Introduction to
High-Performance Computing
What is High Performance Computing?

- **There is no clear definition**
  - Computing on high performance computers
  - Solving problems / doing research using computer modeling, simulation and analysis
  - Engineering design using computer modeling, simulation and analysis

- **My understanding**
  - A huge number of computational and memory requirements
  - Cannot be afforded by a PC efficiently
  - Speeds and feeds are the keywords

- **Who uses High-Performance Computing**
  - Research institutes, universities and government labs
    - Weather and climate research, bioscience, energy, military etc.
    - Engineering design: more or less every product we use
      - Automotive, aerospace, oil and gas explorations, digital media, financial simulation
      - Mechanical simulation, package designs, silicon manufacturing etc.

- **Similar concepts**
  - Parallel computing: computing on parallel computers
  - Super computing: computing on world 500 fastest supercomputers
When Do We Need High Performance Computing?

- **Case 1: Complete a time-consuming operation in less time**
  - I am an automotive engineer
  - I need to design a new car that consumes less gasoline
  - I’d rather have the design completed in 6 months than in 2 years
  - I want to test my design using computer simulations rather than building very expensive prototypes and crashing them

- **Case 2: Complete an operation under a tight deadline**
  - I work for a weather prediction agency
  - I am getting input from weather stations/sensors
  - I’d like to predict tomorrow’s forecast today

- **Case 3: Perform a high number of operations per seconds**
  - I am an engineer at Amazon.com
  - My Web server gets 1,000 hits per seconds
  - I’d like my web server and databases to handle 1,000 transactions per seconds so that customers do not experience bad delays
What Does High Performance Computing Include?

- **High-performance computing is fast computing**
  - Computations in parallel over lots of compute elements (CPU, GPU)
  - Very fast network to connect between the compute elements

- **Hardware**
  - Computer Architecture
    - Vector Computers, MPP, SMP, Distributed Systems, Clusters
  - Network Connections
    - InfiniBand, Ethernet, Proprietary

- **Software**
  - Programming models
    - MPI (Message Passing Interface), SHMEM (Shared Memory), PGAS, etc.
  - Applications
    - Open source, commercial
Rise and Fall of HPC Computer Architectures

- **Vector Computers (VC) - proprietary system**
  - Provided the breakthrough needed for the emergence of computational science, but they were only a partial answer

- **Massively Parallel Processors (MPP) - proprietary systems**
  - High cost and a low performance/price ratio.

- **Symmetric Multiprocessors (SMP)**
  - Suffers from scalability

- **Distributed Systems**
  - Difficult to use and hard to extract parallel performance

- **Clusters – commodity and highly popular**
  - High Performance Computing - Commodity Supercomputing
  - High Availability Computing - Mission Critical Applications
Clusters have become the most used HPC system architecture.

More than 86% of Top500 systems are clusters.
Parallel Computing on a Large Number of Servers is More Efficient than using Specialized Systems
Since the 1990s, there has been an increasing trend to move away from expensive/specialized proprietary parallel supercomputers to clusters of computers. From specialized supercomputers to cost effective, general purpose systems.

So What’s So Different about Clusters?
- Commodity, standard, affordable, cost effective, scalable and reliable architecture.

Cluster Architecture:

- Server
- Communications Software
- Network Interface Hardware

Cluster Interconnect Network
Interconnect Technology: The Need for Speed and Intelligence

40G

50G

100G

200G

400G

Inefficient

100 Nodes

1,000 Nodes

10,000 Nodes

100,000 Nodes

1,000,000 Nodes

LS-DYNA (FEA)
OpenFOAM (CFD)
Weather
Homeland Security
Cosmological Simulations
Human Genome
The Large Hadron Collider (CERN)
Brain Mapping

1,000,000 Nodes

Human Genome
Cosmological Simulations
Brain Mapping

Homeland Security

Weather

The Large Hadron Collider (CERN)
• Commoditization/standardization are the clustering and interconnect driving forces
• InfiniBand and Ethernet are the most used interconnect solutions for HPC systems
The HPC Advantage: Reduction in Time to Market

Source: IDC

Product Development Process

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HPC: High Performance Computing
Summary

• From concept to engineering, from design to test and manufacturing, from weather prediction to medical discoveries, our day to day life depends more and more on HPC simulations
  – Safer products, accurate predictions, research, etc.

• High-performance compute clusters provide the most efficient, flexible, cost effective HPC environment for any HPC simulation