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Holistic HPC I/O

Performance assessment and parallel IO

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Learning Objectives

- Describing relevant performance factors for systems
- Listing peak performance of relevant components
- Assessing/Judging observed performance

Outline

Motivation

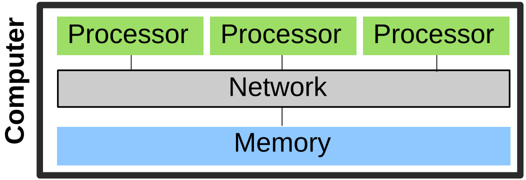
- Admins must know basic performance aspects to design suitable systems
  - Capacity planning (how many servers are needed)
  - Optimizing systems (higher efficiency)
- Goal (system perspective):
  - Efficiency: Good utilization of (hardware) resources means less hardware
  - Cheap hardware, i.e., less performance
  - (Simple deployment and easy management)
  - (Security + Privacy + Compliance with laws)
- User perspective: Minimal time to solution, easy to use

Outline

Parallel & Distributed Architectures

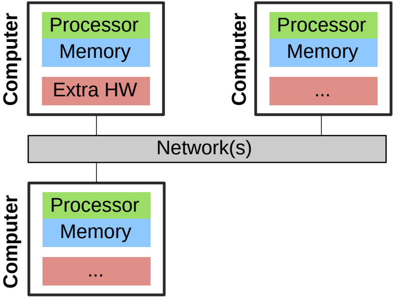
In practice, systems are a mix of two paradigms:

Shared memory



- Processors access joint memory
  - Communication/coordination
- Cannot be scaled up to any size
- Expensive to build big system

Distributed memory systems



- Processor see only own memory
- Performance of the network is key

Example: Characteristics of an HPC Cluster

- High-end components
- Extra fast interconnect, global/shared storage with dedicated servers
- Network provides high (near-full) bisection bandwidth.

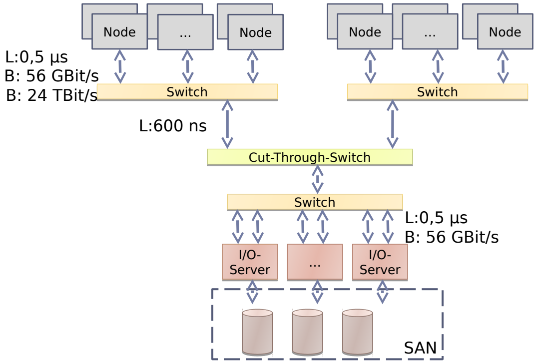


Figure: Architecture of a typical HPC cluster (here fat-tree network topology)

Hardware Performance

Computation

- CPU performance (frequency × cores × sockets)
  - E.g.: 2.5 GHz × 12 cores × 2 sockets = 60 Gcycles/s
  - The number of cycles per operation depend on the instruction stream
- Memory (throughput × channels)
  - E.g.: 51.2 GiB/s per DDR5 module × 8 channels (AMD Epyc) = 400 GiB/s

Communication via the network

- Throughput, e.g., 1250 MiB/s with 10 GbE Ethernet
- Latency, e.g., 0.1 ms with Gigabit Ethernet

Input/output devices

- Access data consecutively and not randomly
- Performance depends on the I/O granularity
  - E.g.: HDDs 150 MiB/s with 10 MiB blocks, even Flash suffers by small access

Influence of Software on Performance

- Allow monitoring of components to detect overloaded services
  - For instance, using Grafana, Prometheus, ...
- Java: 1.2x - 2x of cycles compared to C[1]
- Balance and distribute workload among all available servers/services
  - Linear scalability of the solution is important
  - Add 10x servers, achieve 10x performance (or process 10x data)
- Avoid I/O, if possible and keep data in memory
- Host depending services locally

Outline

Strategy

Guiding question

Is the observed performance *acceptable*?

- My observation: often a simple approximative model is sufficient
  - Knowing that something is 100x slower than it should be...
- You must understand the basic architecture of the software system
- You must understand most important hardware characteristics
- Advice
  - Start with simple models for workload and hardware performance
  - Refine the model as needed, e.g., include details about intermediate steps

Approximation – Simple Example on Computation

Example: Summing up data in an array of 10M ints

- Workload: 10M integers
- System: 3.7 GHz PC
- Python (for loop): 0.39s = 98 MB/s, 144 cycles per op
  $(10 \cdot 1000 \cdot 1000) \cdot 4$ bytes $/ \; 0.39s = 98 MiB/s$
  $3700 \cdot 1000 \cdot 1000 cycles \cdot 0.39s/(10 \cdot 1000 \cdot 1000 op) =$ 144 cycles/op
- Numpy: 0.0055s, 7000 MB/s, 2 cycles per op
- Python (sum up numbers): 0.14s, 272 MB/s, 52 cycles per op
- One line to measure the performance in Python using Numpy:

```
timeit.timeit(stmt="np.sum(d)", setup="import numpy as np; d = np
# Just sum up numbers: sum(range(1,10*1000*1000))
```

Methodology

1. Measure time for the execution of your workload
2. Quantify the workload with some metrics
   - E.g., amount of tuples or data processed, computational operations needed
   - E.g., you may use the statistics output for each Hadoop job
3. Compute W, the workload you process per time
4. Compute expected performance P based on system's hardware characteristics
5. Compare W with P, the efficiency is $E = \frac{W}{P}$
   - If $E << 1$, e.g., 0.01, you are using only 1% of the potential!

Example: Object Storage

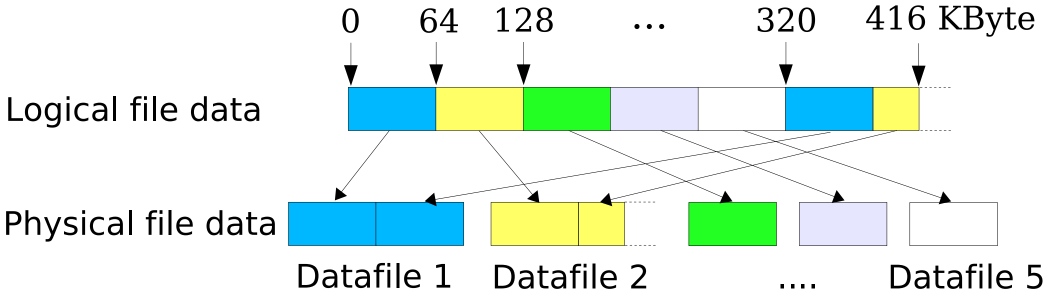
Scenario: Accessing data on object storage

1. Time: 0.1s (3x measured, between 0.09 and 0.11s)
2. Workload: 100 MiB of data fetched from object storage
3. $W = 100MiB/0.1s = 1000MiB/s$
4. System: Client and server are interconnected via a 100 GbE network
   Characteristics: $P = 12,500GiB/s$ throughput
   Latency doesn't matter for large files
5. Efficiency: $E = 1,000/12,500 = 8\%$

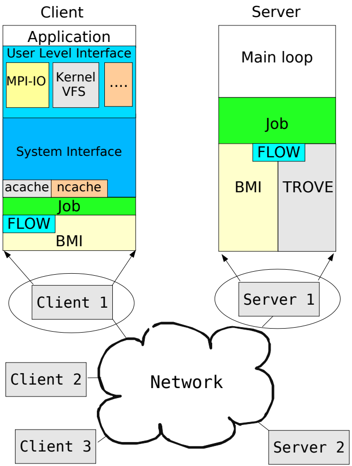
For a 10 GbE interconnect, 80% efficiency would have been achieved!

Example: Parallel File System

- Workload: Reading/writing X amount of data from a parallel file system
- One file is distributed across multiple datafiles and servers

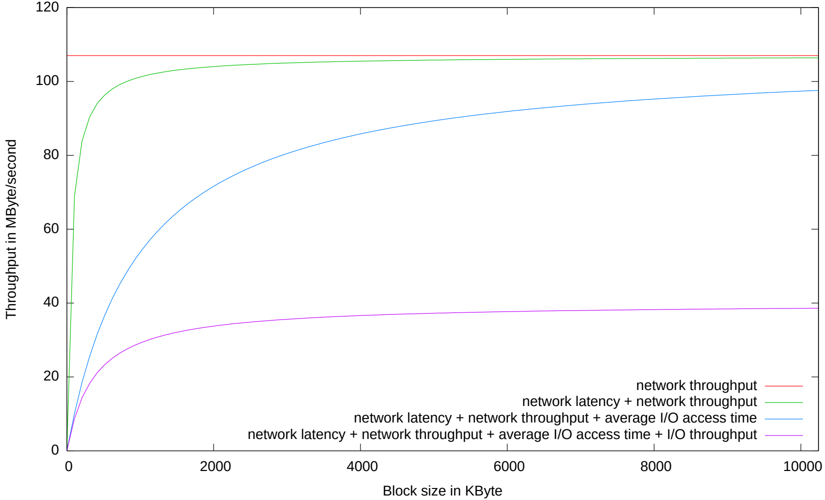


Parallel File System Architecture: Here PVFS2

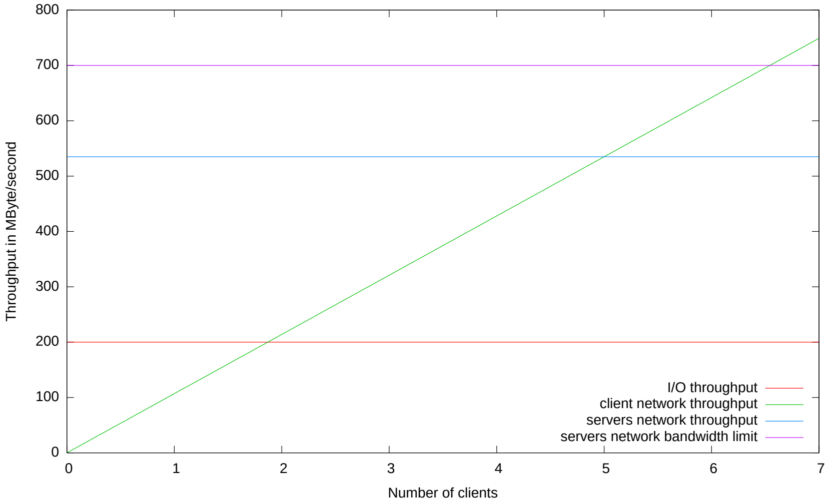


- We can ignore the layers
- C clients connect to S servers
- Clients may access the same file
  Concurrently - at the same time
- System: GbE Ethernet, HDDs with 40 MiB/s
- Let's build performance models!
  Start from a simple model and refine

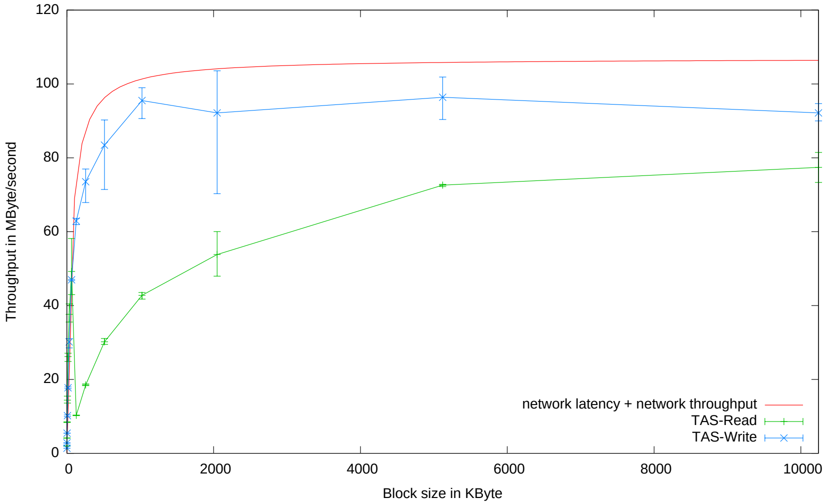
Small I/O Access (Single Client)



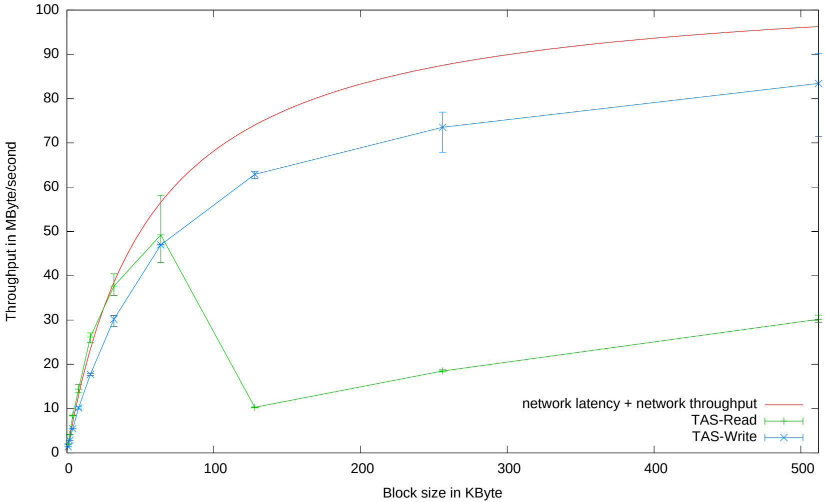
Large Access (Multiple Clients)



Actual Measured Performance (Single Client)



Actual Measured Performance (Single Client) - Small Block Sizes



Summary

- Understanding hardware characteristics helps to assess performance
- Basic performance analysis
    1. Estimate the workload
    2. Compute the workload throughput per node
    3. Compare with hardware capabilities
- Exercise: You’ll do an own performance estimation!

Exercise

As part of this task, you will apply the methodology for performance estimation on a use case. Understanding if observed performance is acceptable is important to identify optimization potential. In this task, imagine you have obtained a set of performance measurements on different systems, and you shall assess the performance.

Consider the following alternative system characteristics:

1. Network: 10 GBit Ethernet, or 100 GBit Infiniband.
2. 10 or 100 storage servers. A server may have either 1 or 4 network interfaces.
3. Storage nodes are equipped with either SSDs or HDDs, and either 1, 5, 8, or 16 storage media.
4. There are a various number of client nodes available, but a node has only one network interface.

We measured the following client configurations with given total amount of data and measured runtime of the overall applications:

- 1 Client node, 100 MByte of data in 0.1s.
- 10 Client nodes, 10 GByte of data in 1s.
- 100 Client nodes, 1 TByte of data in 100s.
- 1000 Client nodes, 100 TByte of data in 100s.

- Analyze one system configuration and workload – hint: start with the simplest configuration
- Calculate the expected performance for the system configuration and the efficiency
- Analyze the other cases based on your initial approach
- Discuss which combination of system configuration is probably impossible, efficient or rather inefficient.