -
fun N.
    (omega fun f,m.(
        if (leq m 1)
           m
           (merge fun _.(f f (sub m 1))
                  fun _.(f f (sub m 2))
                  add)) N)
```

```
$ els pfib.els      (Compile the script)
$ ./pfib.ex -r 10   (Finds the 10th Fibonacci number)
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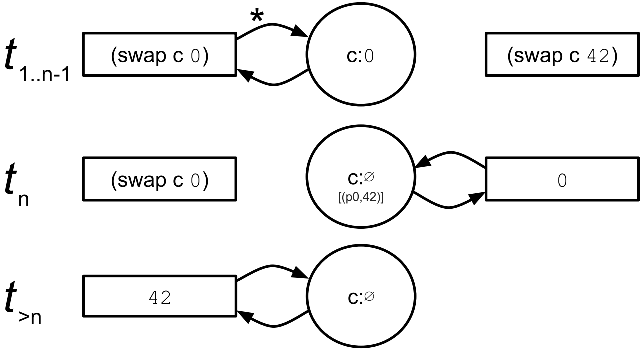
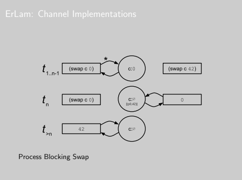
- R option is to run program applied to 10.
- To add more to this presentation than just reading paper I want to also give more detail as to system usage.
- Explain this Common Usage Pattern.

ErLam: Channel Implementations

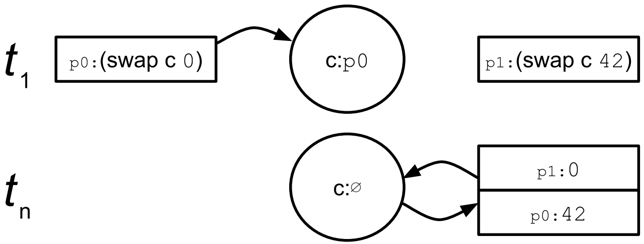


Process Blocking Swap

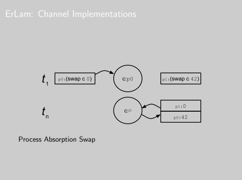


- Blocking: Maintains state of current and previous swap value until swap is completed.
- Mention expected effects on scheduler.
  - Scheduler will keep hold of the process, needs to recheck if blocked.
  - If all communicating, large process queue of blocked processes.
- Blocking is default, passing '-a' to els for absorb

ErLam: Channel Implementations



Process Absorption Swap



Absorption swap is visually easier to recognize.

1. Whole process gets absorbed by channel, away from scheduler.
2. When the second process completes the swap, the process gets removed from channel.
   - The p0 process can go back to its original scheduler,
   - OR to scheduler which unblocked it.

- Effects on scheduler are obvious.

ErLam: Simulation & Visualization

- System Behaviours:
  - Degree of Parallelism
  - Consistency of Cooperation
  - Degree of Longevity/Interactivity
  - Partial System Cooperativity
- Logging & Report Generation

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- System Behaviours:
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- We first want to look at four types of system behaviour ranges:
  - Parallelism: Gets back to Ring vs Cloud, Compare the two.
  - Consistency: Ring/Star=consistent, but if given a random choice.
  - Longevity: Ratio of Communicating/Computing processes.
    - Longevity = Time spent reducing (low=communicator)
    - Interactivity, also takes into account user interaction.
  - Full vs Partial Cooperation: Multiple groups of Stars or Rings.
- Definitely won't get to all behaviour tests that were in report, but will focus on the key ones for each scheduler mechanic.
- Finally, quickly, go over the current report generation that ErLam can perform.

ErLam: Simulation & Visualization

System Behaviours: Degree of Parallelism

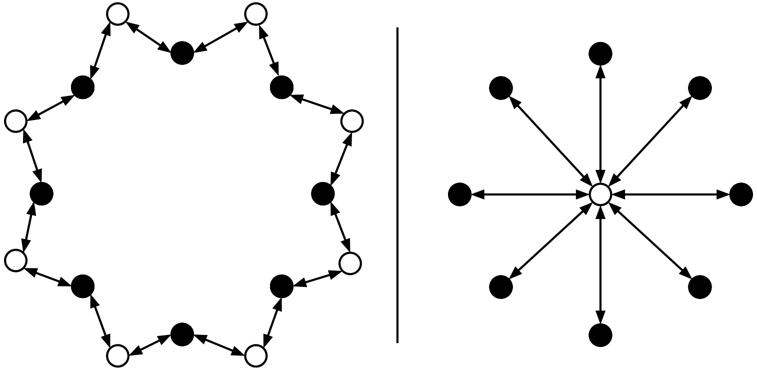
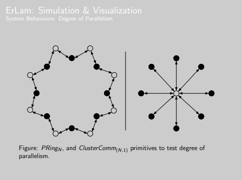


Figure: $PRing_N$, and $ClusterComm_{(N,1)}$ primitives to test degree of parallelism.



- Brings back the Ring and Star.
- We call the left, PRing, with the parameter N = number of processes.
- We call the right, *ClusterComm* with two parameters, *N* like *PRing*, $M = 1$ in this cas

ErLam: Simulation & Visualization

System Behaviours: Consistency of Cooperation

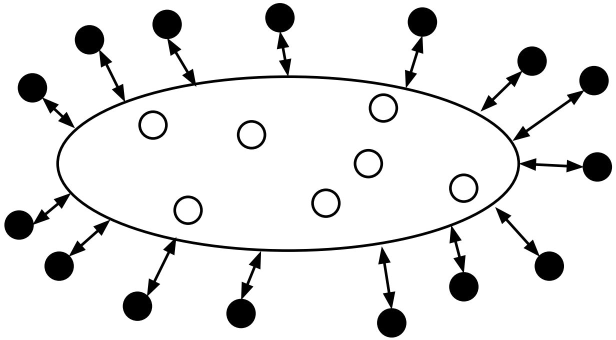
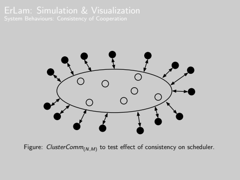


Figure: *ClusterComm*$_{(N,M)}$ to test effect of consistency on scheduler.



- We can vary number of channels in relation to processes to check the effects of inconsistency on Cooperative-Conscious schedulers.
- Worst case scenario for C-C schedulers.

ErLam: Simulation & Visualization

System Behaviours: Degree of Interactivity

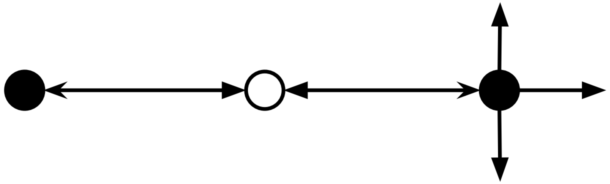
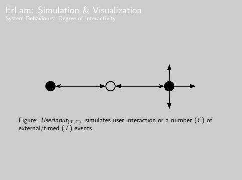


Figure: $UserInput_{(T,C)}$, simulates user interaction or a number (C) of external/timed (T) events.



- To test longevity we can just vary the length of time the processes chug for all tests.
- To test interactivity though, we need a way to simulate user interaction.
- *UserInput* captures hanging for a single event. We can compose these: $< NEXT >$
- With our cloud of processes (also called chugmachine) for simulating a program with consistent working processes and processes which are interactive.

ErLam: Simulation & Visualization

System Behaviours: Degree of Interactivity

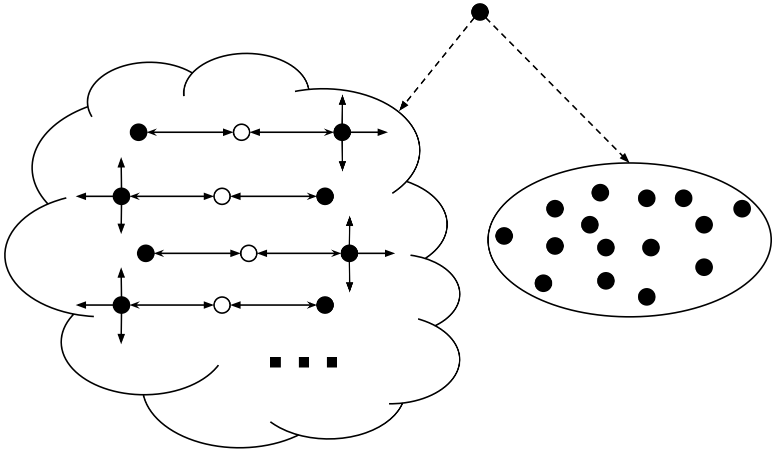
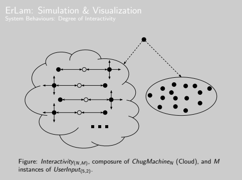


Figure: *Interactivity*$_{(N,M)}$, composure of *ChugMachine*$_N$ (Cloud), and M instances of *UserInput*$_{(5,2)}$.



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ErLam: Simulation & Visualization

System Behaviours: Partial System Cooperativity

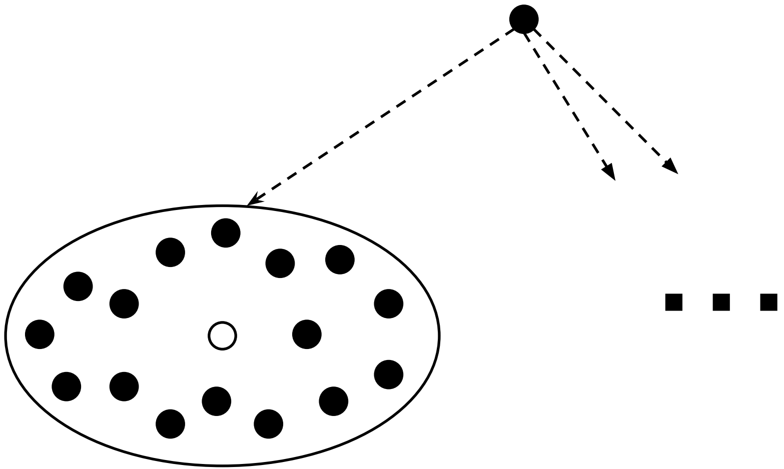
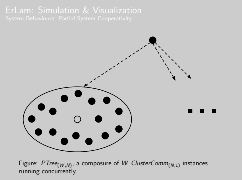


Figure: $PTree_{(W,N)}$, a composure of W $ClusterComm_{(N,1)}$ instances running concurrently.



- Previously (besides Interactivity), all systems were full system cooperation.
- We can of course use Interactivity for our partial system cooperativity tests, but we would instead like to see logical grouping.
- Hence the set of Work groups (or stars).

Things we could log:

ErLam: Simulation & Visualization
Logging & Report Generation
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Logging & Report Generation

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- Process Queue Size (per LPU)

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- Tick-Action: Visualize the density of computation/communication.

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2014-08-11
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└─Current Section:

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Scheduler Implementations: Example Schedulers

- Single-Thread Dual-Queue
  - Translation of CML scheduler
- Round-Robin with Single Global Queue (MTRRGQ)
  - No Work-Stealing
  - # LPUs can vary
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- First tested translating a known scheduler to the discrete step scheduler semantics.
- MTRRGQ: all synchronization around a single global queue, test P=1 or max.
- MTRRWS-SQ:
  - Schedulers can access a random LPU's queue end and steal from their bottoms.
- MTRRWS-IS:
  - Uses a secondary queue to advertise desire to steal.
  - Scheduler can check secondary queue as desired.
  - No requirement for synchronization on private process queue.

Scheduler Implementations: Feedback Schedulers

Three types of mechanics:

- Longevity-Based Batching
- Channel Pinning
- Bipartite-Graph Aided Sorting

Scheduler Implementations: Feedback Schedulers
Three types of mechanics:
- Longevity-Based Batching
- Channel Pinning
- Bipartite-Graph Aided Sorting

- Instead of a single cooperativity-conscious scheduler, we implemented three mechanics which take cooperativity into account on top of the basic schedulers.

Scheduler Implementations: Feedback Schedulers

Longevity-Based Batching

- Choose via Round-Robin
  - from batch rather than queue
  - keeps track of number of rounds (batch size)
- Work-Steal whole batches
- Spawn to batch unless: $|b_i| \geq B$
  - Make singleton with new process.
  - Push parent and child into new batch.

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- Batching processes based on longevity.
  - Based on occam-Π.
  - if a process communicates frequently then it will be batched (absorption), singleton if very computation-bound.
- We are normal RR but with one extra layer.
- If batch is too big during spawns we can:
  - Make singleton, best if child is needed to start work right away. Map-Reduce.
  - Make push-back, parent can get another chance to spawn more children sooner.

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GOAL: Can batching based on longevity account for fine/coarse parallelism in application?

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Channel-Pinning

- Upon call to *newchan*, pin to LPU based on spread algorithm:
  - *same* - LPU *newchan* is called is where it is pinned.
  - *even* - Cycle through LPUs and pin based on that.
  - ...
- Work-steal based on channel that's been pinned to you.

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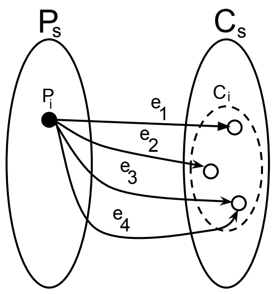
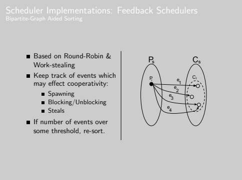
Scheduler Implementations: Feedback Schedulers
Bipartite-Graph Aided Sorting

- Based on Round-Robin & Work-stealing
- Keep track of events which may effect cooperativity:
  - Spawning
  - Blocking/Unblocking
  - Steals
- If number of events over some threshold, re-sort.





- Keep a list of all communications as a graph between set of processes and channels.

Scheduler Implementations: Feedback Schedulers

Bipartite-Graph Aided Sorting

- Based on Round-Robin & Work-stealing
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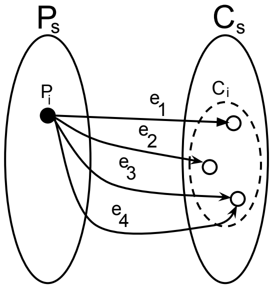
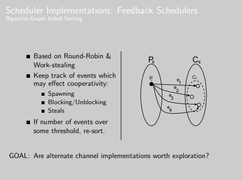


GOAL: Are alternate channel implementations worth exploration?



- Keep a list of all communications as a graph between set of processes and channels.

Current Section:

4 Results

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Results:

Longevity-Based Batching

- *Can batching based on longevity recognize fine/coarse parallelism in an application?*

Channel Pinning

- *Can an* even-*like spread increase early saturation?*

Bipartite-Graph Aided Sorting

- *Are alternate channel implementations worth exploration?*

Results:
Longevity-Based Batching
Can batching based on longevity recognize fine/coarse parallelism in an application?
Channel Pinning
Can an even-like spread increase early saturation?
Bipartite-Graph Aided Sorting
Are alternate channel implementations worth exploration?

- Remind about the goals of the talk. However there are other things we can of course study now that we have a simulator:
- LBB: Can also look at how the batch size effects different types of behaviours.
- CP: Could also look at a stealing mechanism.

Results: Longevity-Based Batching

$PRing_N$

	$N = P = 8$	$N = B = 10$	$N = 2 * B = 20$

Reduc. Density

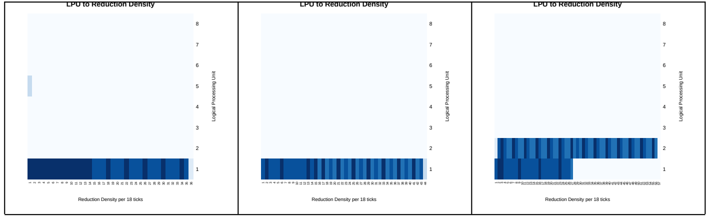
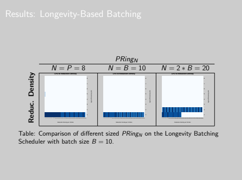
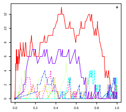
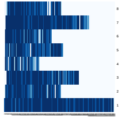
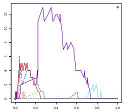
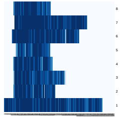
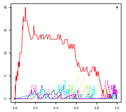
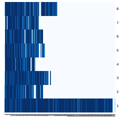
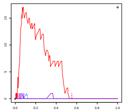
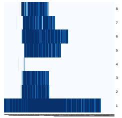
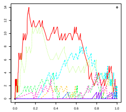
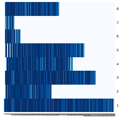
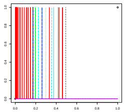
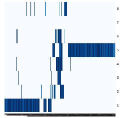


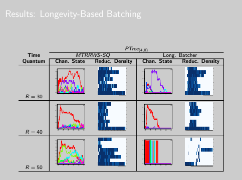
Table: Comparison of different sized $PRing_N$ on the Longevity Batching Scheduler with batch size $B = 10$.



- Early tests gave promising results.
- Here is $PRing_N$ which shows the reabsorption and containment on a single LPU as expected and hoped.
- So does batching based on longevity really recognize fine/coarse parallelism in an application?
- Sort of, if you know what the right time-quantum is to make that distinction.

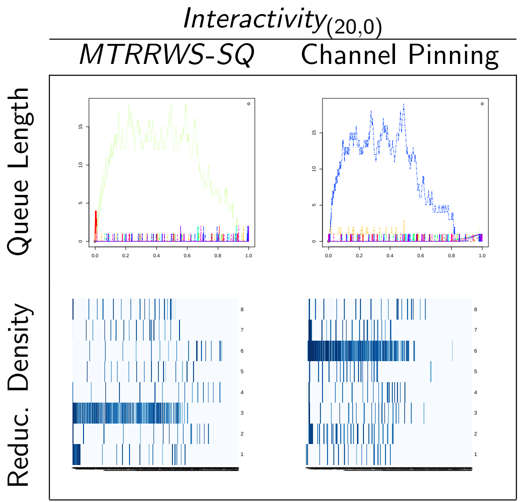
Results: Longevity-Based Batching

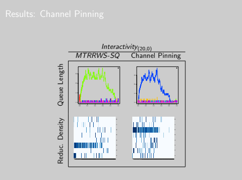
	$PTree_{(4,8)}$			
	MTRRWS-SQ		Long. Batcher	
Time Quantum	**Chan. State**	**Reduc. Density**	**Chan. State**	**Reduc. Density**
$R = 30$				
$R = 40$				
$R = 50$				



- Comparison of $PTree_{(4,8)}$ running with the Longevity-Based Batching Scheduler and *MTRRWS-SQ* at different time-quantums.
- At lower time quantums Long. Batcher starts to look like RRWS-SQ, however batching and absorption channels tend to lead to consolidation.
- At higher time quantums Long. Batcher results in the originally expected work-groups. But it turns out to be inefficient due to lost chances of parallelism of each "star" of each group.
- Heuristical adjustement of the time-quantum would definitely be possible.

Results: Channel Pinning



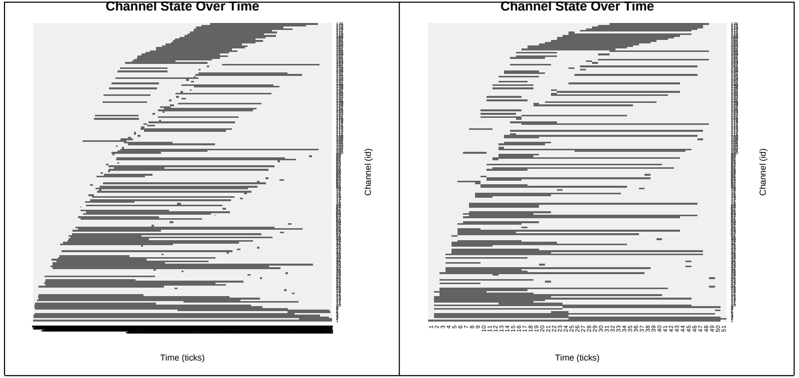


- Comparison of Uniform synchronization for *MTRRWS-SQ* and the Channel Pinning Scheduler on Absorption Channels.
- This used the *even* spread type.
- Note the speed at which it saturates all cores.
- Despite Naive WS, we still have decent spread.

Results: Bipartite-Aided Graph Sorting

Parallel Fibonacci

MTRRWS-SQ	Sorting Scheduler



- Had to deviate from the primitives. No primitive relied on process order.
- PFib has a strong reliance on order of execution.
- Channel State comparison of Parallel Fibonacci executed on *MTRRWS-SQ* and the Bipartite-Graph Aided Sorting Scheduler.
- Note the large reduction in number of ticks.

Current Section:

5 Conclusions & Future Work

- ErLam Toolkit
- Cooperative Schedulers
- Cooperativity as a Metric

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ErLam Toolkit
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Conclusions & Future Work: ErLam Toolkit

- Test Primitives were nicely composable process behaviours.
  - More research into generating behaviours.
  - More compositions: PTree with Rings.
- Log generation, lots of overhead, but good observations.

Conclusions & Future Work: ErLam Toolkit
- Test Primitives were nicely composable process behaviours.
  - More research into generating behaviours.
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- Log generation, lots of overhead, but good observations.

- Overall pleased with simulator and achieved its goal.
- Future Work:
  - Generate more test primitives, a good library of them would be nice.
  - Compose them easier and more frequently. Perhaps generating work groups as PRing might have made a better comparison than Interactivity.
  - Clean up log generation (reduce overhead).
  - Process evaluation uses alpha-reduction (can be sped up substantially).
  - Make schedulers more adjustable (different spawn/yields/etc).
  - More Channel implementations

Conclusions & Future Work: Cooperative Schedulers

- **Longevity Batching:**
  - Would benefit from heuristic based Quantum selection.
  - As it stands, limited gain from longevity recognition.
- **Channel Pinning:**
  - Promising saturation and work-stealing mechanic.
- **Bipartite-Graph Aided Sorting:**
  - Supprising results on MapReduce style applications.
  - Worth studying Blocking-Channels further for gains from sorting.

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  - Worth studying Blocking-Channels further for gains from sorting.

- SS: Would benefit from merging with Channel Pinning. Increase likelihood that sorting puts channel partners close.
- LBB + CP might be interesting as channels could own batches.
- Overhead of Sorting? If implemented in a practicle language, would it be worth it? Seems counter-intuitive but promising as is.

Conclusions & Future Work: Cooperativity as a Metric

- Possible to recognize and benefit from.
- The three example mechanics are promising and can be extended for practicle modern languages, despite simplistic simulation language.
- More to explore:
    - Alternate Message-Passing Types (Asymmetric?)
    - ...

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- Promising scheduling mechanics
- More research is necessary in the message-passing implementation for it to be practical in common languages.
- (Asymmetric/Directionality would be first on the list)

Questions/Comments?

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Thank You!

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Links

- https://github.com/dstar4138/erlam
- https://github.com/dstar4138/thesis_cooperativity
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