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Automatic Parallelization and Transparent Fault Tolerance

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Trends in Functional Programming, June 8-10, 2016

Scientific Computing in our Microcosm

Local evolution of scientific computing

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- Serial Fortran programs
  Simple, imperative.

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- Serial Fortran programs
- C
  Similar. More pleasant syntax (Free form source code!)

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- Vendor communication libraries
  Non-portable, but parallel

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- MPI everywhere (inter- and intra-node)
  De facto standard emerges to solve portability

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- MPI everywhere (inter- and intra-node)
- C++
  Object oriented goodness (and more!)

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- MPI everywhere (inter- and intra-node)
- C++
- MPI+{Pthreads, OpenMP, OpenCL, CUDA, etc}
  We augment MPI now with other explicit parallel models

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- MPI everywhere (inter- and intra-node)
- C++
- MPI+{Pthreads, OpenMP, OpenCL, CUDA, etc}
- Parallel runtimes, e.g., Cilk Plus, Intel Threading Building Blocks, Stanford's Legion, etc.
  Automated scheduling for irregularly shaped problems.

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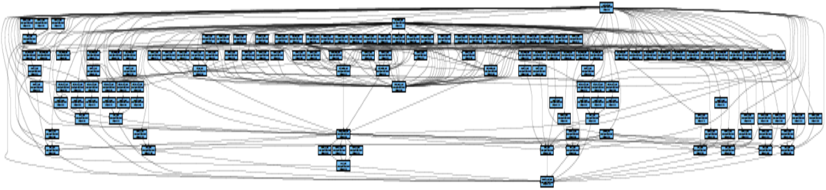
Currently MPI+threading model dominates.

In Search of Automatic Parallelization
or at least automatic scheduling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S3D task dependency, combustion chemistry calculation

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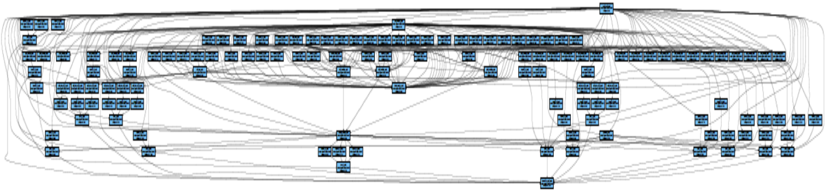 [1]

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Simplest interesting chemistry, task graph much larger with more complex reactants. Schedule by hand?

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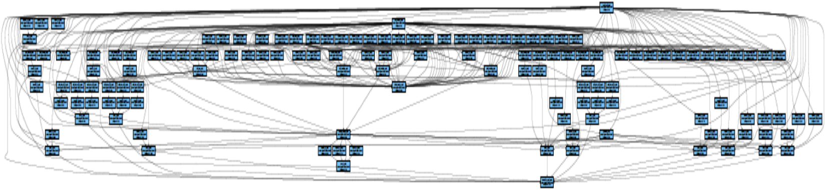

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This comes for free in the pure functional world

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Transparent Fault Tolerance?

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Obviously, we can't just hope to get lucky on a months-long calculation

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2. Stop the world;
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With referential transparency, this is a much smaller problem

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But, these are not computer scientists:

- Passing functions as arguments is familiar (since early Fortran).
- Implicit space leaks are confusing.
- Non-strict evaluation is largely irrelevant.
- Unboxed primitives and arrays of the same (unboxed vector) are the primary data.

Claimed Trends

Trends in functional programming

- Appreciation of the virtues of strict-by-default semantics.
  GHC Strict and StrictData for HPC

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Trends in functional programming

- Appreciation of the virtues of strict-by-default semantics.
- Transparent fault tolerance.
  Stewart's HdpH-RS

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Trends in scientific computing

- Implementation of pure functional computational concepts/components.
- Recognition that checkpoint/restart is increasingly intractable and unscalable.
  Legion is “pure with respect to *X*”
  Also adding task-restarting for fault-tolerance

Non-strictness/laziness Anathema to Parallelism

(Semantic) function strictness $\Longrightarrow$

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  Can be inconclusive.

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- Bang patterns in bindings

  Prone to error. Hard to read.

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- Par/pseq, other specifications on expressions

  Ditto.

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- Par/pseq, other specifications on expressions
- Speculative evaluation
  Difficult to get right without annotation.

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Similarly constructors.

Update: Strict `let` bindings.

Musings

Suppose we had a strict(-er) pure functional language implementation than Haskell?

- Could we keep a large number of hardware threads (e.g., up to 256) busy with *implicit* parallelism?
  - With what parallel efficiency?
    - With different scheduling strategies?

Musings

Suppose we had a strict(-er) pure functional language implementation than Haskell?

- Could we keep a large number of hardware threads (e.g., up to 256) busy with *implicit* parallelism?
  - With what parallel efficiency?
    - With different scheduling strategies?
- How often do new functional programmers/old scientific programmers make essential use of non-strictness? *(very rarely)*
  - Laziness? *(never)*

Project

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1. Haskell to STG (or Core) via GHC *(todo)*;
   STG and Core are higher-order polymorphic functional languages in their own right.

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   Fairly faithful to STG papers

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   Close to ML, syntactically

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4. Fault tolerance *TBD*.

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- Know exactly what is going on under the hood;
- There exist conduits for getting student interns up to speed inexpensively.

Technical hurdles: tail calling and unwinding the stack

Following SPJ/STG our control structure is a stack of continuations.

Each continuation contains an address to *go to next*, not *go back to*, so we want something like *goto* or *tail calling*.

SPJ identifies defines the term *code label* as something that can be

- used to name an arbitrary block of code;
- can be manipulated, i.e., stored for later use;
- can be used as the destination of a jump (not just call).

All the myriad ways in C

- setjmp/longjmp;
  Significant overhead and bookkeeping

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- setjmp/longjmp;
- giant switch;
  Ugly hack, not really linkable

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  Limited to gcc

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- trampoline, the simplest of which parameterless C functions return the address (function pointer) of where to go to next:

```
while (1) f = (*f)();
```

  Our initial implementation used this approach

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- implement an intermediate language, e.g., C--/Cmm, where tail call is primitive;

  Fun, but out of scope

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- implement an intermediate language, e.g., C--/Cmm, where tail call is primitive;
- generate assembly code, e.g., LLVM, directly.
  Ambitious. Haskell LLVM bindings are unreliable

Modern compilers to the rescue: sibling call

Clang/LLVM and GCC implement a restricted form of tail call, the *sibling* call, i.e, jump reusing the TOS frame. Here

```
void f() {
  ...
  g();
}
```

function `g` is jumped to; there is no (implicit) return following `g();`.

Critically, this also works for indirect calls to previously stored addresses.

```
    (getInfoPtr(stgCurVal.op)->entryCode)();
```

Sibling Call

The restrictions are due to the x86(-64)/*nix/C calling conventions—caller clean-up—and the possibility of pointer aliasing.

Sufficient formula for recent gcc and Clang/LLVM on Linux or Mac OS X

- Call in leaf position of CFG;
- Caller and callee have the same type signature
- No addresses taken of formal params;
- -O3.

Obviously this is not portable.

Unwinding stacks

In one version of GHC, Harris et al. identify the need to unwind thread stacks for shared memory parallelism.

Again, we do not want to contemplate using, e.g., setjmp/longjmp.

Therefore, we do not want the C main stack or Pthreads stacks to grow.

Exception: calls to the runtime.

Again, sibling call saves us.

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- Experimentation with non-trivial code
- Fault tolerance sometime thereafter

Acknowledgments

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Thank you

Questions?