并行计算
Parallel Computing

主讲人　孙广中

Spring, 2022

Overview

- Course Administration
- Course Style and Structure
- Intro to Parallel Computing

Course Administration

- Instructor:
  孙广中　　计算机学院、国家高性能计算中心（合肥）

- Email：gzsun@ustc.edu.cn

- TA：孙经纬、徐中天、刘家强

- Textbook:
  并行计算-结构·算法·编程，***陈国良编著，北京:高等教育出版社，***2011

Course Administration

- Reference Book:
  - *Kai Hwang,Zhiwei Xu,"Scalable Parallel Computing",McGraw-Hill,1998*
  - *J.JaJa,"Introduction to Parallel Algorithms",Addison Wesley,1992*
  - *V.Kumar etal, “Intro to Parallel Computing”, Benjamin/Cummings, 1994*
  - 陈国良，并行算法的设计与分析（第3版），高等教育出版社，2009
  - 陈国良等，并行计算机体系结构，高等教育出版社，2002
  - 陈国良等，并行算法实践，高等教育出版社，2003
  - J.Dongarra etal, “Sourcebook of Parallel Computing” (莫则尧等译), 电子工业出版社, 2005
  - Shameem Akhter, et. al.著, 李宝峰等译. 多核程序设计技术，电子工业出版社，2007
  - Richard Gerber, et. al.著, 王涛等译. 软件优化技术，电子工业出版社，2007

Grading

Grade breakdown

• Final Exam	60%
• Homework Assignments	20%
• Experiments	15%
• Class Participation and Activity	5%

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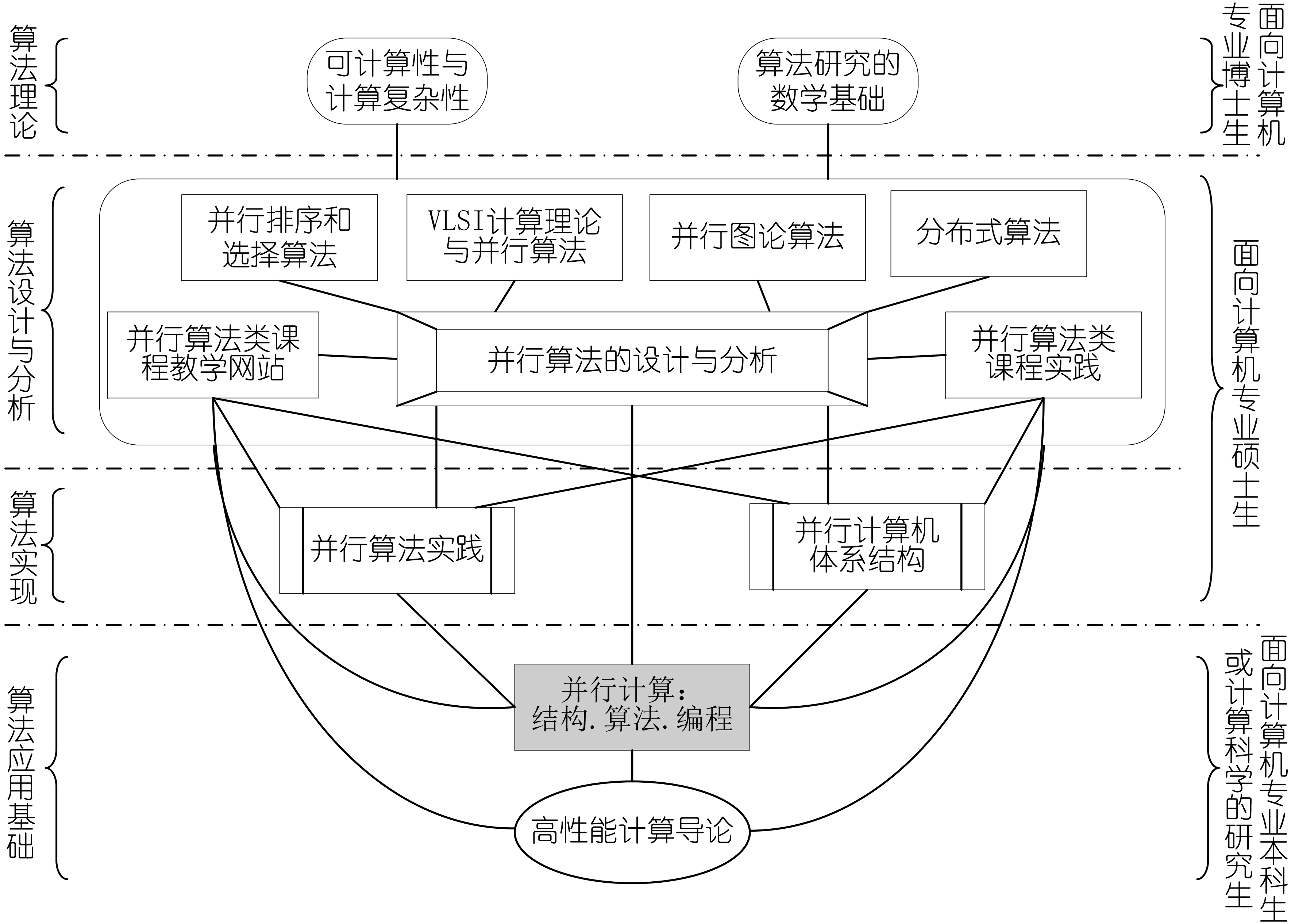
About the Textbook

- Authors:
  - 陈国良教授，中科院院士，国家高性能中心（合肥）主任，第一届全国高等学校“国家级教学名师奖”、2009年国家教学成果二等奖
  - 并行算法学科体系：并行算法的设计与分析、并行计算机体系结构、并行算法实践、并行计算
  - 并行计算模型：三层并行计算模型
- Textbook:
  - 2003年度国家精品课程教材
  - 并行算法学科体系中面向计算机专业及其相关专业的本科生教材


算法理论
可计算性与计算复杂性
算法研究的数学基础
面向计算机专业博士生
算法设计与分析
并行排序和选择算法
VLSI计算理论与并行算法
并行图论算法
分布式算法
并行算法类课程教学网站
并行算法的设计与分析
并行算法类课程实践
面向计算机专业硕士生
算法实现
并行算法实践
并行计算机体系结构
算法应用基础
并行计算：结构. 算法. 编程
高性能计算导论
面向计算机专业本科生或计算科学的研究生

Parallel Computing

- Parallel Architectures
- Parallel Algorithms
- Parallel Programming
- Parallel Applications

Abstract

- Generally speaking, parallel computing deals with the parallel computer architectures, parallel algorithms and parallel programming. In this lecture we will discuss briefly them separately.
- In part I, we will discuss the contemporary parallel computer system architectures and memory access models, parallel system interconnections and parallel system performance evaluation.
- In part II, we will discuss the parallel computational models, the design methods, techniques and methodology of parallel algorithms, as well as some parallel numerical algorithms.
- In part III, we will discuss the parallel programming models,shared-memory, message-passing and dataparallel programming, as well as parallel programming environment and tools.
- In part III, we will discuss …

Part I : Parallel Hardware System

Hardware Platform for Parallel Computing:

- System Architectures and Models
- System Interconnections
- Performance Evaluation

- Parallel Computer System Architectures
  - PVP : Parallel Vector Processors
  - SMP : Symmetric Multiprocessors
  - MPP : Massively Parallel Processors
  - DSM : Distributed Shared Memory
  - COW : Cluster Of Workstations
- Parallel Computer Memory Access Models
  - UMA : Uniform Memory Access
  - NUMA : Non-Uniform Memory Access
  - COMA : Cache-Only Memory Access
  - NORMA : NO-Remote Memory Access

Part I : Parallel Architectures - System Interconnections

- Network Environments
  - Inter-node Interconnections(Buses , Switches)
  - Inter-node Interconnections(SAN)
  - Inter-system Interconnections(LAN , MAN , WAN)
- Interconnection Topologies
  - Static-Connection Networks(LA,RC,MC,TC,HC,CCC)
  - Dynamic-Connection Networks (Buses, Crossbar, MIN)
- Wide-Band Networks
  - FDDI(Fiber Distributed Data Interface)
  - FE/GE(Fast Ethernet / Gigabit Ethernet)
  - ATM(Asynchronous Transfer Mode)
  - SCI(Scalable Coherence Interface)

Part I : Parallel Architectures - Performance Evaluation

- Speed up of Systems
  - Amdahl's Law
  - Gustafson's Law
  - Sun and Ni's Law
- Scalability of Systems
  - Iso-efficiency
  - Iso-speed
  - Average Latency
- Performance of Systems : Benchmarks
  - LINPACK
  - SPEC
  - PARKBENCH
  - NAS etc

Theoretical Base for Parallel Computing:

- Computational Models
- Design Policy
- Design Methodology
- Design Techniques
- Parallel Numerical Algorithms

- PRAM : Parallel Random Access Machines
- APRAM : Asynchronous PRAM
- BSP : Bulk Synchronous Parallel
- LogP : Latency , Overhead , Gap , Processors

Part II : Parallel Algorithms - Design Policy

- Parallelizing a Sequential Algorithm
- Designing a new Parallel Algorithm
- Borrowing Other Well-known Algorithm

- PCAM : Partitioning
- PCAM : Communication
- PCAM : Agglomeration
- PCAM : Mapping

- Balanced Trees
- Doubling Technique
- Partitioning Strategy
- Divide and Conquer
- Pipelining

- Dense Matrix Algorithms
- Solving Systems of Linear Equations
- Fast Fourier Transform

Software Support for Parallel Computing:

- Programming Models
- Shared-Memory Programming
- Message-Passing Programming
- Data-Parallel Programming
- Programming Environment and Tools

Applications for Parallel Computing:

- Application Backgrounds
- Parallel Computing for Atmospheric Model
- Software Packages of Numerical Computing
- Others: 3D Fourier Transform, Image Feature extraction, Seepage Computing,…

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什么是并行计算？

- A parallel computer is a "collection of processing elements that communicate and cooperate to solve large problem fast". –David E. Culler
- Or all processors cooperate to solve a single problem
- Daily life examples:
  - House construction //综合：并发、分布、流水
  - Car manufacturing //流水线
  - Grocery store operation //分布

为什么需要并行计算？

- Interest in parallelism since the very ancient era of computers(e.g. ILLIAC IV of 1967 had 64 processors)
- Parallel Processing is an effective answer for the tremendous future computing requirements.
- applications impulses:
  - Data-intensive applications: videoconferencing, virtual reality, large database and data mining, speech recognition, biology, image and signal processing, etc
  - Computing-intensive applications: numerical simulation(e.g. forecasting, manufacturing, chemistry, aerodynamics)
  - Network-intensive applications
  - Multicore and manycore and cloud computing

为什么需要并行计算？

- Grand challenges:
  - Science today: experimentation, theory, simulation(or computation)
  - Simulation relies heavily on parallel processing
- USA HPCC project, ASCI project
- Parallel processing promises increase of
  - Performance(e.g. large, fast, cost)
  - Reliability
  - Large set of computational problems are inherently parallel in nature. But their existing applications are designed for uniprocessor systems. Their parallelization is required.

应用需求

Cite from CRAY Inc.

CRAY RESEARCH
A Silicon Graphics Company

OAK RIDGE NATIONAL LABORATORY

Government-Classified Work

Government - Research

(Severe) Weather Prediction
& Climate Modeling

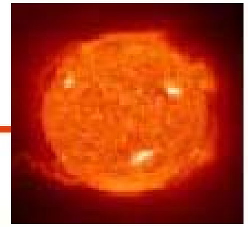
Instituto Nacional de Meteorologia España

Automotive Design & Safety

Drug Discovery &
Genomic Research

Aircraft/Spacecraft Design
& Fuel-Efficiency

Oil Exploration &
Energy Research



Basic Scientific Research

加速战略计算实施ASCI

- 美国能源部
- 10年投资10亿美元
- 模拟核实验及核武器储备管理问题

- 1998 → 3 TFLOPS
- 2004 → 100 TFLOPS
- 2010 → 1 PFLOPS
- 2019 → 1 EFLOPS，高性能计算的发展符合“千倍定律”

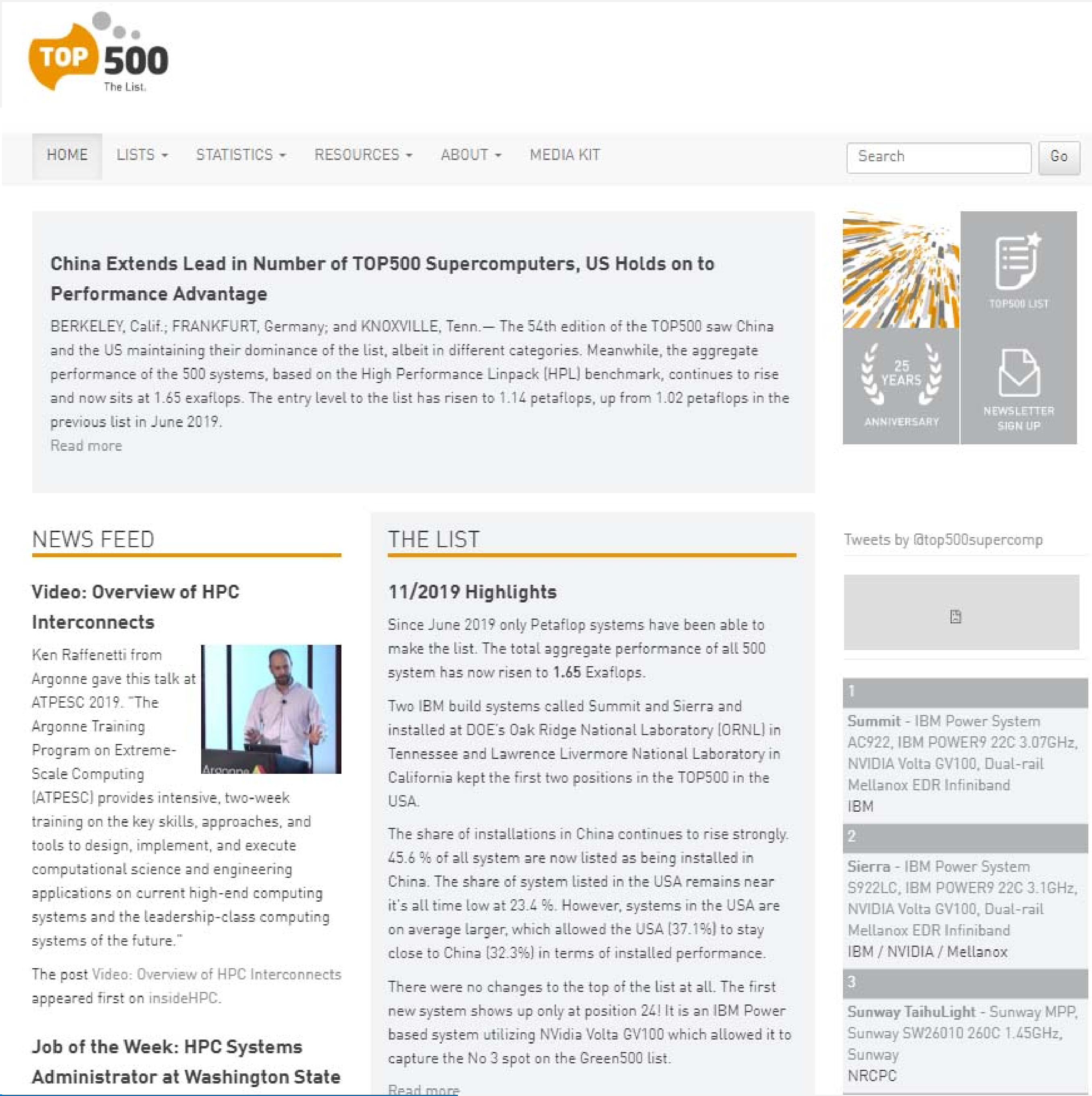
并行计算的粒度

- Coarse-grained(粗粒度)： Level of jobs
- Middle-grained(中等粒度)： Level of processes
- Fine-grained(细粒度)： Level of machine instructions(or lower)

并行计算的研究领域

- Design of parallel computers: How to the number of processors, communication throughput, data sharing, etc.
- Design of parallel algorithms: Parallel algorithms may be quite different from their sequential counterparts.
- Design of parallel software:
  - Operating systems
  - Compiles
  - Libraries
  - Tools: debuggers, performance analyzers
- Applications of parallel computing

http://www.top500.org



每年更新两次

- 十一月： SC（美国）
- 六月： ISC（欧洲）

自1993年至今， 2021年11月是第58版

TOP 10 Sites for November 2015

For more information about the sites and systems in the list, click on the links or view the complete list.

RANK	SITE	SYSTEM	CORES	RMAX (TFLOP/S)	RPEAK (TFLOP/S)	POWER (KW)
1	National Super Computer Center in Guangzhou China	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P NUDT	3,120,000	33,862.7	54,902.4	17,808
2	DOE/SC/Oak Ridge National Laboratory United States	**Titan** - Cray XK7 , Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x Cray Inc.	560,640	17,590.0	27,112.5	8,209
3	DOE/NNSA/LLNL United States	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom IBM	1,572,864	17,173.2	20,132.7	7,890
4	RIKEN Advanced Institute for Computational Science (AICS) Japan	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect Fujitsu	705,024	10,510.0	11,280.4	12,660
5	DOE/SC/Argonne National Laboratory United States	**Mira** - BlueGene/Q, Power BQC 16C 1.60GHz, Custom IBM	786,432	8,586.6	10,066.3	3,945
6	DOE/NNSA/LANL/SNL United States	**Trinity** - Cray XC40, Xeon E5-2698v3 16C 2.3GHz, Aries interconnect Cray Inc.	301,056	8,100.9	11,078.9	
7	Swiss National Supercomputing Centre (CSCS) Switzerland	**Piz Daint** - Cray XC30, Xeon E5-2670 8C 2.600GHz, Aries interconnect , NVIDIA K20x Cray Inc.	115,984	6,271.0	7,788.9	2,325
8	HLRS - Höchstleistungsrechenzentrum Stuttgart Germany	**Hazel Hen** - Cray XC40, Xeon E5-2680v3 12C 2.5GHz, Aries interconnect Cray Inc.	185,088	5,640.2	7,403.5	

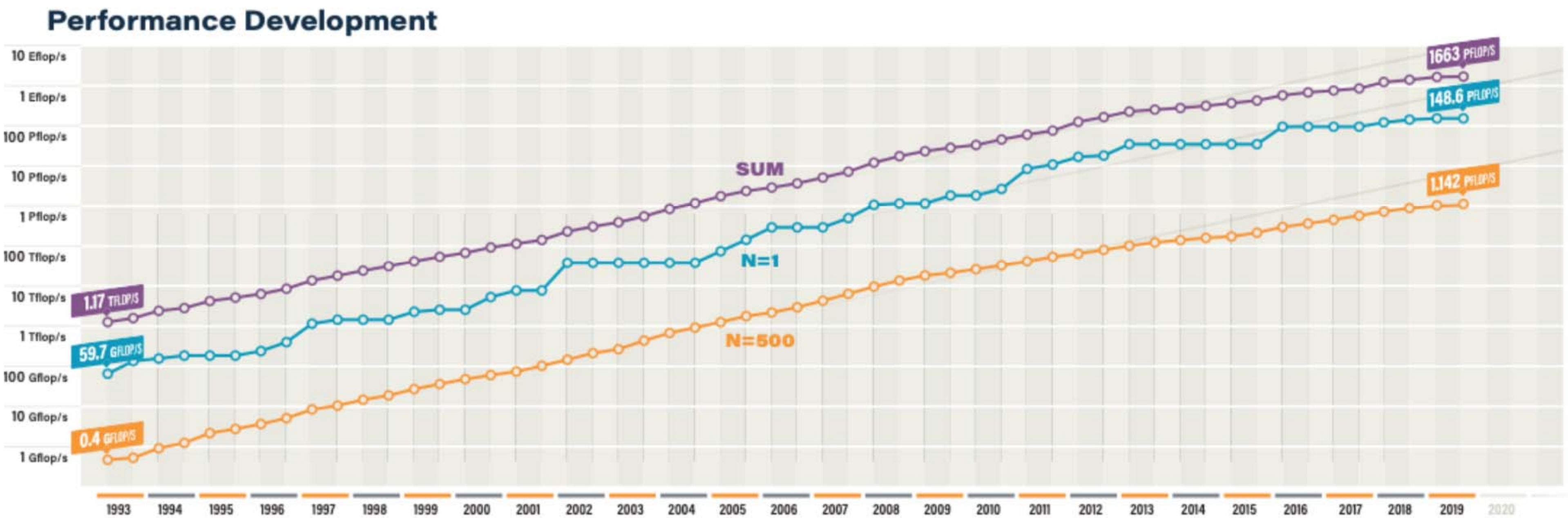
TOP 10 Sites for November 2017

For more information about the sites and systems in the list, click on the links or view the complete list.

1-100	101-200	201-300	301-400	401-500

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
2	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P , NUDT National Super Computer Center in Guangzhou China	3,120,000	33,862.7	54,902.4	17,808
3	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray Inc. Swiss National Supercomputing Centre (CSCS) Switzerland	361,760	19,590.0	25,326.3	2,272
4	**Gyoukou** - ZettaScaler-2.2 HPC system, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 700Mhz , ExaScaler Japan Agency for Marine-Earth Science and Technology Japan	19,860,000	19,135.8	28,192.0	1,350
5	**Titan** - Cray XK7, Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x , Cray Inc. DOE/SC/Oak Ridge National Laboratory United States	560,640	17,590.0	27,112.5	8,209
6	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom , IBM DOE/NNSA/LLNL United States	1,572,864	17,173.2	20,132.7	7,890
7	**Trinity** - Cray XC40, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect , Cray Inc. DOE/NNSA/LANL/SNL	979,968	14,137.3	43,902.6	3,844

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM DOE/SC/Oak Ridge National Laboratory United States	2,414,592	148,600.0	200,794.9	10,096
2	**Sierra** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	1,572,480	94,640.0	125,712.0	7,438
3	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
4	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000 , NUDT National Super Computer Center in Guangzhou China	4,981,760	61,444.5	100,678.7	18,482
5	**Frontera** - Dell C6420, Xeon Platinum 8280 28C 2.7GHz, Mellanox InfiniBand HDR , Dell EMC Texas Advanced Computing Center/Univ. of Texas United States	448,448	23,516.4	38,745.9	
6	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray/HPE Swiss National Supercomputing Centre (CSCS) Switzerland	387,872	21,230.0	27,154.3	2,384
7	**Trinity** - Cray XC40, Xeon E5-2698v3 16C 2.3GHz, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect , Cray/HPE DOE/NNSA/LANL/SNL United States	979,072	20,158.7	41,461.2	7,578
8	**AI Bridging Cloud Infrastructure (ABCI)** - PRIMERGY CX2570 M4, Xeon Gold 6148 20C 2.4GHz, NVIDIA Tesla V100 SXM2, Infiniband EDR , Fujitsu National Institute of Advanced Industrial Science and Technology (AIST) Japan	391,680	19,880.0	32,576.6	1,649
9	**SuperMUC-NG** - ThinkSystem SD650, Xeon Platinum 8174 24C 3.1GHz, Intel Omni-Path , Lenovo Leibniz Rechenzentrum Germany	305,856	19,476.6	26,873.9	
10	**Lassen** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, Dual-rail Mellanox EDR Infiniband, NVIDIA Tesla V100 , IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	288,288	18,200.0	23,047.2	


Performance Development
10 Eflop/s
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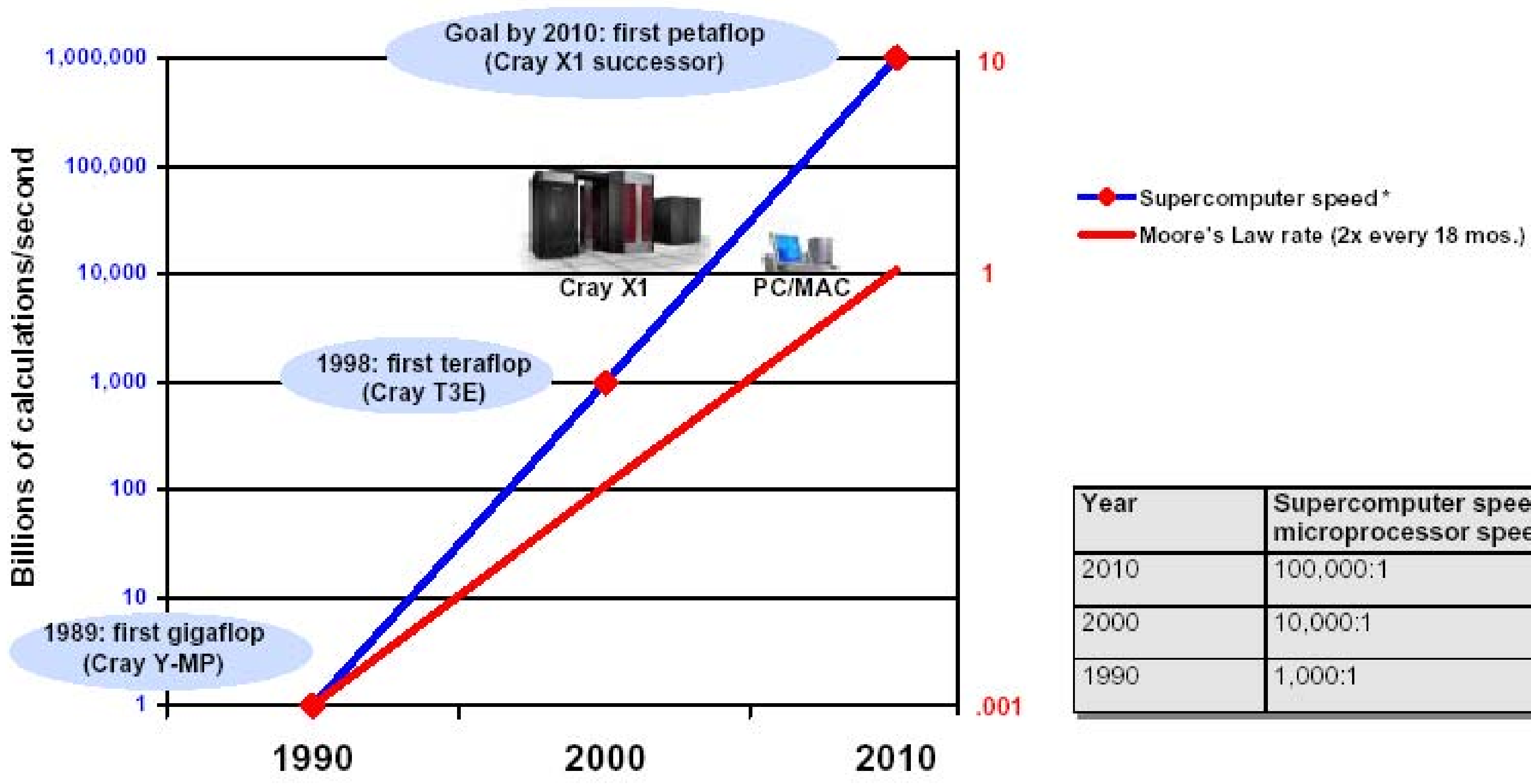
超级计算机的增长速度——超过摩尔定律100倍

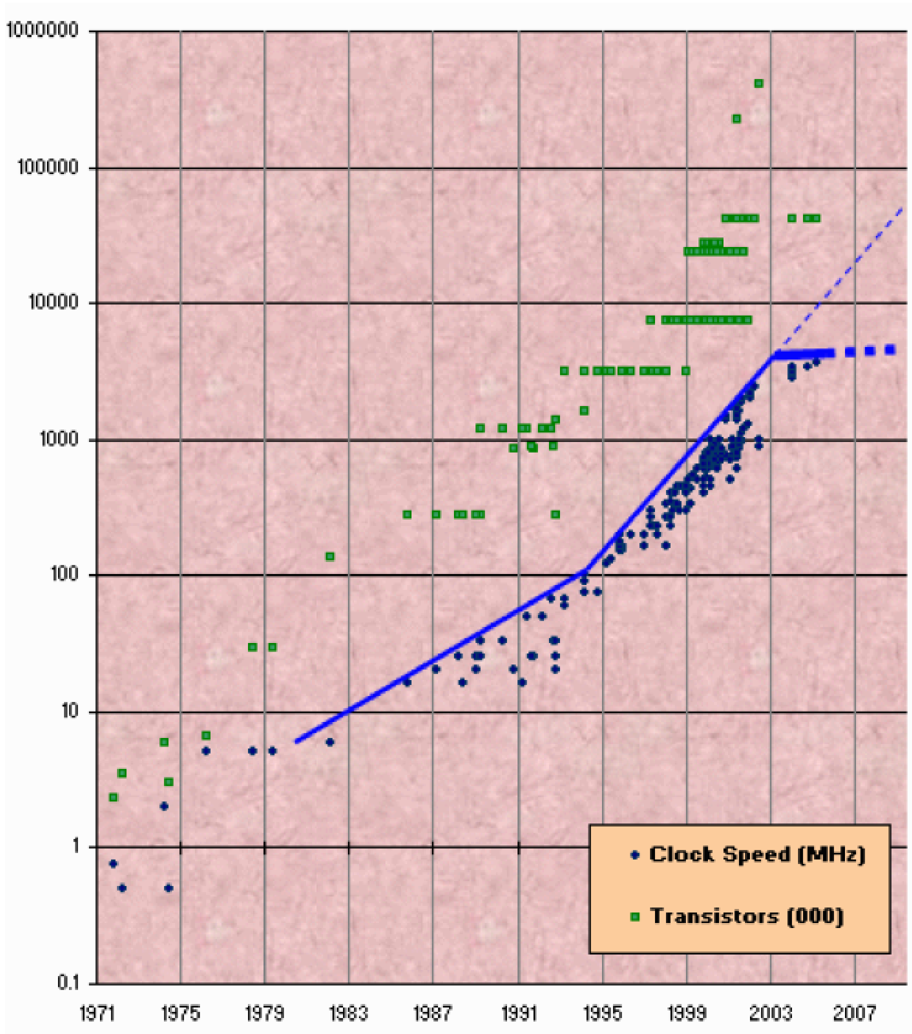


Year	Supercomputer speed: microprocessor speed
2010	100,000:1
2000	10,000:1
1990	1,000:1

练习：2022年超算与微机的速度比例如何?

Cite from CRAY Inc.

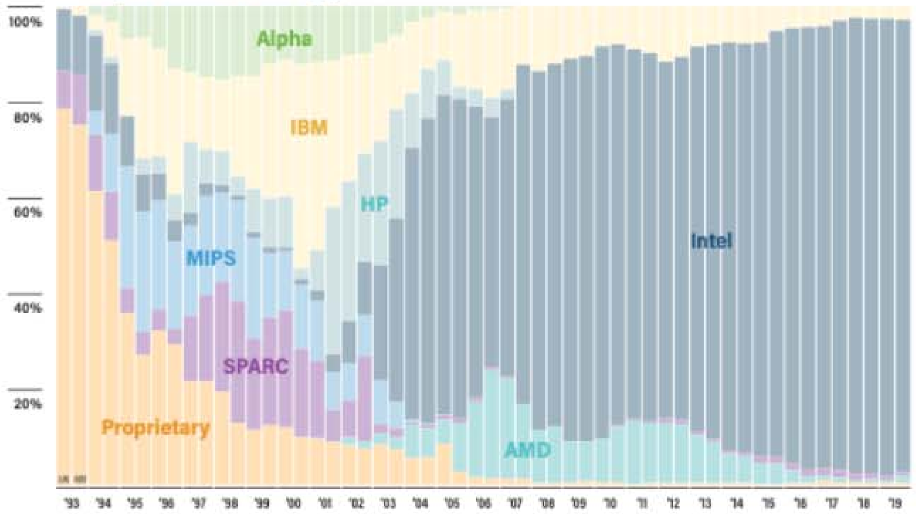
- 狭义的摩尔定律已失效，提高主频的趋势已停止
- 并行环境已逐渐成为我们周围最常见计算机的基本结构的一部分
- 如何做并行程序设计的问题变成对每个计算机工作者的挑战



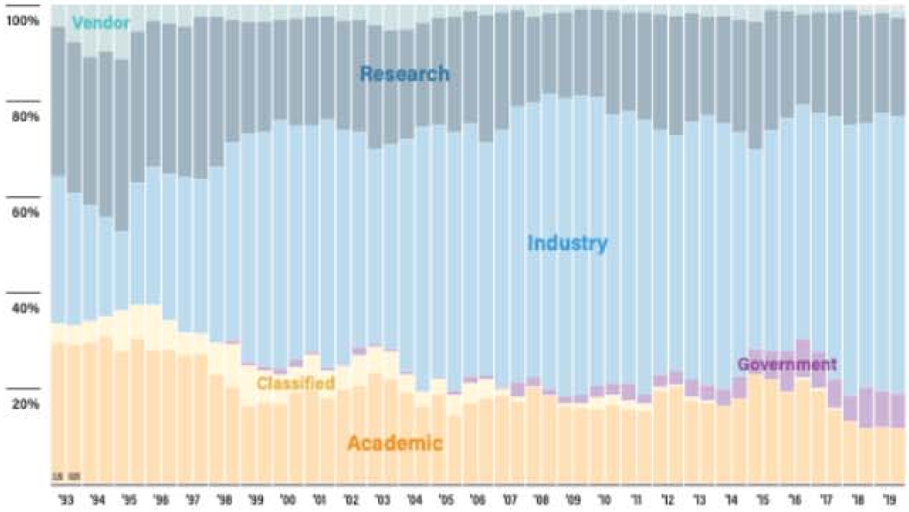
- 2008年：“软件革命即将到来”
- 思考：哪些应用需要并行化？

Architectures

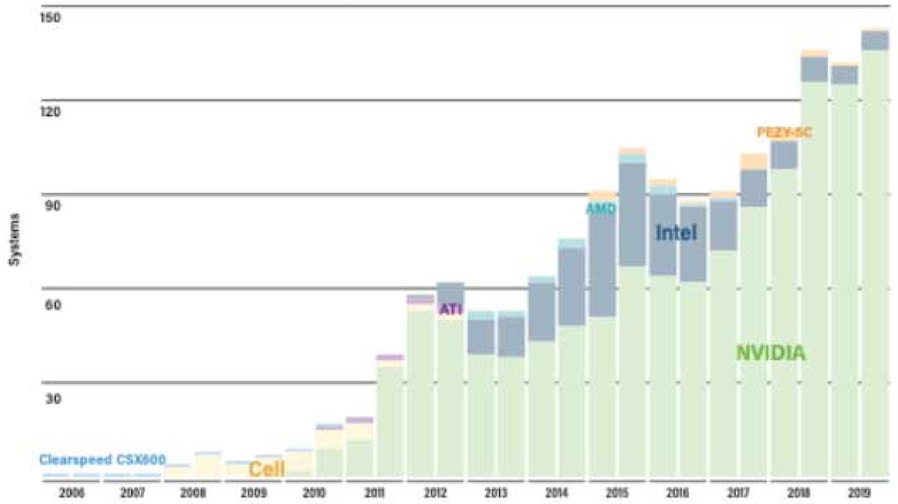
Chip Technology



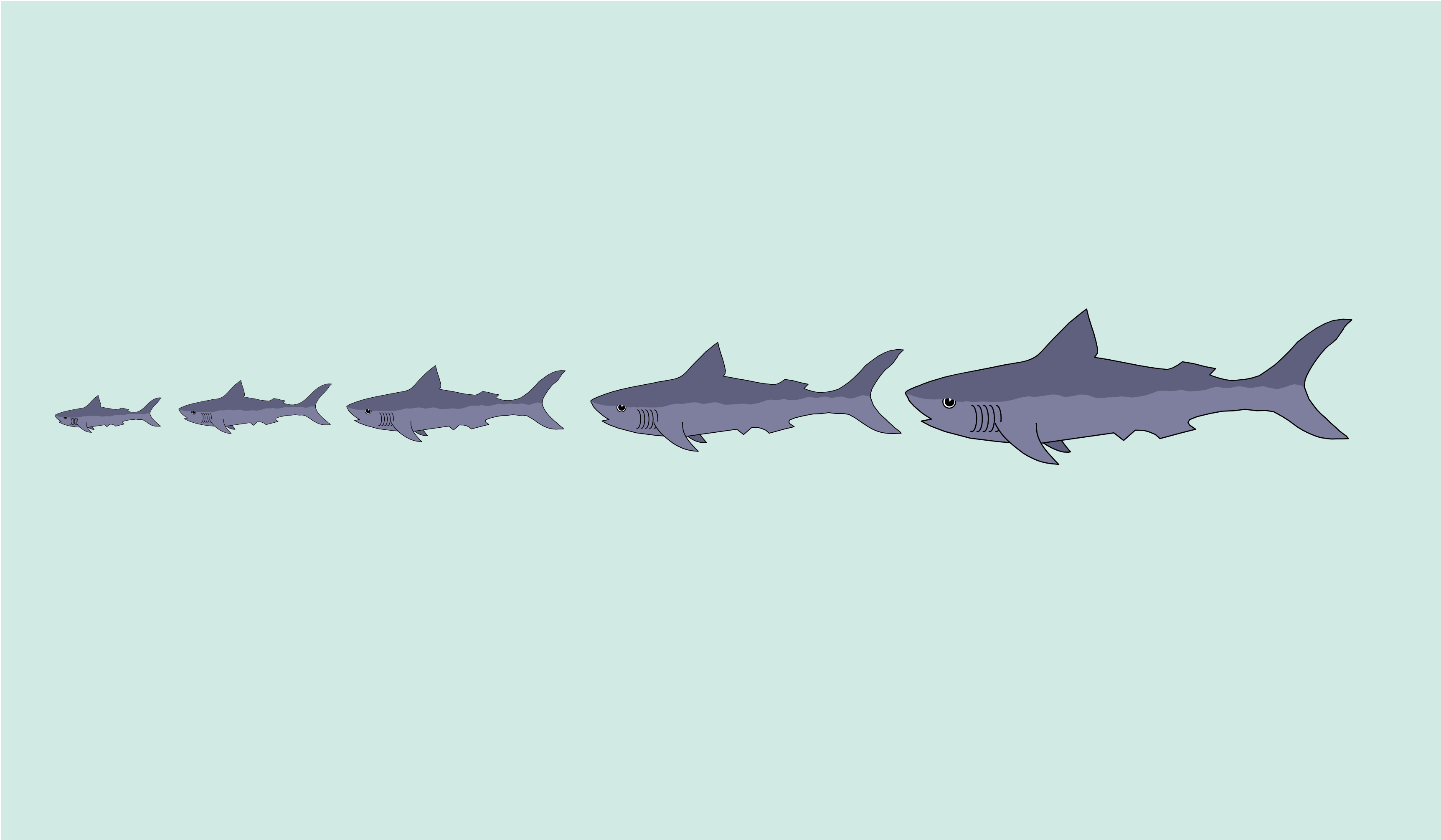
Installation Type



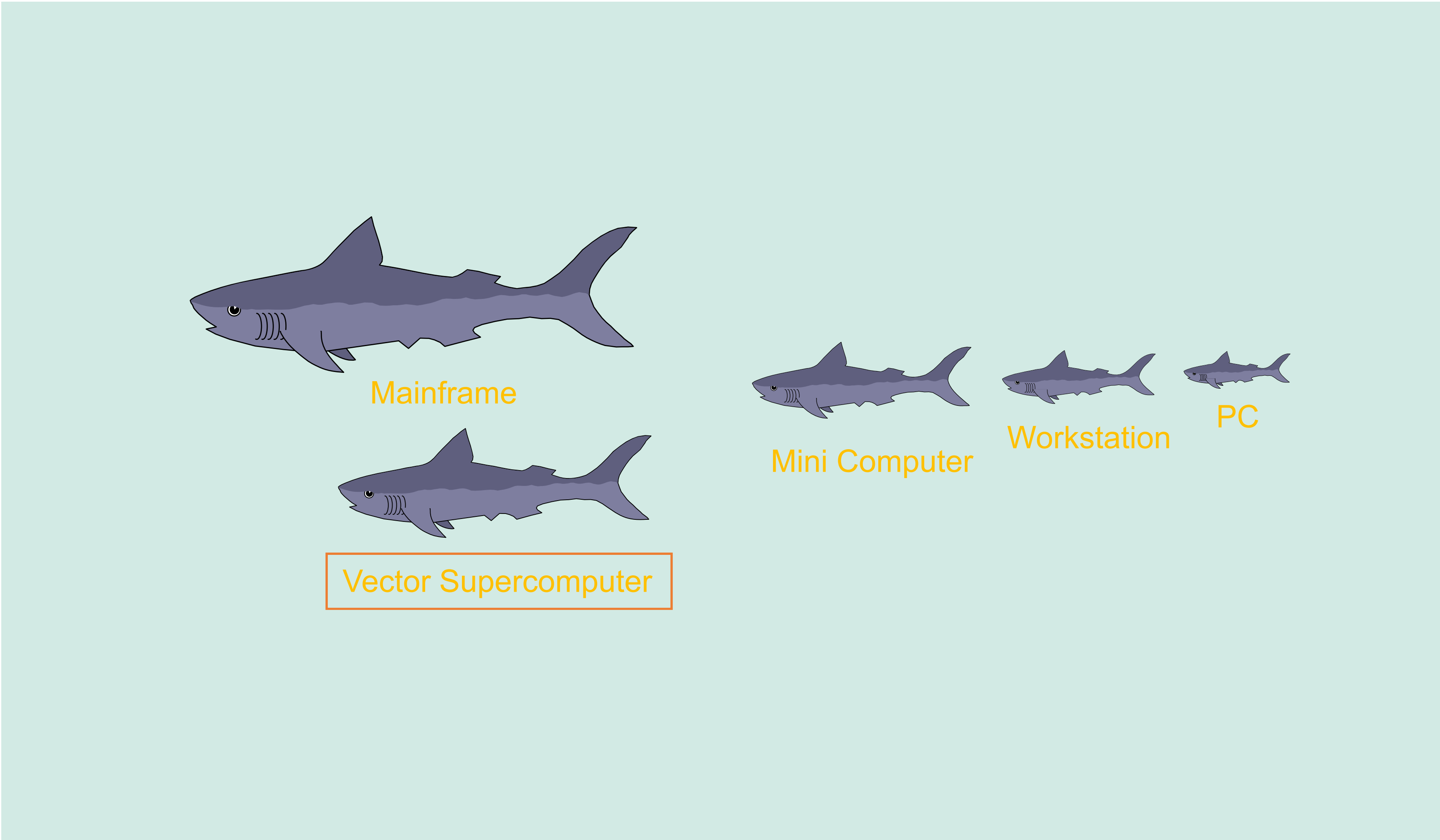
Accelerators/Co-processors



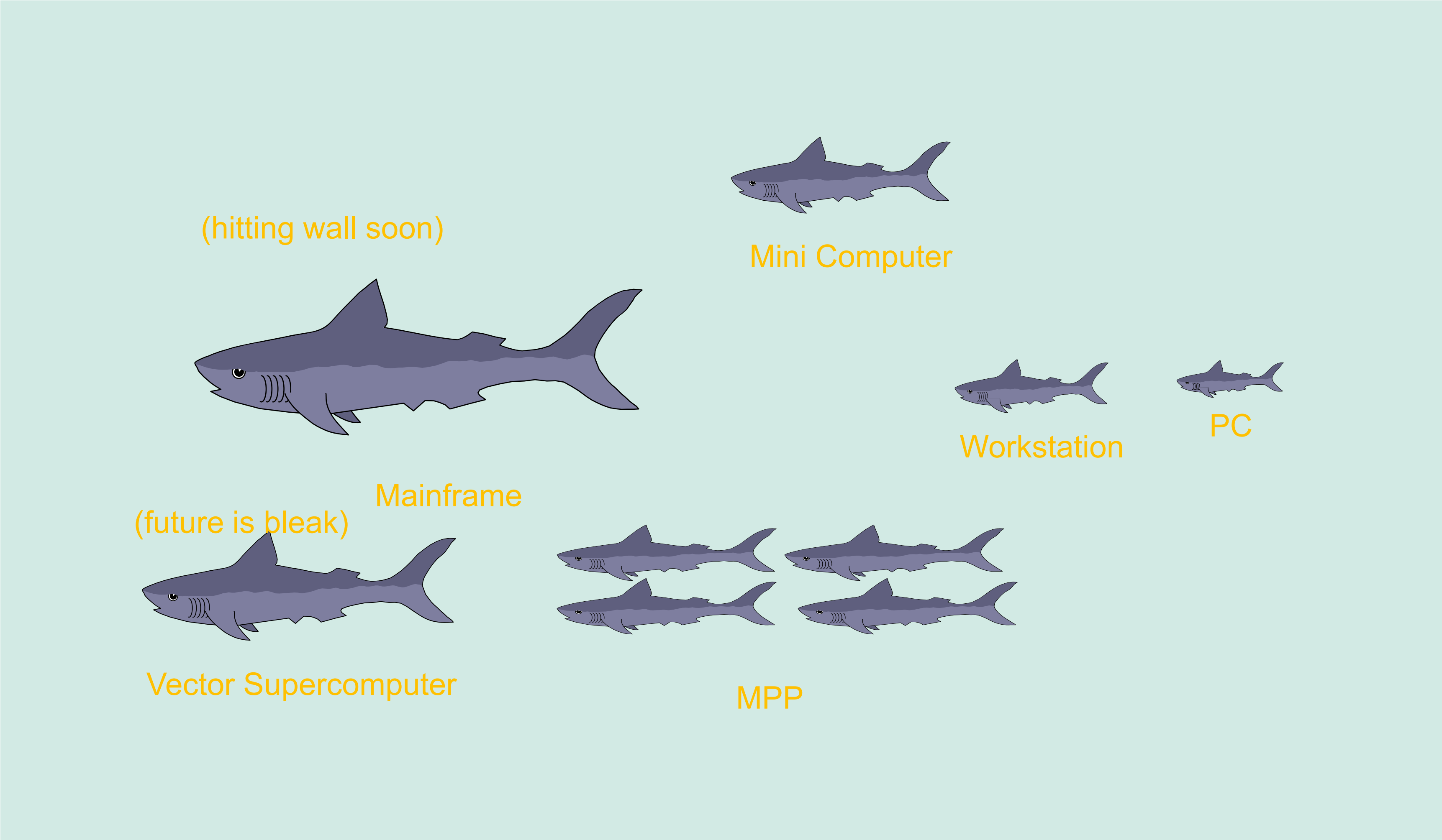
Trends？ - 动物食物链



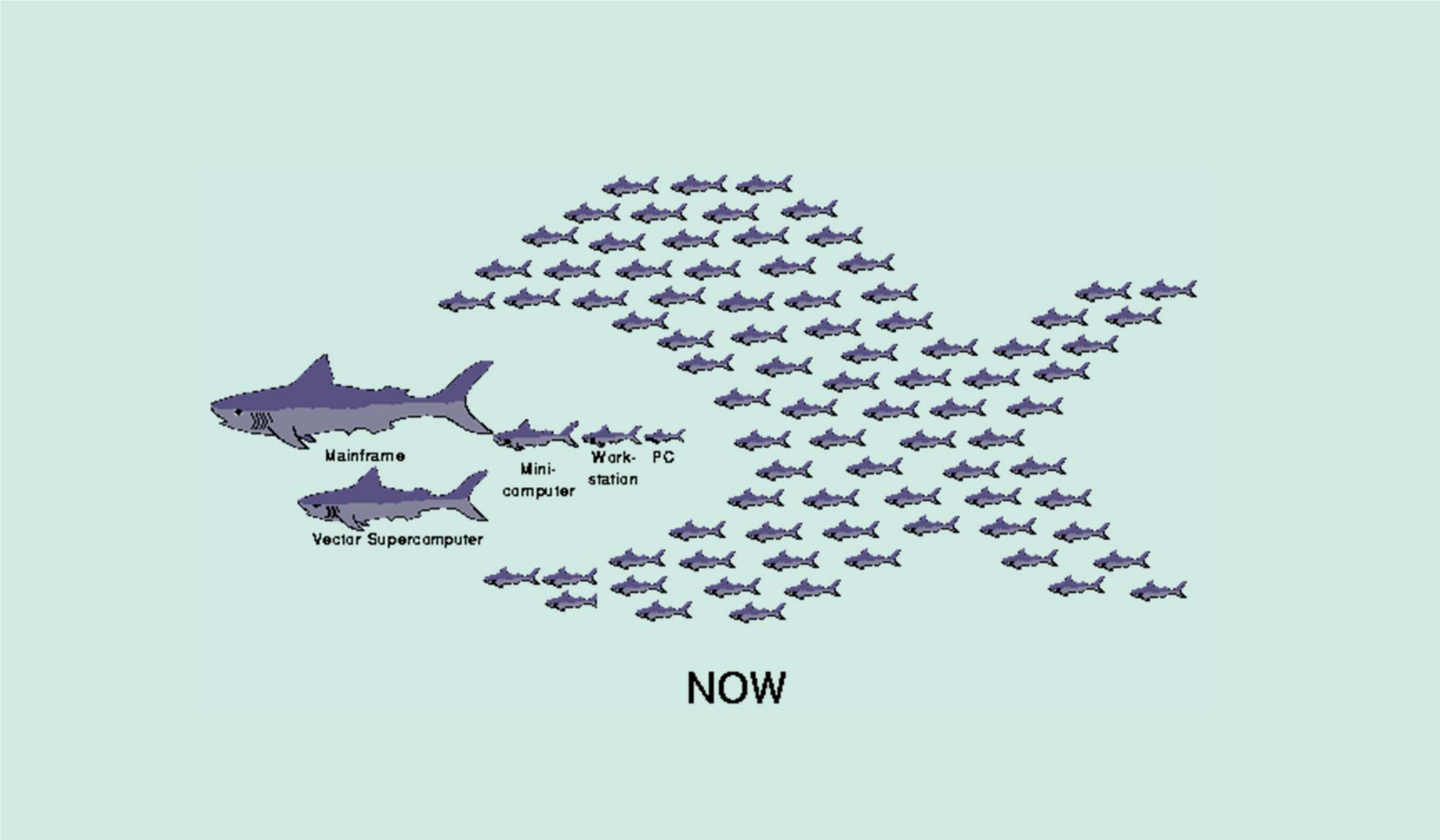
Trends？ - 1984计算机食物链



Trends？ - 1994计算机食物链



Trends？ - 计算机食物链(现在和将来)



http://now.cs.berkeley.edu

思考题1

- 问题1:
  谈谈你所知道的高性能计算与云计算的区别?
- 问题2:
  并行程序的描述应如何？与串行程序有什么不同?
- 问题3:
  如何并行地尽快求解n个元素的最大值或排序？

- 第一篇 并行计算硬件平台： 并行计算机
  - 第一章 并行计算与并行计算机结构模型
  - 第二章 并行计算机系统互连与基本通信操作
  - 第三章 典型并行计算机系统介绍
  - 第四章 并行计算性能评测

第一章 并行计算及并行机结构模型

- 1.1 计算与计算机科学
- 1.2* 单处理机与指令级并行
- 1.3* 多核处理器与线程级并行
- 1.4 并行计算机体系结构
  - 1.4.1 并行计算机结构模型
  - 1.4.2 并行计算机访存模型
  - 1.4.3* 并行计算机存储模型
- 1.5 并行计算概述

并行计算、计算科学、计算需求

- 并行计算：并行机上所作的计算，又称高性能计算或超级计算。

- 计算科学：计算物理、计算化学、计算生物等。
- 计算是科学发现的三大支柱之一。

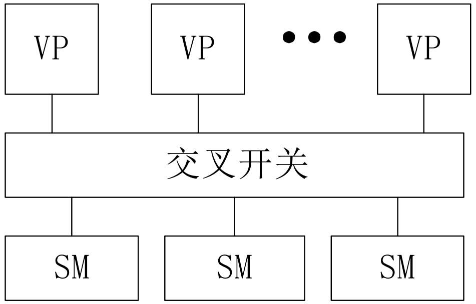
- 科学与工程问题的需求：气象预报、油藏模拟、核武器数值模拟、航天器设计、基因测序等。
  - 美国ASCI计划(1996)：核武器数值模拟。

- 需求类型：计算密集、数据密集、网络密集。

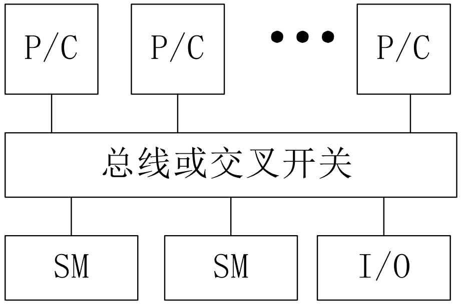
第一章 并行计算及并行机结构模型

- 1.1 计算与计算机科学
- 1.2* 单处理机与指令级并行
- 1.3* 多核处理器与线程级并行
- 1.4 <u>并行计算机体系结构</u>
  - 1.4.1 并行计算机结构模型
  - 1.4.2 并行计算机访存模型
  - 1.4.3* 并行计算机存储模型
- 1.5 并行计算概述

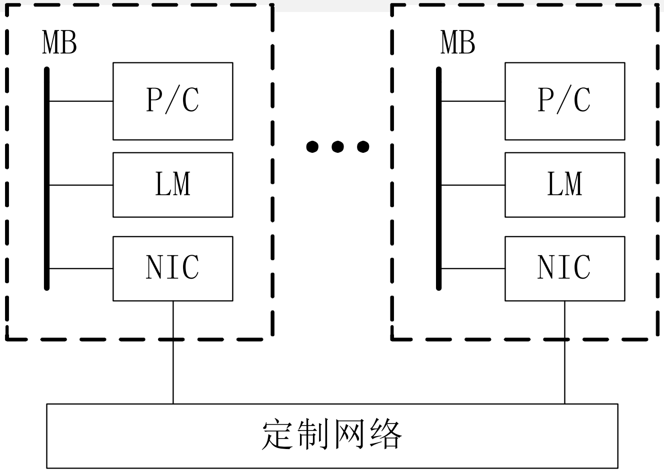
并行计算机结构模型（1）



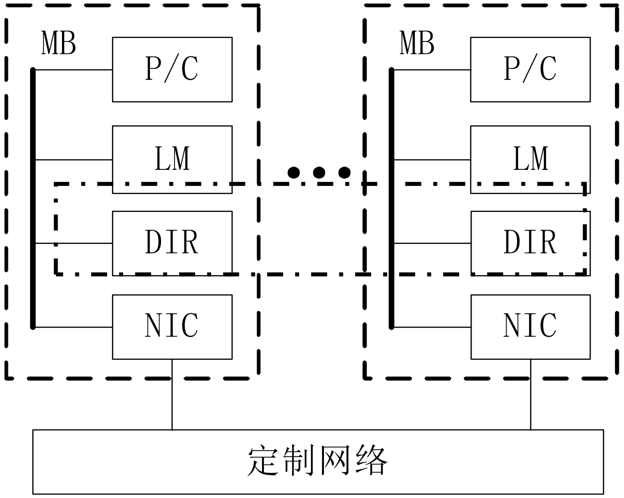
(a) PVP



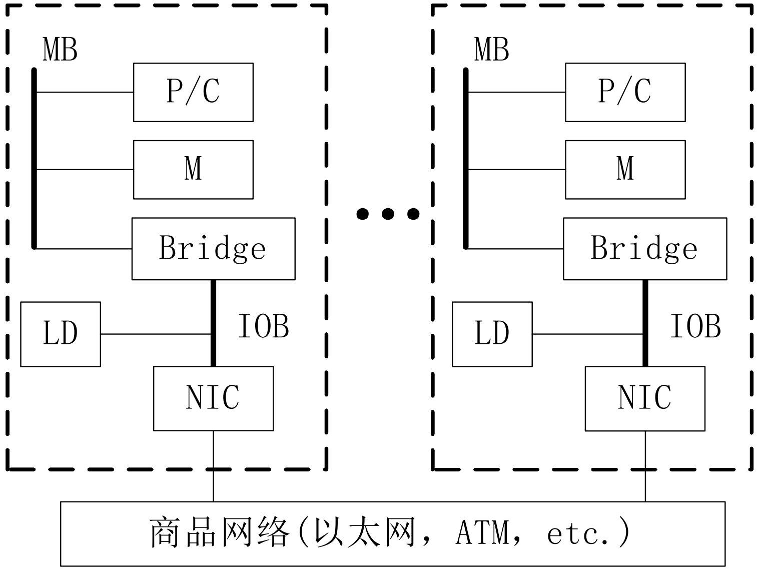
(b) SMP



(c) MPP

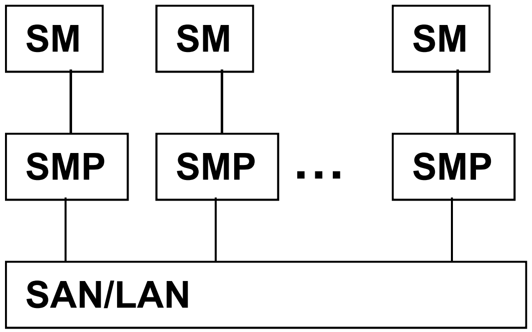


(d) DSM

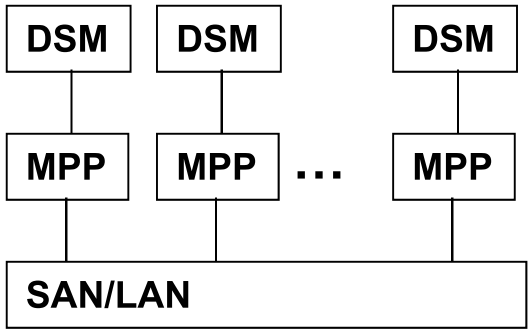


(e) COW

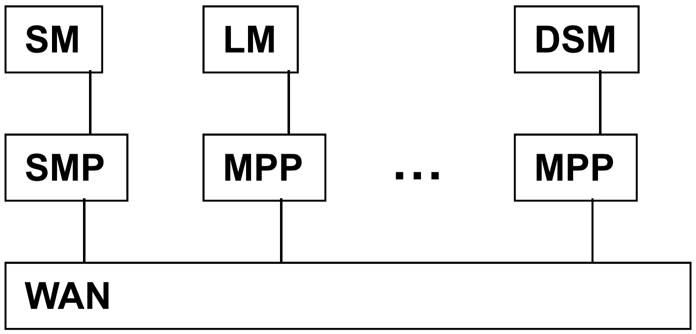
并行计算机结构模型（2）



(f) SMP-Cluster



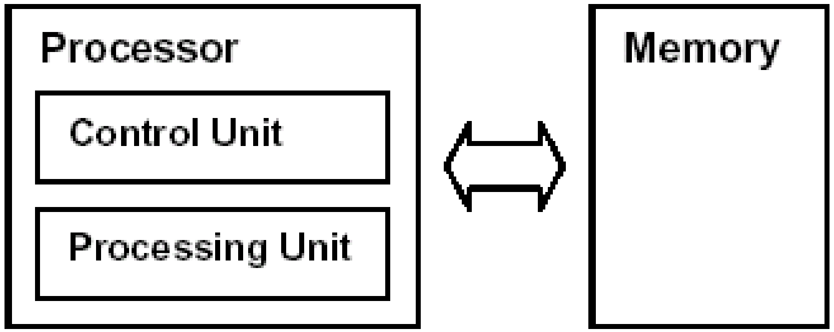
(g) DSM-Cluster



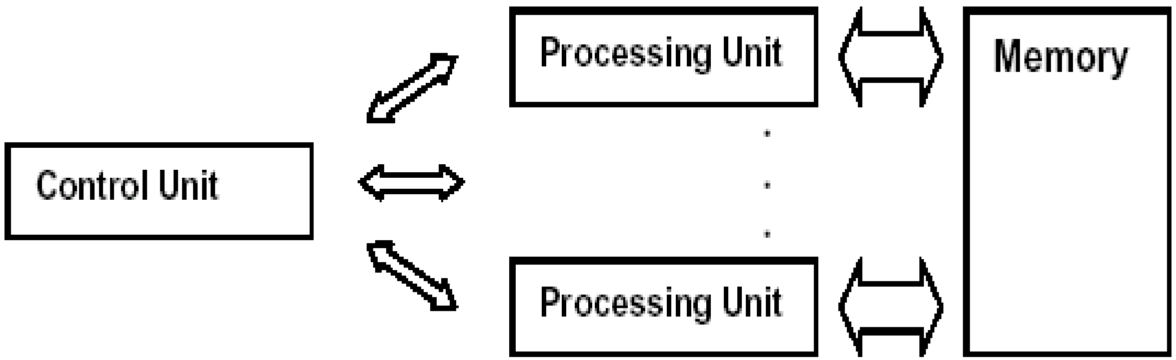
(h) Grid (Cluster of Clusters)

并行计算机结构模型（3）

SISD computer -Von Neumann's model

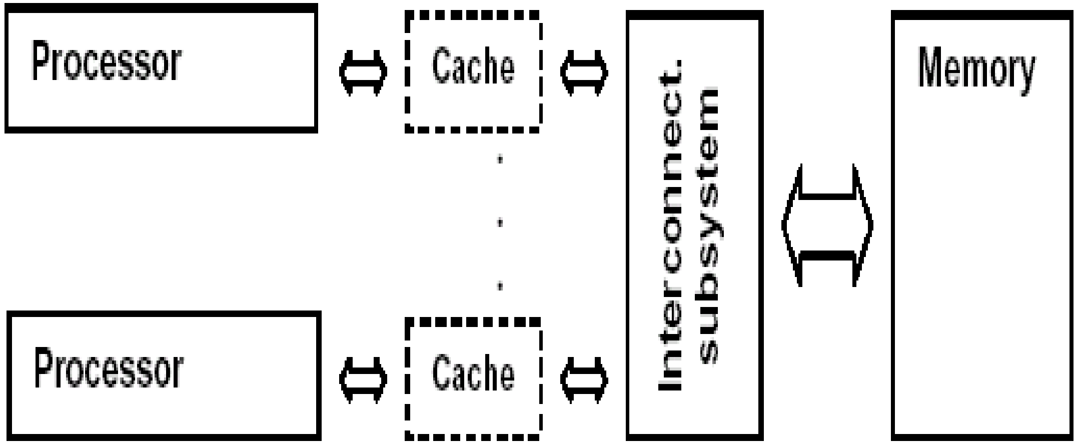


SIMD computer

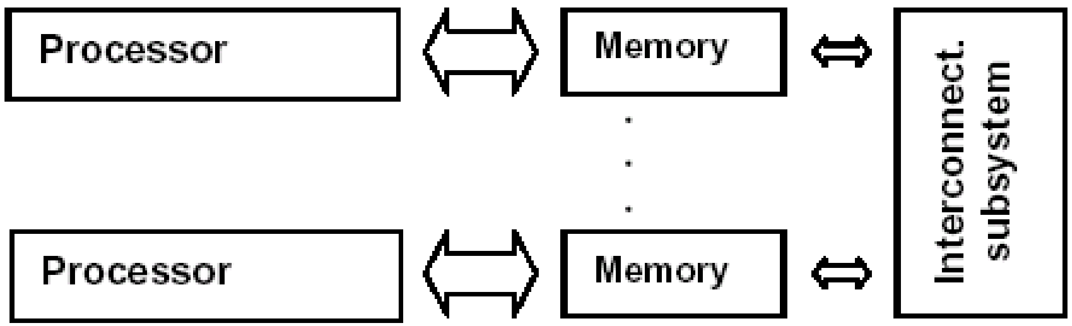


并行计算机结构模型（4）

Symmetric multiprocessor – MIMD-SM

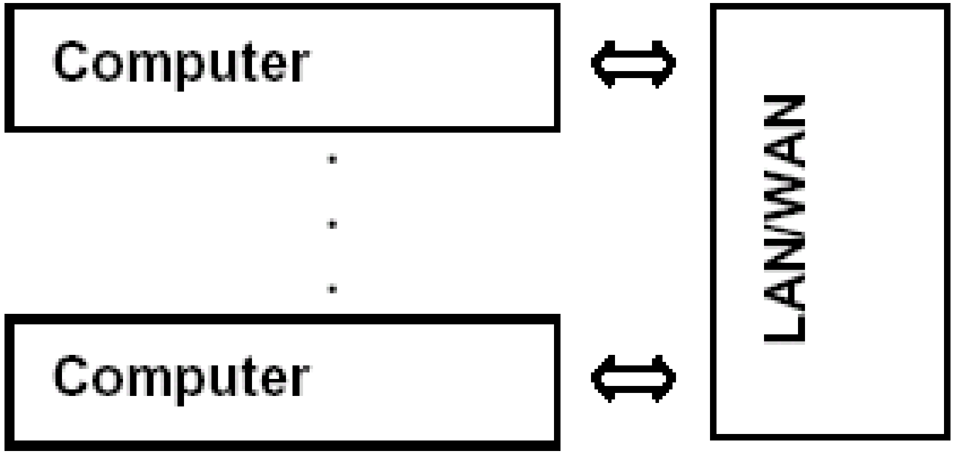


Massively parallel processor – MIMD-DM



并行计算机结构模型（5）

Cluster of workstations – MIMD-DM

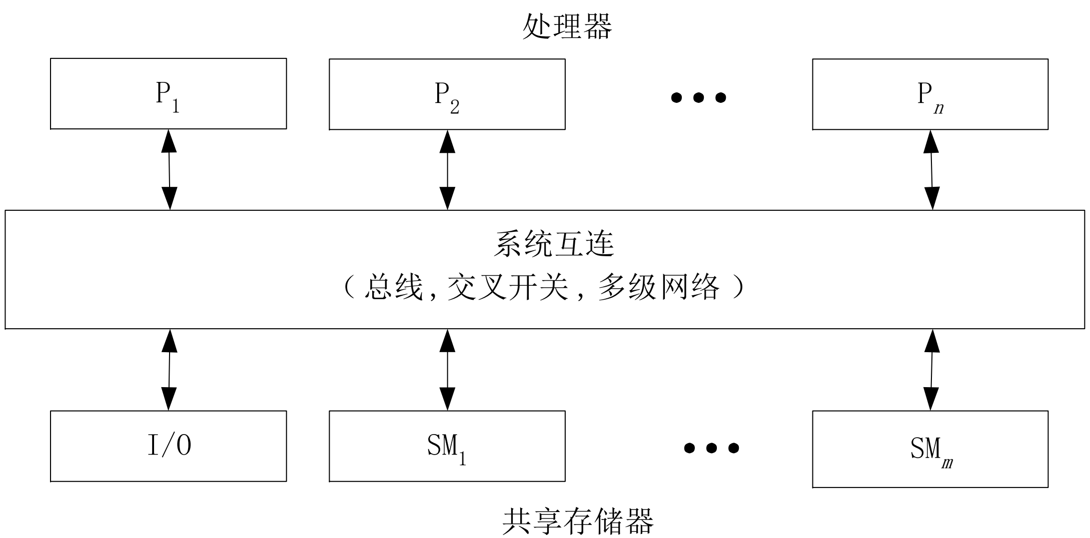


并行计算机结构模型（6）——五种结构小结

属性	PVP	SMP	MPP	DSM	COW
结构类型	MIMD	MIMD	MIMD	MIMD	MIMD
处理器类型	专用定制	商用	商用	商用	商用
互连网络	定制交叉开关	总线、交叉开关	定制网络	定制网络	商用网络（以太ATM）
通信机制	共享变量	共享变量	消息传递	共享变量	消息传递
地址空间	单地址空间	单地址空间	多地址空间	单地址空间	多地址空间
系统存储器	集中共享	集中共享	分布非共享	分布共享	分布非共享
访存模型	UMA	UMA	NORMA	NUMA	NORMA
代表机器	Cray C-90，Cray T-90，银河1号	IBM R50，SGI Power Challenge，曙光1号	Intel Paragon，IBMSP2，曙光1000/2000	Stanford DASH，Cray T 3D	Berkeley NOW，Alpha Farm

并行计算机访存模型（1）——UMA

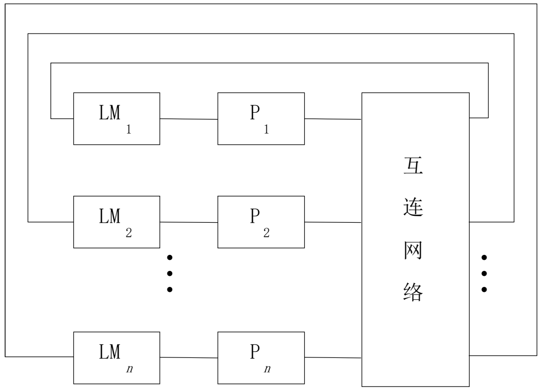
- UMA（Uniform Memory Access）模型是均匀存储访问模型的简称。其特点是：
  - 物理存储器被所有处理器均匀共享；
  - 所有处理器访问任何存储字取相同的时间；
  - 每台处理器可带私有高速缓存；
  - 外围设备也可以一定形式共享。



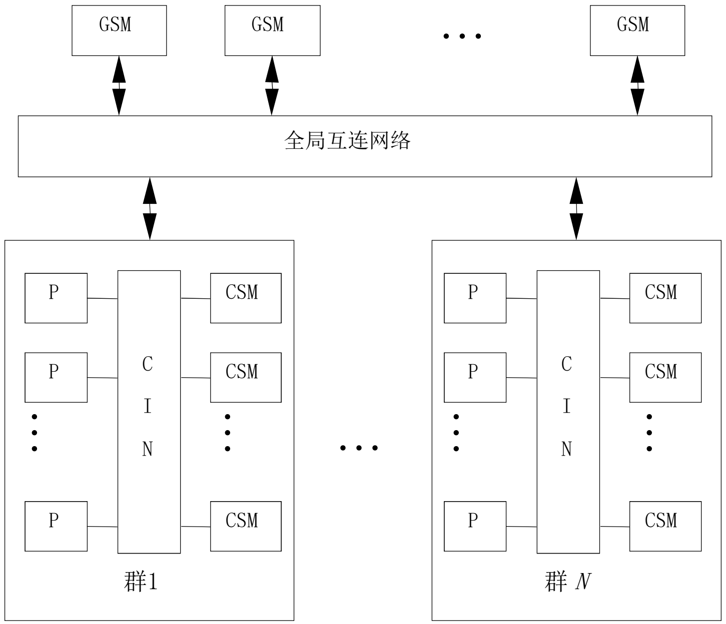
并行计算机访存模型（2）——NUMA

- NUMA(Nonuniform Memory Access)模型是**非均匀存储访问**模型的简称。特点是:
  - 被共享的存储器在物理上是分布在所有的处理器中的，其所有本地存储器的集合就组成了全局地址空间;
  - 处理器访问存储器的时间是不一样的；访问本地存储器LM或群内共享存储器CSM较快，而访问外地的存储器或全局共享存储器GSM较慢(此即非均匀存储访问名称的由来);
  - 每台处理器照例可带私有高速缓存，外设也可以某种形式共享。

并行计算机访存模型（2）——NUMA



(a)共享本地存储模型

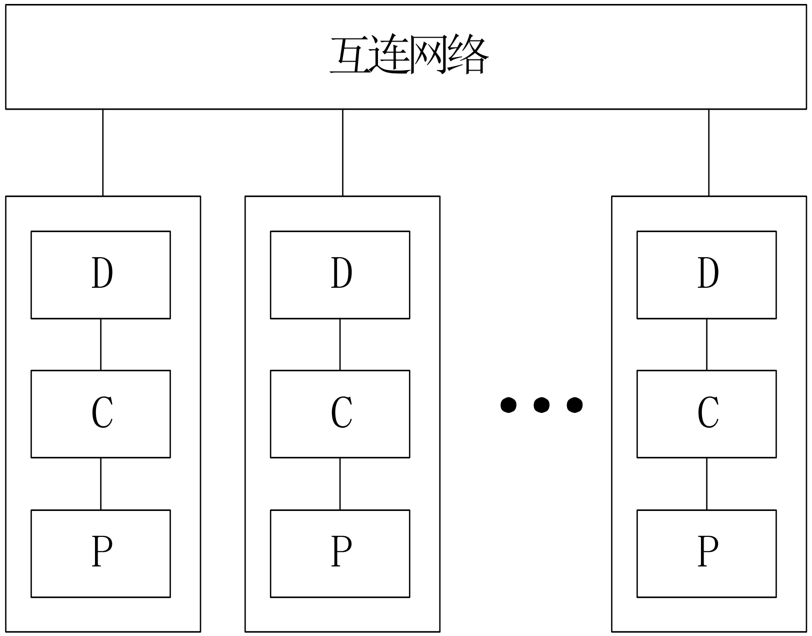


(b)层次式机群模型

并行计算机访存模型（3）——COMA

- COMA(Cache-Only Memory Access)模型是**全高速缓存存储访问**的简称。其特点是:
  - 各处理器节点中没有存储层次结构，全部高速缓存组成了全局地址空间;
  - 利用分布的高速缓存目录D进行远程高速缓存的访问;
  - COMA中的高速缓存容量一般都大于2 级高速缓存容量;
  - 使用COMA时，数据开始时可任意分配，因为在运行时它最终会被迁移到要用到它们的地方。

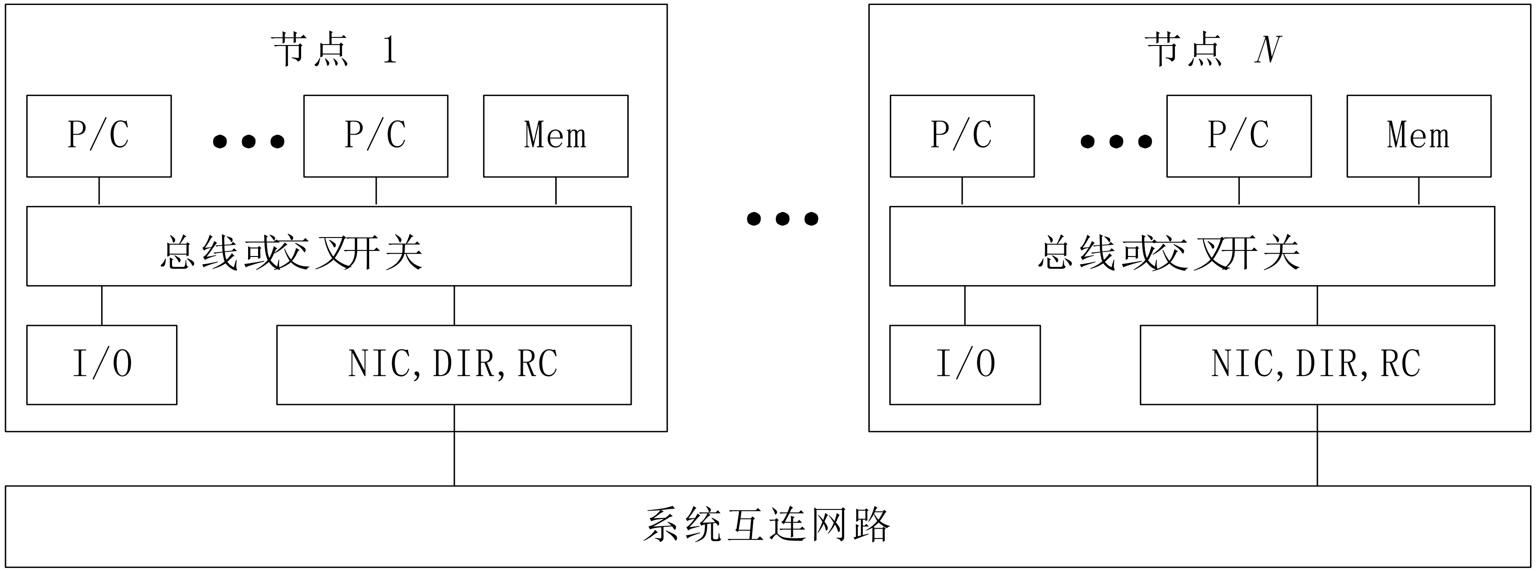
并行计算机访存模型（3）——COMA



并行计算机访存模型（4）——CC-NUMA

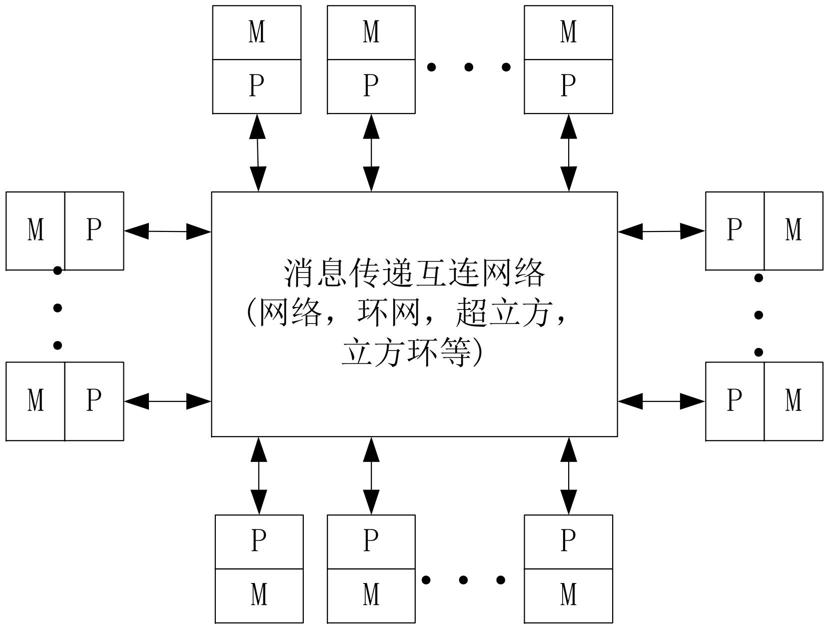
- CC-NUMA（Coherent-Cache Nonuniform Memory Access）模型是**高速缓存一致性非均匀存储访问**模型的简称。其特点是：
  - 大多数使用基于目录的高速缓存一致性协议；
  - 保留SMP结构易于编程的优点，也改善常规SMP的可扩放性；
  - CC-NUMA实际上是一个分布共享存储的DSM多处理机系统；
  - 它最显著的优点是程序员无需明确地在节点上分配数据，系统的硬件和软件开始时自动在各节点分配数据，在运行期间，高速缓存一致性硬件会自动地将数据迁移至要用到它的地方。

并行计算机访存模型（4）——CC-NUMA

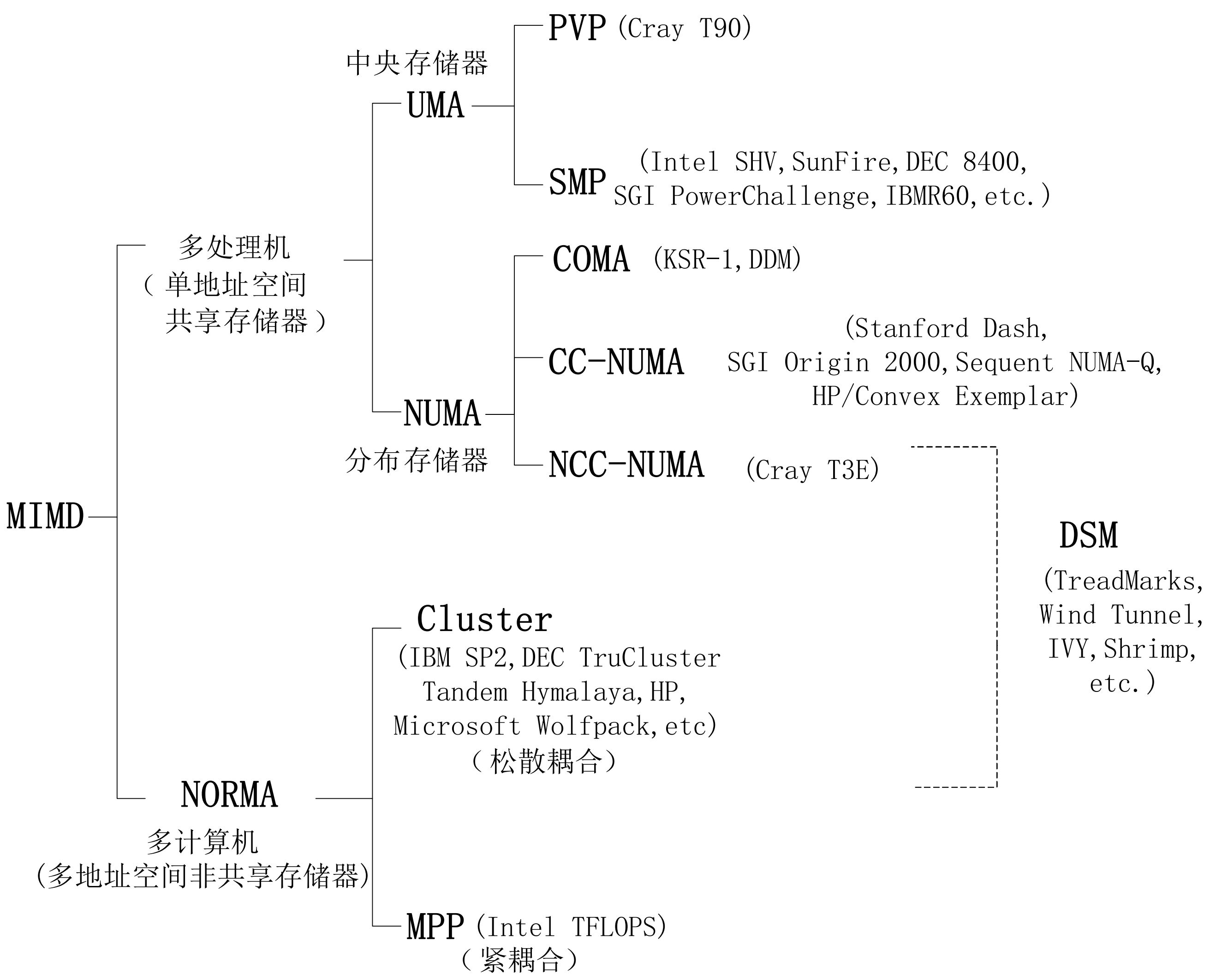


并行计算机访存模型（5）——NORMA

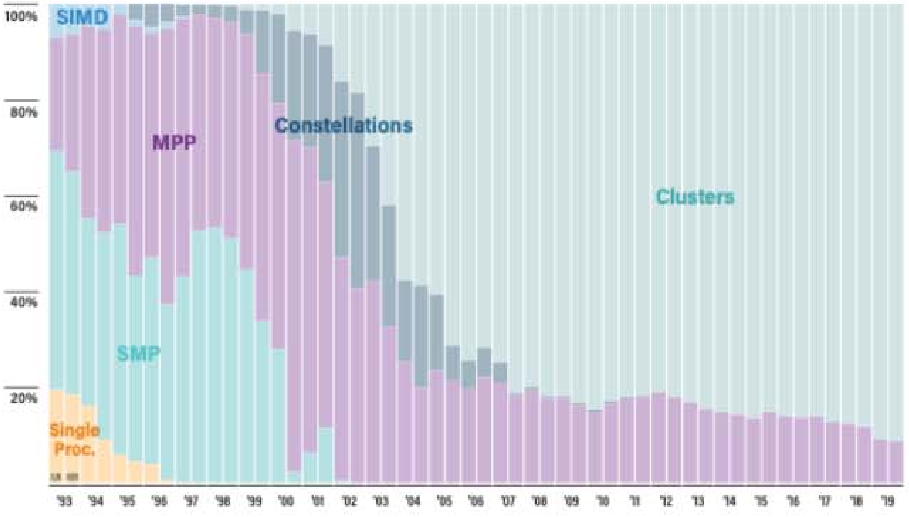
- NORMA（No-Remote Memory Access）模型是**非远程存储访问**模型的简称。NORMA的特点是：
  - 所有存储器是私有的，仅能由其处理器访问；
  - 绝大数NORMA都不支持远程存储器的访问；



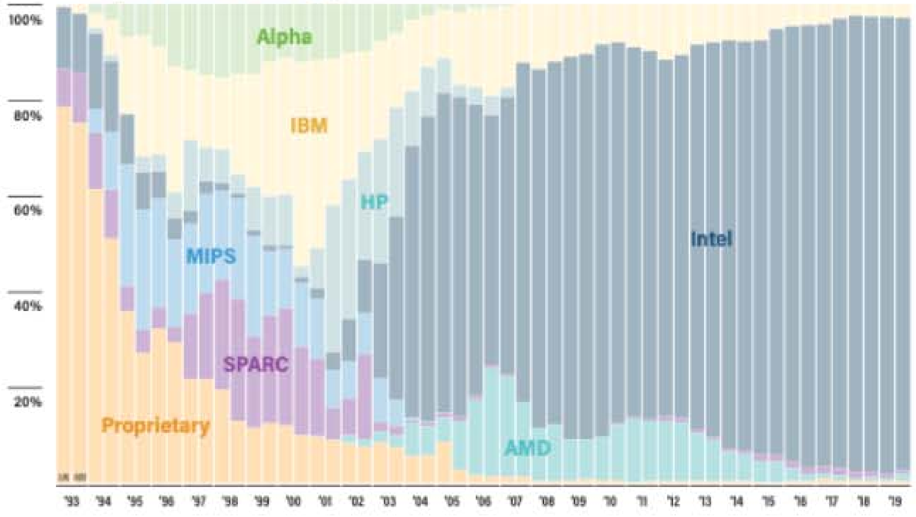
并行机系统的不同存储结构



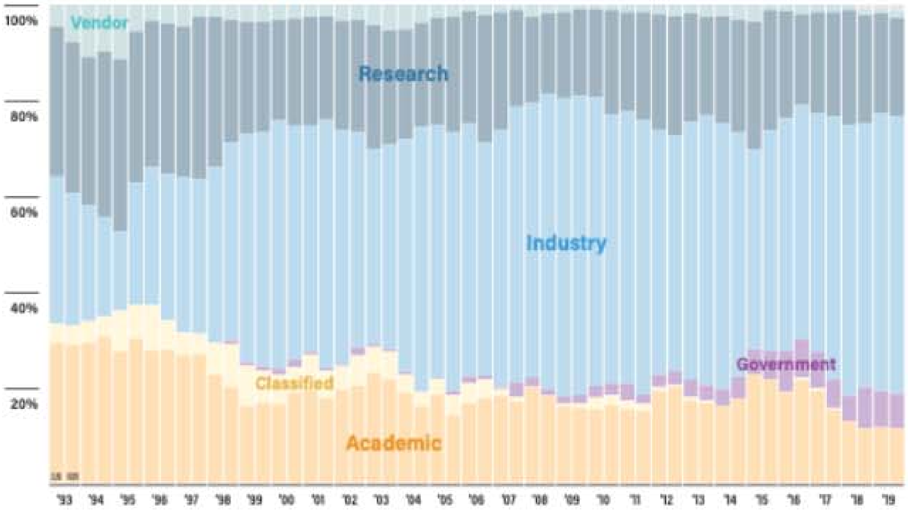
Architectures



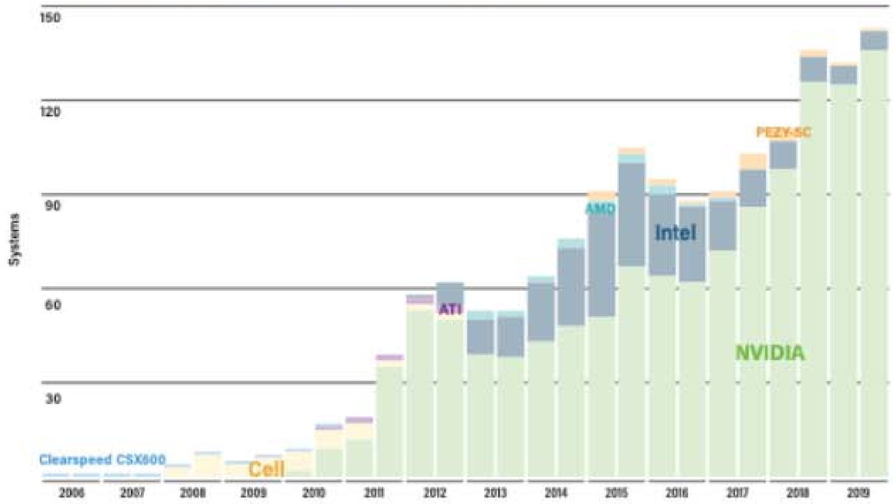
Chip Technology



Installation Type



Accelerators/Co-processors



第一章 并行计算及并行机结构模型

- 1.1 计算与计算机科学
- 1.2* 单处理机与指令级并行
- 1.3* 多核处理器与线程级并行
- 1.4 并行计算机体系结构
  - 1.4.1 并行计算机结构模型
  - 1.4.2 并行计算机访存模型
  - 1.4.3* 并行计算机存储模型
- 1.5 并行计算概述

The Landscape of Parallel Computing Research

- 2006年白皮书。计算数学、计算物理、计算机（软件、硬件、算法）、电子学等多个学科20余名教授，半年时间研讨。
  https://people.eecs.berkeley.edu/~krste/papers/BerkeleyView.pdf

The Landscape of Parallel Computing Research:

A View from Berkeley

Krste Asanovíc, Rastislav Bodik, Bryan Catanzaro, Joseph Gebis,
Parry Husbands, Kurt Keutzer, David Patterson,
William Plishker, John Shalf, Samuel Williams, and Katherine Yelick

EECS Technical Report UCB/EECS-2006-183

December 18, 2006

Abstract

The recent switch to parallel microprocessors is a milestone in the history of computing. Industry has laid out a roadmap for multicore designs that preserves the programming paradigm of the past via binary compatibility and cache coherence. Conventional wisdom is now to double the number of cores on a chip with each silicon generation.

A multidisciplinary group of Berkeley researchers met nearly two years to discuss this change. Our view is that this evolutionary approach to parallel hardware and software may work from 2 or 8 processor systems, but is likely to face diminishing returns as 16 and 32 processor systems are realized, just as returns fell with greater instruction-level parallelism.

We believe that much can be learned by examining the success of parallelism at the extremes of the computing spectrum, namely embedded computing and high performance computing. This led us to frame the parallel landscape with seven questions, and to

A view from Berkeley

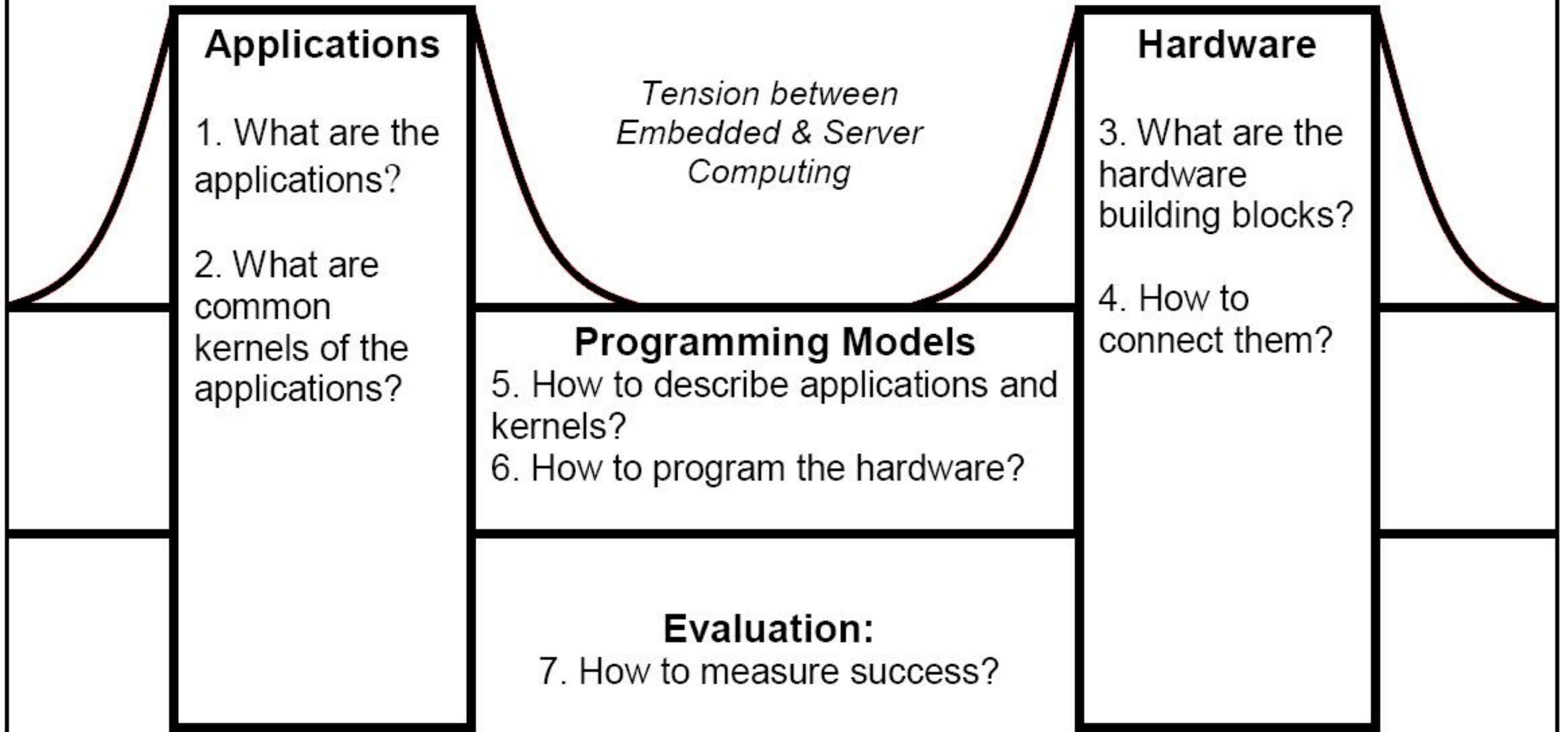
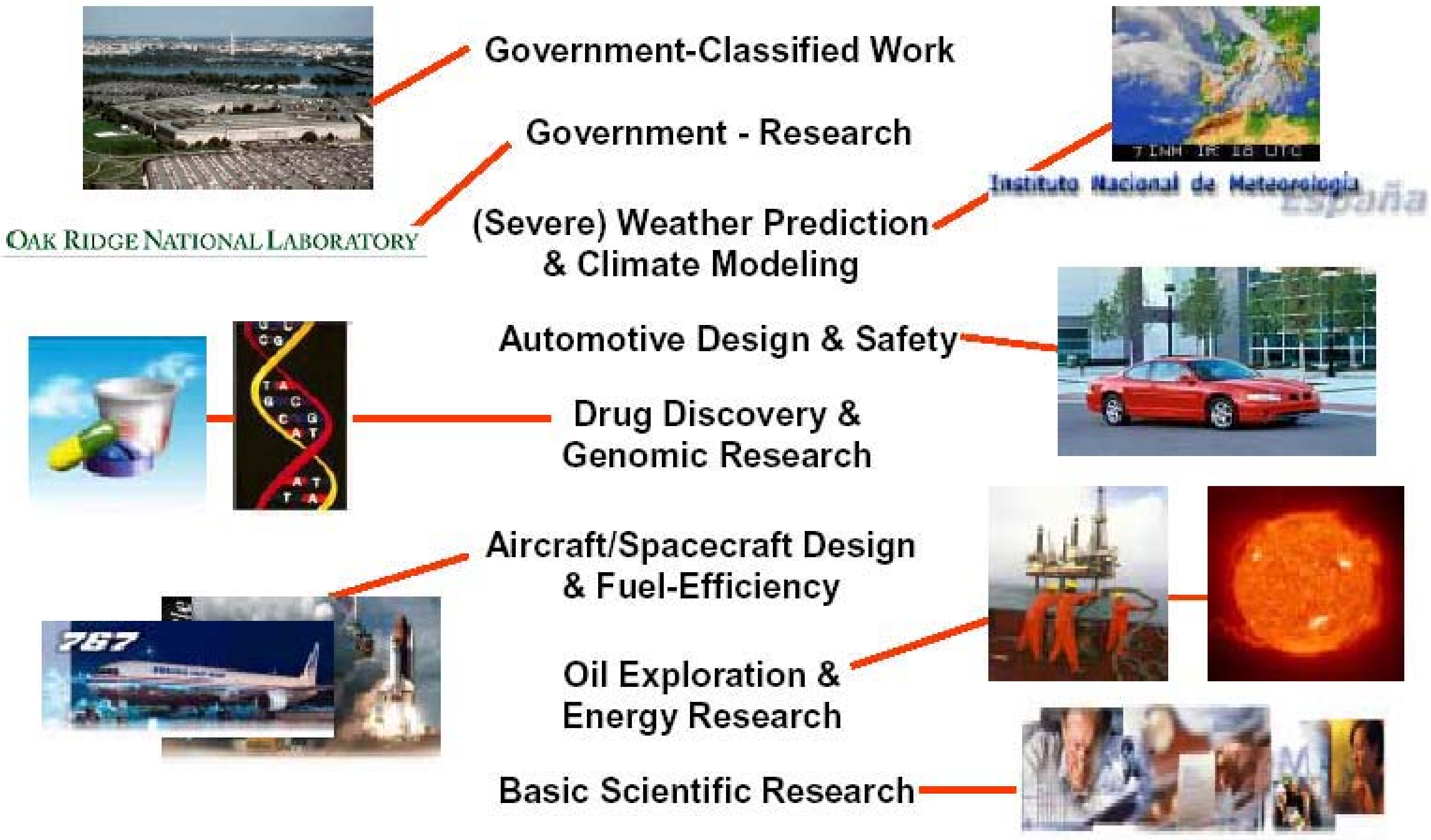
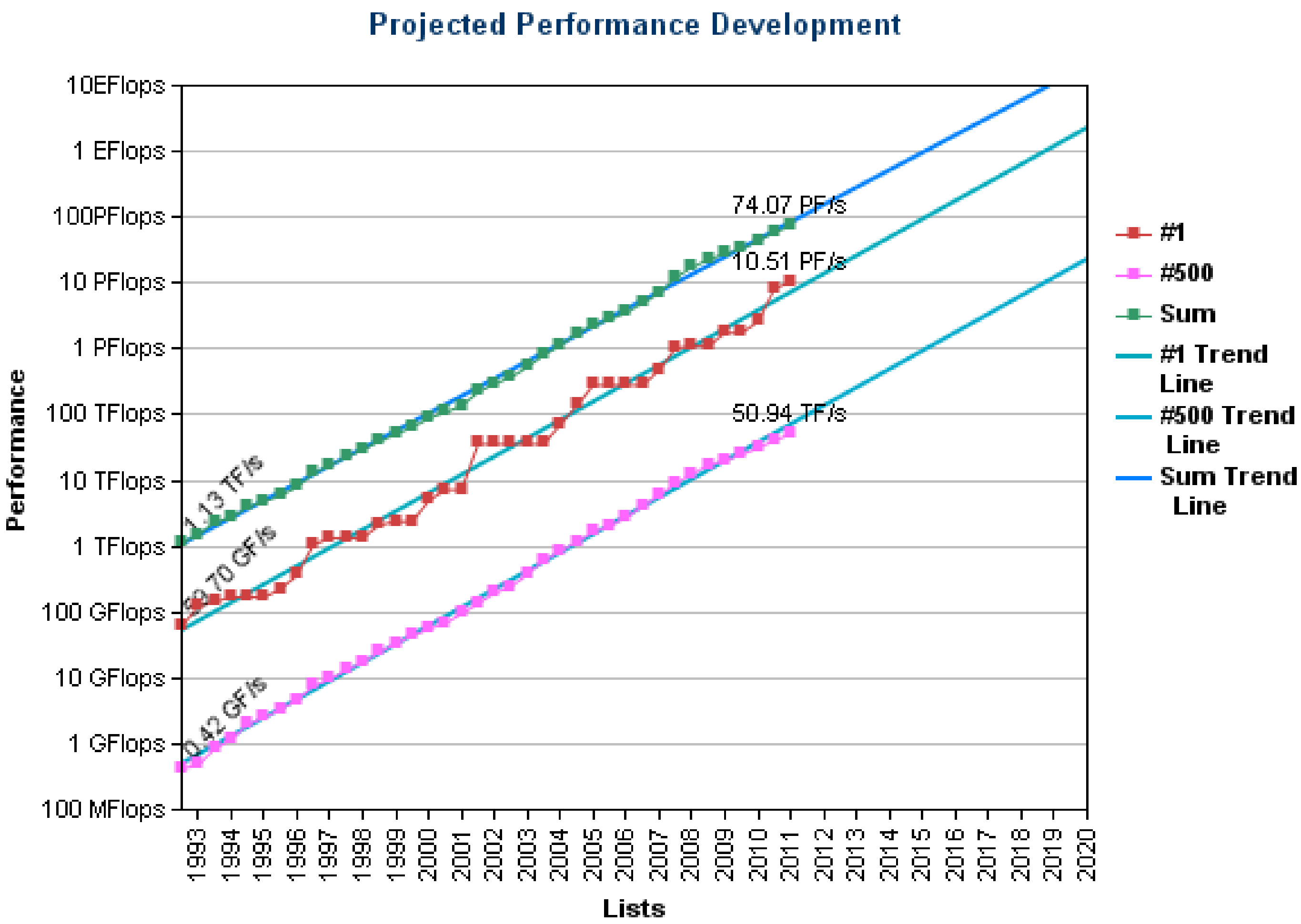


Figure 1. A view from Berkeley: seven critical questions for 21st Century parallel computing. (This figure is inspired by a view of the Golden Gate Bridge from Berkeley.)

高性能计算应用需求


Government-Classified Work
Government - Research
(Severe) Weather Prediction
& Climate Modeling
Automotive Design & Safety
Drug Discovery &
Genomic Research
Aircraft/Spacecraft Design
& Fuel-Efficiency
Oil Exploration &
Energy Research
Basic Scientific Research
OAK RIDGE NATIONAL LABORATORY
Instituto Nacional de Meteorologia
España
767

超级计算机性能的发展趋势



作业1

（1）课本第35页1.11题。并行计算应用调研。

（2）根据调研的应用需求，预算100万人民币购置计算设备。请确定购买的机器配置。

文档不超过2页

提交截止时间：2020年3月4日（周五）18:00

提交方式：BB系统

思考题2

- 与串行计算相比，并行机系统的存储结构更为复杂。试描述缓存一致性（cache coherence）问题。请考虑可以如何解决这个问题。