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# Debugging and Profiling with Arm Tools

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# Agenda

- Introduction to Arm Tools
- Remote Client Setup
- Debugging with Arm DDT
- Other Debugging Tools
- Break
- Examples with DDT
- Lunch
- Profiling with Arm MAP
- Examples with MAP
- Obtaining Support

# Introduction to Arm HPC Tools



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# Arm Forge

## An interoperable toolkit for debugging and profiling

Commercially supported by Arm

Fully Scalable

Very user-friendly

- The de-facto standard for HPC development
  - Available on the vast majority of the Top500 machines in the world
  - Fully supported by Arm on x86, IBM Power, Nvidia GPUs and Arm v8-A.
- State-of-the art debugging and profiling capabilities
  - Powerful and in-depth error detection mechanisms (including memory debugging)
  - Sampling-based profiler to identify and understand bottlenecks
  - Available at any scale (from serial to petaflopic applications)

Easy to use by everyone

- Unique capabilities to simplify remote interactive sessions
- Innovative approach to present quintessential information to users

 

# Arm Performance Reports

## Characterize and understand the performance of HPC application runs

Commercially supported by Arm

Accurate and astute insight

Relevant advice to avoid pitfalls

### Gathers a rich set of data

- Analyses metrics around CPU, memory, IO, hardware counters, etc.
- Possibility for users to add their own metrics

### Build a culture of application performance & efficiency awareness

- Analyses data and reports the information that matters to users
- Provides simple guidance to help improve workloads' efficiency

### Adds value to typical users' workflows

- Define application behaviour and performance expectations
- Integrate outputs to various systems for validation (e.g. continuous integration)
- Can be automated completely (no user intervention)

 

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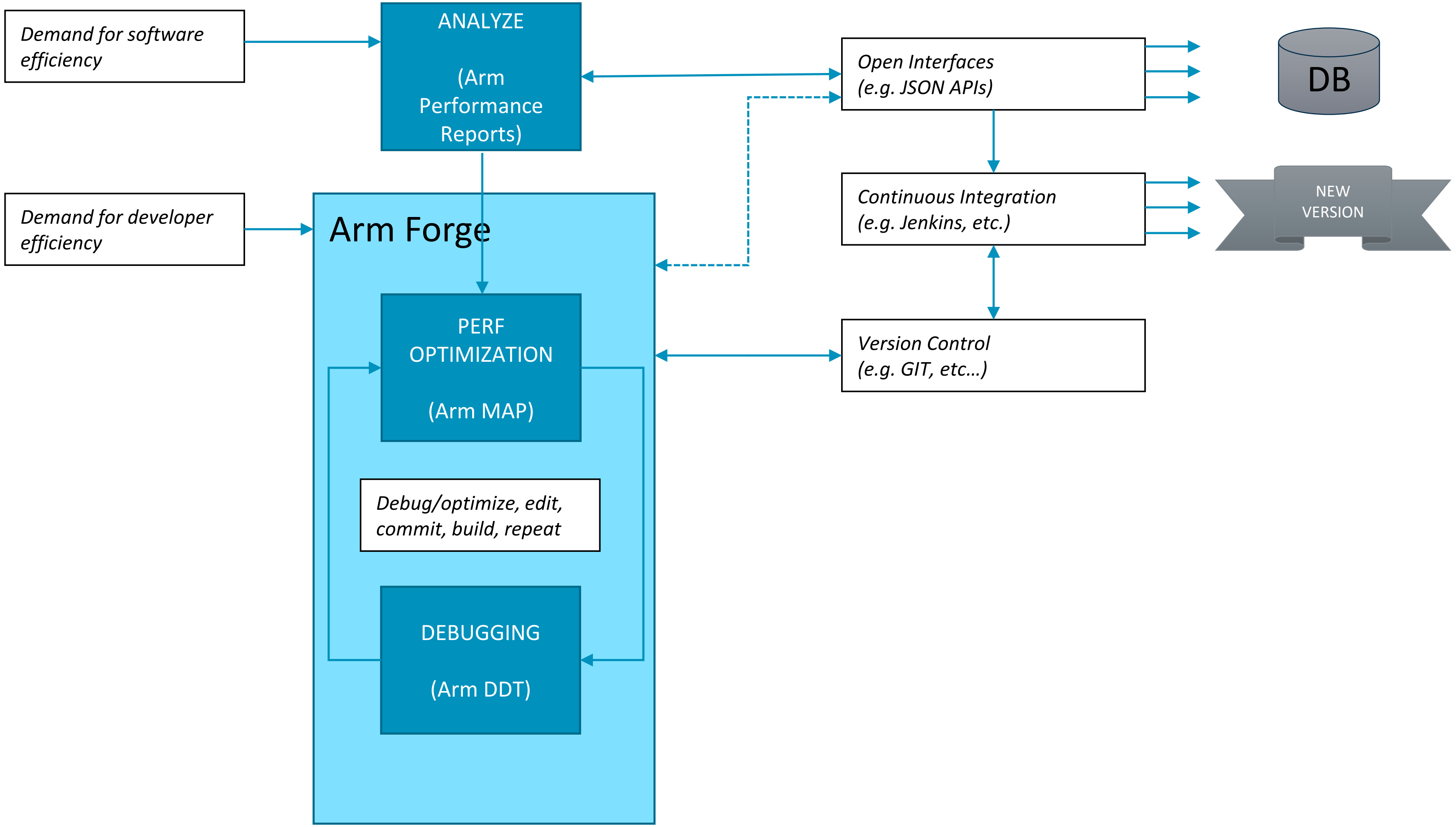
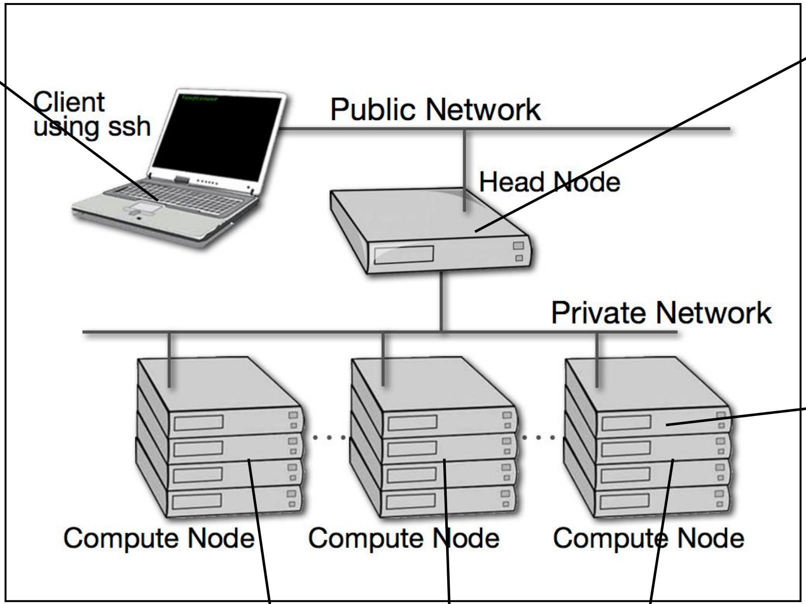
# Software tools-centric view



# Using Forge and the remote client

# Different ways to run Arm Forge…

Here
(remote launch +
reverse connect)




There
(interactive mode +
reverse connect)

There
(offline OR
interactive mode)

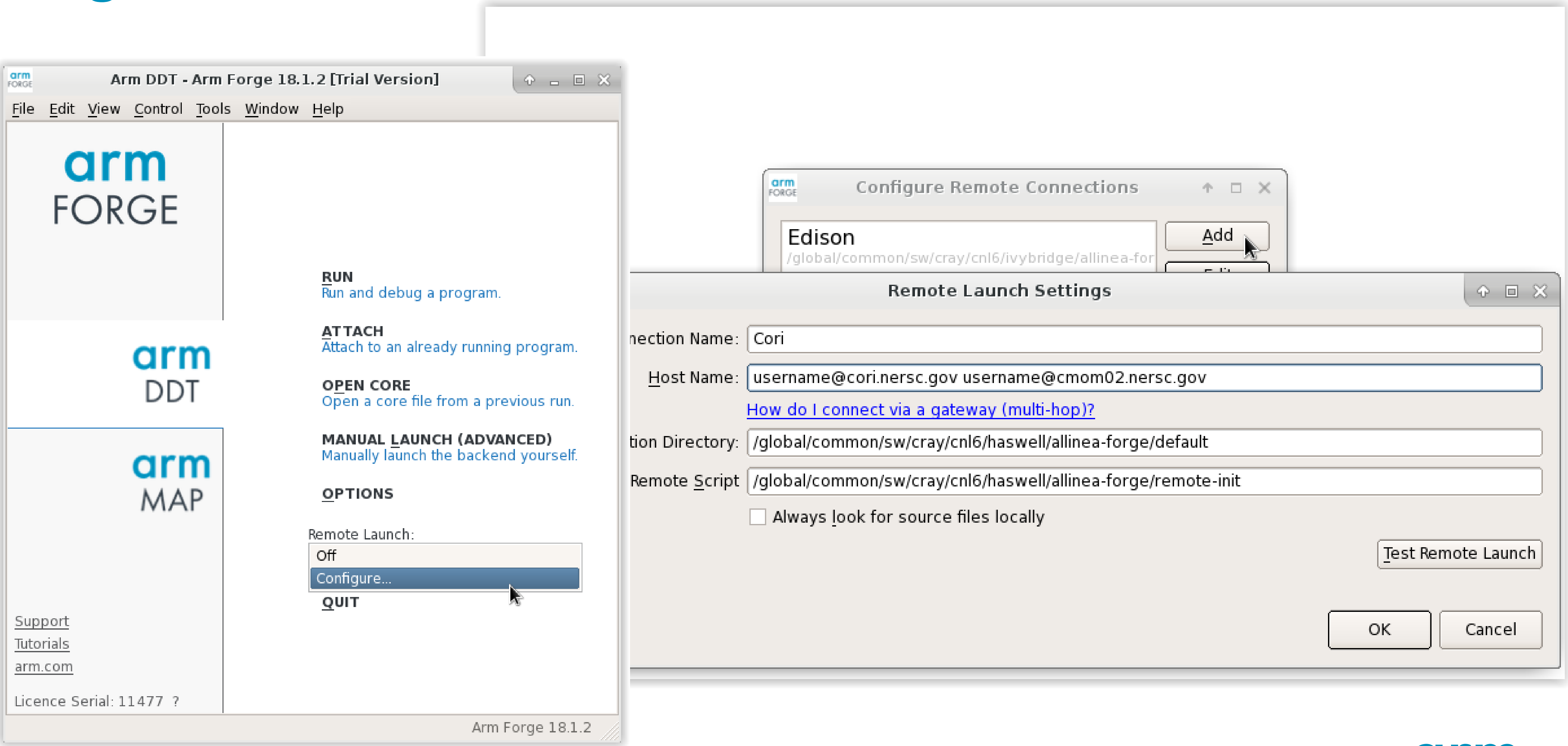
Ultimately, that’s where the tools will run.
But what about the GUI?

# Forge Remote Client

- The latest version of Forge can be downloaded from https://developer.arm.com/products/software-development-tools/hpc/downloads/download-arm-forge

- It is important to have the remote client version match what is installed on the system

# Forge Remote Client



http://www.nersc.gov/users/software/performance-and-debugging-tools/ddt/

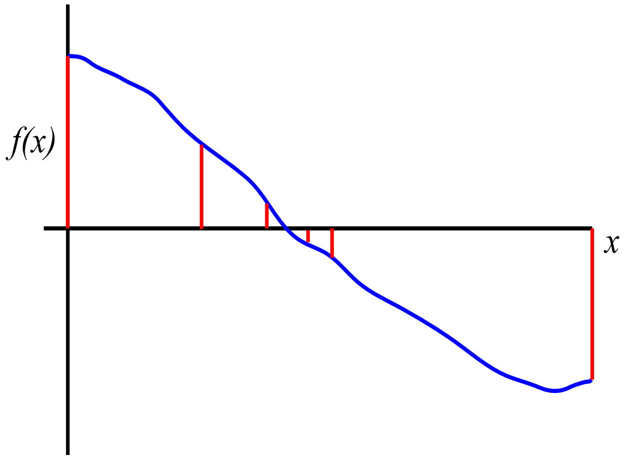
# Debugging with Arm DDT

# Print statement debugging

- The first debugger: print statements
  - Each process prints a message or value at defined locations
  - Diagnose the problem from evidence and intuition

- A long slow process
  - Analogous to bisection root finding

- Broken at modest scale
  - Too much output – too many log files



# Typical types of bugs

- Steady and dependable, I'll be there for you.

**BOHR BUG**

- Oh, you are debugging? Let me hide for a sec!

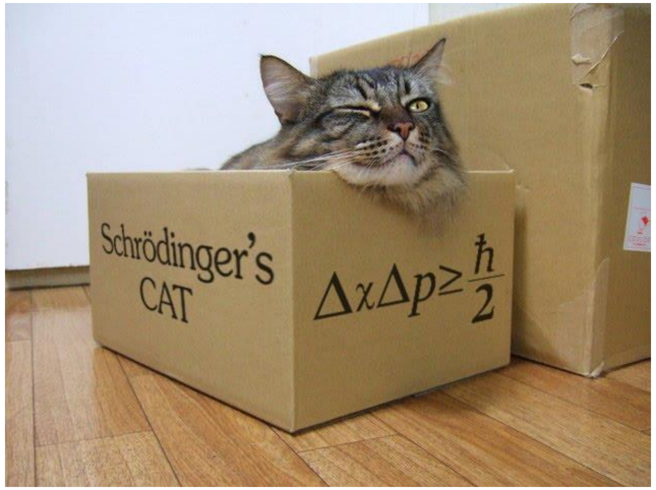
**HEISEN BUG**

- Chaos is my name and you shall fear me.

**MANDEL BUG**

- I am buggy ***AND*** not buggy. How about that?

**SCHRODIN BUG**



# Debugging by discipline

**Debugging a problem is much easier when you can:**

- Make and undo changes fearlessly
  - Use a **source control** (CVS, …)
- Track what you've tried so far
  - Write **logbooks**
- Reproduce bugs with a single command
  - Create and use **test script**

```
$ mkdir logs
$ vim logs/segfault-at-4096-procs

When running lu.E.4096 with the trace-4410.dat set,
the job exited with: "An error occurred in MPI_Send
[li346-209:25319] on communicator MPI_COMM_WORLD
MPI_ERR_RANK: invalid rank".

To reproduce: mpiexec -n 4096 lu.W.4096 trace-4410.dat
on supermuc. Seems to happen every time.

* Tried reading core file with gdb, "File truncated"
* Set ulimit -c unlimited and ran again: ...
```

```
$ logs/segfault-at-4096-procs.sh
Sep 27 15:29: Queued as job.43214
Sep 27 18:01: Running...
Sep 27 19:29: FAIL
```

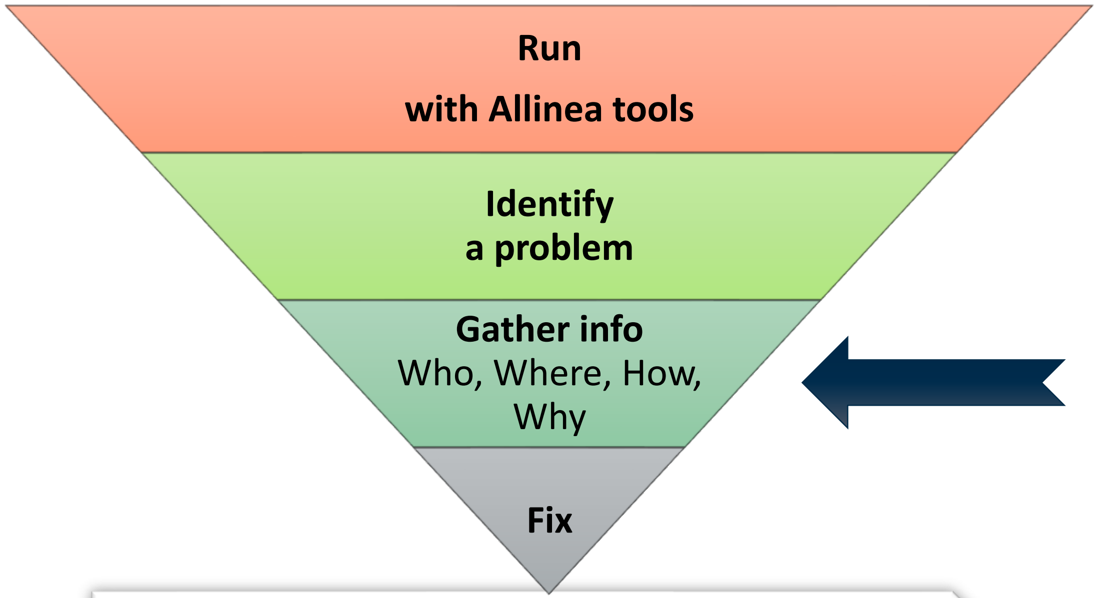
# Arm DDT – the debugger

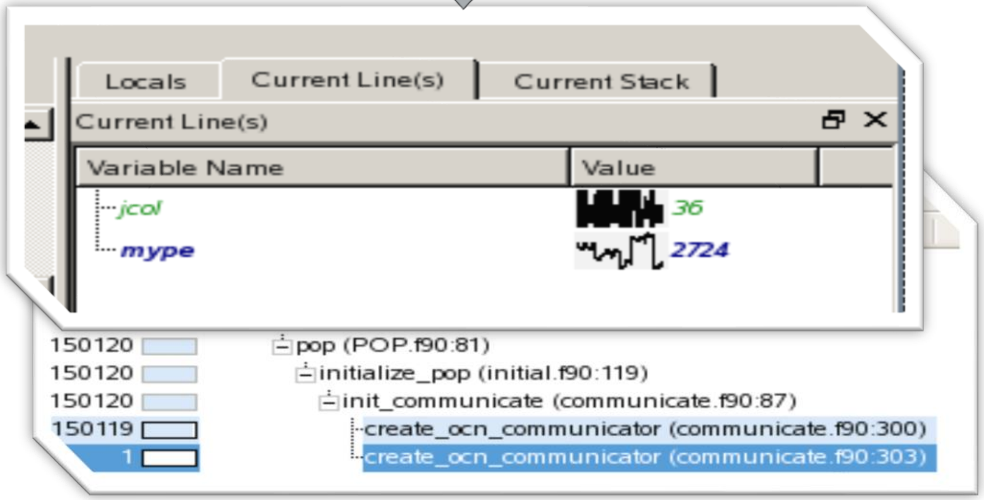
## Who had a rogue behaviour ?
- Merges stacks from processes and threads

## Where did it happen?
- leaps to source

## How did it happen?
- Diagnostic messages
- Some faults evident instantly from source

## Why did it happen?
- Unique “Smart Highlighting”
- Sparklines comparing data across processes



# Arm DDT cheat sheet

Load the environment module (on Cori/Edison)

- $ module load **allinea-forge**

Prepare the code

- $ cc **-O0 -g** myapp.c –o myapp.exe

Start Allinea DDT in interactive mode

- $ **ddt** srun -n 8 ./myapp.exe arg1 arg2

Or use the reverse connect mechanism

- On the login node:
  - $ ddt &
- (or use the remote client)
- Then, edit the job script to run the following command and submit:
  - **ddt --connect** srun -n 8 ./myapp.exe arg1 arg2

# Examples

# Example Files

- Once connected to cori, download the examples to your home directory
- **cp /project/projectdirs/training/DebugProfile_201804/NERSC_Training.tar.gz ~/**

# DDT Demonstration



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# Exercise:
# Fixing a simple crash



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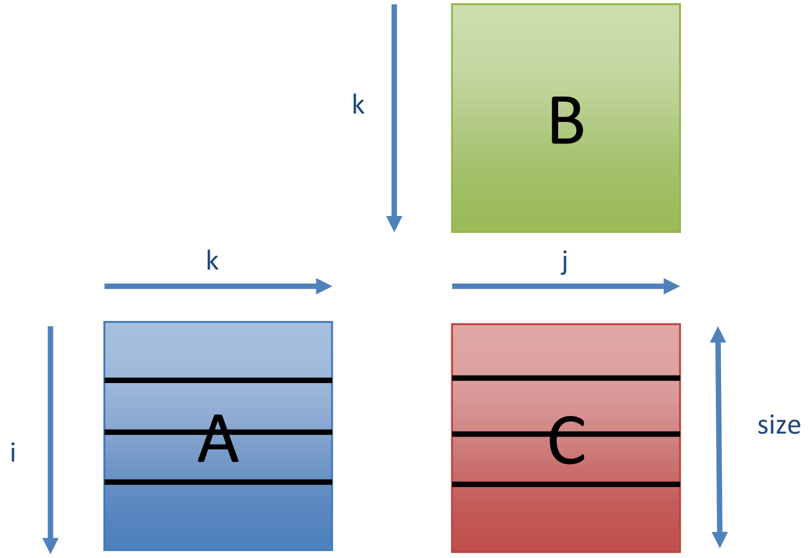
# Algorithm: C = A x B + C




i, j, k: loop indexes

nslices = 4

## Algorithm

1- Master initialises matrices A, B & C

2- Master slices the matrices A & C, sends them to slaves

3- Master and Slaves perform the multiplication

4- Slaves send their results back to Master

5- Master writes the result Matrix C in an output file

# Fix a simple crash in a MPI code

**Objectives:**

- Discover Arm DDT’s interface
- Debug a simple crash in a MPI application interactively
- Use the tool in a cluster environment

**Key commands:**

- Compile the application: $ make
- Clean and recompile for debugging: $ make clean && make DEBUG=1
- Use the debugger with reverse connect
- Accept the incoming connection!
- Can you find out and fix the bug?

# Exercise: Identifying Out-of-Memory Accesses

# Critical memory crash

**Objectives:**

- Use the memory debugging feature
- Diagnose and fix a memory problem

**Key commands:**

- Compile the application with debugging flags: $ make
- Recompile using the memory debugging library (statically link through Makefile LFLAGS)
- Enable memory debugging in the “Run window”
- Change the amount of checks, enable guard pages
- Can you see the memory issue can you fix it?

# Exercise: Understanding hangs

# Deadlock

**Objectives:**

- Witness a deadlock and attach to the running processes
- Use Arm DDT Stack feature
- Use Arm DDT evaluation window

**Key commands:**

- Compile with: $ make
- Submit the job to run the application with 10 processes: it works.
- Run it again with 8 processes: it hangs!
- Leave the application run in the queue and attach to it with the debugger
- OR (if attaching is not supported) Submit the job again with the debugger
- Observe where it hangs. Can you fix the problem?

# Exercise:
# Detecting memory leaks

# Memory leaks

## Objectives:

- Use Arm DDT's offline mode
- Use the memory debugging feature
- Diagnose and fix a memory leak problem

## Key commands:

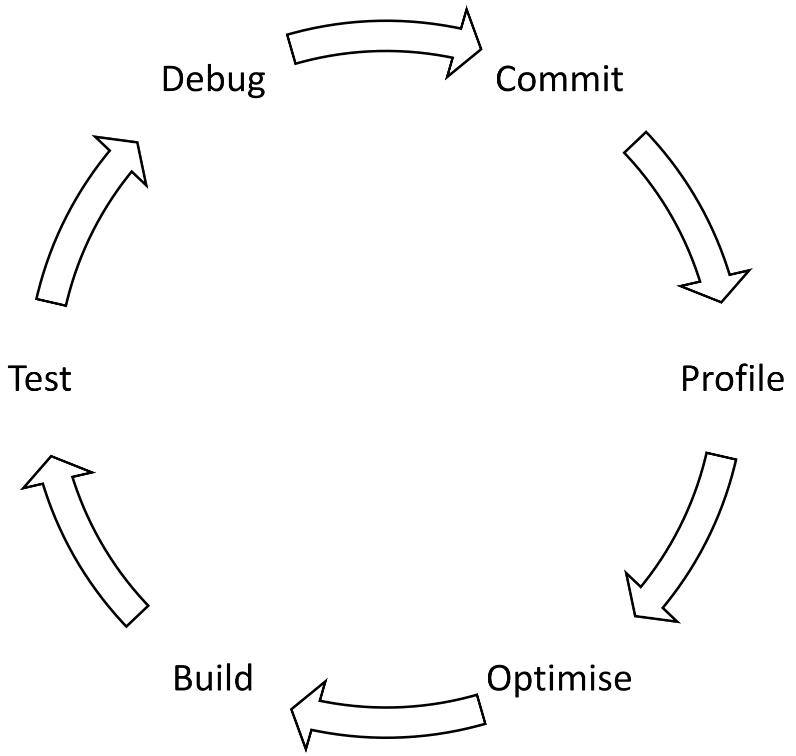
- Compile the application for debugging

  $ make

- Edit a job script to use the debugger in offline mode with memory debugging on and submit the job
- Open the resulting *.html file
- Can you see the memory leak?
- Restart the debugger in interactive mode. Can you see any hint from the debugger?

# Profiling with Arm MAP

# The complete HPC developer workflow




- System access made simple
  - Work remotely or locally
  - Same full capabilities
- Be confident changes work
  - Re-use Scheduler reservation …
  - ... Edit
  - … Build
  - … Test
  - Commit

# Why profiling?

How to improve the performance of an application?

*Profiling: a form of dynamic program analysis that measures, for example, the space (memory) or time complexity of a program, the usage of particular instructions, or the frequency and duration of function calls. Most commonly, profiling information serves to aid program optimization.*

(Wikipedia)

How?

- Select representative test case(s)
- Profile
- Analyse and find bottlenecks
- Optimise
- Profile again to check performance results and iterate

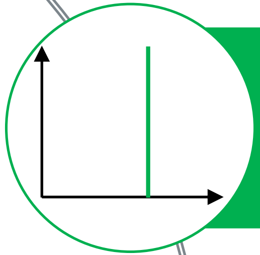
# How to profile?

Different methods

- Tracing
  - Records and timestamps all operations
  - Intrusive
- Instrumenting
  - Add instructions in the source code to collect data
  - Intrusive
- Sampling
  - Automatically collect data
  - Not intrusive

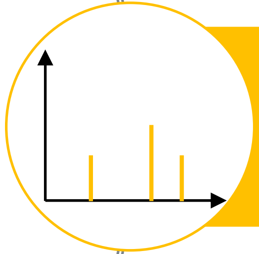
 

# Some types of profiles



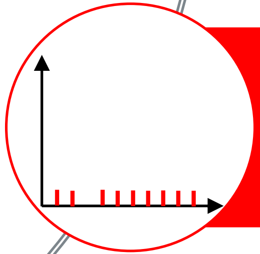
## Hotspot

- One function corresponds to more 80% of the runtime
- Large speed-up potential
- Best optimisation scenario



## Spike

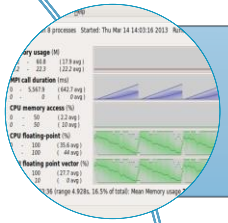
- The application spends most of the time in a few functions
- Speed-up potential depends on the aggregated time
- Variable optimisation time



## Flat

- Runtime split evenly between numerous functions, each one with a very small runtime
- Little speed-up potential without algorithmic changes
- Worst optimisation scenario

# Arm MAP: Performance made easy

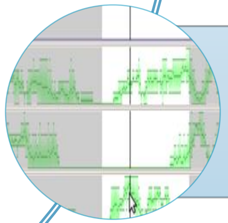


### Low overhead measurement

- Accurate, non-intrusive application performance profiling
- Seamless – no recompilation or relinking required

### Easy to use

- Source code viewer pinpoints bottleneck locations
- Zoom in to explore iterations, functions and loops



### Deep

- Measures CPU, communication, I/O and memory to identify problem causes
- Identifies vectorization and cache performance

# Arm MAP cheat sheet

Load the environment module

- $ module load **allinea-forge**

Prepare the code

- $ cc –O3 **-g** myapp.c –o myapp.exe

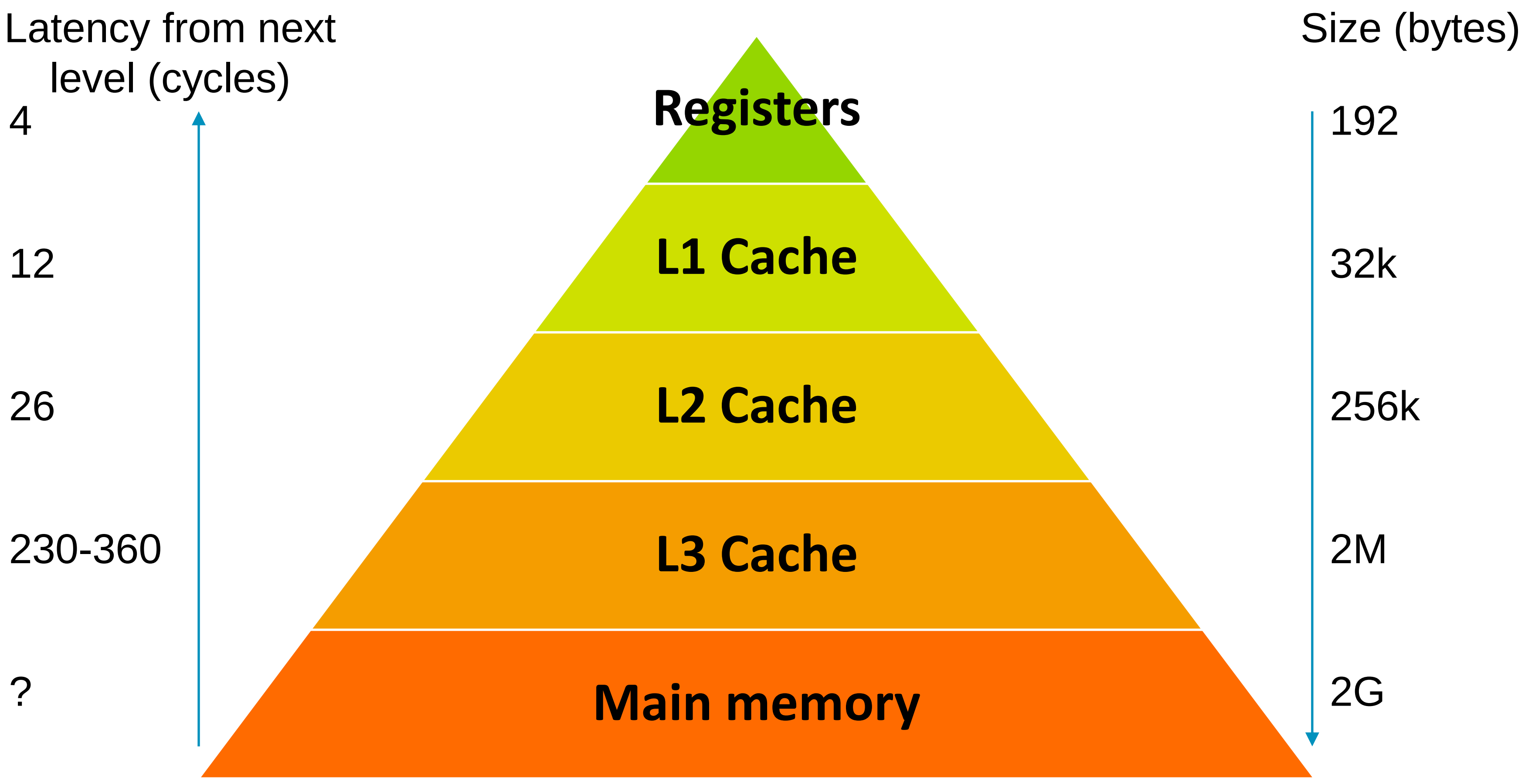
Edit the job script to run Arm MAP in “profile” mode

- $ **map --profile** srun ./myapp.exe arg1 arg2

Open the results

- On the login node:
  - $ map myapp_Xp_Yn_YYYY-MM-DD_HH-MM.map
- (or load the corresponding file using the remote client connected to the remote system or locally)

# Typical memory hierarchy

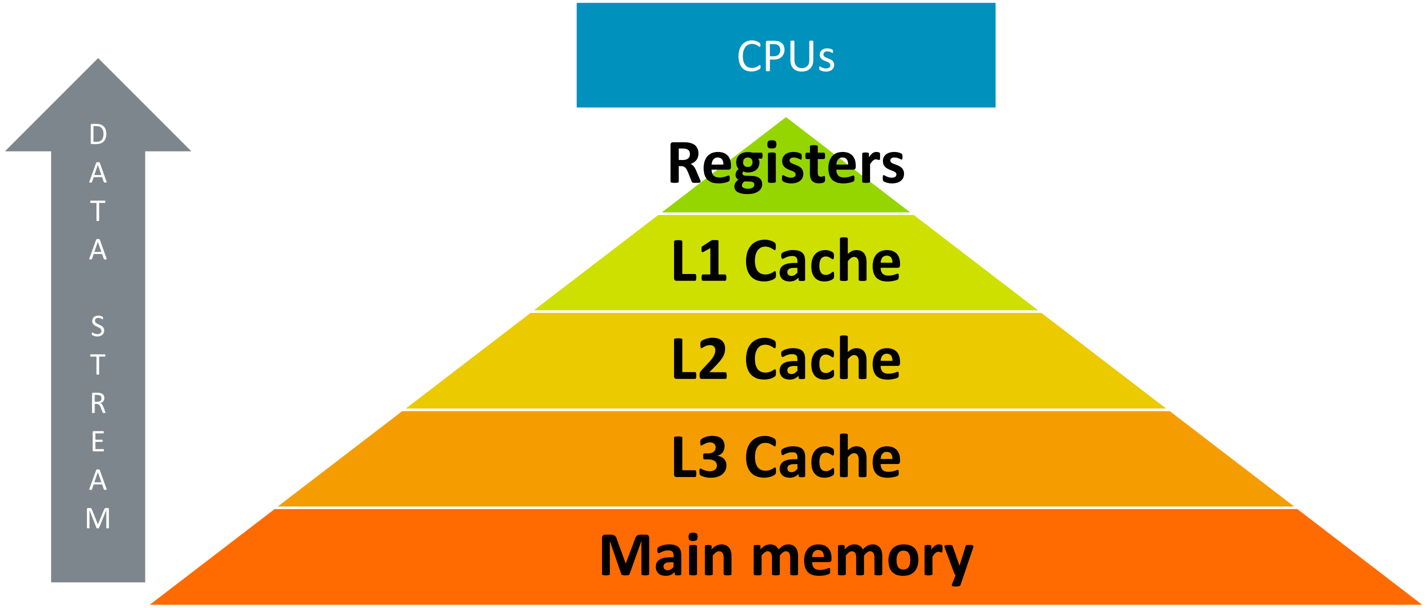



Example of Intel Sandy Bridge

# Speeding up memory accesses

High performance is possible when:

- There is an opportunity for cache re-use
- Data is local to the core for quick usage
- CPU gets data from memory to cache before it is actually needed



# Memory access patterns

Data locality

- Temporal locality: use of data within a short time of its last use
- Spatial locality: use memory references close to memory already referenced

**Temporal locality example**

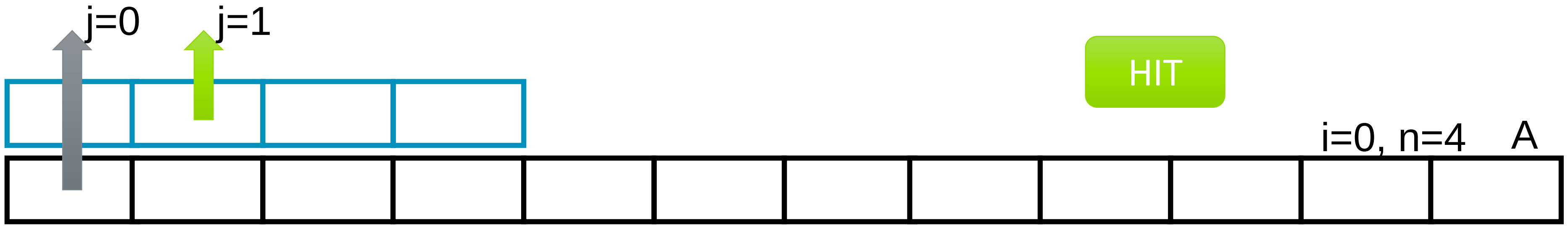
```
for (i=0 ; i < N; i++) {
    for (loop=0; loop < 10; loop++) {
        … = … x[i] …
    }
}
```

**Spatial locality example**

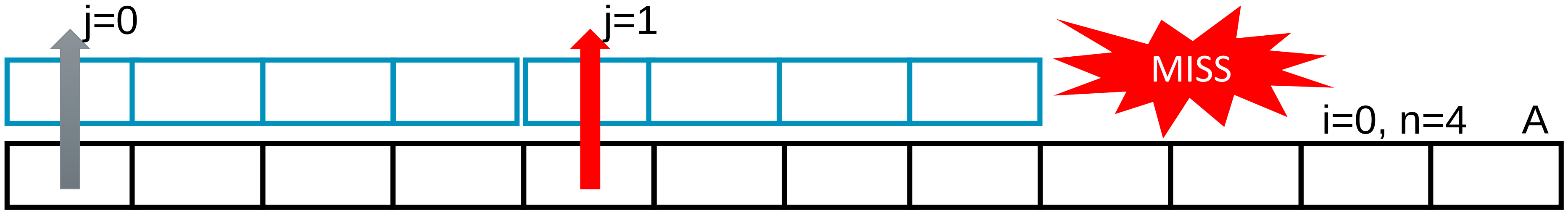
```
for (i=0 ; i < N*s; i+=s) {
    … = … x[i] …
}
```

# Memory Accesses and Cache Misses

```
for(i=0; i<n; i++) {
  for(j=0; j<n; j++) {
    A[i*n+j]=…
  }
}
```




```
for(i=0; i<n; i++) {
  for(j=0; j<n; j++) {
    A[j*n+i]=…
  }
}
```



# Exercise: Optimizing memory accesses

# Resolve high memory accesses issues

Objectives:

- Discover Arm MAP's interface
- Profile the MPI matrix multiplication example and find out the performance issue
- Use the tool in a cluster environment

Key commands:

- Compile the application

  $ make
- $ map --profile srun myApp.exe
- Open the result in the GUI on the login node once the job has completed

  $ map *.map
- What is the bottleneck of the application? Can you identify performance problems?

# Resolving workload imbalances

# 9 Step guide: optimizing high performance applications

Improving the efficiency of your parallel software holds the key to solving more complex research problems faster. This pragmatic, 9 Step best practice guide will help you identify and focus on application readiness, bottlenecks and optimizations one step at a time.

### 1 Bugs

- ✔ Correct application.

### 2 Analyze before you optimize

- ✔ Measure all performance aspects. You can't fix what you can't see.
- ✔ Prefer real workloads over artificial tests.

### 3 I/O

- ✔ Discover lines of code spending a long time in I/O.
- ✔ Trace and debug slow access patterns.

### 4 Workload

- ✔ Detect issues with balance.
- ✔ Slow communication calls and processes. Dive into partitioning code.

### 5 Communication

- ✔ Track communication performance.
- ✔ Discover which communication calls are slow and why.

### 6 Memory

- ✔ Reveal lines of code bottlenecked by memory access times.
- ✔ Trace allocation and use of hot data structures.

### 7 Cores

- ✔ Discover synchronization overhead and core utilization.
- ✔ Synchronization-heavy code and implicit barriers are revealed.

### 8 Vectorization

- ✔ Understand numerical intensity and vectorization level.
- ✔ Hot loops, unvectorized code and GPU performance revealed.

### 9 Verification

- ✔✔ Validate corrections and optimal Performance.

Key:

- ✔ arm PERFORMANCE REPORTS
- ✔ arm FORGE

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# Load balancing in theory

Balancing the workload is critical because:

– Processors may be idle for an extended period of time

– They could have been doing some work instead of burning energy

Examples of load balancing

- *Owner computes*

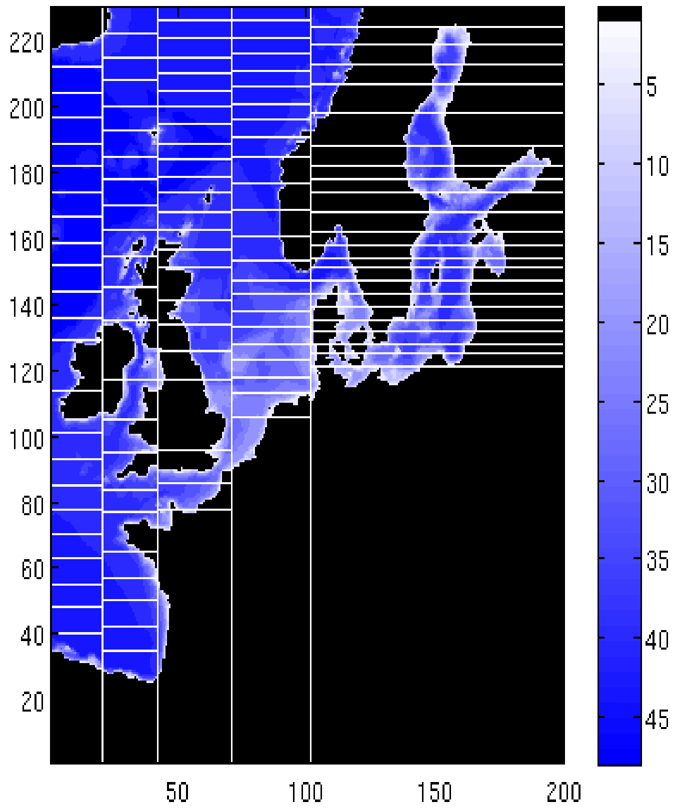
Balance done through data distribution

- *Independent tasks*

Balance done through prediction/statistics

- *A mix of various components*

Balance between scalar workload and communications (for instance)



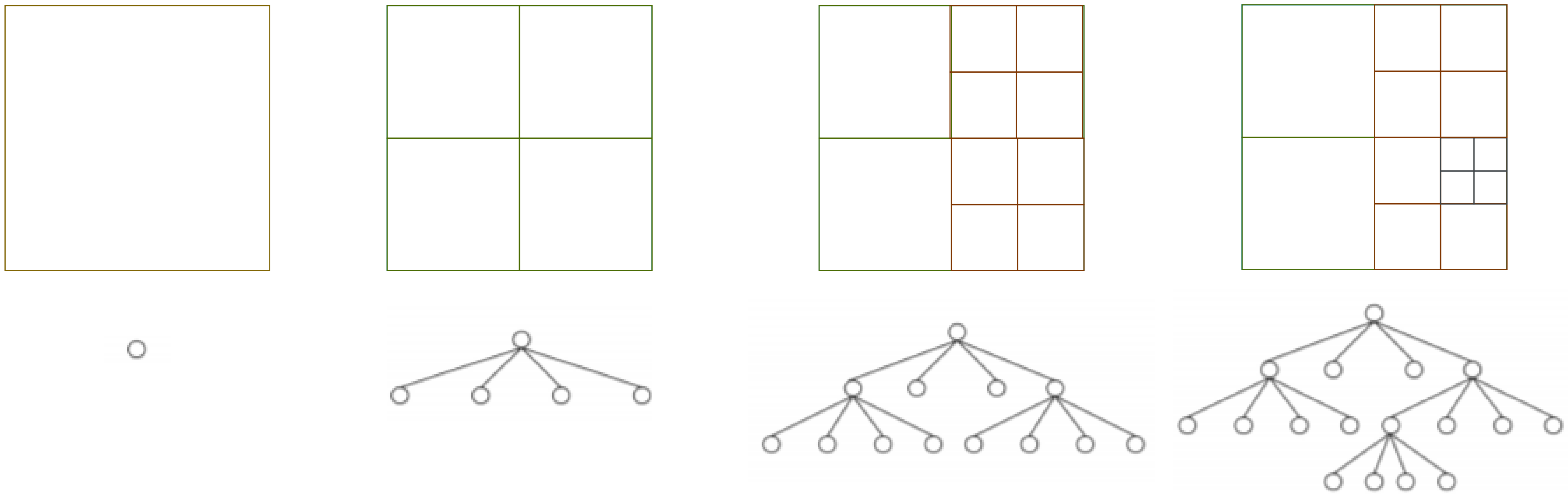
# Redistributing the workload

Several techniques exist to balance the workload

- “Simple” redistribution of data
- Dynamic balancing using space filling curves

Example

Step 1: Adaptive Refinement of a domain in subsequent levels

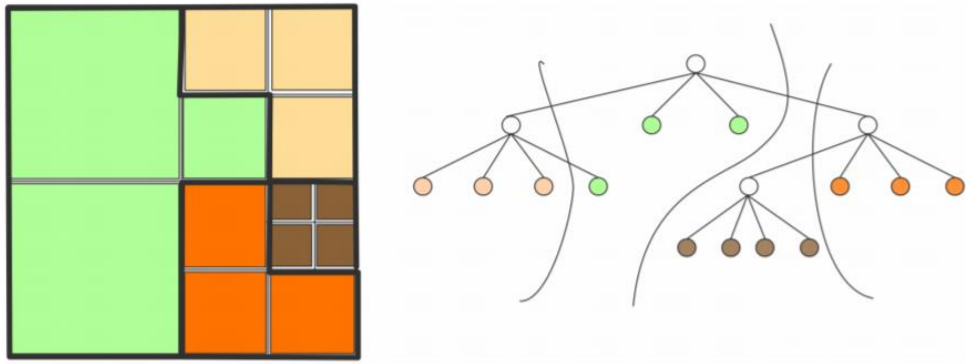


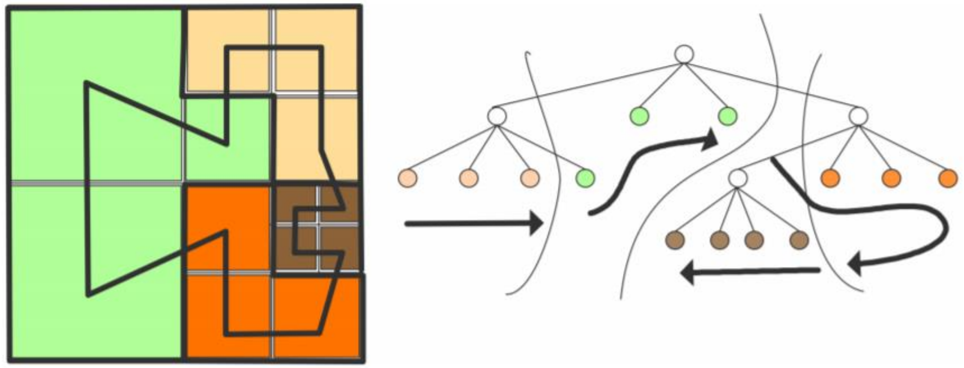
# Redistributing the workload

## Example

Step 2: Load distribution of an adaptively refined domain

Step 3: Space Filling Curv





# Load balancing can be counter intuitive

There is an asymmetry between processors having too much work and having not enough work. It is better to have one processor that finishes a task early than having one that is overloaded so that all others wait for it.

**Corollary:**

**When it comes to load balancing, the "*costliest*" function shown by the profiler is not the bottleneck.**
**The bottleneck is the "*cheapest*" one.**

Workload imbalance webinar video
[https://youtu.be/MScwYTNGOp0](https://youtu.be/MScwYTNGOp0)

# Exercise: Improving IOs

# Detect workload imbalance and optimise IO

Objectives:

- Exhibit the workload imbalance in the code (on 1 or 2 nodes)
- Make suggestions to fix the problem

Key commands:

- Compile the application

  $ make
- $ map --profile srun -n 8 ./myApp.exe
- Open the profiling results in the GUI on the login node once the job has completed

  $ map *.map
- How can you fix the imbalance problem?

# Maximizing application efficiency with Performance Reports



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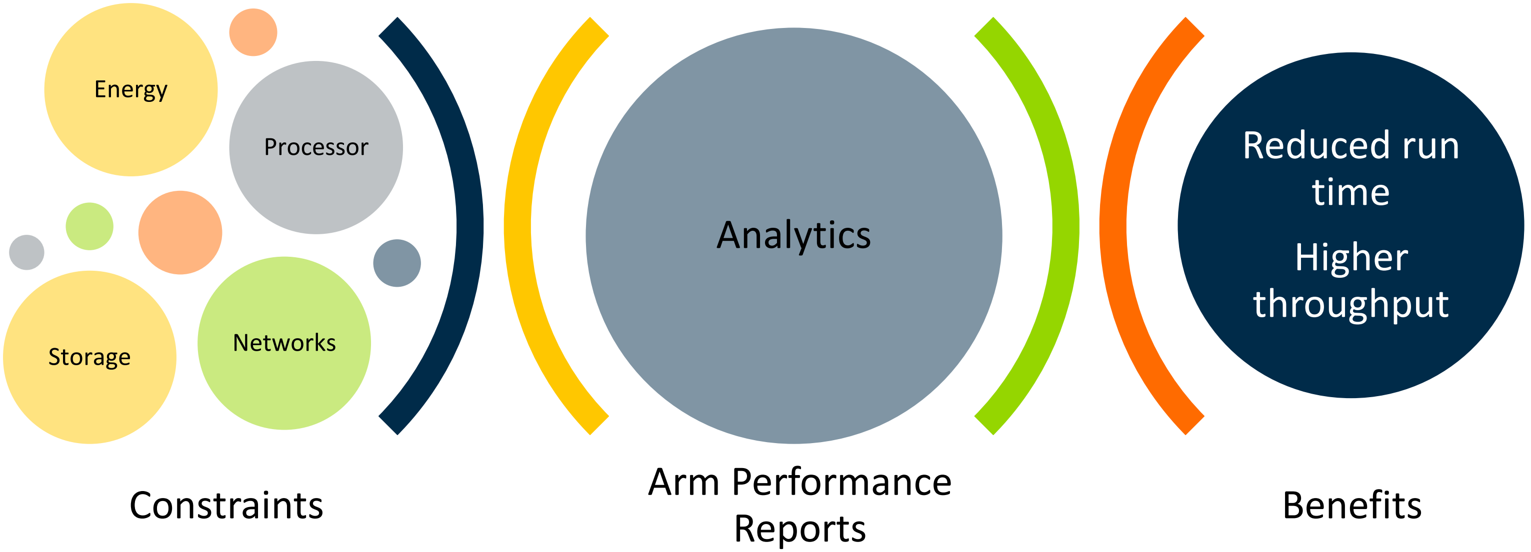
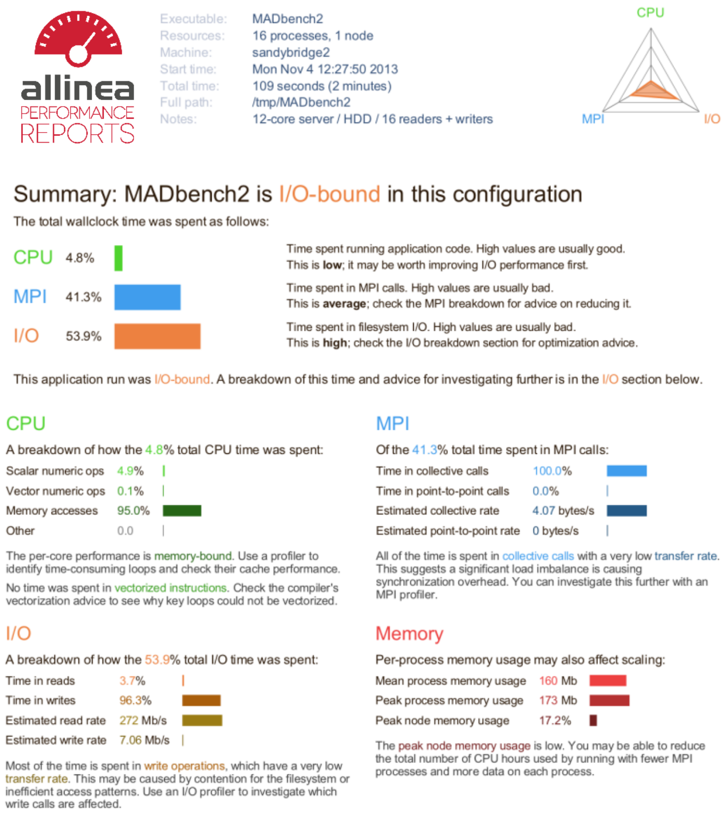
# Arm Performance Reports benefits



# “Learn” with Arm Performance Reports



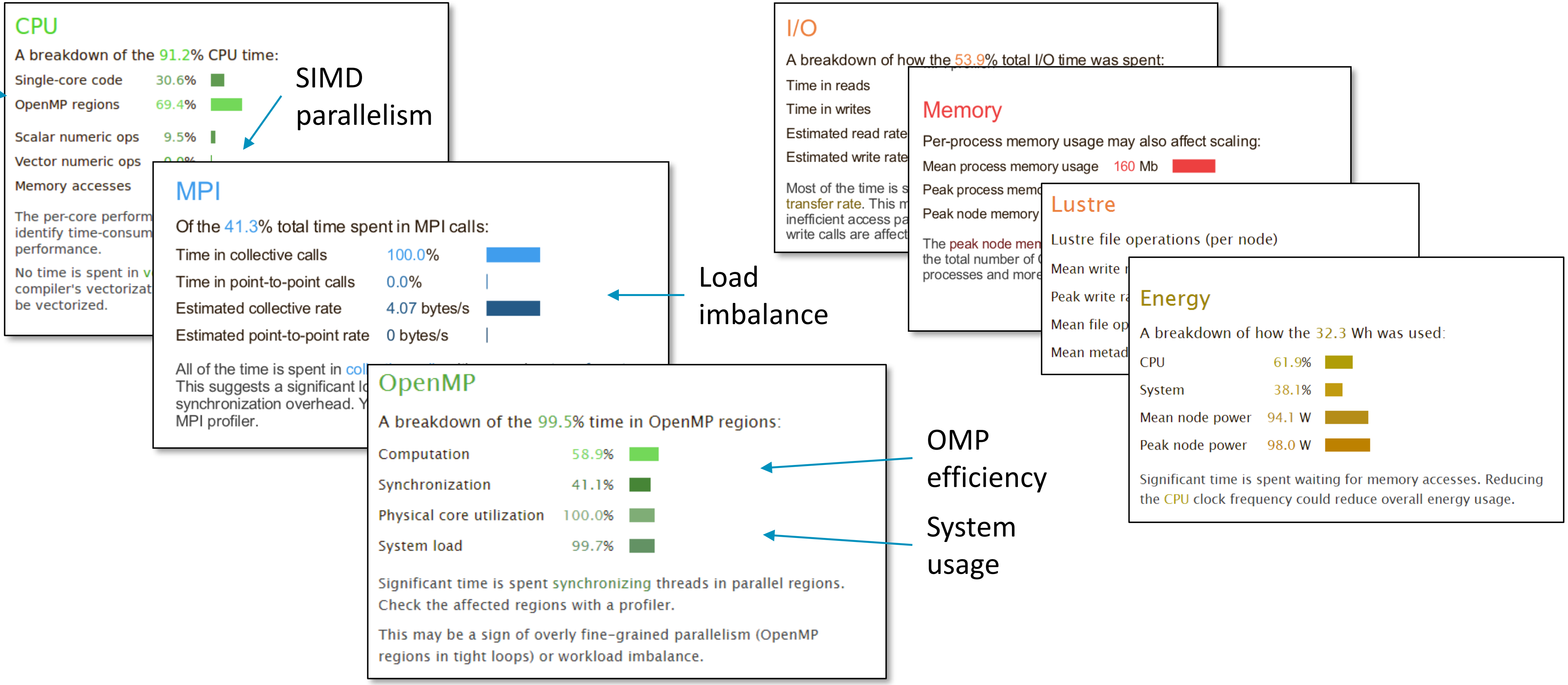

- Very simple start-up
- No source code needed
- Fully scalable, very low overhead
- Rich set of metrics
- Powerful data analysis

# Metrics overview

Multi-threaded parallelism

SIMD parallelism




Load imbalance

OMP efficiency

System usage

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# Arm Performance Reports cheat sheet

Load the environment module

- $ module load **allinea-reports**

Edit the job script to prefix the mpirun command

- **perf-report** srun -n 8 ./myapp.exe

Analyse the results

- $ cat myapp_8p_1n_YYYY-MM-DD_HH:MM.txt
- $ firefox myapp_8p_1n_YYYY-MM-DD_HH:MM.html

 

# Exercise: Maximizing scientific output



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# Maximise efficiency

Objectives:

- Generate a performance report of a simple code
- Find the best parameters to maximize the application efficiency
  - Compilation flags
  - Number of processes
  - Number of nodes

Key commands:

- Compile:

$ make

- $ perf-report srun -n 8 ./myapp.exe

# User Guide

# Forge User Guide

- Online documentation is always available at https://developer.arm.com/products/software-development-tools/hpc/documentation
- Direct link to DDT User Guide https://developer.arm.com/docs/101136/latest/ddt

- Local user guide is available in your Forge installation /path/to/arm/forge/doc/userguide-forge.pdf

# Obtaining Support



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# Obtaining Support

- For simple queries, use the web form at https://www.arm.com/products/development-tools/hpc-tools/contact-support

- For more advanced issues, email support-hpc-sw@arm.com
  This allows you attach screenshots, source code, and debug log files

# Debug Log Files

# Debug Log Files

- In the event that DDT crashes or does not work like expected, a debug log file will be helpful to the arm support team
- Debug log files can be generated by passing arguments to DDT
- For Example:

```
ddt --debug --log=crash.log aprun -n 16 ./myProgram.exe
```

# Q&A

Thank You

Danke

Merci

谢谢

ありがとう

Gracias

Kiitos

감사합니다

धन्यवाद

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