The Manticore Project
(a status report)

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People

The Manticore project is a joint project between the University of Chicago and the Rochester Institute of Technology.

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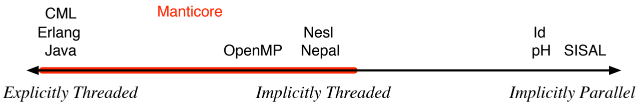
Background and motivation

- Well-known sea change in the design of microprocessors.
- Hardware supports parallelism at multiple levels: SIMD, SMT, multicore, and small-scale SMP.
- Likewise, many commodity applications exhibit parallelism at multiple levels.
- For applications to take advantage of future CPU improvements they need to be parallel.
- The Manticore project is our effort to address the programming needs of commodity applications running on the commodity parallel hardware.



Talk overview

This talk is divided into three parts:

1. Overview of Parallel ML.
2. Current status.
3. Future work.

Please see `http://manticore.cs.uchicago.edu` for papers.

Language Overview

Language design

The initial design of PML is purposefully conservative [ICFP ’08; JFP ’10] It can be summarized as the combination of three distinct sub-languages:

- A “pure” (mutation-free) subset of SML.
- Language mechanisms for implicitly-threaded parallel programming.
- Language mechanisms for explicitly-threaded parallel programming (*a.k.a.* concurrent programming).

Language design *(continued ...)*

PML provides several light-weight syntactic forms for introducing parallel computation.

- Parallel tuples provide a basic fork-join parallel computation.
- Parallel bindings provide data-flow parallelism with cancelation of unused subcomputations.
- Parallel arrays provide fine-grain data-parallel computations over sequences.
- Parallel case provides non-deterministic speculative parallelism.

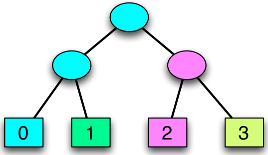
These forms are hints to the compiler and runtime that a computation is a good candidate for parallel execution.

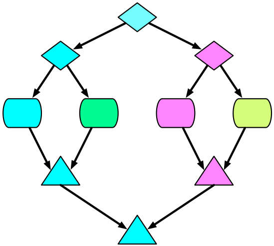
Parallel tuples

Parallel tuples provide fork-join parallelism. For example, consider summing the leaves of a binary tree.

```
datatype tree = LF of long | ND of tree * tree

fun treeAdd (LF n) = n
  | treeAdd (ND(t1, t2)) =
            (op +) (| treeAdd t1, treeAdd t2 |)
```





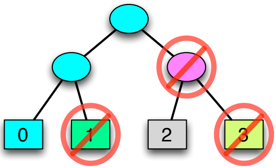
Parallel bindings

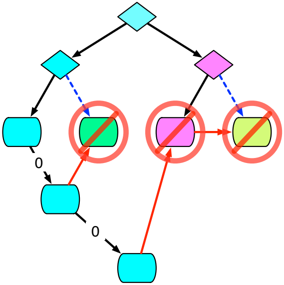
Parallel bindings provide more flexibility than parallel tuples. For example, consider computing the product of the leaves of a binary tree.

```
fun treeMul (LF n) = n
  | treeMul (ND(t1, t2)) = let
      pval b = treeMul t2
      val  a = treeMul t1
      in
        if (a = 0) then 0 else a*b
      end
```

NOTE: the computation of `b` is speculative.

Parallel bindings *(continued ...)*





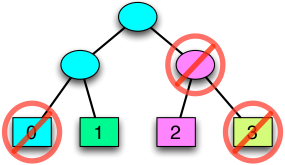
Parallel case

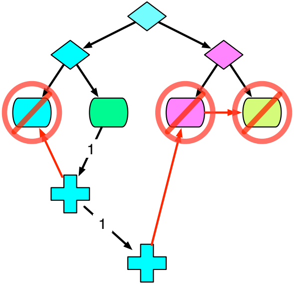
Parallel case supports speculative parallelism when we want the quickest answer (e.g., search problems). For example, consider picking a leaf of the tree:

```
fun treePick (LF n) = n
  | treePick (ND(t1, t2)) = (
      pcase treePick t1 & treePick t2
         of ? & n => n
          | n & ? => n)
```

There is some similarity with join patterns.

Parallel case *(continued ...)*





Nested data parallelism (NDP)

We support fine-grained, nested data-parallel computation using a parallel array comprehension form (NESL/Nepal/DPH):

[| *exp* **|** pat_i **in** exp_i **where** *pred* **|]**

For example, the parallel point-wise summing of two arrays:

```
[| x+y | x in xs, y in ys |]
```

NOTE: zip semantics, not Cartesian-product semantics.

Nested data parallelism *(continued ...)*

Mandelbrot set computation:

```
fun x i = x0 + dx * itof i;
fun y j = y0 - dy * itof j;
fun loop (cnt, re, im) =
      if (cnt < 255) andalso (re*re + im*im > 4.0)
        then loop(cnt+1, re*re - re*im + re, 2.0*re*im + im)
        else cnt;
[|
  [| loop(0, x i, y j) | i in [| 0..N |] |]
  | j in [| 0..N |]
|]
```

Explicit threading

Based on Concurrent ML design.

- Explicit threading with preemptive scheduling. Threads may contain implicitly-threaded parallelism.
- Threads do not share state; instead they communicate and synchronize via message passing.
- Synchronization and communication abstractions are supported by the mechanism of first-class synchronous operations (called events) [PLDI '91'].
- In addition to supporting abstraction, events also provide a uniform framework for synchronous system interfaces (*e.g.*, I/O).

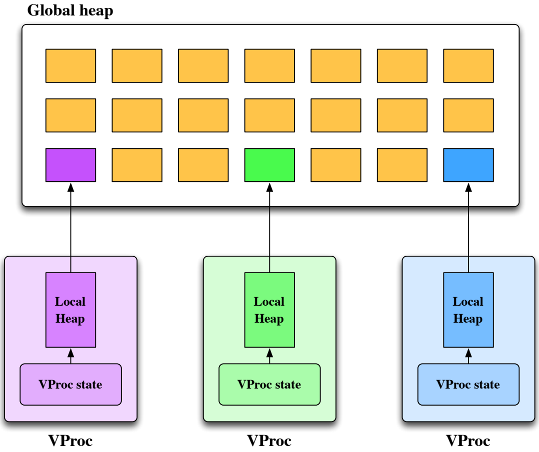
Current Status

Implementation highlights

- *De novo* implementation.
- Efficient work-stealing techniques for managing parallelism [ICFP '10; JFP '12; Rainey's PhD 2010].
- Use ropes to implement NDP [Shaw's MS '07; ICFP '11].
- New protocol for CML on SMP [ICFP '09].
- NUMA aware parallel GC [MSPC '11].

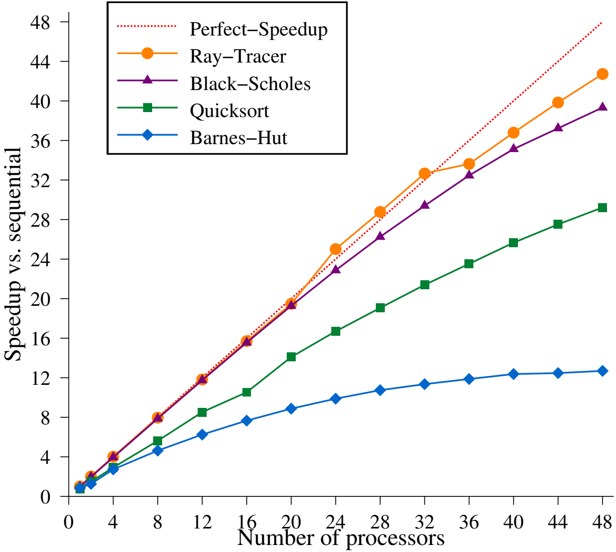
Memory model

GC is a combination of the Appel Semi-generational collector and the Doligez-Leroy-Gonthier parallel collector.



- Minor GCs are completely asynchronous.
- Major GC are mostly asynchronous.
- NUMA-aware global GCs are parallel stop-the-world.

Performance

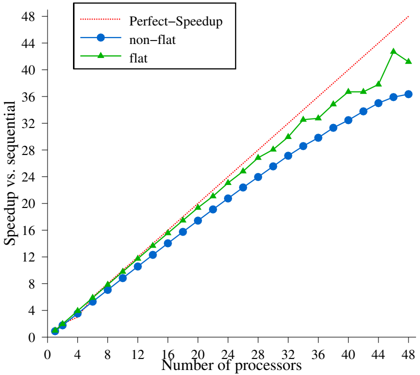


Future Work

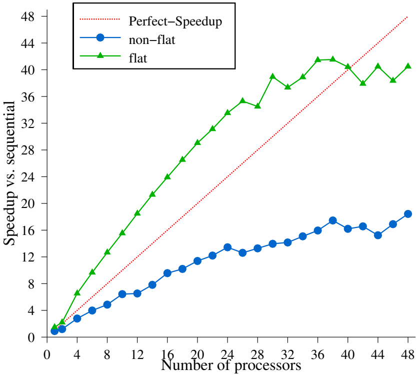
Data-only flattening

- Traditional NDP implementation techniques are based on flattening (aka vectorization).
- Manticore does not flatten NDP, but instead relies on efficient work-stealing to get NDP speedups.
- **Observation:** flattening improves data access and allows SIMD instructions, but distorts the control-flow of the program.
- New approach: flatten data representations, but not code [Shaw's Ph.D. '11]. Avoids replication problem.

Data-only flattening *(continued ...)*



Mandlebrot



SxVM

Adding shared state to PML

- Shared state can provide asymptotic performance improvements (*e.g.*, transposition tables in search).
- Shared mutable data structures lead to clearer algorithms (*e.g.*, mesh refinement).
- **Observation:** mutable shared memory is a hardware accelerated broadcast mechanism.

Adding shared state to PML *(continued ...)*

- Low-hanging fruit: idempotent state (memoization).
- Mostly-non-conflicting computations over shared data structures (*e.g.*, meshes) supported by inferred STM.
- Shared high-contention data structures with relaxed semantics (*e.g.*, shared worklists).

Implementation improvements

We have a number of projects to improve sequential performance and robustness:

- Shao-Appel closure conversion.
- Reflow analysis for better inlining.
- Switching to a modified version of MLton's front end.
- Provide complete Basis Library
- Considering possible LLVM back end.

Final comments

- Strict, pure FP is a really good base for parallelism.
- State is evil (but necessary).
- It is better to build for parallelism from the start.

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