Node-Level Performance Analysis

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Learning Objectives

- To help develop ideas on how to use performance tools to explore the optimization space of widely used computational kernels in common computer architectures.

Node-Level Performance Analysis

- Performance Modelling
- Performance Measurements

LIKWID Toolset

- Topology
- Affinity
- Hardware Performance Counters
- MPI Wrapper
- Micro-benchmarking
- Roofline Model

Node-Level Performance Analysis

Node-Level Performance Analysis

- Modelling: Derivation of a model based on the functionality and topology of interconnected elements of a computational unit of a specific architecture.
- Measurements: Collection of events data through program instrumentation and events sampling.
- Visualization: Usage of performance tools to visualize collected events' data and traces.

Node-Level Performance Analysis
Modelling

Performance models are important in application's performance engineering and analysis. Models are key for:

- Comparing application performance against the machine capabilities
- Evaluating the optimality of application
- Identify possible bottlenecks in application computational performance
- Identifying software and hardware limitations

Node-Level Performance Analysis

Measurements: Machine and Application Characterizations

1. Data Collection and Sampling
   - Automatic instrumentation - increases overhead, e.g. Compilers, Vampir, Score-P,
   - Manual instrumentation. e.g. Print-statements, Score-P
   - Binary instrumentation - requires re-addressing, replacements and patching of instructions and memory accesses, e.g. Gprof, Valgrind, GDB
   - Sampling - execution is itnerupted at regular intervals to sample addresses of executed instruction, e.g. LIKWID, Gprof
2. Data Processing
   - For simple applications with small amount of events, events can be counted and performance data can be processed and displayed in a graphical viewer in real-time.
3. Data transfer and storage
   - For complex applications, events data should be stored in disks. e.g. Vampir

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LIKWID Toolset

LIKIWD

- LIKWID: A toolset for performance-oriented developers and users:
  - `likwid-topology` : Get system (thread/core/cache/NUMA) topology
  - `likwid-pin` : Pin threads to cores according to system's topology (for maintenance of spatial locality)
  - `likwid-bench` : Provides a set of micro-benchmark kernels including stream, triad and daxpy, to check system features as *FLOPS*, bandwidth and vectorization efficiency.
  - `likwid-perfctr` : Measure hardware events during application runs and show derived metrics including *FLOPS*, bandwidth, TLB misses and power. integrates the `likwid-pin` functionality.
  - `likwid-mpirun` : MPI wrapper for `likwid-pin` and `likwid-perfctr` . Profiles MPI and Hybrid applications. Utilizes `likwid-pin` and `likwid-perfctr` at the backend.

LIKWID: Topology

Check the options using `likwid-topology -h`

```
$ module load likwid
$ likwid-topology -h
likwid-topology -- Version 5.2.0

Options:
-h, --help       Help message
-v, --version        Version information
-V, --verbose            Set verbosity
-c, --caches         List cache information
-C, --clock      Measure processor clock
-O           CSV output
-o, --output             Store output to file. (Optional: Apply text filter)
-g           Graphical output
```

LIKWID: Affinity

- Provides thread-to-core pinning for an application for maintenance of spatial locality.
- `likwid-pin` accepts 6 options for processor lists:
  1. **physical numbering**: processors are numbered acording to the numbering in the operating system
  2. **logical numbering**: processors are logically numbered over the whole node - N
  3. **logical numbering in socket**: processors are logically numbered in every socket - S#
  4. **logical numbering in cache group**: processors are logically numbered in last level cache group - C#.
  5. **logical numbering in memory domain**: Processors are logically numbered in NUMA domain - M#
  6. **logical numbering within cpuset**: processors are numbered inside Linux cpuset - L

LIKWID: Hardware Performance Counters

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- Uses the Linux msr module to access the model specific registers stored in `/dev/cpu/*/msr` then alculates performance metrics, *FLOPS*, bandwidth, etc, based on the formula defined by LIKWID or customized by user.
- `likwid-perfctr -a` lists performance metrics and/or groups supported by LIKWID
- `likwid-perfctr -e` lists all hardware events or counters available
- `likwid-perfctr -E <perf group>` shows the events or counters used to calculate a particular performance group.
- `likwid-perfctr -H -g <perf group>` reveals the formula being used to derive performance metrics using the performance counters.

LIKWID: MPI wrapper

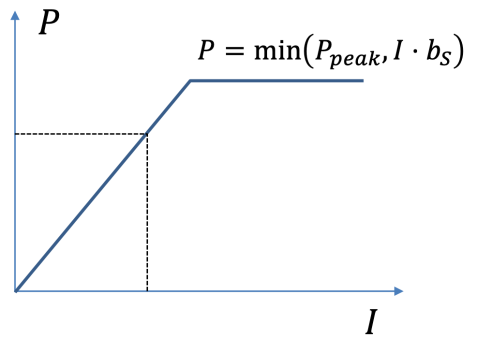
- Detects MPI environments and wraps a job launcher around `likwid-perfctr` to measure performances for MPI and hybrid applications.
- It also integrates the functionality of `likwid-pin`

LIKWID: Micro-benchmarking

- Provides a list of benchmark kernels for users to quickly test some characteristics of an architecture.
- A number of basic benchmark kernels are readily available:
  - `copy` Standard memcpy benchmark. $A[i] = B[i]$
  - `copy_mem` The same as above but with non temporal store.
  - `load` One load stream. This one does some software prefetching you can experiment with.
  - `store` One store stream.
  - `store_mem` The same as above but with non temporal store.
  - stream Classical STREAM triad. $A[i] = B[i] + aC[i]$
  - `stream_mem` The same as above but with non temporal store.
  - `triad` Full vector triad. $A[i] = B[i] + C[i] * D[i]$
  - `triad_mem` The same as above but with non temporal store

Emperical Roofline Model with LIKIWD

Roofline Model: A visually-intuitive graphical representation of a machine's performance (P) characteristics considering two principal performance bounds, computation and communication.[1]



- Memory bandwidth, b_s: Communication is bounded by the characteristics of the machine's processor-memory interconnect.
- Arithmetic Intensity, I [flops:bytes]: The ratio of kernel's computation to memory traffic (volume of data to a particular memory).

[1] Samuel W. Williams. *Auto-tuning Performance on Multicore Computers*. Berkley: University of California at Berkley, 2008.

Tutorial

- Download the tutorials
- Load LIKWID module

Note: Use slurm to start an interactive session in a compute node.