Adding Parallelism with Intel® Parallel Studio: No Parallelism Experience Required

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Developer Products Division
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Agenda

• Overview
• Find where parallelism can be usefully added to a program
• Fix the parts of the program that prevent parallelism
• Add parallelism
• Test the revised program for correctness and performance
• Don’t panic
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Overview – adding parallelism

• What is parallelism?
  – Overlapping portions of a serial algorithm, so it runs faster
    • Eg: Search both sides of a tree at the same time

• Start with a serial algorithm

• Modify it to be a parallel-ready serial algorithm

• Add code to
  – Perform statements in parallel
  – Synchronize the sharing of common resources

Analysis, preparation and testing of the serial code is key to simplifying adding parallelism
Overview - the tools

- **Decide where to add the parallelism**
  - Analyze the serial program
  - Prepare it for parallelism
  - Test the preparations

- **Add the parallelism**
  - Cilk, Intel® Threading Building Blocks, OpenMP*, o/s threads

- **Find logic problems**
  - Only fails sometimes
  - Place of failure changes

- **Find performance problems**

Adding and using parallelism requires enhanced tools
Overview - Intel Parallel Advisor

original serial C/C++ program
Overview - Intel Parallel Advisor

Run Survey tool to measure where your application is spending time
Overview - Intel Parallel Advisor

- Run Survey tool to measure where your application is spending time.
- Add annotations to describe how you might divide the work of the hot-spot into parallel tasks.

Original serial C/C++ program

Advisor Survey tool

Annotated serial C/C++ program
Overview - Intel Parallel Advisor

The annotated program still has serial semantics. Working on it is just normal programming.
Overview - Intel Parallel Advisor

Use the performance modeling (suitability) and race detection (Correctness) tools to identify potential issues.

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Adjust the annotations or the program code itself to resolve performance and correctness issues.
Overview – Intel Parallel Advisor

The final version of the annotated program is projected to have good performance and no races.
Now, it’s time to change the annotations into real parallel code – TBB or Cilk or your favorite model. This straightforward translation is done by the programmer.
Overview - Intel Parallel Advisor

Use the other tools in Intel Parallel Studio to work with your parallel application (compile, debug, tune, etc)

parallel C/C++ program

other tools

Intel Parallel Studio
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Finding where to add parallelism

• Find steps which are using lots of time

• Measure the number of steps needed to make a good size task

• Find how the steps interact

Analyze, don’t guess. Computers are good at analysis.
Tachyon Ray-tracer: Serial
Finding where to add parallelism

- Find steps which are using lots of time
  - Profile the serial algorithm: production build+ data
  - Find outer calls/loops that take lots of time, and that the architect thinks could be done in parallel
Survey Report - Profile: Hot Call Chain(s)

<table>
<thead>
<tr>
<th>Function</th>
<th>Self Time</th>
<th>Total Time</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0s</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>GdipTranslateWorldTransform</td>
<td>0s</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>thread_video</td>
<td>0s</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>tachyon_video::on_process</td>
<td>0s</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>r_t_renderscene</td>
<td>0s</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>renderscene</td>
<td>0s</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>trace_region</td>
<td>0s</td>
<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>trace_shm</td>
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<td>100.0%</td>
<td></td>
</tr>
<tr>
<td>thread_trace</td>
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<td>100.0%</td>
<td></td>
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<td>33.3%</td>
<td>shade.cpp</td>
</tr>
<tr>
<td>shader::reflection</td>
<td>0s</td>
<td>33.0%</td>
<td>shade.cpp</td>
</tr>
<tr>
<td>trace</td>
<td>0s</td>
<td>33.0%</td>
<td>shade.cpp</td>
</tr>
<tr>
<td>shader</td>
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<td>shade.cpp</td>
</tr>
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<td>15.5%</td>
<td>shade.cpp</td>
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<td>shade.cpp</td>
</tr>
<tr>
<td>Shader</td>
<td>7.5%</td>
<td></td>
<td>shade.cpp</td>
</tr>
<tr>
<td>shader::reflection</td>
<td>0s</td>
<td>7.9%</td>
<td>shade.cpp</td>
</tr>
<tr>
<td>shader</td>
<td>1.575e-002s</td>
<td>7.9%</td>
<td>trace.cpp</td>
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<tr>
<td>shader::intersection</td>
<td>0s</td>
<td>3.2%</td>
<td>shade.cpp</td>
</tr>
<tr>
<td>shader::loop</td>
<td>0s</td>
<td>2.7%</td>
<td>shader.cpp</td>
</tr>
<tr>
<td>shader::intersect_objects</td>
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<td>1.9%</td>
<td>intersect.cpp</td>
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<td>3.9%</td>
<td>shader.cpp</td>
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<tr>
<td>shader::loop</td>
<td>0s</td>
<td>3.6%</td>
<td>shader.cpp</td>
</tr>
<tr>
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<td>0s</td>
<td>8.7%</td>
<td>shader.cpp</td>
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<tr>
<td>shader::loop</td>
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<td>8.6%</td>
<td>shader.cpp</td>
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<td>shader::loop</td>
<td>3.242e-002s</td>
<td>0.2%</td>
<td>vector.cpp</td>
</tr>
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</table>

**Beta appearance**
Finding where to add parallelism

- Annotate the chosen sites and tasks
  - Sites contain where the tasks start, won’t exit until the contained tasks end
  - Tasks are modeled as if they run in parallel

```c
for (int s2 = 0; s2 < s2Count; s2++) {
    ANNOTATE_SITE_BEGIN(s2)
    delay();
    char lock;
    for (int t2 = 0; t2 < t2Count; t2++) {
        ANNOTATE_TASK_BEGIN(t2)
        ANNOTATE_LOCK_ACQUIRE(&lock)
        delay();
        ANNOTATE_LOCK_RELEASE(&lock)
    }
    ANNOTATE_TASK_END(t2)
}
ANNOTATE_SITE_END(s2)
```

Macro use expands to a call to a stub function that can be hooked
Finding where to add parallelism

• Measure the site and task times
  – Profile the annotated algorithm: release program + data
  – Annotations in bad places may slow execution

• How the measurement is done
  – Runtime binary instrumentation (Pin)
    • Intercept the calls to the stub functions
  – Measure the times between the calls
    • Uses the QPC() function and _rdtsc instruction
  – Compress and write to disk
    • Same as the other Intel Parallel Studio tools
  – Analyze
    • To understand the counts and times of the site, task, and lock execution
Suitability Report - *Model Parallel Performance*

**All Sites**

- **Modeling for:**
  - Target CPU Number: 32
  - Threading Model: Intel TBB

<table>
<thead>
<tr>
<th>Annotation</th>
<th>Label</th>
<th>Source</th>
<th>Instances</th>
<th>Self Time</th>
<th>Max Time</th>
<th>Average Time</th>
<th>Min Time</th>
<th>Deviation</th>
<th>Site Max Gain</th>
<th>Program Max Gain</th>
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<tr>
<td>Site</td>
<td>allRows</td>
<td>tachyon_annotated.cpp:155</td>
<td>1</td>
<td>11.69</td>
<td>11.69</td>
<td>11.69</td>
<td>11.69</td>
<td>0</td>
<td>27.61</td>
<td>27.61</td>
</tr>
</tbody>
</table>

**Selected Site**

- **Choose overhead items that you will fix for this site**
  - Site Overhead
  - Task Overhead
  - Lock Overhead
  - Lock Contention
  - Enable Chunking

<table>
<thead>
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<th>Self Time</th>
<th>Average Time</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task</td>
<td>eachRow</td>
<td>tachyon_annotated.cpp:155</td>
<td>512</td>
<td>11.65</td>
<td>2.276e-002</td>
<td>0</td>
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</table>

*Beta appearance*
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Finding code preventing parallelism

- Intel® Parallel Advisor runs the annotated *serial* program
  - It is serial, so violations of data dependencies don’t crash the run

- Binary instrumentation (Pin) watches memory traffic and annotations
  - Use small data sets
    - Slow-down can be substantial

- Analyzes the data to determine what could go wrong when the tasks are done in parallel
  - Use debug builds, so problems can be mapped to sources

- Only memory sharing issues and locking problems are found
Correctness Report - **Model Parallel Behavior**

### Memory Reuse: Observations

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Source</th>
<th>Function</th>
<th>Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>X4</td>
<td>Parallel site</td>
<td>tachyon_annotated.cpp</td>
<td>parallel_thread</td>
<td>2_tachyon_annotated.exe</td>
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<tr>
<td>X5</td>
<td>Write</td>
<td>tachyon_annotated.cpp</td>
<td>render_one_pixel</td>
<td>2_tachyon_annotated.exe</td>
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<tr>
<td>X6</td>
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<td>tachyon_annotated.cpp</td>
<td>parallel_thread</td>
<td>2_tachyon_annotated.exe</td>
</tr>
<tr>
<td>X7</td>
<td>Read</td>
<td>tachyon_annotated.cpp</td>
<td>render_one_pixel</td>
<td>2_tachyon_annotated.exe</td>
</tr>
</tbody>
</table>
Source for *Data Communication Error (Race)*

**Did the annotated tasks expose data sharing problems? (Source)**

**Focus Observation:** winvideo.h:266 - Read

```c
263   //ADVISOR COMMENT: Don't forget to uncomment the #include "annotat
264   //ADVISOR COMMENT: Alternatively, the lock can be put around the c
265   //ANNOTATE_LOCK_ACQUIRE(0)
266   g_updates++; // fast but inaccurate counter - race condition is ac
267   //ANNOTATE_LOCK_RELEASE(0)
268   if(!threaded) while(loop_once(this));
269   else if(g_handles[1]) {
270     SetEvent(g_handles[1]);
```

**Related Observation:** winvideo.h:266 - Write

```c
264   //ADVISOR COMMENT: Alternatively, the lock can be put around the c
265   //ANNOTATE_LOCK_ACQUIRE(0)
266   g_updates++; // fast but inaccurate counter - race condition is ac
267   //ANNOTATE_LOCK_RELEASE(0)
268   if(!threaded) while(loop_once(this));
269   else if(g_handles[1]) {
270     SetEvent(g_handles[1]);
271     YIELD TO THREAD();
```

**Beta appearance**

**Data communication: Observations**

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Source</th>
<th>Function</th>
<th>Module</th>
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</thead>
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<td>Parallel site</td>
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<td>parallel_thread</td>
<td>2_tachyon_annotated.exe</td>
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<tr>
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<td>next_frame</td>
<td>2_tachyon_annotated.exe</td>
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<tr>
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<td>Read</td>
<td>winvideo.h:266</td>
<td>next_frame</td>
<td>2_tachyon_annotated.exe</td>
</tr>
</tbody>
</table>
Resolving roadblocks to parallelism

• Change the serial code to remove these
  – Debug these changes like you do any other change

• Learn about and use existing parallelized libraries; or thread-safe libraries

• Use per-task resources rather than shared resources
  – local variables, own files, other resources

• Use reductions
  – Supported directly by Cilk, Intel® TBB, OpenMP™

• Use locks only if none of the above are suitable

Fix the issues in the serial code
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Adding parallelism

• Choose your parallel framework
  – Will depend on your programming language, portability needs, future growth needs
    • Cilk, Intel® Threading Building Blocks (Intel® TBB), OpenMP®, o/s threads
    • Intel® Parallel Composer supports these

• Modify your build and deployment environments
  – Compiler switches
  – Libraries may need to be installed on target machines

• Insert parallel framework statements for each annotation, implementing its “parallel” semantics

Choose the best framework for you
Tachyon - Parallel (Intel TBB), 4 cores

Appears divided into quarters

Thread stealing to finish
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Correctness and Performance

• Parallel programs are sensitive to timing issues
  – A failure may only happen only a few times in a million runs of the program, or only on some hardware
  – Intel® Parallel Advisor correctness analysis depends on the annotations matching what you implemented
  – Intel® Parallel Inspector detects problems that may happen, even if they did not happen this time

• Parallel program timings are sensitive to task sizes, thread interactions, memory caches
  – Intel® Parallel Amplifier measures where the time is spent

Measure, don’t guess
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Don’t Panic

• Parallel programming has been around for a long time, and is perceived as very difficult

• But any programmer can do it and get worthwhile benefits IF
  – They go step by step
  – They use modern frameworks and tools
  – They avoid the more complex techniques

• Intel® Parallel Advisor documentation introduces the programmer to this world
Summary

• Analysis, preparation and testing of the serial code simplifies adding parallelism
• Adding and using parallelism requires enhanced tools

• Analyze, don’t guess, where to add
• Fix the issues in the serial code
• Choose the best parallel framework for you
• Measure, don’t guess, performance issues
• Intel® Parallel Studio helps with each step
Additional sources of information on this topic:


- Search the internet for
  - “Intel Parallel Studio”
  - “Intel Parallel Advisor”
  - “TBB”
  - “Cilk”
  - …

  - Especially anything from James Reinders
Q&A
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