LCALS: Livermore Compiler Analysis Loop Suite

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LCALS: Outline

- LCALS Overview
- LCALS Serial Performance Comparison
- LCALS Parallel Performance Comparison
- Future work
LCALs: Background

- **LCALS: Livermore Compiler Analysis Loop Suite**
  - Loop kernels designed to measure compiler performance
  - Developed by LLNL
  - [https://codesign.llnl.gov/LCALS.php](https://codesign.llnl.gov/LCALS.php)

- **Three loop subsets (30 kernels total)**
  - Subset A: Loops representative of application codes
  - Subset B: Simple, basic loops
  - Subset C: Loops extracted from “Livermore Loops coded in C”

- **Each kernel is run for three sizes (Short, Medium, Long)**

- **Each kernel is implemented in a number of “variants”**
  - RAW (traditional C usage), OpenMP, C++ template-based, etc.
LCALS: Chapel Port

- Chapel LCALS port consists of
  - ~2400 lines of framework Chapel code
  - ~2200 lines of kernel Chapel code

- Implements two kernel variants
  - RAW+Serial: 30 kernels
  - RAW+Parallel: 11 kernels
    - RAW+Parallel kernels are a modified subset of the RAW serial kernels
    - The OpenMP variant in the reference

- Performance compared vs. reference versions
  - Executed on one Cray XC40 compute node
  - 24 Intel Xeon cores per node
  - Compiled with: gcc 5.3.0
  - The following charts show results for the “Long” size
LCALS: Serial Kernel Format

• Each serial kernel follows the pattern:

```c
initArrays();
startTimer();
for (isamp=0; isamp<num_samples; isamp++) {
    for (i=0; i<len; i++) {
        <main kernel body>
    }
}
stopTimer();
```

C reference

```chapel
initArrays();
startTimer();
for isamp in 0..#num_samples {
    for i in 0..#len {
        <main kernel body>
    }
}
stopTimer();
```

Chapel

• A few kernels have additional inner loops
LCALS: Performance Comparison

Serial Kernels

Normalized time –
Serial reference is 1.0

- g++ -Ofast -fopenmp
- chpl --fast
  --no-ieee-float

- Serial Reference
- Serial Chapel
LCALS: Array Inner Multiplications

- LCALS serial performance lags C for many kernels
  - Chapel uses an integer multiply for an array’s innermost dimension
    - Unnecessary for typical arrays, only for more advanced ones
    - e.g., rank-change, reindexing of strided slices, …
  - For typical cases, adds overhead relative to C
    - Ongoing work is striving to eliminate multiplies in these cases
  - Meanwhile, can be squashed manually using a config param
    - Results in dramatic serial performance improvements for most loops…
    - …bringing them in line with C except for a few outliers
LCALS: Performance Comparison

Serial Kernels
(inner multiply removed)

Normalized time –
Serial reference is 1.0

Normalized time

Serial Reference
Serial Chapel

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**LCALS: Parallel Kernel Format**

- Parallel kernels are derived from serial kernels
- Usually one parallel loop inside the ‘num_samples’ loop

**C reference**

```c
initArrays();
startTimer();
for (isamp=0; isamp<num_samples; isamp++) {
    #pragma omp parallel for
    for (i=0; i<len; i++) {
        <main kernel body>
    }
}
stopTimer();
```

**Chapel**

```chapel
initArrays();
startTimer();
for isamp in 0..#num_samples {
    forall i in 0..#len {
        <main kernel body>
    }
}
stopTimer();
```

- A few kernels have additional inner loops
LCALS: Performance Comparison

Parallel Kernels vs. Serial Kernels

Normalized time – Serial reference is 1.0

- g++ -Ofast -fopenmp
- chpl --fast
--no-ieee-float
-s assertNoSlicing

- Serial Reference
- Parallel Chapel
- Parallel Reference
LCALS: Performance Comparison

Parallel Kernels

Normalized time –
Parallel reference is 1.0

<table>
<thead>
<tr>
<th>g++  -Ofast  -fopenmp</th>
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<tbody>
<tr>
<td>chpl  --fast</td>
</tr>
<tr>
<td>--no-ieee-float</td>
</tr>
<tr>
<td>-s  assertNoSlicing</td>
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</tbody>
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Most kernels are ~3x slower than OpenMP reference

- ...except for pressure_calc (5x) and energy_calc (9x)
- ...the two parallel kernels with multiple inner loops

These used an obvious translation:

OpenMP Reference

```c
#pragma omp parallel
{
    #pragma omp for nowait
    for (i=0; i<len; i++) {
        ...work1()...
    }
    #pragma omp for nowait
    for (i=0; i<len; i++) {
        ...work2()...
    }
}
```

Parallel Chapel

```chapel
forall i in 0..len {
    ...work1()...
}
forall i in 0..len {
    ...work2()...
}
```

Combined foralls

```chapel
forall i in 0..len {
    ...work1()...
    ...work2()...
}
```

nowait clause doesn’t have an obvious Chapel equivalent. So instead, combined consecutive forall loops.

Not always possible, but works for these kernels.
LCALS: Performance Comparison

Parallel kernels (with combined foralls)

Normalized time – Parallel reference is 1.0

<table>
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Normalized time

- Parallel Reference
- Chapel 1.13
- Combined foralls
LCALS: Parallel loop startup cost

● ‘forall’ startup is more costly than OpenMP ‘parallel for’
  ● Allocates and initializes an argument bundle per task
  ● Should be able to eliminate most of this overhead

● The parallel loops are short, even in the ‘long’ size
  ● Around 45,000 iterations in each parallel loop
  ● … split between 24 tasks
  ● … and repeated 15,000 times
  ● Magnifies startup cost difference

● Increasing the iteration count would mask the difference
  ● But need task startup improvements to match OpenMP at small sizes
LCALS: Next Steps

● Eliminate array inner multiplies when unnecessary
  ● The -sassertNoSlicing hammer is too big
  ● A new feature is planned to do this in a more principled way

● Optimize the last few uncompetitive serial kernels

● Improve task startup overhead
  ● If the problem size is increased this overhead is masked
  ● But should be able to match OpenMP performance for small loops too

● Explore more elegant Chapel loop expressions
  ● Use whole-array operations, array slicing, etc.
  ● Make sure the elegant versions perform well too
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