Using OpenMP to Detect and Speculate Dynamic DOALL Loops
(IWOMP 2020)

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DOALL Loop vs DOACROSS Loop
Loop Carried Dependences

Read After Write (RAW)

```
for(j = 1; j < n; j++)
S1: a[j] = a[j-1];
```

Write after Write (WAW)

```
for(j = 0; j < n; j++)
S1: c[j] = j;
S2: c[j+1] = 5;
```

Write after Read (WAR)

```
for(j = 0; j < n; j++)
S1: b[j] = b[j+1];
```
Loop Carried Dependences

Read After Write (RAW)
Write after Write (WAW)
Write after Read (WAR)

Bad Loops For Parallelization!

for(j = 1; j < n; j++)
    S1: a[j] = 5;
Motivation

- DOALL and DOACROSS loops can be detected
- Why Dynamic Detection and Not Static?
- 180 loops (>10% TOTAL CPU TIME)
- 45 benchmarks
- 3 benchmark suites (cBench, Parboil, Rodinia)
Motivation

ICC Vectorization report flags: -qopt-report5 and -qopt-report-phase=vec
GOAL:
Extend OpenMP to Enable Runtime Loop Analysis
Runtime Loop Analysis

- The main goal is to discover loops that can be parallelized but compilers could not determine statically that they were free of dependences.
  - Looked at the DOACROSS Loops.
  - If the Runtime Analysis says a loop has no LCD, we call it Dynamic Doall (D-DOALL). Otherwise, we call it D-DOAX.
- Runtime analysis can be more accurate and offer more loop information. Overhead is high, taking more time and memory consumption.
- Dependence Report is limited to the input used.
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Speculate Loops
- Hardware based speculation (HTM - Hardware Transactional Memory)
- Start, commit or abort transactions.
- Aborts happen when data conflicts happen or hardware capacity resources are exhausted.
Runtime Loop Analysis

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- Runtime analysis can be more accurate and offer more loop information. Overhead is high, taking more time and memory consumption.

- Dependence Report is limited to the input used.
- D-DOAX loops could be speculated too!
Metrics

- Can a loop be speculated?
- Does it has enough iterations?
- If it is DOACROSS, how many dependences?
- What is the frequency of these dependences?
# Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Visits</td>
<td>The number of times a loop was visited and fully executed.</td>
</tr>
<tr>
<td>Total Number of Iterations</td>
<td>Average number of iterations a single loop visit has.</td>
</tr>
<tr>
<td>Innermost Loop Indicator</td>
<td>Indicates if a loop is the innermost in a loop nest.</td>
</tr>
<tr>
<td>First Eviction Iteration (FEI)</td>
<td>Indicates in which iteration of a loop the first cache eviction happens.</td>
</tr>
<tr>
<td>Total Loop-Carried Dependences (LCD)</td>
<td>The total sum of unique loop-carried dependences (LCD) of a loop.</td>
</tr>
<tr>
<td>Total Loop-Carried Probability (LCP)</td>
<td>Total probability of a LCD appearing in the loop.</td>
</tr>
</tbody>
</table>
The Check Clause

- Implemented on LLVM compiler framework
- Using libtooling for source-to-source transformations
The Check Clause

Syntax:

#pragma omp parallel check (attributes)
Loop
  Loop-body
## The Check Clause Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Operation (What it Reports)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>File Name, Line Number, CPU Time, Iterations and Visits</td>
</tr>
<tr>
<td>Dependence</td>
<td>LCD, LCP, FEI, INNER</td>
</tr>
<tr>
<td>First</td>
<td>Detects if loop has at least one LCD or not</td>
</tr>
<tr>
<td>Verbose</td>
<td>Visual representation of loop dependence</td>
</tr>
</tbody>
</table>
#pragma omp parallel \
check(verbose)
for(i=0; i < N; ++i){
const int value = img[i];
if(histo[value] < UINT8_MAX) {
    ++histo[value];
}
}

define for (i=0; i <= N; ++i){
    ...
    --> if (histo[value]...}
    |  .
    |  .
    <-- >--< ++histo[value];
    .
Heuristics

- How to decide when a loop is parallelizable or not?
# Heuristics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visits</td>
<td>Lower or equal to 1000</td>
</tr>
<tr>
<td>ITER</td>
<td>Higher or equal to 2</td>
</tr>
<tr>
<td>LCD</td>
<td>If LCP is higher than 30%, LCD is at most 15; Else, LCD is at most 30.</td>
</tr>
<tr>
<td>FEI (condition 1)</td>
<td>If FEI&gt;1, Loop is parallelizable</td>
</tr>
</tbody>
</table>
| FEI (condition 2)| If FEI = 1, Search through perfect nested loops until a loop that satisfies these two conditions is found:  
                      ● Visits is lower or equal to 1 Million  
                      ● FEI>1 |
Experimental Results
## Do the Heuristics Work?

<table>
<thead>
<tr>
<th>ID</th>
<th>Benchmark</th>
<th>Filename</th>
<th>Line</th>
<th>%</th>
<th>Total(s)</th>
<th>Mean(s)</th>
<th>Type</th>
<th>Visits</th>
<th>INNER</th>
<th>ITER</th>
<th>FEI</th>
<th>LCP</th>
<th>LCD</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>sad</td>
<td>sad_cpu.c</td>
<td>39</td>
<td>96.88</td>
<td>52.29</td>
<td>7.80e-01</td>
<td>D-DOALL</td>
<td>67</td>
<td>NO</td>
<td>120.0</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>sad</td>
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<td>69</td>
<td>96.88</td>
<td>52.29</td>
<td>6.50e-03</td>
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<td>20</td>
<td>96.70</td>
<td>13</td>
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<td>D-DOAX</td>
<td>8755560</td>
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<td>D-DOALL</td>
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Do the Heuristics Work?
Do the Heuristics Work?

1.92x Speedup!
Breakdown without Heuristics

- D-DOAX
- D-DOALL
- DOALL

Bar chart showing the breakdown of cBench, Parboil, and Rodinia without heuristics.
Breakdown With Heuristics

- NON-PAR
- D-DOAX
- D-DOALL
- DOALL

cBench | Parboil | Rodinia
---|---|---
0% | 25% | 25%
25% | 50% | 50%
50% | 75% | 75%
75% | 100% | 100%
Conclusion

- 36% of loops with parallelization opportunities are missed by compilers. (53 out of 167)
- Compilers only manage to determine 7.8% of the loops to be DOALL. (13 out of 180)
- Future work is to exploit these opportunities.
Thank you!