Application parallelization for multi-core Android devices

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Multi-core ARM and Android conquer the world

- Google Nexus 10
  2-core Samsung A15

- Asus Transformer Prime
  “4”-core Nvidia Tegra3

- HTC J Butterfly
  4-core Qualcomm

- Samsung Galaxy SIII
  4-core Samsung

- Sony Experia P
  2-core ST-Ericsson

- Huawei Honor2
  4-core Huawei
Multi-core usage in Mobile

- 2 core processors:
  Assume the OS has **multiple processes** and/or kernel threads to occupy the two cores. *Easy!*

- 4 core processors (and beyond):
  Requires **multi-threaded applications** *Hard!*
    - To obtain sufficient concurrent workload
    - To obtain top user experience

*Who makes such applications??*
Creating parallel programs is hard…

Herb Sutter, chair of the ISO C++ standards committee, Microsoft:
“Everybody who learns concurrency thinks they understand it, ends up finding mysterious races they thought weren’t possible, and discovers that they didn’t actually understand it yet after all”

Steve Jobs, Apple:
“The way the processor industry is going, is to add more and more cores, but nobody knows how to program those things. I mean, two yeah; four not really; eight, forget it.”
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- Multi-threaded concurrency: Data-versus Task-partitioning
- Parallelization with dependencies: Reduction expressions or Streaming
- Multi-threading: difficult…
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- Conclusion
Creating multi-threaded concurrency

Basic fork-join pattern, created through different higher-level programming constructs

Main program thread

Concurrent computation threads

Creation of threads is application responsibility. Operating System handles run-time scheduling across available processors!
Parallelization – two partitioning options

Source code:

```c
for (i=0; i<4; i++) {
    A(i);
    B(i);
    C(i);
}
```

Sequential execution order:

A(0) A(1) A(2) A(3)
B(0) B(1) B(2) B(3)
C(0) C(1) C(2) C(3)

Data partitioning:

Task partitioning:

Fork

A(0) A(1) A(2) A(3)
B(0) B(1) B(2) B(3)
C(0) C(1) C(2) C(3)

Join

A(0) A(1) A(2) A(3)
B(0) B(1) B(2) B(3)
C(0) C(1) C(2) C(3)
Issue: Data dependencies

Adjust program source for parallelization:

- When feasible, remove inter-thread data dependencies
- Implement required data synchronization
Example Data dependencies

**Variable assigned in loop body, used in later iteration**

```c
// search linked-list for matching items
// save matches in ‘found’ array of pointers
for (p = head, n_found = 0; p; p = p->next)
    if (match_criterion(p))
        found[n_found++] = p;
```

Cannot (easily/trivially) spawn data-parallel tasks!

- No direct parallel access to list members *p*
- No direct way to assign index to matched item *n_found*
- Maybe more problems hidden in `match_criterion()`
Introduction

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Can do: reduction data dependencies

- Reduction expressions: accumulate results of loop bodies with commutative operations
- Freedom of re-ordering allows to break sequential constraints

```c
// conditionally accumulate results
int acc = 0;
for (i=0; i<N; i++)
{
    int result = some_work(i);
    if (some condition(i))
        acc += result;
}
...use of acc ...
```

- Commutative operations are basic math like +, *, &&, &, ||, but also more complex operations like ‘add item to set’.
- Three(?) different methods to handle these ...
Three methods for reduction dependencies

- Create thread-local copies of the accumulator. Accumulate over local copy in each thread. Merge the partial accumulators after thread-join. Eg. created automatically by:

```
#pragma omp parallel for reduction(...)  
```

- Maintain single accumulator, synchronize updates through atomic operations. Eg. in C11 or C++11:

```
atomic_add_fetch( &acc, result);
std::atomic<int> acc;
acc += result;
```

- Maintain single accumulator, synchronize updates through protection by acquiring and releasing semaphores. Eg. Used by Intel “Threaded Building Blocks” (C++):

```
concurrent_unordered_set<...> s;
s.insert(...);
```
PAREON: Schedule data dependencies

Note: this is a preview on a potential parallelization
Pipelining: Data deps and task partitioning

Task partitioning with inter-thread dependencies:

A(0) A(1) A(2) A(3)  
B(0) B(1) B(2) B(3)  
C(0) C(1) C(2) C(3)

Producer-Consumer pattern:

Application

Thread A()  Queue  Thread B()  Queue  Thread C()

Queue implementation solves dependencies:

- **Solve Data dependencies**: Consumer thread waits for available data (stalls until queue is non-empty)
- **Solve Anti dependencies**: Producer thread creates next item in next memory location (prevents overwriting previous value)
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Concurrent C/C++ programming: Pitfalls

Risc introduction of functional errors:

- Overlooking use of shared/global variables (deep down inside called functions, or inside 3rd party library)
- Overlooking exceptions that are raised and caught outside studied scope
- Incorrect use of semaphores: flawed protection, deadlocks

Unexpected performance issues:

- Underestimation of time spent in added multi-threading or synchronization code and libraries
- Underestimation of other penalties in OS and HW (inter-core cache penalties, context switches, clock-frequency reductions)

Parallel programming remains hard!
Concurrent programming remains hard

- C++11 standardizes valuable primitives
- Provides good insight in C++ concurrency
- Warns for many subtle problems
Development of parallel code

Guidelines:

- Base upon a sequential program: functional and performance reference
- Apply higher-level parallelization patterns and primitives: clear semantics, re-use code, reduce risk
- Use tooling for analysis and verification
  - Prevent introduction of hard-to-find bugs
  - Prevent recoding effort that does not perform

Managable development process!
PAREON tool workflow

1. Developer builds C/C++ application with Pareon’s compiler
   Compiler creates instrumented code

2. Execute application with input data set
   Pareon captures trace with call stack and ld/st memory traffic
   Pareon analyzes data dependency patterns

3. Developer browses application model
   Selects loops for parallelization from performance estimate
   Performs source-code transformation
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Android Application 1: Plain, just Java

Many apps have no critical CPU load
For now, no Java support in Pareon
Android Application 2: with native libraries

Apps can include “native” binary code for best performance

Your Java Application code

Dalvik
Java Virtual Machine

Android Libraries

JNI

System Libraries

Your custom native library from C/C++ source code

Trace to Pareon

Linux Kernel
“Native activities” are created without Java source code

- Native Activity
- Dalvik
  - Java Virtual Machine
- Android Libraries
- JNI
- System Libraries
- Your custom C/C++ ‘Application’
- Trace to Pareon

Linux Kernel
Application Analysis on Android target

Real Target Hardware (ARM)

Application

instrumented

Host PC

Pareon

Trace data

eth

eth
System Setup using Android Simulator

Application
instrumented

Host PC

Android Simulator

Pareon
NDK plasma demo app analyzed on Android
Finding data parallelism on Android
Finding data parallelism on Android
Finding data parallelism on Android
Not parallelized: JNI call to render frame
Performance Verification

For example: PERF ‘flame graph’
- sampling-based profiling
- multi-thread support
- with view into kernel-level
Conclusion

Today’s gap:
- Multi-core CPUs are everywhere,
- Yet multi-threaded programming remains hard:
  - Risk of creating hard-to-locate bugs regarding dynamic data races and semaphore issues
  - Obtained speedup is lower than expected

- A sequential functional reference implementation ...
  ... helps to set a baseline for parallelization

- Android sets a new record in development complexity
- Proper tooling is needed to save on edit-verify development cycles
Questions?

Today’s gap:
- Multi-core CPUs are everywhere.
- Yet multi-threaded programming remains hard:
  - Risk of creating hard-to-locate bugs regarding dynamic data races and semaphore issues.
  - Obtained speedup is lower than expected.
- A sequential functional reference implementation ...
  ... helps to set a baseline for parallelization.
- Android sets a new record in development complexity.
- Proper tooling is needed to save on edit-verify development cycles.
Thank you!

Check [www.vectorfabrics.com](http://www.vectorfabrics.com) for a free demo on concurrency analysis