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Investigation of Parallel Programmability and Performance of a Calxeda ARM Server Using OpenCL

ARL

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Outline

- Hardware
  - ARM multi-core CPUs
  - Calxeda ARM server
- Software Stack
  - OpenCL, CLRPC, STDCL
  - Distributed task parallel programming model
- Configurations tested
- Benchmarks
- Conclusion and future work

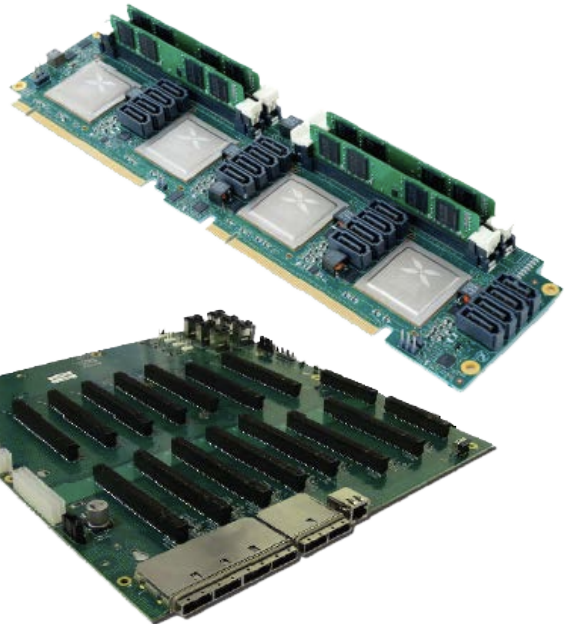
ARM CPU Architecture

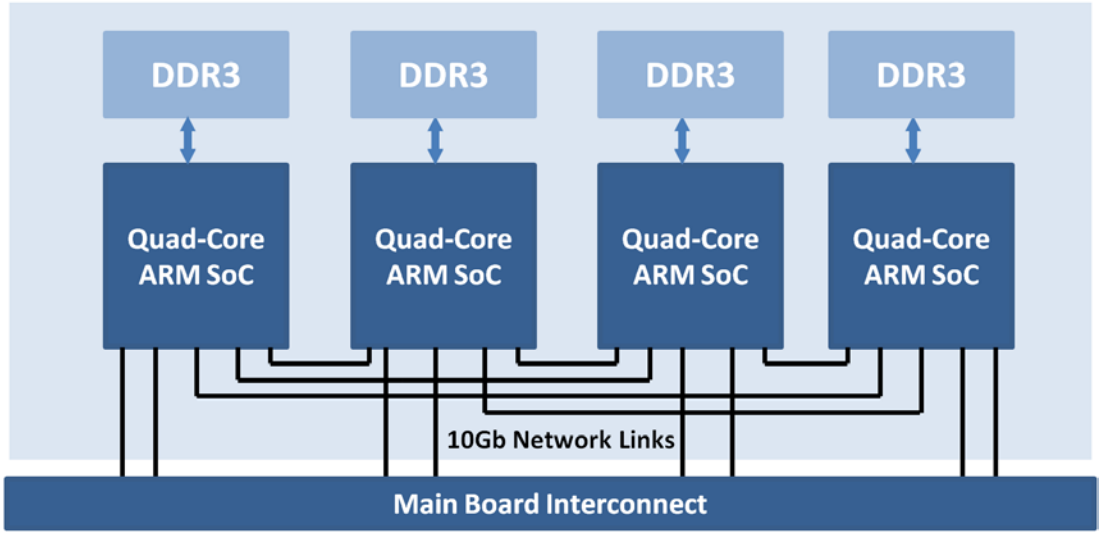
- ARM is a family of RISC CPUs targeting low-power and embedded markets.
- ARM Holdings licenses the IP core to third parties
- You likely have one in your pocket. They appear in about 95% of smartphones

Enterprise ARM Platforms	Enterprise x86 Platforms
“RISC” - reduced complexity ISA	“CISC” – specialized ISA
Power and Energy priority (<5 W)	Speed and Performance priority (~100W)
Lower clock speeds ~1-2 GHz	Higher clock speeds ~3 GHz
Generally four (4) cores per system	Eight (8) to 16 core systems
Low memory per system (up to 4 GB)	High memory systems (16-256 GB)
64-bit Vector Floating Point coprocessor	256-bit SSE and AVX instructions
Smaller die size (~5 mm^2)	Larger die size (~100 mm^2) adds cost

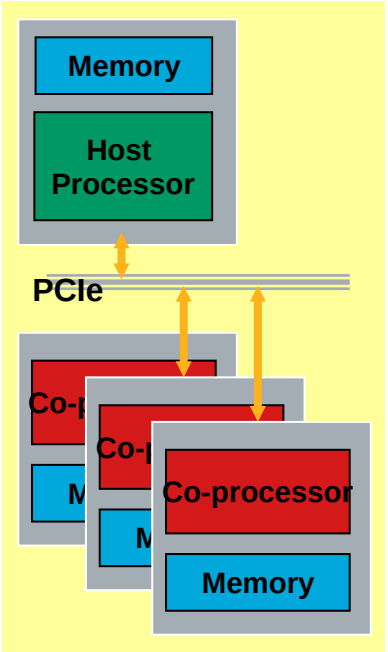
Calxeda ARM Server

- Fully populated 2U box contains 48 quad-core SoCs
  - 192 ARM Cortex-A9 cores @ 1.1-1.4 GHz
  - 192 GB DDR3 (1GB/core)
  - Five (5) 10 Gb network links per SoC
  - 900W PSU (usage typically < 300 W)
  - Up to four (4) SATA ports per SoC





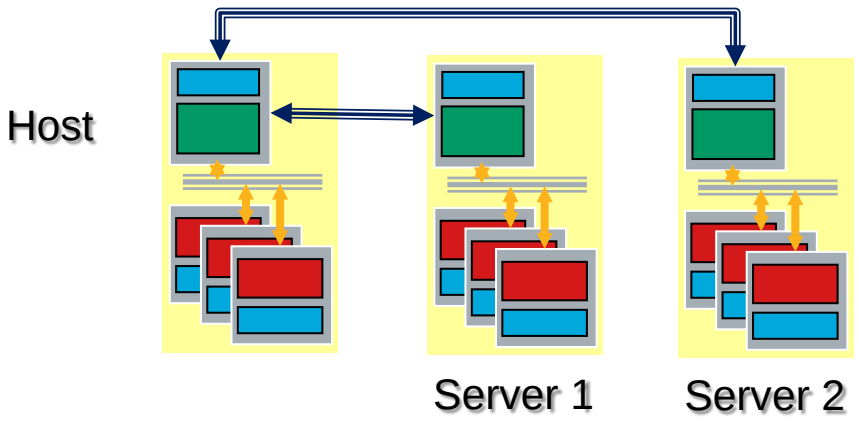
- OpenCL™ is an industry standard programming API
- Issues addressed by OpenCL
  - Distributed memory management
  - Concurrency of data movement and device execution
  - Platform/vendor portability of APIs
- OpenCL provides ...
  - Platform and runtime layer for managing concurrent execution of operations across multiple devices
  - C language extension for programming compute devices
  - Platform/device independent API with broad industry support



- Alternatives:
  - **MPI** – Data parallel, not task parallel. Runs on multi-core CPUs and clusters
  - **OpenMP** – Runs on Symmetric Multiprocessor (SMP), single node
  - **CUDA** – Similar to OpenCL. Nvidia GPUs only, single node.

CLRPC: Basic Idea

- The OpenCL API forces natural separation between high-level functionality (host code) and heavy compute tasks (kernel)
- OpenCL RPC (Remote Procedure Call) can extend the host code transparently to access the compute resources across networked platforms
- OpenCL RPC provides access to larger pool of OpenCL devices from single application
- This is the inspiration for CLRPC



CLRPC

- CLRPC: Remote Procedure Call (RPC) implementation of OpenCL
  - OpenCL capabilities of a node exported to the network
  - Transparent layer to developer
  - OpenCL code doesn’t need to be modified
  - Devices still separated by OpenCL platform concept
    - Programmer needs a separate OpenCL context per CLRPC server
  - Host able to execute OpenCL program even if it lacks any remote OpenCL implementation or compute device
- CLRPC Daemon (clrpcd) runs in background on a node and forwards CLRPC commands to local OpenCL library
  - Daisy chaining of networked nodes as a means to create tiered execution to possibly reduce bottlenecks

CLRPC: Server-Side

- Compute resources are exported using a CLRPC server (clrpcd)
- clrpcd is run in the background on each node, for example:

  clrpcd -a 192.168.1.36

- The server will listen for CLRPC requests on the default port, and perform all host API calls on behalf of the client
- On client-side the available OpenCL platforms can be augmented with one or more clrpcd servers identified by IP address and port

- FAQ: Does the server just have “wrappers” for the OpenCL API calls?
  - In a sense, yes, but there are non-trivial issues that must be resolved, mostly related to implicitly asynchronous behaviors expected from within the OpenCL client applications
  - A naive implementation that “blocked on everything” would be useless

STDCL

- STDCL™ (STandard Compute Layer) as an interface to OpenCL
- Lightweight UNIX-style C API interface for HPC
- Similar simplicity and features to CUDA, yet more portable
- Creates standard OpenCL contexts: *stdcpu*, *stdgpu*, *stddev*, *stdnpu*
- The context *stdnpu*, is unique in that it is a “super context” of networked OpenCL devices through CLRPC
- *stdnpu* context ignores platform details and presents to user all available devices across multiple platforms

STDCL

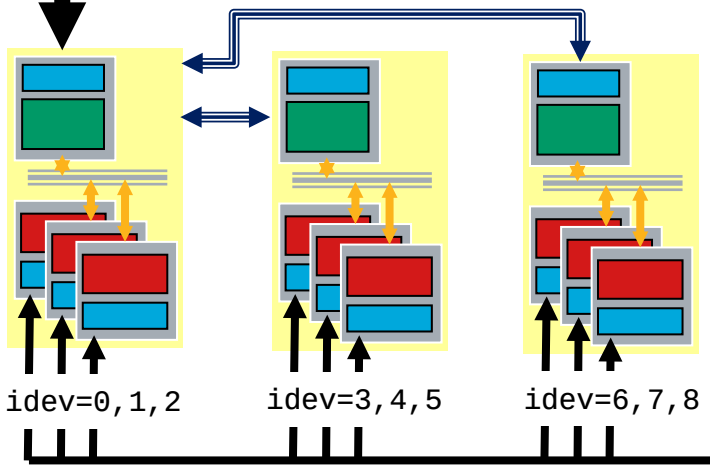
- Without STDCL *stdnpu*, directing devices requires management:
  - For each Node
    - For each OpenCL Platform
      - For each OpenCL Context
        - » For each OpenCL Command Queue
          - » For each OpenCL Device
- STDCL stdnpu abstracts these layers so code becomes:
  - For each OpenCL Device
- Reduces source code complexity significantly with very little overhead

- Concurrent execution of an OpenCL kernel on multiple networked devices

```
// Loop over all networked devices
for(idev = 0; idev < ndev; idev++)
   clforka(stdnpu, idev, krn, &ndr, CL_EVENT_NOWAIT, a, b, c);

// Wait on each device in turn
for(idev = 0; idev < ndev; idev++)
   clwait(stdnpu, idev, krn, 0);
```

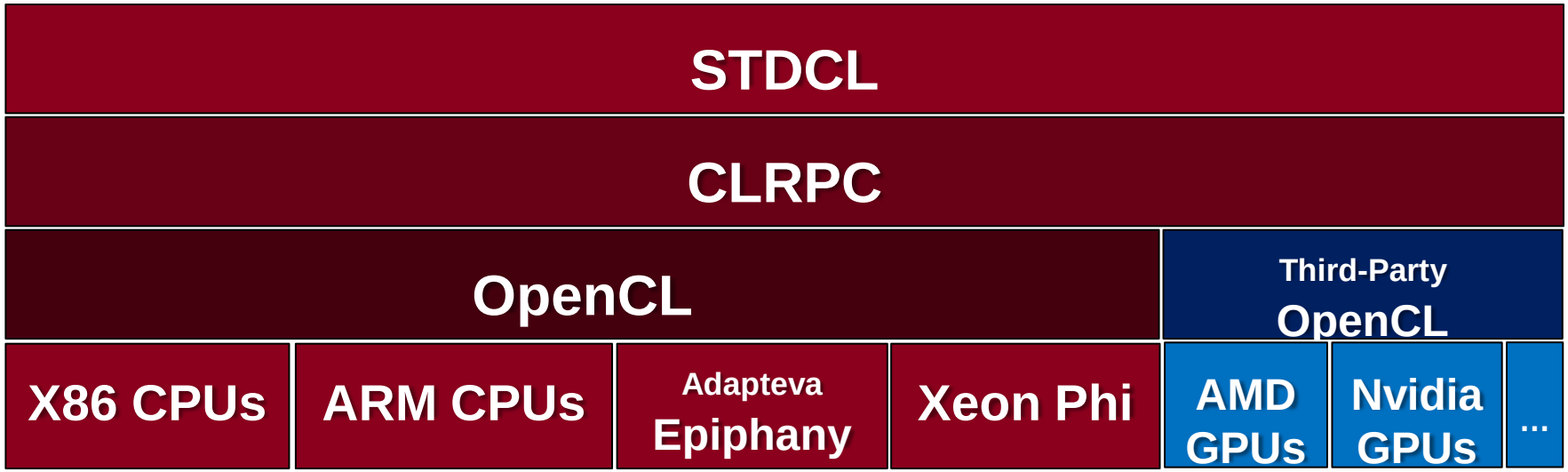
Host program runs on a single host



Compute kernel runs on each device *concurrently*

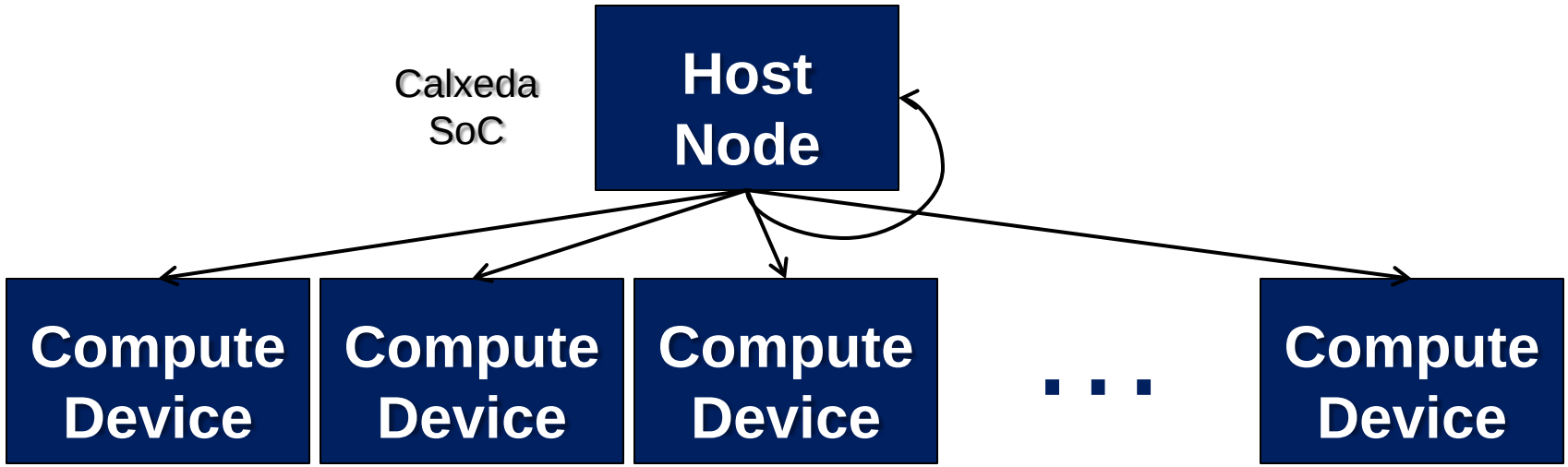
COPRTHR SDK Software Stack

- CO-PRocessing THReads™ (*COPRTHR™*) *SDK*
- Write STDCL code once, run on any architecture, multiple devices and nodes
- Includes OpenCL for x86 and ARM multi-core CPUs, Adapteva Epiphany RISC Arrays, and Xeon Phi (beta). ARM has no vendor-supplied implementation
- COPRTHR SDK allows for the most portable source code for our group
- Besides those listed above, we've investigated AMD, Nvidia, and Adreno GPUs
- Primary support for Linux/BSD and some support for Android and Windows



Programming Model

- We are investigating a task-parallel programming model for distributing work across a cluster of Calxeda nodes based on STDCL
- A dedicated host node distributes work via OpenCL/STDCL calls and treats networked nodes as OpenCL compute devices
- Host may also use it's own resources for compute

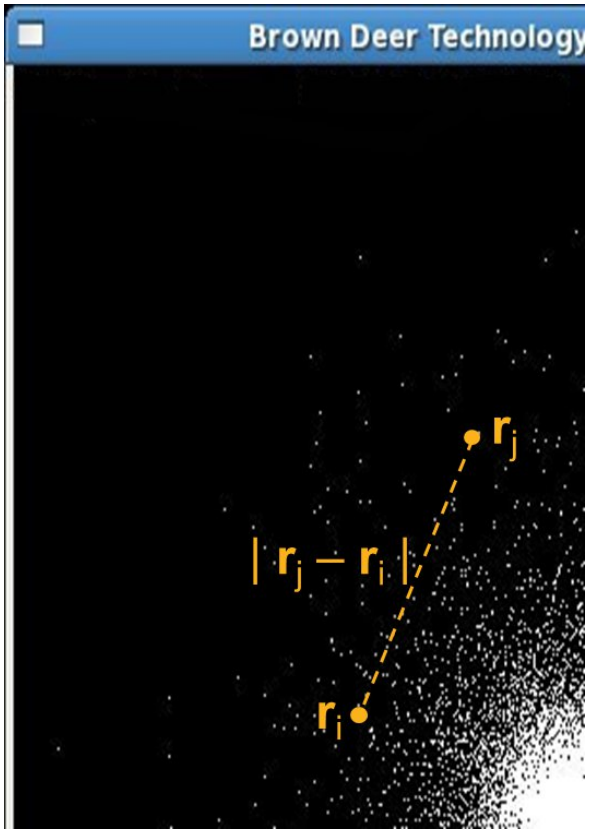


Configurations Tested

- Access to the Calxeda box was provided by Exxact Corporation
- At the time, five (5) quad-core nodes were available for use
  - Running Ubuntu 12.10
  - GCC 4.7 and common utilities for a Linux development platform
  - Includes baseboard management controller (BMC) utility for measuring and recording power of individual nodes within the system
- Tested configurations included:
  - OpenCL direct
  - CLRPC remote
  - CLRPC local (special case)
  - *stdnpu*

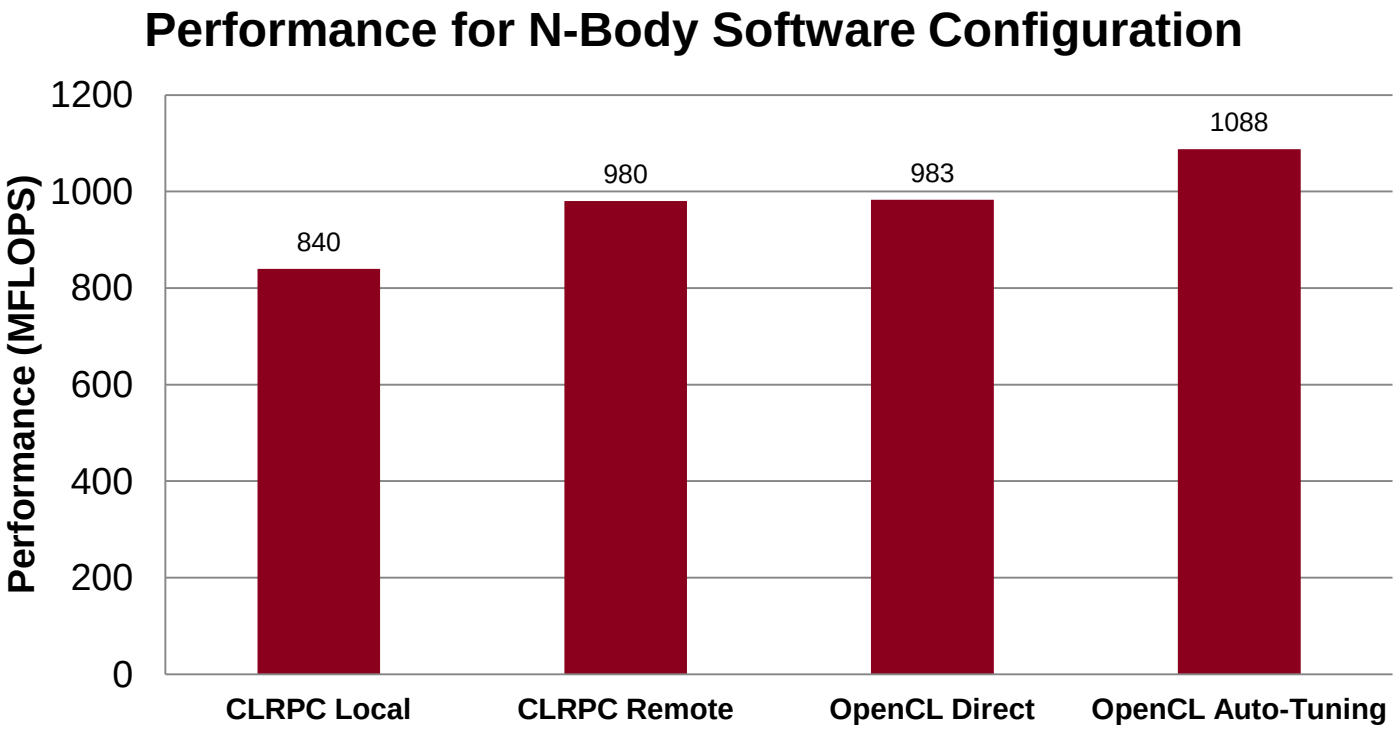
N-Body Benchmark

- We chose a gravitational n-body benchmark to flex the architecture
  - $O(N^2)$ compute and O(N) communication
  - Particle positions generate a force on all other particles
  - Accumulated acceleration changes particle velocity at each step
- Algorithm has two main steps:
  - Calculate total force on each particle
  - Update particle position/velocity over some small time-step (Newtonian dynamics)
  - Contains multiply, add, subtract, divide, and square root operations
- Entire (unoptimized) algorithm can be written in C with a few dozen lines of code

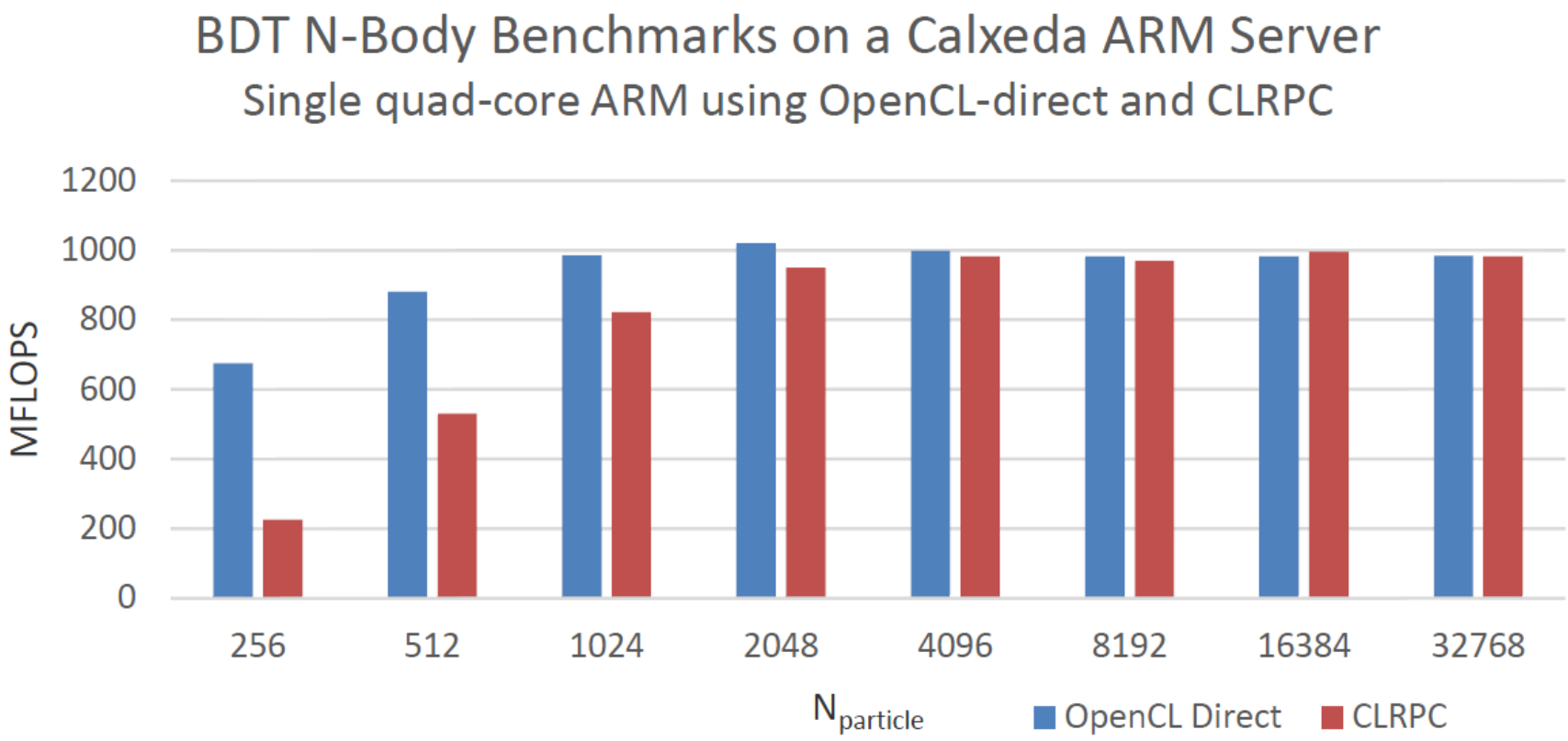


$$\mathbf{f}_i = \sum_{i \neq j} m_j \frac{\mathbf{r}_j - \mathbf{r}_i}{|\mathbf{r}_j - \mathbf{r}_i|^3}$$

Benchmarks

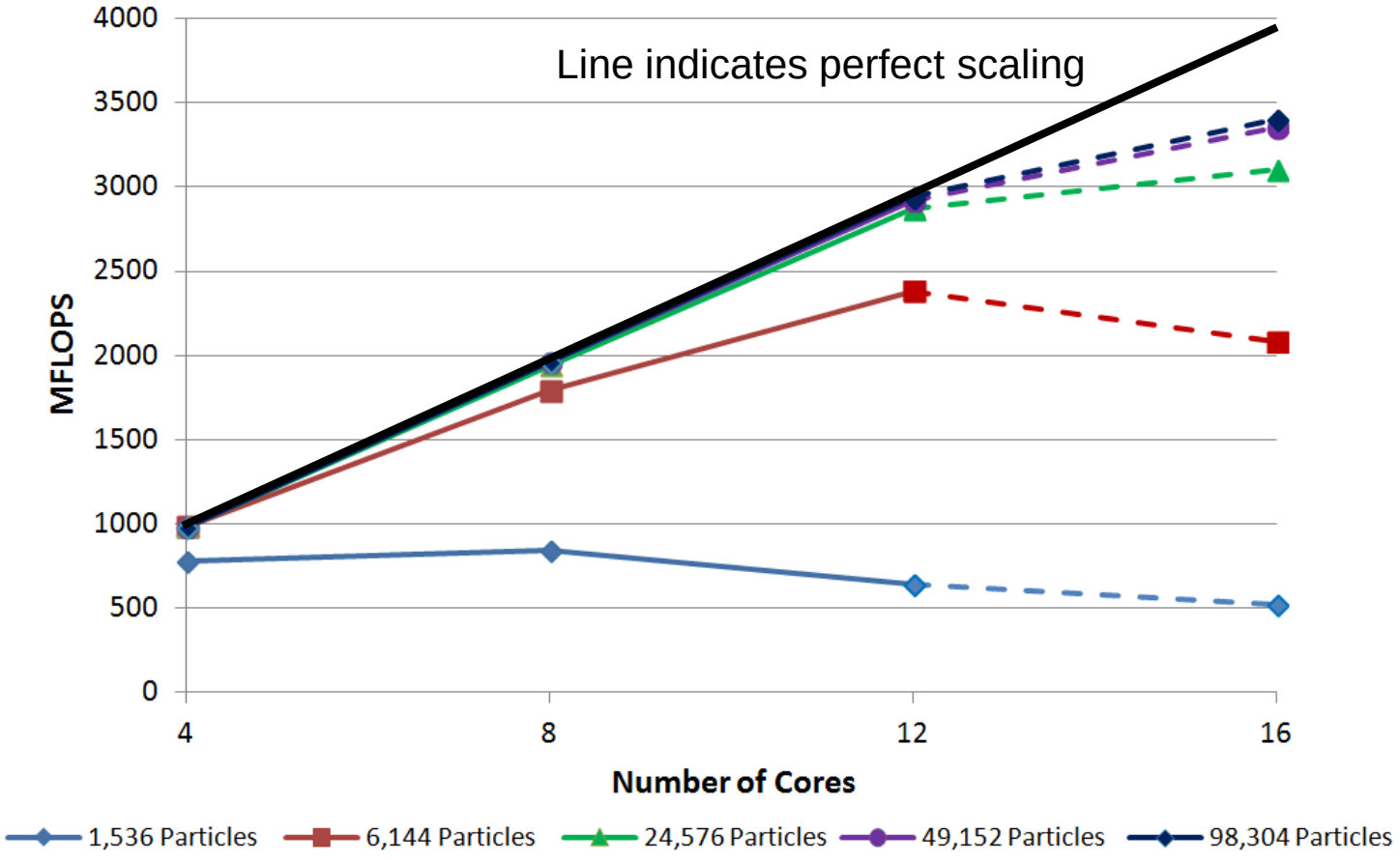

Performance for N-Body Software Configuration
Performance (MFLOPS)
1200
1000
800
600
400
200
0
840
980
983
1088
CLRPC Local
CLRPC Remote
OpenCL Direct
OpenCL Auto-Tuning

- A single node tells a story



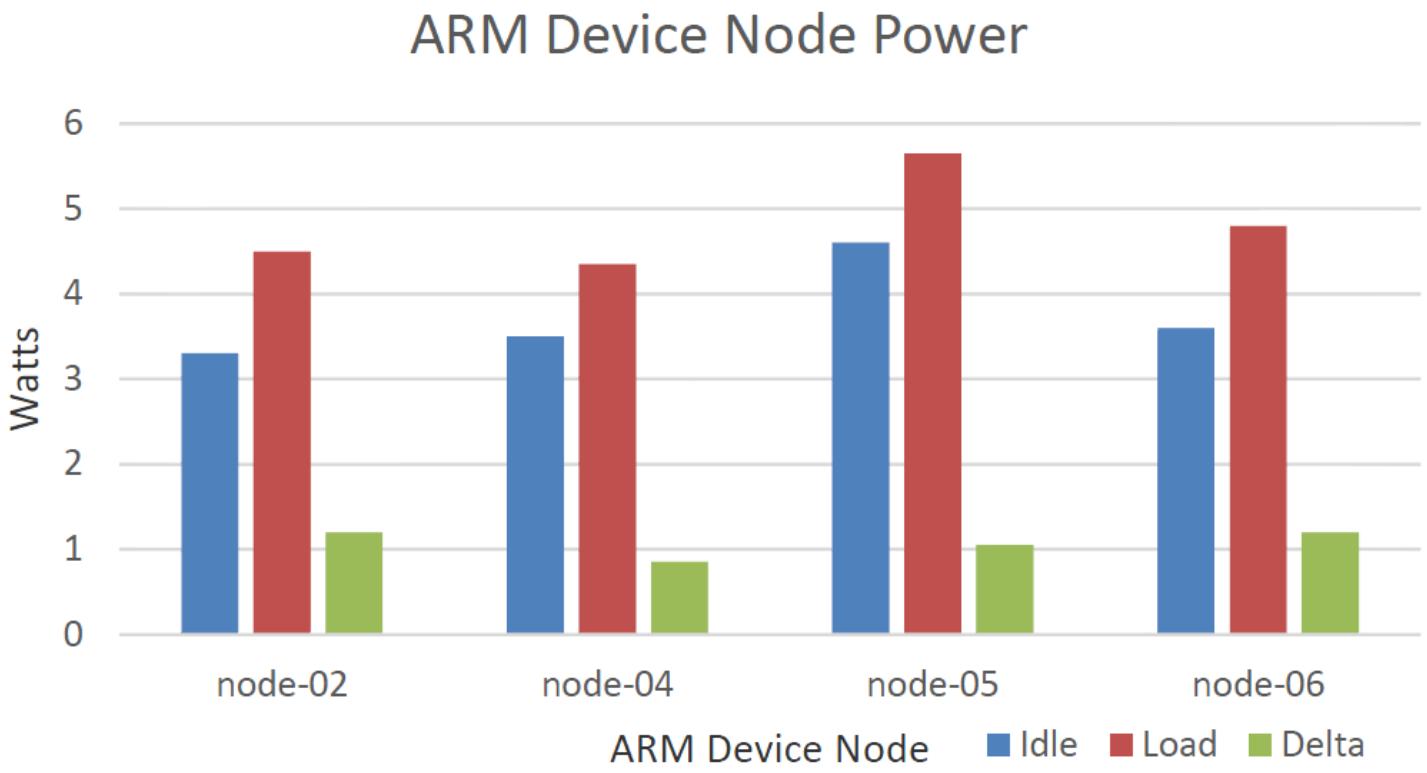
Benchmarks

- BDT N-Body Benchmarks on a Calxeda ARM Server
  - Scaling over 4 Quad-Core ARM SoCs Using a Single STDCL Context
  - Host is used for compute at 16 cores. This leads to performance issues



Power

- Idle power is a significant portion of load power (~80%)
- This is almost the opposite case for x86 servers where the CPU under load consumes a significant portion of the power budget



Conclusion and Future Work

- First effort to investigate OpenCL on Calxeda ARM server
- Novel OpenCL-based parallel programming model with abstraction to access networked compute devices
- Empirical results of n-body including auto-tuning code
- Power measurements during benchmarking insufficient to determine power efficiency rank compared to x86-based machines
- Future work includes investigating scaling on a much larger number of cores

References and Acknowledgments

- COPRTHR SDK:
  - https://github.com/browndeer/coprthr.git
- Exxact Corporation Calxeda Platform:
  - http://exxactcorp.com/index.php/solution/solu_list/59
- Khronos OpenCL:
  - http://www.khronos.org/opencl/

We wish to thank Exxact Corporation for providing access to their Calxeda based ARM server platform

EXXACT CORPORATION

www.exxactcorp.com