Virtual Platform Software Simulation for Enhanced Multi-core Software Verification

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Agenda

- Background – the changing needs of embedded product development
- “Traditional” Embedded Software development solutions
- Working with Multi-core hardware and software
  - The next generation of Embedded Software development systems
- Example – using assertions on software
  - shared memory monitor
- Summary
The changing hardware

- Multi-core [is going to be in] [is in] everything
  - AMP, SMP, homogeneous, heterogeneous
The changing software

- Layer and Layers of software
**The changing SW Verification Requirements**

- **Hardware Dependent Software (HDS)**
  - Most complex foundation layer
    - Drivers, hypervisors, assembly libraries, Operating System
  - Buried problems often appear elsewhere in a system, leading to misdirected analysis
  - Ripe for corner case type issues
  - Post development bugs hardest to fix
  - Testing needs to be platform centric not application centric

- **Modern SoC verification is complex**
  - SMP/AMP Multicore Interaction
  - Shared memory & devices
  - Extensive accelerators, peripherals
  - Complex SW/HW interaction (e.g. security)
  - Externally authored, complex libraries
Current Solutions For Early Embedded SW Development

Traditional Breadboard
- Limited system availability
- Limited external test access
- Limited internal visibility
- Late in arrival

Emulation & Cycle Accurate Models
- Provides reasonable verification capability but 1000x too slow for effective HDS verification
- Hard to get started
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Virtual Platforms: Transforming Engineering Efficiency

SW vs HW development platforms
- Often available earlier for engineering
- Provide more powerful tooling
- Easier to replicate for extended testing
- Real time or faster performance

“Best-in-class manufacturers that make extensive use of simulation early in the design process hit revenue, cost, launch date, and quality targets for 86% or more of their products. Best-in-class manufacturers of the most complex products get to market 158 days earlier with $1.9 million lower costs than all other manufacturers.”

*Simulation-Driven Design, Aberdeen Group Study*
And Virtual Platform simulators can be very fast

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Simulated Instructions</th>
<th>Run time</th>
<th>Simulated MIPS</th>
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Example speed of Imperas simulation models
And booting OS can be fast too

- Boot Linux on ARM Cortex-A15x4 = 6 seconds on Win7 laptop
- Runs simulated Linux applications at 100s of MIPS
ARMv8 simulation using parallel host-cpu resources

- Advanced parallel synchronization algorithm for SMP, AMP and hardware accelerators
- Transparent operation to user: No model, tool, software changes
- Total performance on benchmarks recorded up to 16 Billion ins/sec
- Performance advantage 15x over nearest commercial alternative
Software Quality is Directly Proportional to Test Speed

Less Time

Greater Quality

More Bugs Found

More Tests Run

Faster Tests

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Virtual Platforms: The Right Performance to Capability Trade-off

Virtual Platforms (simulators) with Instruction Accurate (IA) models provide:

- Pre-prototype verification
- Effective verification access
- Reasonable execution performance

However, Virtual Platforms require a simulation foundation to be effective

- Standardized modeling technology
- Services for verification tools
- Tool firewall for execution integrity
- Make use of host parallel resources for maximum performance
**OVP Standardized Modeling Infrastructure**

*Open Virtual Platforms™ (OVP™) standardized set of Modeling APIs for platforms, cpu models and behavioral peripheral models*

- **Model Library**: Extensive (200+), comprehensive open source model collection
- **OVP Modeling**: Easy-to-code modeling APIs
- **Environment**: Interfaces to SystemC, GDB, etc
- **Reference Simulator**: OVPsim
  Easy access simulator for running models
Simulator Architecture to provide services for Verification

- Leveraging JIT Code Morphing simulation algorithms for highest possible performance
- Modeling APIs allow processor/platform functionality to be described efficiently while maintaining easy modeling environment
- Imperas technology allows verification and debug tool code to be combined with model and software execution efficiently and unobtrusively

Enables extensibility
Traditional Debug (1D)

- Debugging application code running on simulated embedded processor

- Trace
  - e.g.: instructions, source lines, register changes

- GDB-like debugger

- Examining registers, variables, source…

- Single step, breakpoints, …

- GUI
Spatial & Temporal Debug (2D)

Spatial
- For AMP/SMP – examine applications on multiple cores across the chip
- Debugging peripheral/behavioral models in context of software running on the embedded cores
  - Programmers view, or model source

Temporal
- Considering the sequences of events over time
  - Sequential assertions, breakpoints
  - Using conditioning events to prime breakpoints
    - e.g.: break on next ISR after character input to UART
Layer-Aware Debug (3D)

- OS Aware
- Middleware or Bare Metal
- Platform (e.g. Drivers)
- Processor Aware
- Model Source Aware

Layered verification matches layered software architecture
Simulator must allow focus and stratification

OS/CPU-Aware Focused Debug
Commands analyze layer operation while excluding irrelevant detail
(easier to view 1000 tasks operations than 1 Billion instructions trace)

Layer-aware Stratified Analysis
Connecting commands through different layers for activity analysis

TRC (SCHD) 242131778: 'mipsle1_TC0': scheduler switched ('khelper')
TRC (TASK) 242137813: 'mipsle1_TC0': do_execve called
TRC (EXEC) 242137813: 'mipsle1_TC0': do_execve called
filename=/sbin/hotplug with:
TRC (EXEC) 242137813: 'mipsle1_TC0': argv virt=0x80
TRC (EXEC) 242137813: 'mipsle1_TC0': argv virt=0x80
TRC (EXEC) 242137813: 'mipsle1_TC0': envp virt=0x80
TRC (EXEC) 242137813: 'mipsle1_TC0': envp virt=0x80
"PATH=/sbin:/bin:/usr/sbin:/usr/bin"
Rich set of commands to operate at all layers of abstraction
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Example 1 - Assertions

Altera Cyclone V Cortex A9MPx2 (AMP Linux/Micrium, SMP Linux) and Nios II (Linux)
Verification challenges…

OS Porting, Bring Up and Verification on Altera Cyclone V SoC FPGA

1) Linux boot on single core ARM Cortex-A9
2) SMP Linux boot on dual core ARM Cortex-A9
3) RTOS boot on single core ARM Cortex-A9
4) AMP boot on dual core ARM Cortex-A9
5) Linux boot on single core Nios II
6) SMP Linux boot on dual core ARM Cortex-A9 plus Linux boot on Nios II
Assertions:
Memory Access Monitor
Accelerates AMP Platform Debug

- Memory access monitor is just C code, loaded into simulation environment
- When simulation is run, monitor produces warning if memory access rules are violated

```c
// Define watch areas for memory and peripherals defined in the platform
//
memWatchT amcWatch[] = {
    // name                        watchLow    watchHigh   allowedCPUs
    { "Linux memory",            0,          0x2fffffff, LINUX_CPU   },
    { "uCOS memory",             0x30000000, 0x31ffffff, UCOSII_CPU  },
    { "gmac0",                   0xff700000, 0xff700fff, LINUX_CPU   },
    { "emac0_dma",               0xff701000, 0xff701fff, LINUX_CPU   },
    { "gmac1",                   0xff702000, 0xff702fff, LINUX_CPU   },
    { "emac1_dma",               0xff703000, 0xff703fff, LINUX_CPU   },
    { "uart0",                   0xffcc0200, 0xffcc02ff, LINUX_CPU   },
    { "uart1",                   0xffcc03000, 0xffcc03fff, UCOSII_CPU  },
    { "CLKMGR",                  0xffd04000, 0xffd04fff, LINUX_CPU   },
    { "RSTMGR",                  0xffd05000, 0xffd05fff, LINUX_CPU   },
    { "SYSMGR",                  0xffd08000, 0xffd08fff, LINUX_CPU   },
    { "GIC",                     0xffec0000, 0xffef00ff, LINUX_CPU   },
    { "L2",                      0xffee0000, 0xfffe0fff, LINUX_CPU   },
    { 0 } /* Marks end of list */
};
```

Warning (AMPCHK_MWV) cpu_CPU0: AMP write access violation in uart1 area. PA: 0xffc03008 VA: 0xffc03008
Warning (AMPCHK_MWV) cpu_CPU0: AMP write access violation in uart1 area. PA: 0xffc0300c VA: 0xffc0300c
Warning (AMPCHK_MWV) cpu_CPU0: AMP write access violation in uart1 area. PA: 0xffc030010 VA: 0xffc03010
Warning (AMPCHK_MRV) cpu_CPU1: AMP read access violation in Linux memory area. PA: 0x00000020 VA: 0x00000020
Summary of verification example

1) Linux boot on single core ARM Cortex-A9
   - Bug found in Linux kernel preemptive scheduling
     - Linux boots and runs, but does not switch tasks properly
     - Not observed in previous virtual platform (different virtual platform vendor) using much slower model of ARM Cortex-A9MPx2
       - Could not run multiple applications for long enough simulation to observe the bug

2) SMP Linux boot on dual core ARM Cortex-A9
   - OK – no problems found

3) RTOS boot on single core ARM Cortex-A9
   - Bugs found and fixed in GIC register accesses using OS-aware tools

4) AMP boot on dual core ARM Cortex-A9
   - Bug found in Linux accesses of GIC registers
   - Bugs found in RTOS access of Linux’s reserved memory

5) Linux boot on single core Nios II
   - No problems found

6) SMP Linux boot on dual core ARM Cortex-A9 plus Linux boot on Nios II
   - No problems found
Summary

- Simulation is necessary but not sufficient
  - Fast simulation finds more bugs
    - Making use of multi-core host is even better
- Trace, temporal, and multi-core debug are essential for AMP/SMP systems
- ‘Layer-aware’ analysis makes debug manageable
  - Allows focus at different levels of abstraction
- Ability to extend functionality and write own tools are the key to providing efficient development environments
Conclusions

- It is inevitable that simulation will form the basis of the next generation of embedded software development methodology.
- Ensure your chosen simulator is fast, has a standardized modeling capability, and has the ability to include integrated advanced tools.
- 2D and 3D verification, analysis and debug tools are essential for multi-core designs.
- To find the most complex bugs and ensure product quality an advanced verification approach is needed using layered, customizable tools.
Thank you

- For more modeling/model information
  - [www.OVPworld.org](http://www.OVPworld.org)

- For technology/product information
  - [www.imperas.com](http://www.imperas.com)

- Questions?