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Design and Implementation of A Compiler Framework for Helper Threading on Multi-Core Processors

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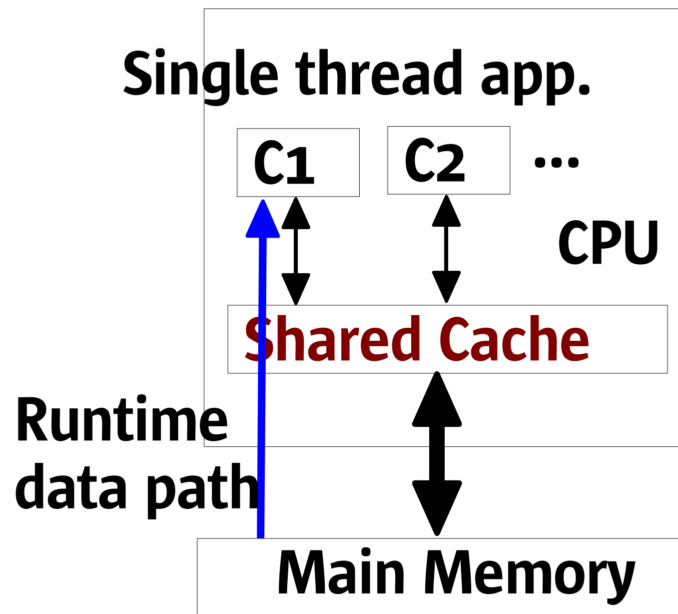
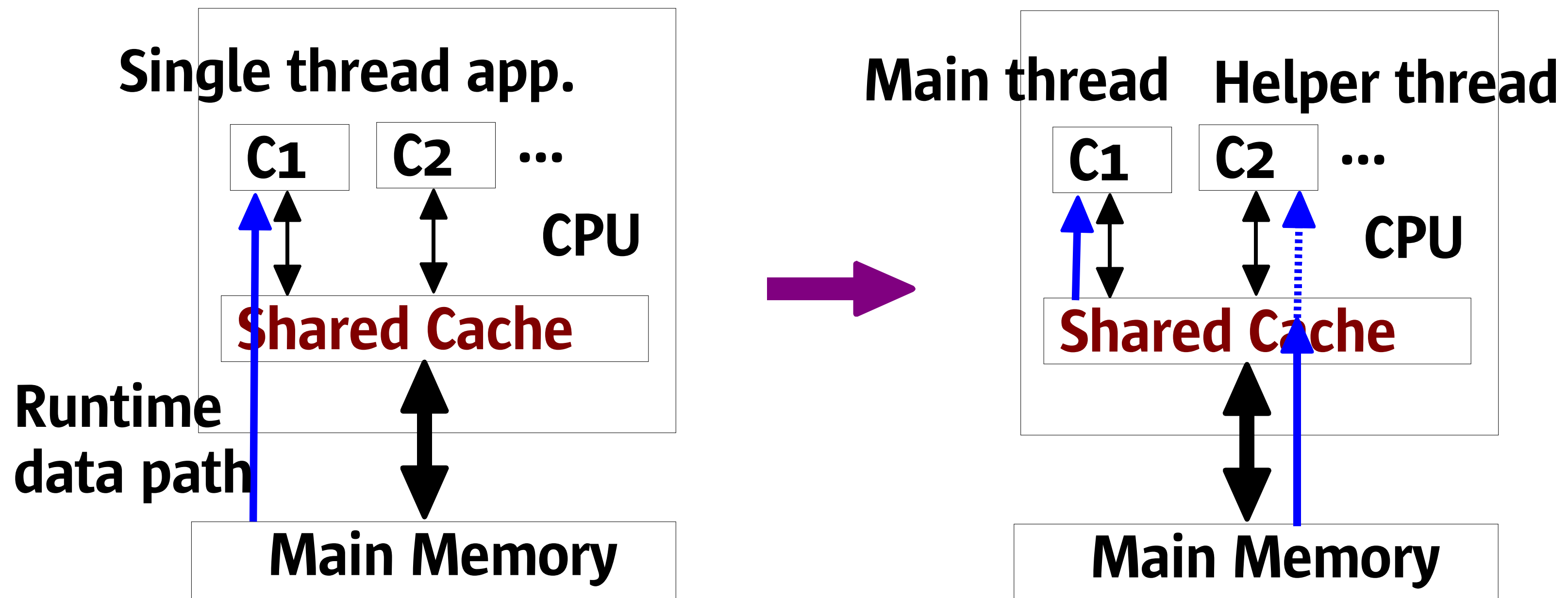
Remember Single-Threaded Application Performance!

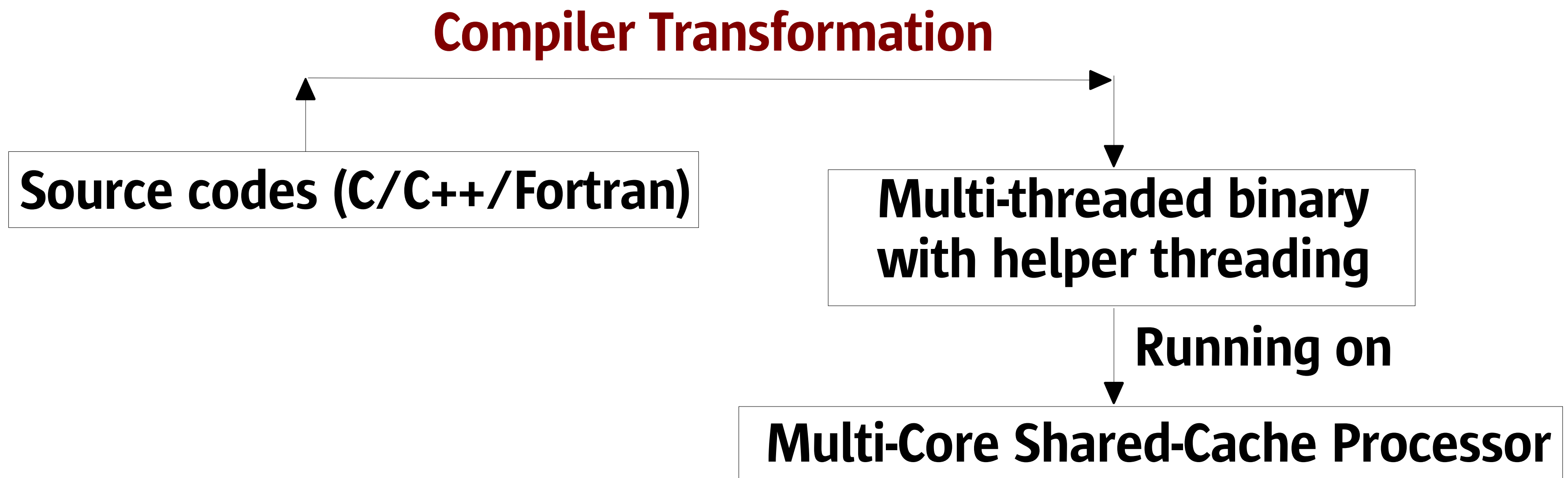
Single Thread Application



Helper Threading



Compiler Framework



Outline

- Motivation for helper threading
- Design requirements
- The compiler framework
- Performance results
- Related works
- Conclusions

Motivation

- Interleaved prefetching in single-threaded applications
- Not effective when
  - Large overhead to compute future even-predictable addresses (e.g., a[index[i]])
  - Pointer-chasing codes

Design Requirements

- Existing hardware
- Avoid slowdown of the main thread
- Ensure the helper thread doing useful work

Helper Thread

- A stripped original code
  - Helper thread expected to run faster than the main thread
- No user visible side effect
- Necessary synchronization code with the main thread

Original Example Code

```
while (p->val > VAL) {
  if (p->data != 0) {
     q = p->data;
     while (q) {
        q->data = c;
        q = q->next;
     }
  }
  p = p->next;
}
```

Potential Benefit

- Ld/st ===> prefetch in helper thread
- Effective prefetch candidates
  - Lds not used to compute branch cond or addess of another ld/st
  - Prefetch analysis disqualify ld/st's hit in the cache

Effective Prefetch Candidate

```
while (p->val > VAL) {
  if (p->data != 0) {
    q = p->data;
    while (q) {
      q->data = c;
      q = q->next;
    }
  }
  p = p->next;
}
```

Effective prefetch candidate

Prefetch (&(q->data))

Computing Benefit

- $\sum$ est_cache_miss_rate * cache_miss_penalty * est_access_count, for all effective prefetch candidates
- Estimated cache miss rate (main thread interleaved?, addr complexity?)
- Access count (compiler analysis, profile feedback, symbolic analysis, predefined)

Profitability

- Cost: startup cost and parameter passing
- Profitable if benefit > cost
- If the access count expressed symbolically, two versioning: one for helper threading and the other for serial execution

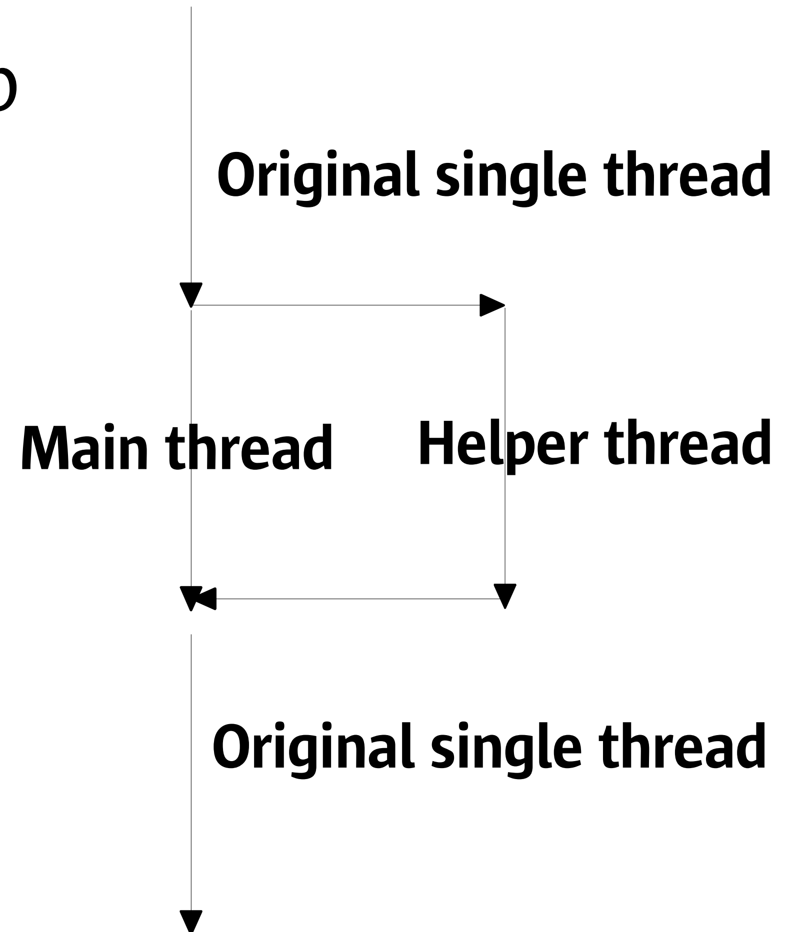
Selecting Candidate Loops

- Loop hierarchy outside-to-inside
- Outer loop possible to amortize startup cost and maximize benefit
  - Large access counts

Code Generation

- Two iteration parallel loop

```
for (t = 0; t <= 1; t++) {
  if (t == 0) {
    <original_code>
  } else {
    <helper_thread_code>
  }
}
```



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Generating Helper Thread (1)

- Data flow/control flow based slicing
- Start with condition codes and effective prefetch candidate address computation
- Effective prefetch candidates to prefetches
- Other loads to speculative loads
- Scalar renaming for live-out scalars

Generating Helper Thread (2)

```
<helper_thread_code>:
 /* assume p live-out, q not */
 tmp_p = p;
 while (tmp_p->val > VAL) {
    if (tmp_p->data != 0) {
       q = tmp_p->data;
       while (q) {
          prefetch (&q->data);
          q = q->next;
       }
    }
    tmp_p = tmp_p->next;
 }
```

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Sync With Main Thread

```
is_mt_done = FALSE;
for (t = 0; t <= 1; t++) {
  if (t == 0) {
     <original_code>
     is_mt_done = TRUE;
  } else {
     <helper_thread_code2>
  }
}
```

- Helper thread may lag behind the main thread

```
<helper_thread_code2>:
if (is_mt_done == FALSE) {
   tmp_p = p;
   tmp_c = 0;
   while (tmp_p->val > VAL) {
      if (tmp_p->data != 0) {
         q = tmp_p->data;
         while (q) {
            prefetch (&q->data);
            q = q->next;
            <check_code>
         }
      }
      tmp_p = tmp_p->next;
      <check_code>
   }
}
next:
```

```
<check_code>:
if (tmp_c >= check_c) {
   if (is_mt_done == TRUE) {
      goto next;
   }
   tmp_c = 0;
}
tmp_c = tmp_c + 1;
```

- Permits inexact control flow in helper thread

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Avoiding Slowdown of Main Thread

- Helper thread for a particular instance could lag behind or be skipped
- Main thread should not wait for helper thread

Problem?

- Certain shared data, passed from the main thread to the helper thread, allocated on the heap
- Helper thread could be skipped!
- Potential out-of-memory issue unless proper freeing allocated heap memory

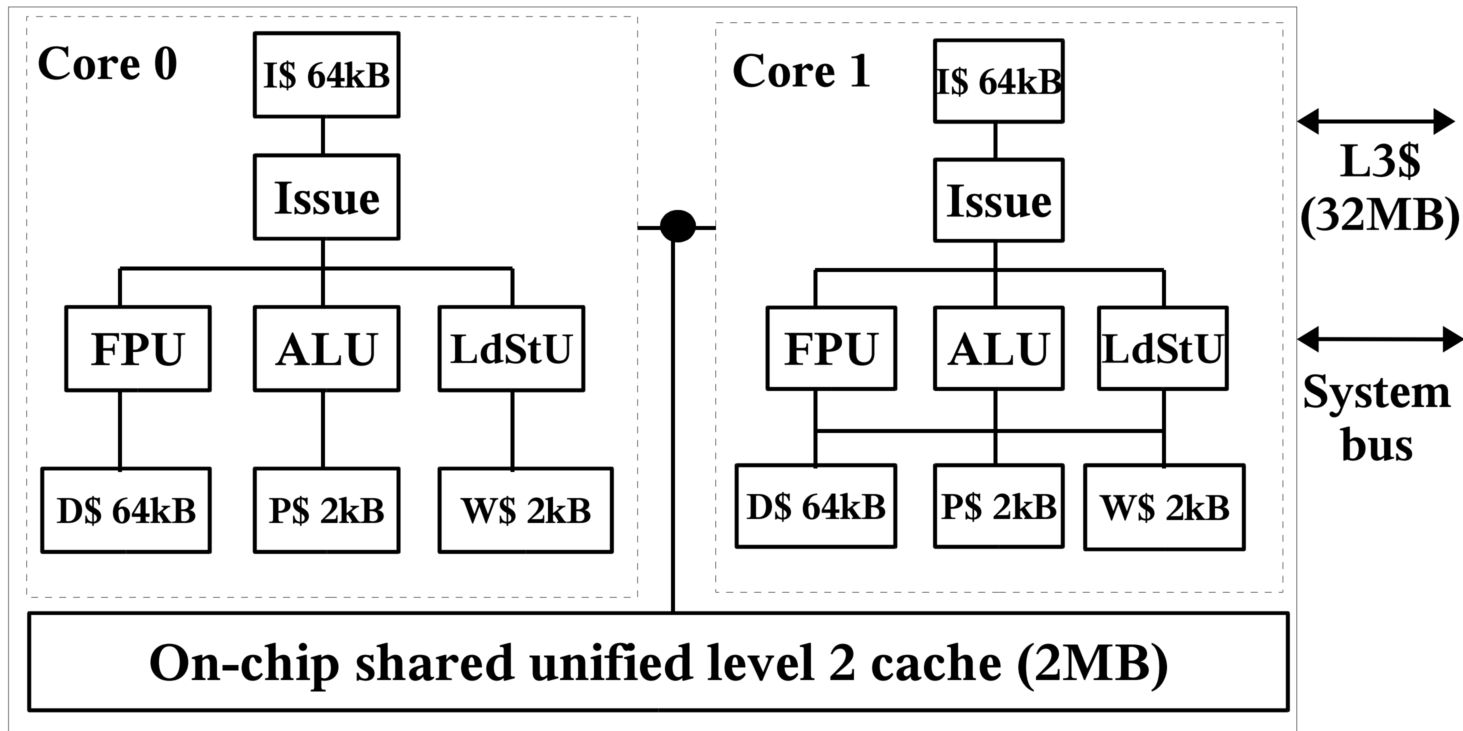
Solution

- Free those shared data inside parallelization runtime by both main thread and helper thread
- Another communication between main thread and helper thread
- Protected by common locks

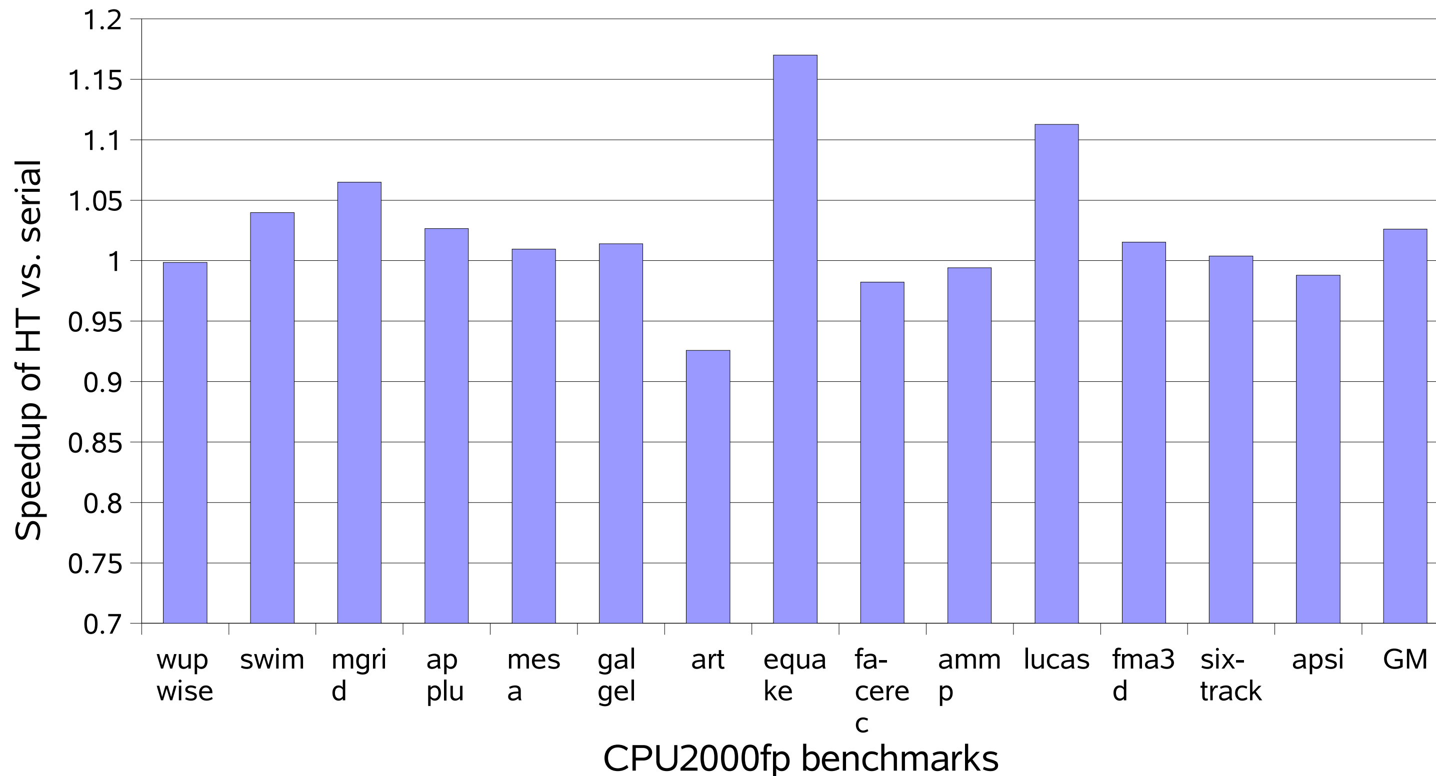
Experiment Methodoligies

- Implemented based on SUN's production compiler
- SPEC CPU2000 benchmark suite
- SUN's UltraSPARC IV+ processor
- Compared to best published serial results

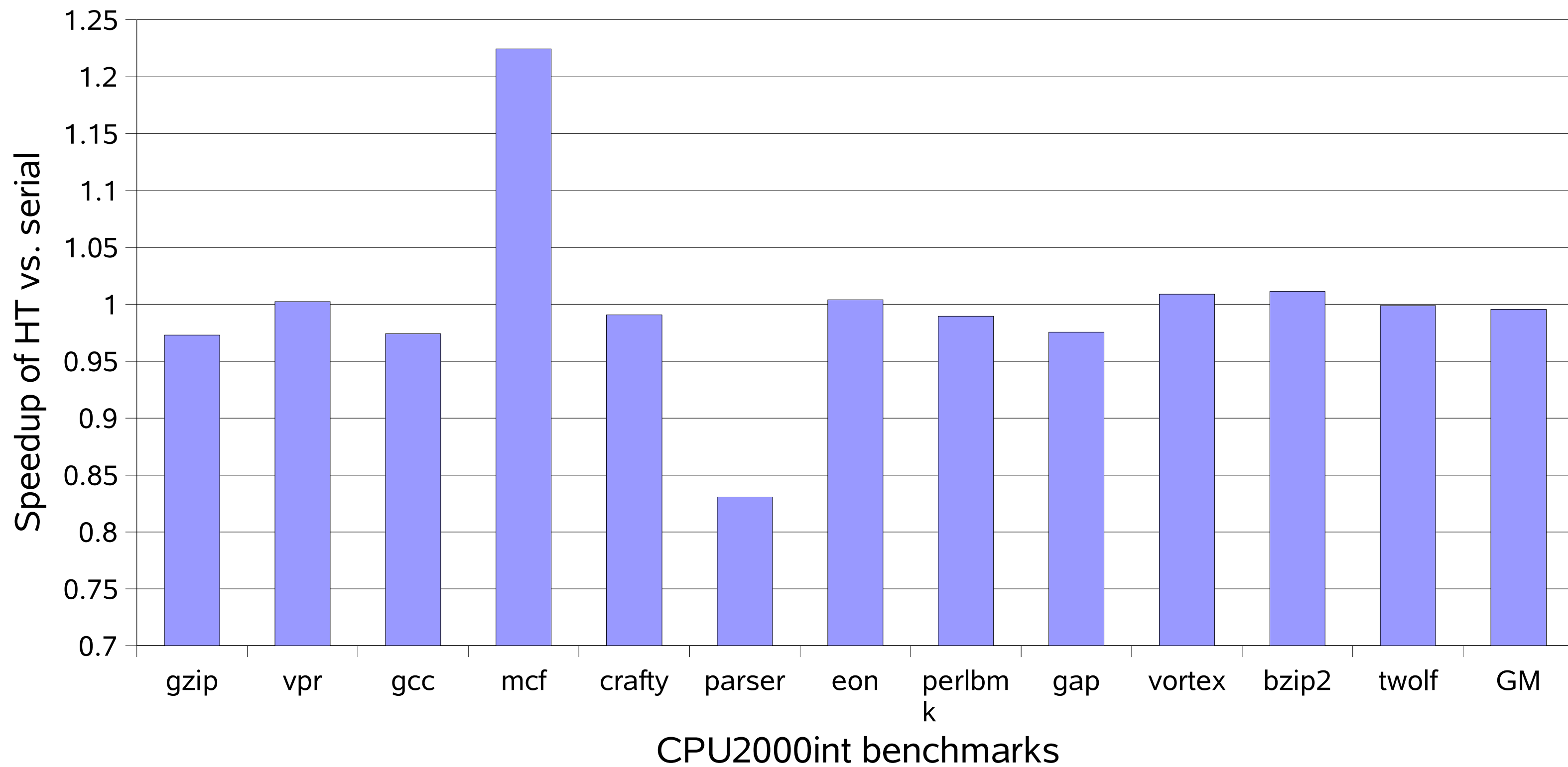
UltraSPARC IV+ Processor



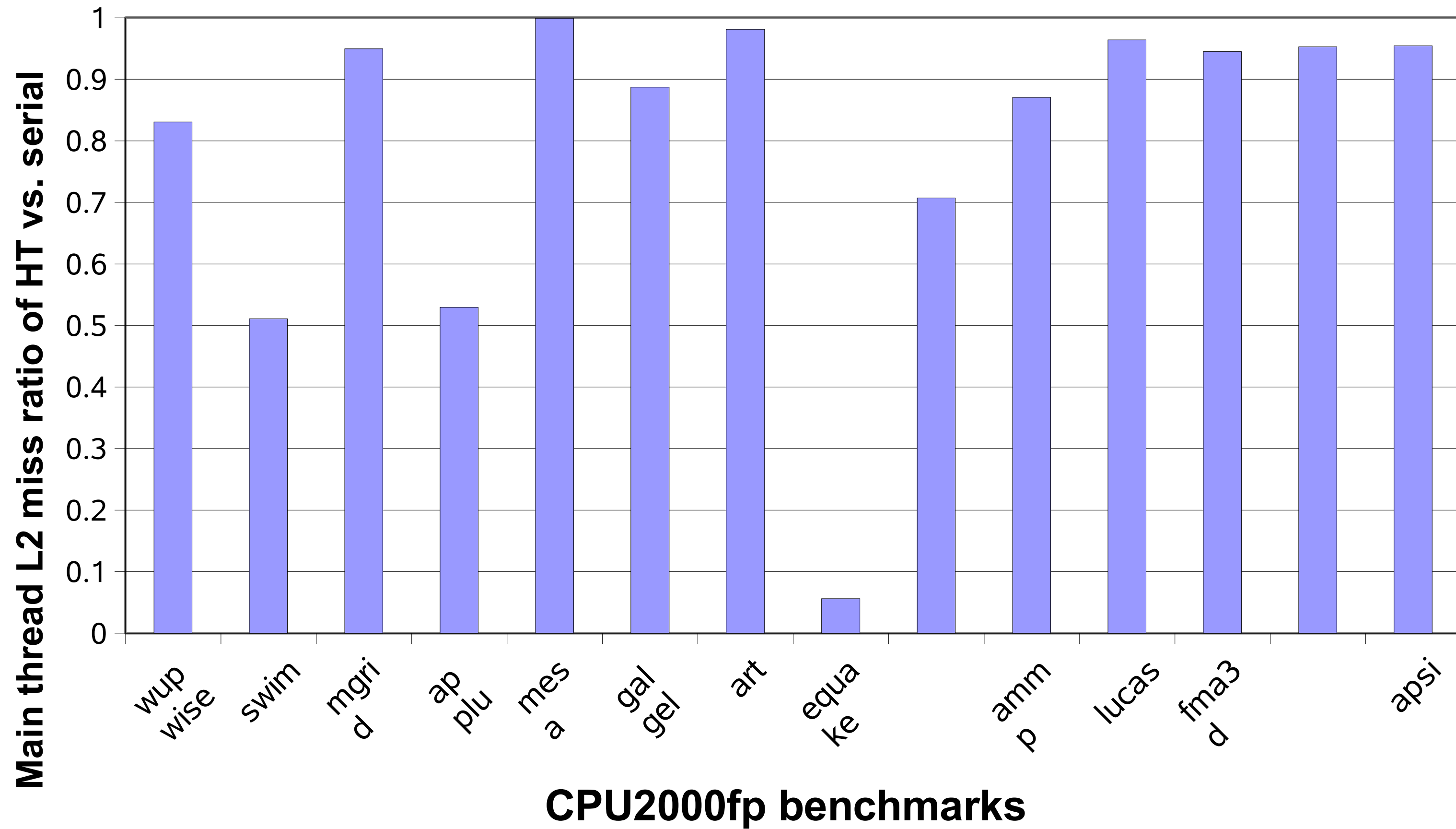
Performance (HT vs. Serial)



Performance (HT vs. Serial)



L2 Cache Misses (HT vs. Serial)



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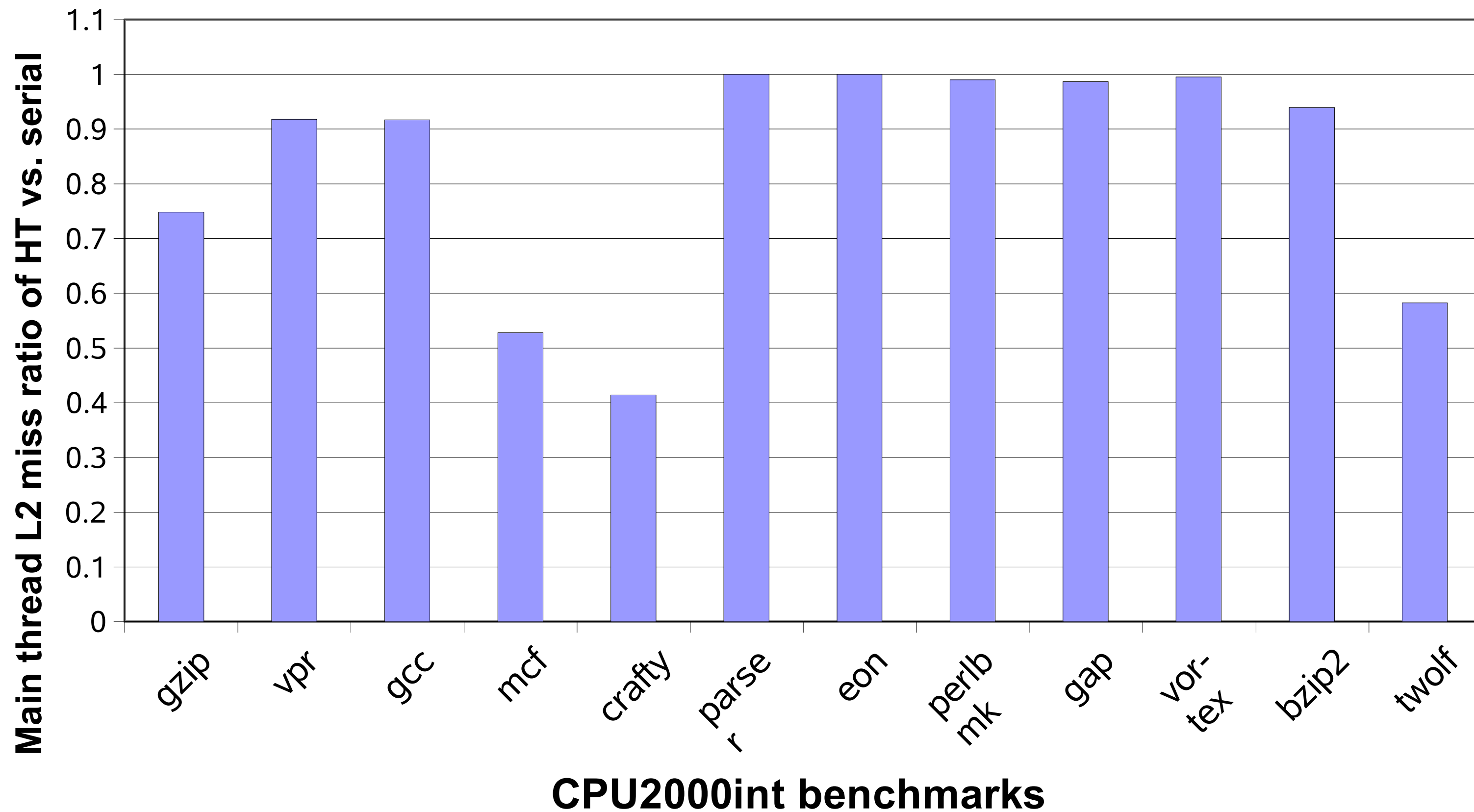
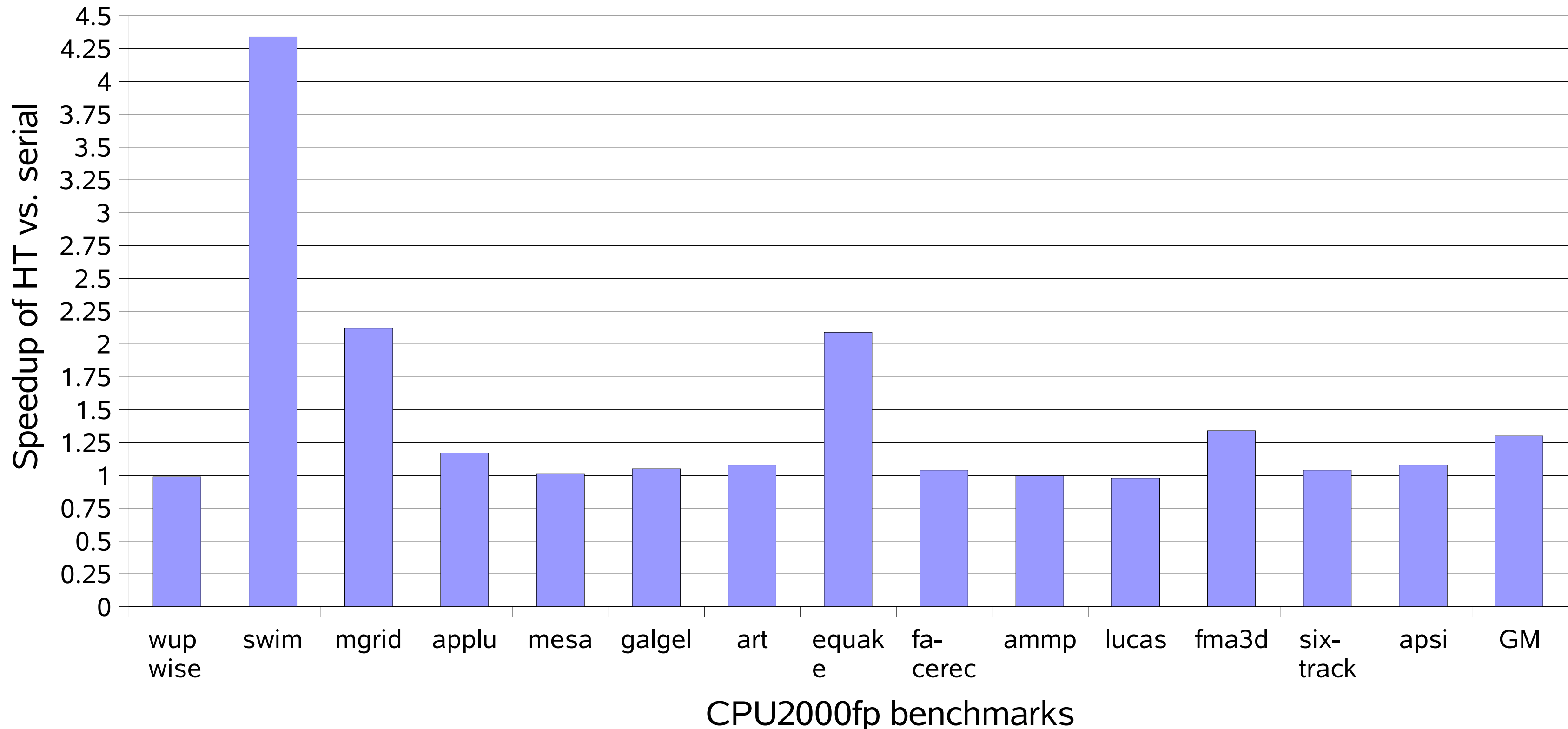
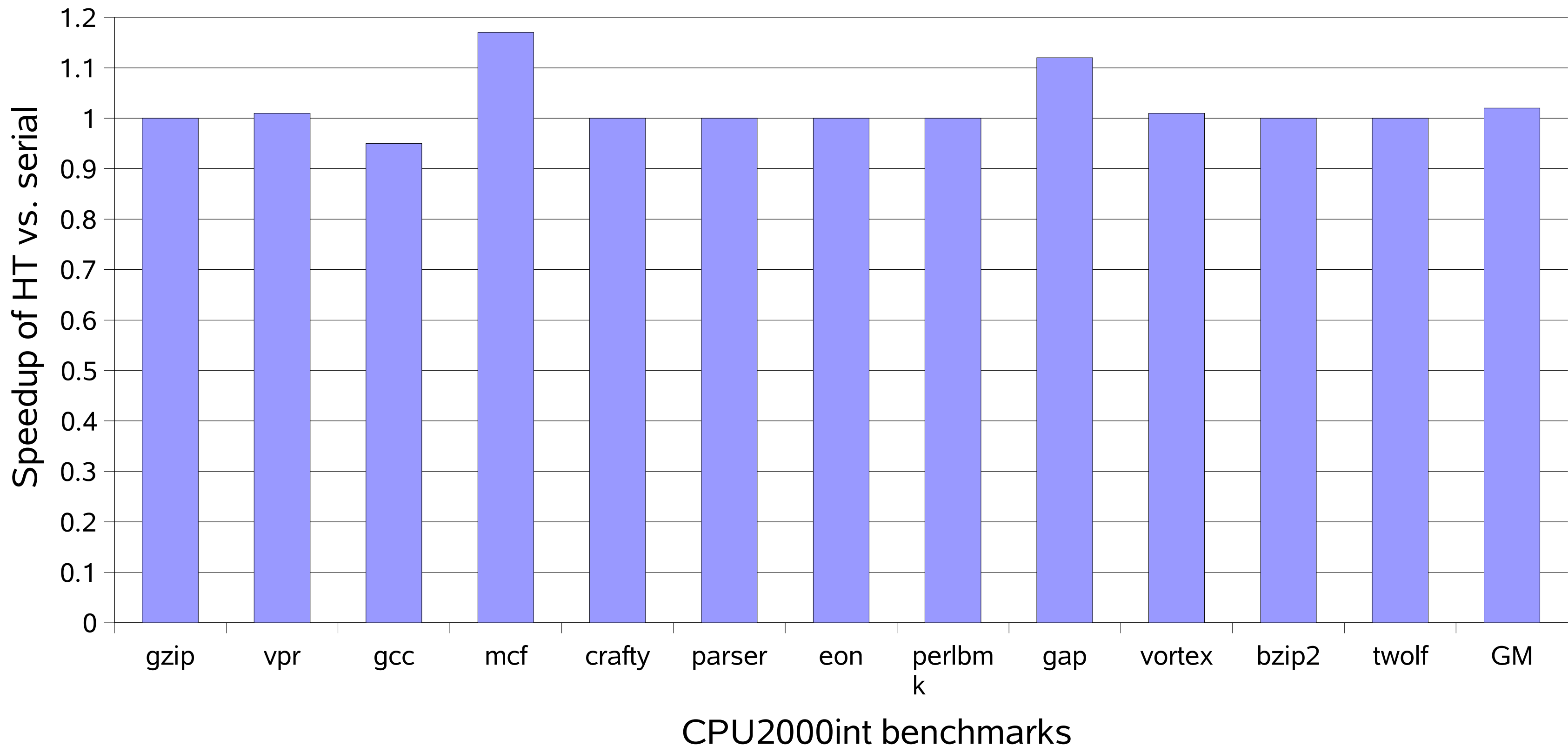


Performance (HT vs. Serial)



HT: no interleaved prefetching in main thread
Serial: no interleaved prefetching

Performance (HT vs. Serial)



HT: no interleaved prefetching in main thread
Serial: no interleaved prefetching

Related Works

- Source-level helper threading (pre-execution) code generation ([ASPLOS02, TOCS04] by Kim et al.)
- Post-binary helper threading code generation ([PLDI02] by Liao et al., [ISCA01] by Luk, ...)
- Runtime helper threading code generation ([ICS01] by Moshovos et al.)

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Conclusions

- Helper threading can deliver perf improvement
- To further improve perf: cache profiling, better runtime, hardware support, various heuristic improvement, ...