Programming and Optimization for Intel® Architecture

The Hands-On Workshop (HOW) Series

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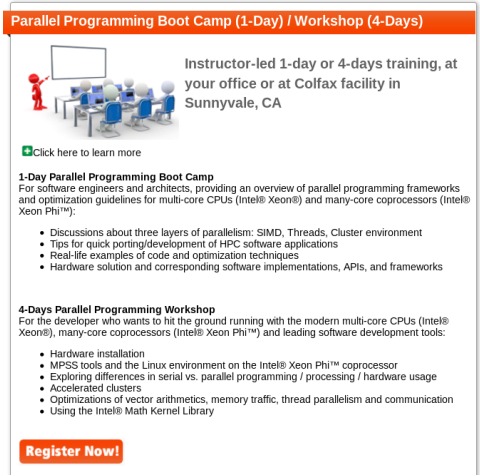
About This Document

This document represents the materials of a Web-based training “Programming and Optimization with Intel Architecture“ developed and run by Colfax International.



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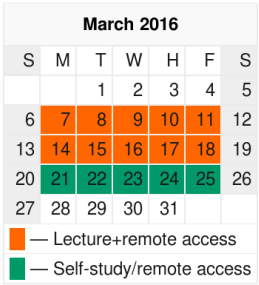
Course Roadmap

1. Why Intel Parallel Architectures?
   - Parallelism and specialization – March 7
   - Programming model continuity – March 7
2. Programming models for Xeon Phi coprocessors
   - Native programming – March 7
   - Offload programming – March 8
3. Expressing Parallelism
   - Introduction to vectorization – March 9
   - Crash-course on OpenMP – March 10
4. Optimization – intro on March 11
   - Vectorization tuning – March 14
   - Multi-threading – March 15, 16
   - Memory traffic – March 17
5. Tools: MKL and VTune – March 18

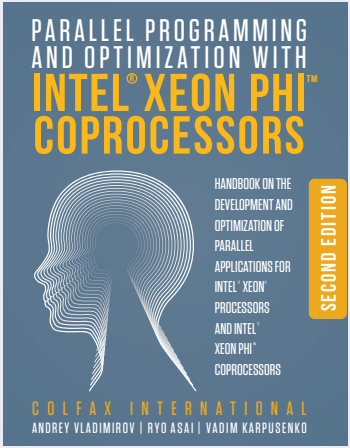


Textbook

ISBN: 978-0-9885234-0-1 (508 pages, Electronic or Print)

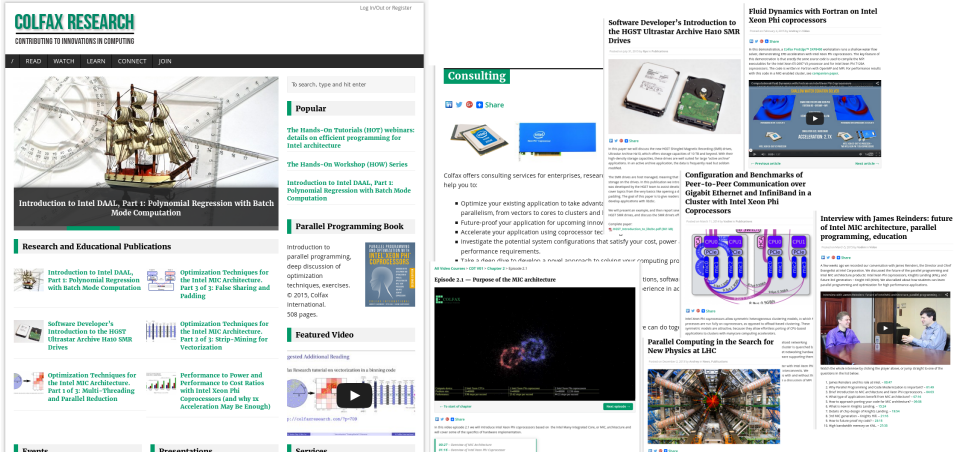
Parallel Programming
and Optimization with
Intel® Xeon Phi™
Coprocessors

Handbook on the Development and
Optimization of Parallel Applications
for Intel® Xeon® Processors
and Intel® Xeon Phi™ Coprocessors



http://xeonphi.com/book

Colfax Research



http://colfaxresearch.com/

(already registered? get $10 off the book)

HOW Online

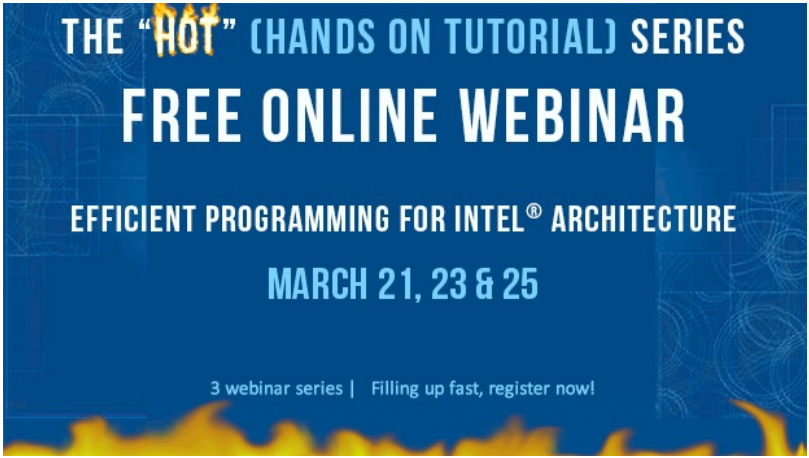
Course page: colfaxresearch.com/how-series

- Slides (including this one), code downloads
- Video of recorded sessions
- Chat (during webinars or offline)

Additional resources:

- More workshops like this one: colfaxresearch.com/how-series
- Video courses: colfaxresearch.com/video-courses
- Intel Many Integrated Core Architecture Forum

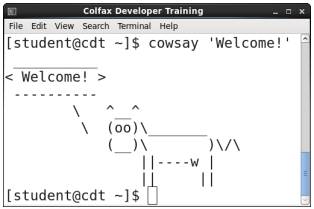
HOT Series



colfaxresearch.com/hot-16-03/

Hands-On Exercises and Remote Access

- 96 people receive a remote access token
- Can access the system the entire 3 weeks of the workshop



- Not among the 96? Stay tuned: follow along with instructor, use own system, or wait for a seat
- Use it or lose it: if you do not log in for a while, remote access token goes to next student on the list

§2. Intel Architecture

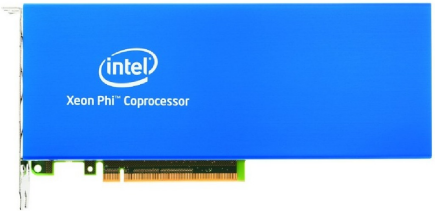
Computing Platforms

Computing Platforms

Intel Xeon Processor

Current: Haswell
Upcoming: Broadwell

Intel Xeon Phi Corocessor, 1st generation



Current: Knights Corner (KNC)

Intel Xeon Phi Processor, 2nd generation*

* socket and coprocessor versions

Upcoming: Knights Landing (KNL)

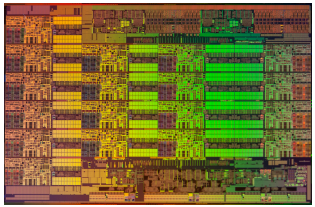
Multi-Core Architecture

Intel Many Integrated Core (MIC) Architecture

Intel Xeon CPU: Purpose and Specifications

General-purpose platform for demanding computing applications.

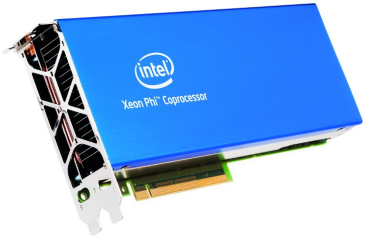
- Up to ~ 1 TFLOP/s in DP
- Up to ~ 2 TFLOP/s in SP
- Up to 768 GiB DDR4 RAM
- ~ 126 GB/s bandwidth
- Hardware-rich: forgiving of sub-optimal code

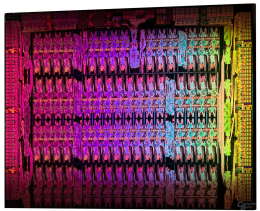


Intel Xeon Phi Processors (1st Gen)

Specialized platform for demanding computing applications.

- PCIe end-point device
- ~ 1.2 TFLOP/s in DP
- ~ 2.4 TFLOP/s in SP
- Up to 16 GiB GDDR5 RAM
- ~ 176 GB/s bandwidth
- Heterogeneous clustering
- Runs special Linux distribution

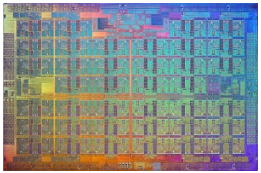




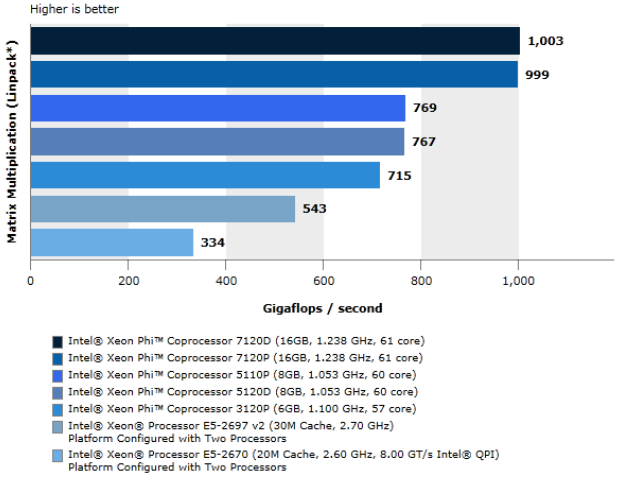
Intel Xeon Phi Processors (2nd Gen)

Specialized platform for demanding computing applications.

- Socket version or coprocessor
- 3+ TFLOP/s in DP
- 6+ TFLOP/s in SP
- Up to 16 GiB MCDRAM
- ~ 400 GB/s MCDRAM bandwidth
- Up to 384 GiB DDR4 RAM
- ~ 90 GB/s DDR4 bandwidth
- Supports common OS
- Public disclosures

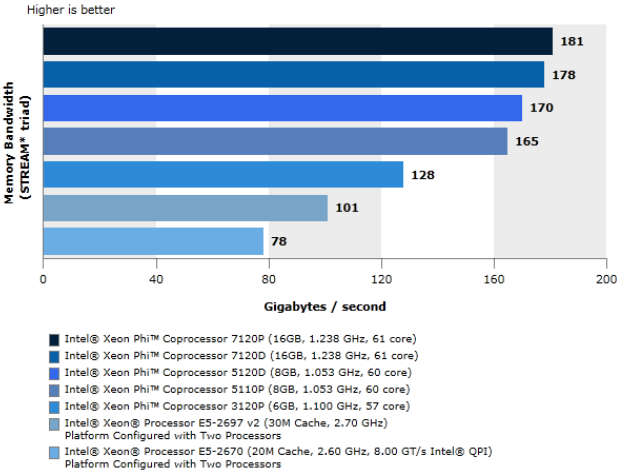


Intel Xeon Phi Coprocessors: HPC LINPACK Benchmark



Source: "Intel Xeon Phi Coprocessor LINPACK* and STREAM* Performance"

Intel Xeon Phi Coprocessors: STREAM Benchmark

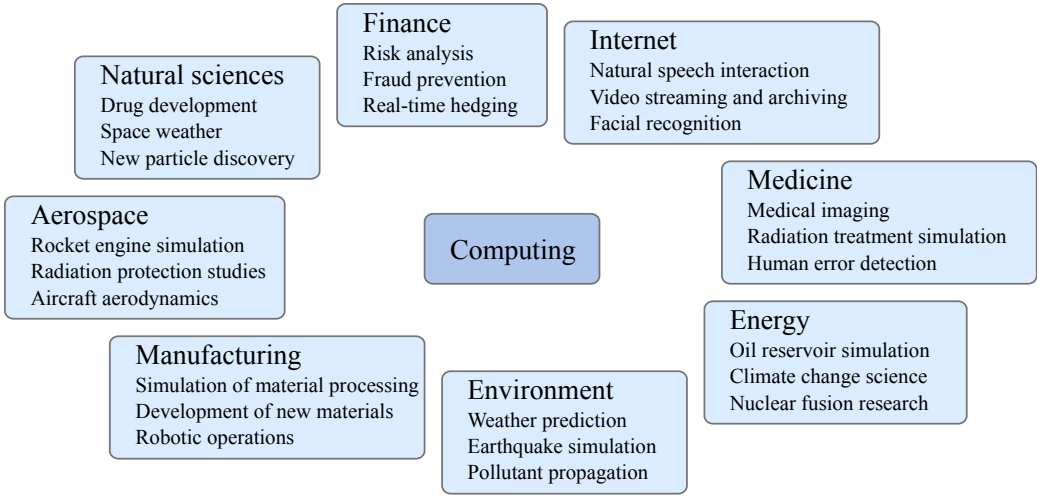


Source: "Intel Xeon Phi Coprocessor LINPACK* and STREAM* Performance"

It Is All About Performance

Computing Applications

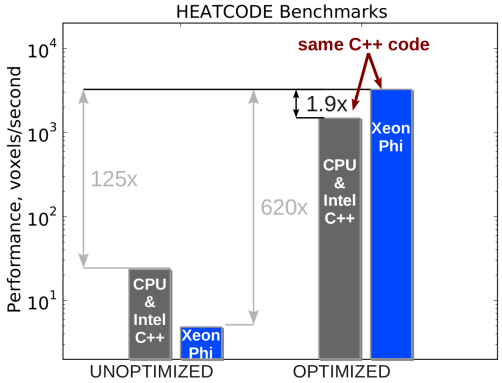
Just some examples



Will My Code Run Faster on KNL?

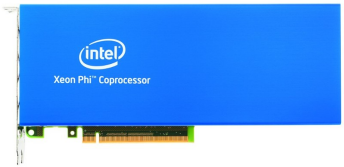
Performance on MIC architecture is a function of optimization Level

- Performance will be disappointing if code is not optimized for multi-core CPUs
- Optimized code runs better on the MIC platform *and* on the multi-core CPU
- Single code for two platforms + Ease of porting = Incremental optimization



See this case study

Coprocessor vs Processor Performance



vs.

One Intel Xeon Phi 7120P coprocessor

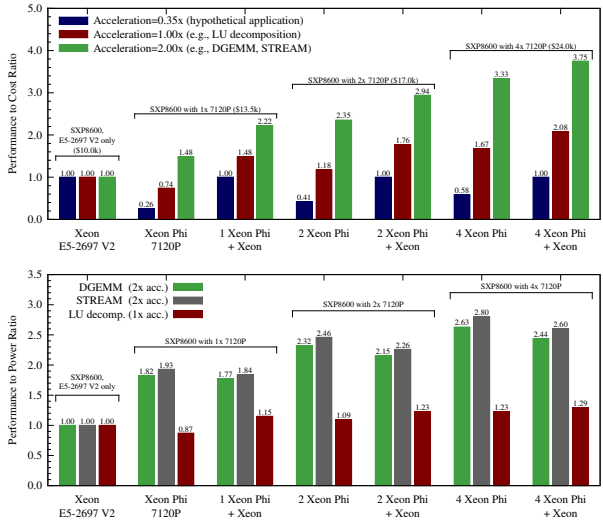
Two Intel Xeon E5-2697 v2 CPUs

- Why compare 1 coprocessor agains 2 processors?
  Same thermal design power (TDP).

See also "Intel Xeon Product Family: Performance Brief"

What is Your Performance Metric?

- Performance per System
- Performance per Watt
- Performance/Cost Ratio

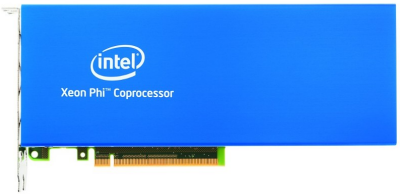


See this paper for details

Common Architecture, Programming Models

Bird's Eye View

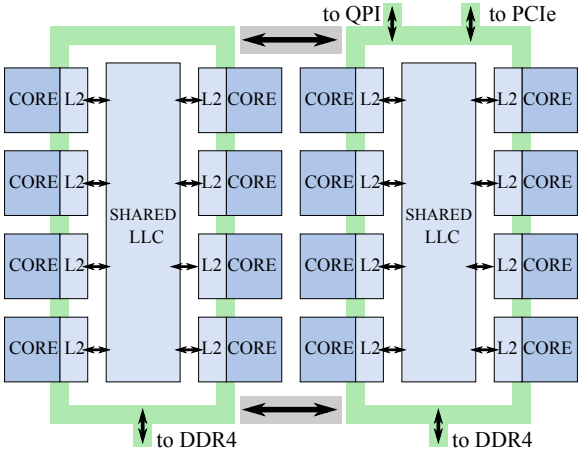
- C/C++/Fortran; OpenMP/MPI
- Standard Linux OS
- Up to 768 GiB of DDR4 RAM
- ≤18 cores/chip ≈3 GHz
- 2 hyper-threads per core
- 256-bit AVX vectors



- C/C++/Fortran; OpenMP/MPI
- Special Linux distribution
- 3–16 GiB cached GDDR5 RAM
- Up to 61 cores at ≈1.2 GHz
- 4 hardware threads per core
- 512-bit IMCI vectors

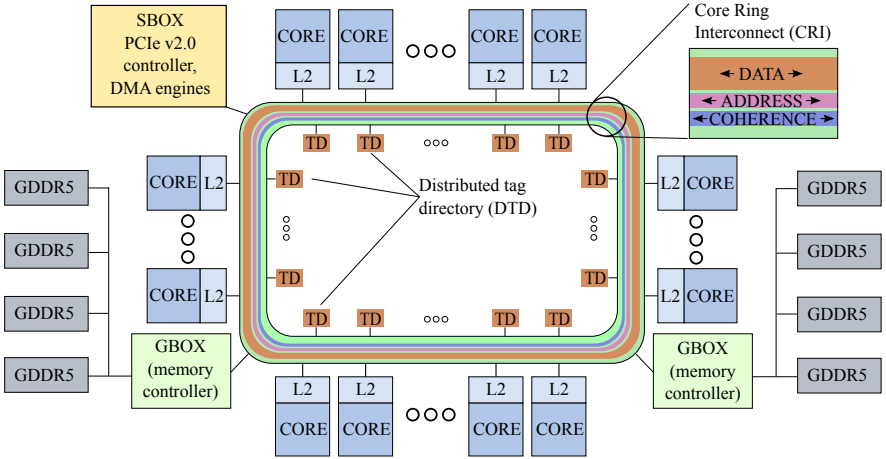
Intel Xeon CPU: Die Organization

Likes data locality, but large LLC is forgiving.



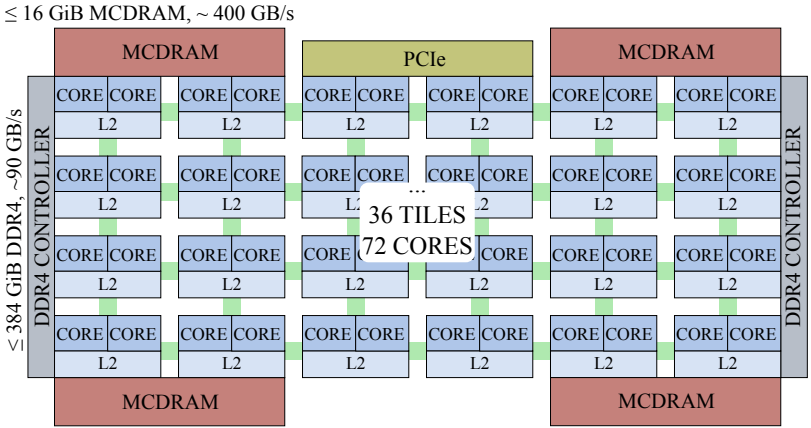
KNC Die Organization

In a ring bus with distributed cache, data access locality is key.



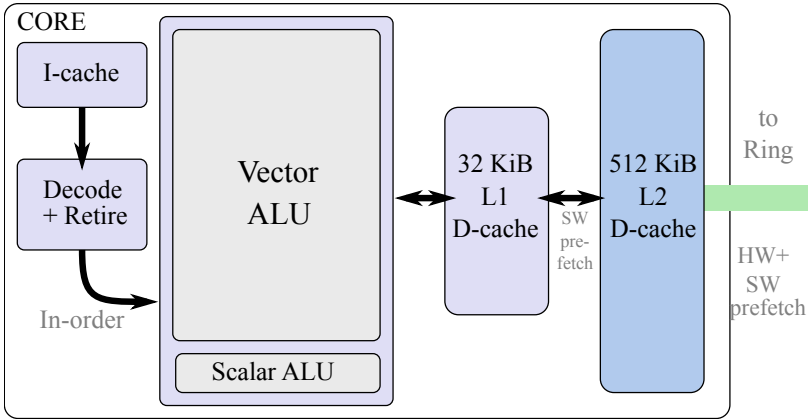
KNL Die Organization

- Mesh interconnect relaxes data locality requirement [somewhat]
- All-to-all, quadrant or sub-numa domain communication in mesh



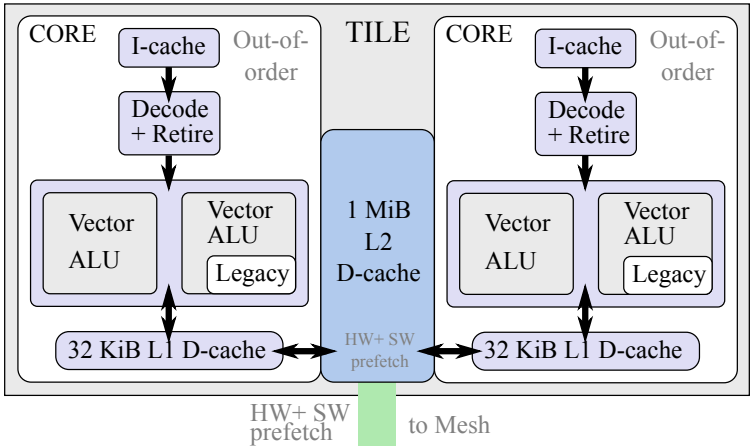
KNC Cores

Computing power is in vector units. Scalar support only for legacy usage.

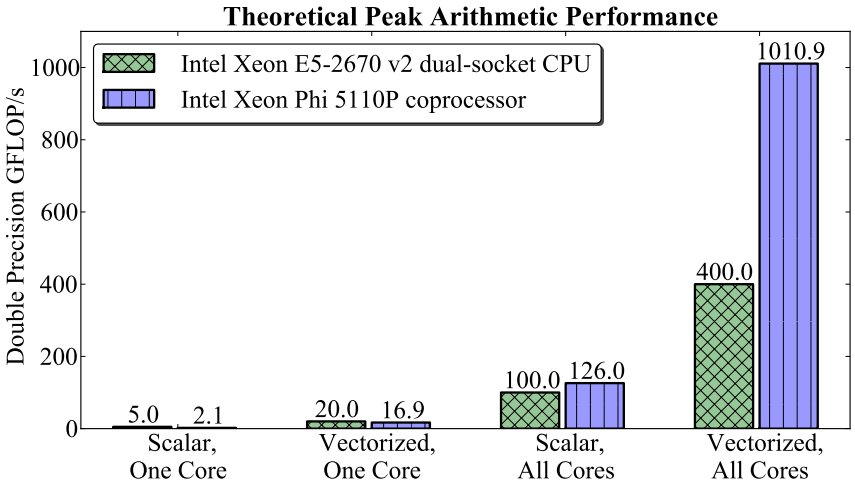


KNL Cores

- Even more power in vector units
- Binary compatible with Xeon, but in legacy mode

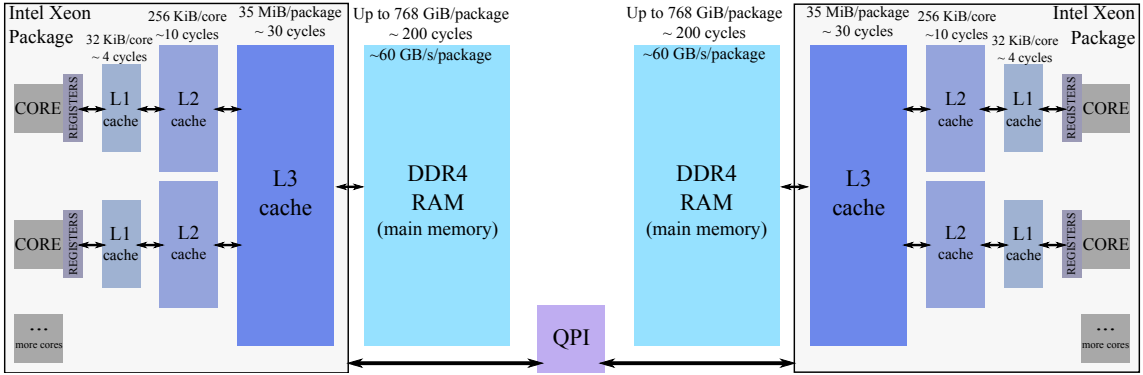


Task and Data Parallelism



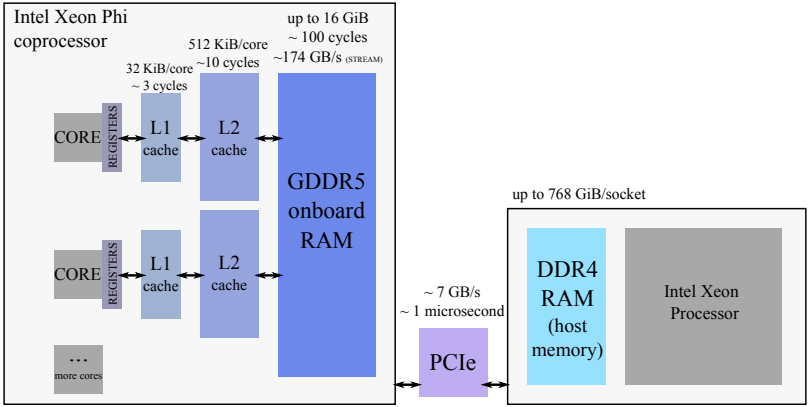
Intel Xeon CPU: Memory Organization

- Hierarchical cache structure
- Two-way processors have NUMA architecture



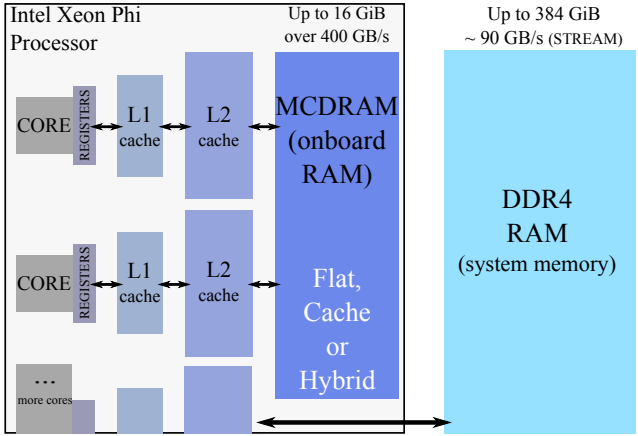
KNC Memory Organization

- Direct access to ≤ 16 GiB of cached GDDR5 memory on board
- No access to system DDR4, connected to host via PCIe

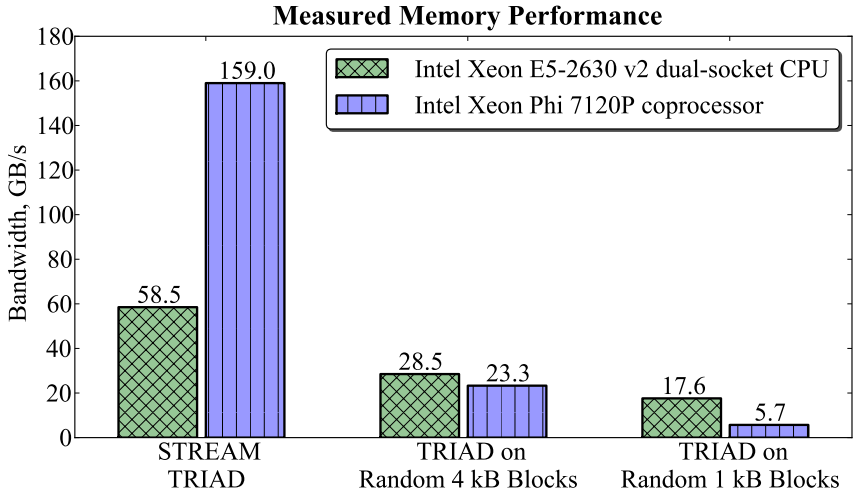


KNL Memory Organization

- Direct access to onboard MCDRAM *and* system DDR4
- Use MCDRAM as cache, in flat mode, or as hybrid



Memory Access Pattern



What's New in Knights Landing

KNL: What's New

	Haswell	**KNC**	**KNL**
Form factor	Socket	PCIe	PCIe, Socket
Core	Out-of-order	In-order	Out of order
Vectors	≤ AVX2	IMCI	≤ AVX2 + AVX-512
Memory	DDR4	GDDR5	MCDRAM+DDR4
RDMA	Over PCIe	Over PCIe	PCIe or Integrated
Programming	Traditional	Native, Offload	Traditional, Offload
Performance, Optimization	High and forgiving	Higher; needs good code	3x KNC 1-threaded and parallel

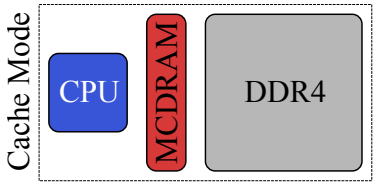
Using High-Bandwidth Memory (MCDRAM)

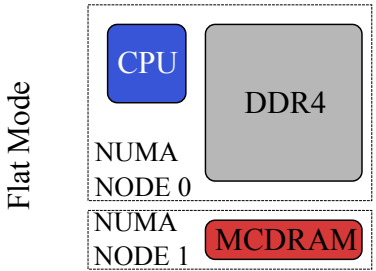
Option 1 : cache/hybrid mode

- Treat it as LLC
- Data locality techniques
- Miss latency 2x the direct DDR4 access

Option 2 : flat mode

- Application fits in 16 GiB? `numactl`
- More than 16 GiB data? Use special allocators (e.g., `memkind`)





Using New Vector Features

Efficient gather/scatter, conflict detection, high-precision exponential and reciprocal, two vector units per core...

Option 1 : automatic vectorization

- No changes to code, possibly adjust to 512-bit vector width
- Recompile with `-xMIC-AVX512`

Option 2 : explicit vectorization

- Bite the bullet

See also this post

Bottom Line

The best way to prepare...

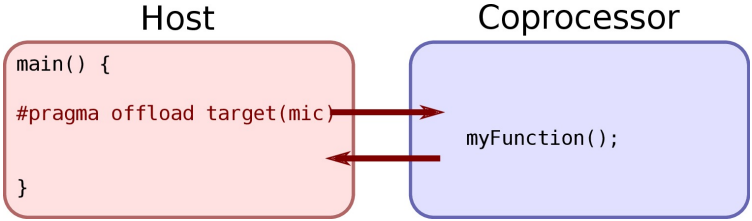
KEEP
CALM
AND
GO
PARALLEL

§3. Programming Coprocessors

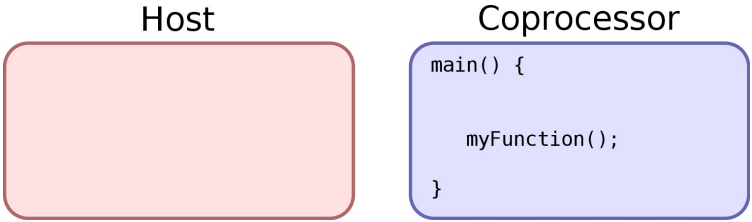
Offload and Native Models

Offload and Native Models

- Offload model (explicit/virtual-shared memory/OpenMP 4.0):



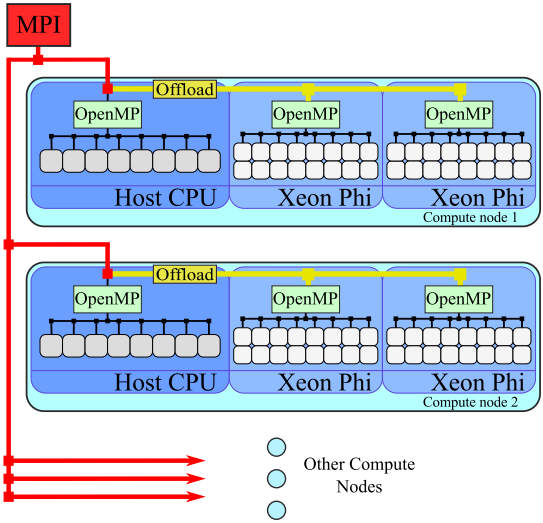
- Native model (standalone application/MPI process):



Heterogeneous Distributed Computing with Xeon Phi

Option 1: MPI+OpenMP with Offload.

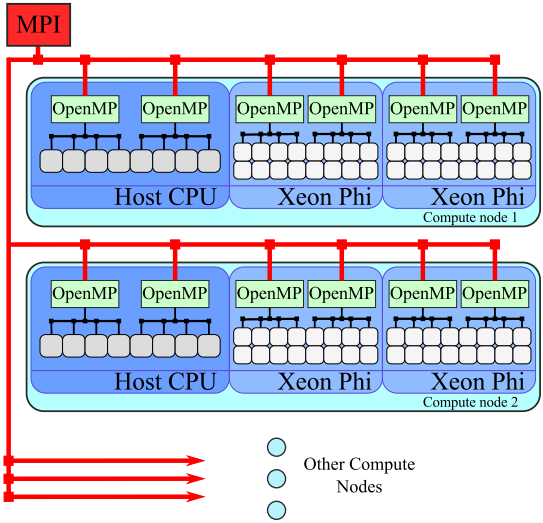
- MPI processes are multi-threaded with OpenMP.
- MPI runs only on CPUs.
- MPI processes offload to coprocessor(s).
- OpenMP in offload regions.



Heterogeneous Distributed Computing with Xeon Phi

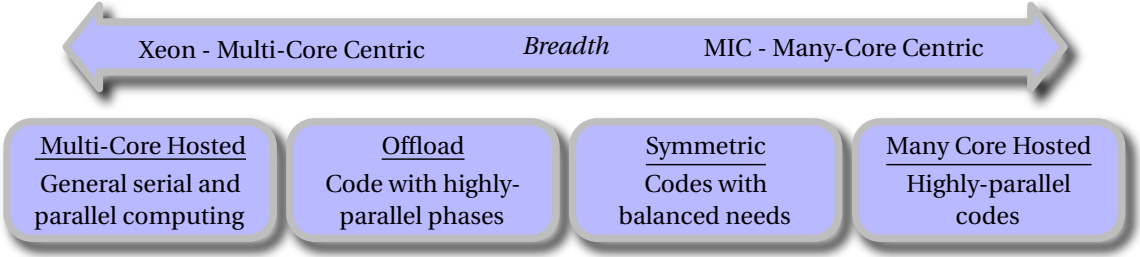
Option 2: Symmetric hybrid MPI+OpenMP.

- MPI processes on hosts
- Native MPI processes on the coprocessor.
- Multi-threading with OpenMP.



Teaming Xeon Processors with Xeon Phi Coprocessors

Programming models allow a range of CPU+MIC coupling modes



Software Configuration

Intel Manycore Platform Software Stack

- `micinfo` – system information
- `micsmc` – monitor and modify the physical paramaters: temperature, power modes, core utilization, etc.
- `micctrl` – configure the Intel Xeon Phi coprocessor operating system
- `miccheck` – verify the Intel Xeon Phi coprocessor configuration
- `micrasd` – log of hardware errors reported by Intel Xeon Phi coprocessors
- `micflash` – flash memory agent

Monitoring MIC activity with `micsmc` (an MPSS tool)

Linux Environment on Intel Xeon Phi Coprocessors

```
vega@lyra% lspci | grep -i "co-processor"
06:00.0 Co-processor: Intel Corporation Xeon Phi coprocessor 7120 series (rev 20)
82:00.0 Co-processor: Intel Corporation Xeon Phi coprocessor 7120 series (rev 20)
vega@lyra% sudo service mpss status
mpss is running
vega@lyra% cat /etc/hosts | grep mic
172.31.1.1  lyra-mic0 mic0
172.31.2.1  lyra-mic1 mic1
vega@lyra% ssh mic0

vega@mic0% cat /proc/cpuinfo | grep proc | tail -n 3
processor: 241
processor: 242
processor: 243
vega@mic0% ls /
amplxe   dev    home   lib64    oldroot  proc   sbin     sys    usr
bin      etc    lib    linuxrc  opt      root   sep3.10  tmp    var
```

Software Necessary to Build Xeon Phi Applications:

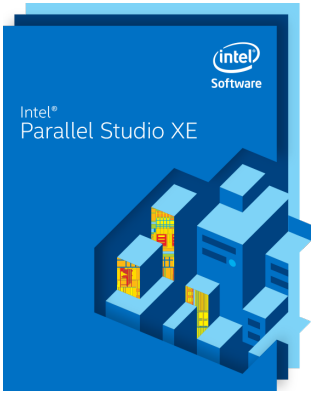
Compilers : Intel C Compiler, Intel C++ Compiler, and Intel Fortran Compiler — mandatory

Optimization tools : Intel VTune Amplifier XE and Intel Trace Analyzer and Collector (ITAC) — highly recommended

Mathematics support : Intel Math Kernel Library (MKL) — highly recommended

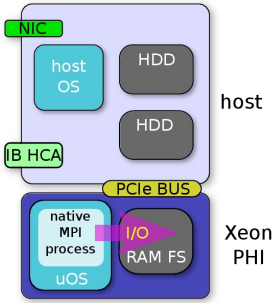
Cluster Development : Intel MPI — industry standard parallel framework

Development : Intel Inspector XE, Intel Advisor XE — optional

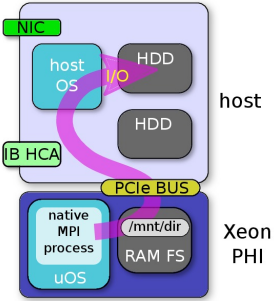


All-in-One bundle,
Intel Parallel Studio XE

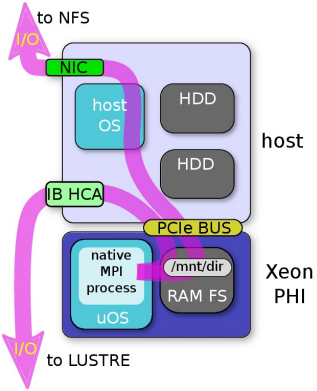
Working with Files on Coprocessors



RAM Filesystem



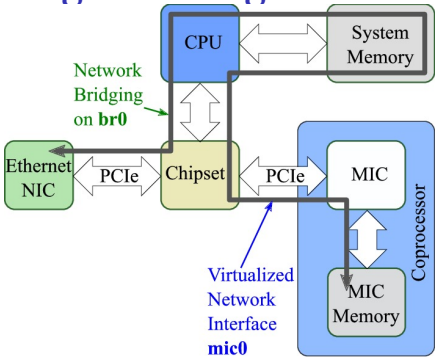
VirtIO Transfer

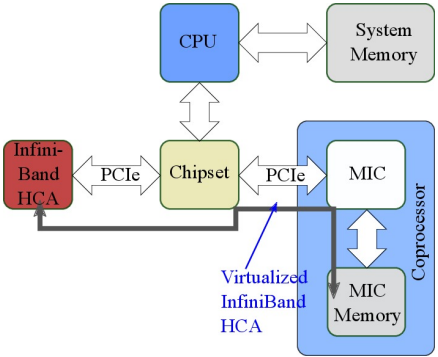


Network Storage

Details: http://xeonphi.com/papers/io

Bridged Configuration for Peer-to-Peer Communication





- Left: Gigabit Ethernet bridging and TCP/IP virtualization
- Right: InfiniBand on Xeon Phi with the Coprocessor Communication Link (CCL) technology
- Details: `http://xeonphi.com/papers/p2p`

§4. Hands-On Part: Native Programming

Native Execution

"Hello World" application:

```
1 #include <cstdio>
2 #include <unistd.h>
3 int main(){
4     printf("Hello world! I have %ld logical cores.\n",
5     sysconf(_SC_NPROCESSORS_ONLN ));
6 }
```

Compile and run on host:

```
vega@lyra% icpc hello.cc
vega@lyra% ./a.out
Hello world! I have 48 logical cores.
vega@lyra%
```


Native Execution

Compile and run the same code on the coprocessor in the native mode:

```
vega@lyra% icpc hello.cc -mmic
vega@lyra% scp a.out mic0:~/
a.out 100% 10KB 10.4KB/s 00:00
vega@lyra% ssh mic0
vega@mic0% pwd
/home/lyra
vega@mic0% ls
a.out
vega@mic0% ./a.out
Hello world! I have 244 logical cores.
vega@mic0%
```

- Use `-mmic` to produce executable for MIC architecture
- Must transfer executable to coprocessor (or NFS-share) and run from shell
- Native MPI applications work the same way (need Intel MPI library)

Alternative Native Application Launcher: micnativeloadex

The tool micnativeloadex automatically transfers code and dependent libraries and runs the application.

```
vega@lyra% export SINK_LD_LIBRARY_PATH=/opt/intel/composerxe/compiler/lib/mic
vega@lyra% icpc hello.cc -mmic
vega@lyra% micnativeloadex a.out
Hello world! I have 244 logical cores.
vega@lyra%
```

- Set SINK_LD_LIBRARY_PATH to help the tool find libraries
- Do not have to SSH into the coprocessor
- Runs under micuser on coprocessor

Native Applications with Autotools

- Use the Intel compiler with flag `-mmic`
- Eliminate assembly and unncecessary dependencies
- Use `--host=x86_64` to avoid "program does not run" errors

Example, the GNU Multiple Precision Arithmetic Library (GMP):

```
vega@lyra% wget https://ftp.gnu.org/gnu/gmp/gmp-5.1.3.tar.bz2
vega@lyra% tar -xf gmp-5.1.3.tar.bz2
vega@lyra% cd gmp-5.1.3
vega@lyra% ./configure CC=icc CFLAGS="-mmic" --host=x86_64 --disable-assembly
...
vega@lyra% make
...
```


Review and What's Next

- Intel Xeon and Intel Xeon Phi – parallel processors
- Xeon Phi (MIC architecture) – specialized for highly parallel workloads without complex memory access
- Coprocessor – either offload device or an additional compute node
- Native+offload programming allow for a range of design options

Next session: details of the offload model.