并行计算
Parallel Computing

主讲人　孙广中

Spring, 2018

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：待定
- 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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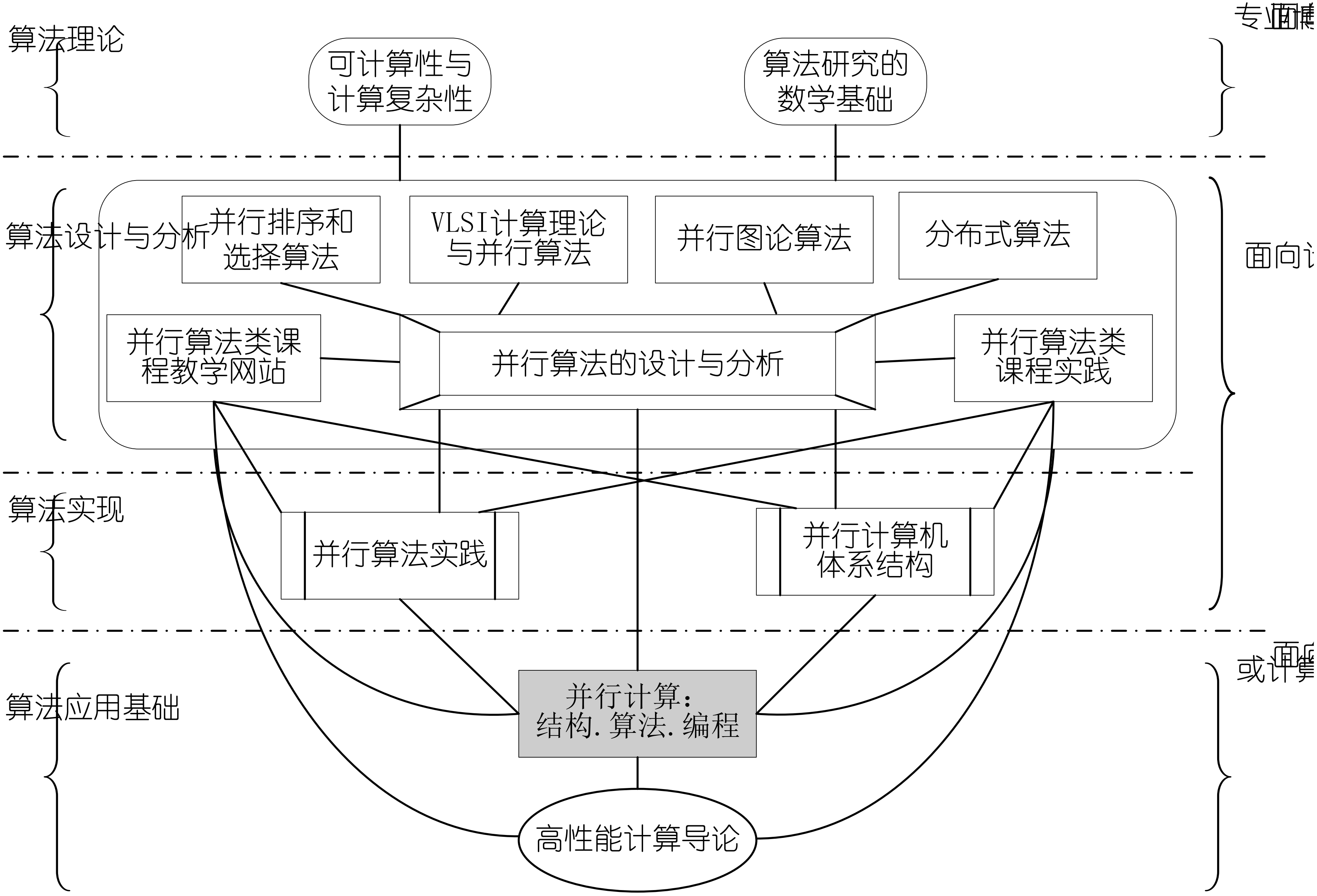
About the Textbook

- 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获主
  - 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
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
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

- 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 …

Hardware Platform for Parallel Computing:

- System Architectures and Models
- System Interconnections
- Performance Evaluation

Part I : Parallel Architectures - System Architectures and Models

- 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

- 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)

- 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

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

Part II : Parallel Algorithms - Design Methodology

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

Part II : Parallel Algorithms - Design Techniques

- 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
- America HPCC project, ASCI project
- In one words: 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.

OAK RIDGE NATIONAL LABORATORY

Instituto Nacional de Meteorología España

Government-Classified Work

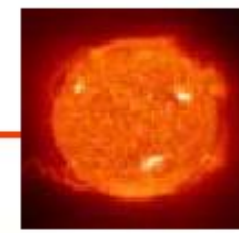
Government - Research

(Severe) Weather Prediction & Climate Modeling

Automotive Design & Safety

Drug Discovery & Genomic Research

Aircraft/Spacecraft Design & Fuel-Efficiency



Oil Exploration & Energy Research

Basic Scientific Research

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
- 2018 → 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

TOP500 SUPERCOMPUTER SITES

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NERSC Flips Switch on New Flagship Supercomputer, Edison

Feb. 3, 2014, 4:24 p.m.

The National Energy Research Scientific Computing (NERSC) Center recently accepted "Edison," a new flagship supercomputer designed for scientific productivity. Named in honor of American inventor Thomas Alva Edison, the Cray XC30 will be dedicated in a ceremony held at the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) on February 5, 2014, and scientists are already reporting results.

How Can Supercomputers Survive a Drought?

Jan. 29, 2014, 9:45 a.m.

Water scarcity has been surfacing as an extremely critical issue worth addressing in the U.S. as well as around the globe nowadays. A McKinsey-led report shows that, by 2030, the global water demand is expected to exceed the supply by 40%. According to another recent report by The Congressional Research Service (CRS), more than 70% of the land area in the U.S. underwent drought condition during August, 2012.

Japan's Manufacturers Cozy Up to Supercomputing

Jan. 28, 2014, 10:33 a.m.

Beyond a pure passion for technology and the thrill of turning ideas into reality, there is a hugely practical basis for investment in advanced computing. Supercomputers and other computational technologies bolster

TOP10 November

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	

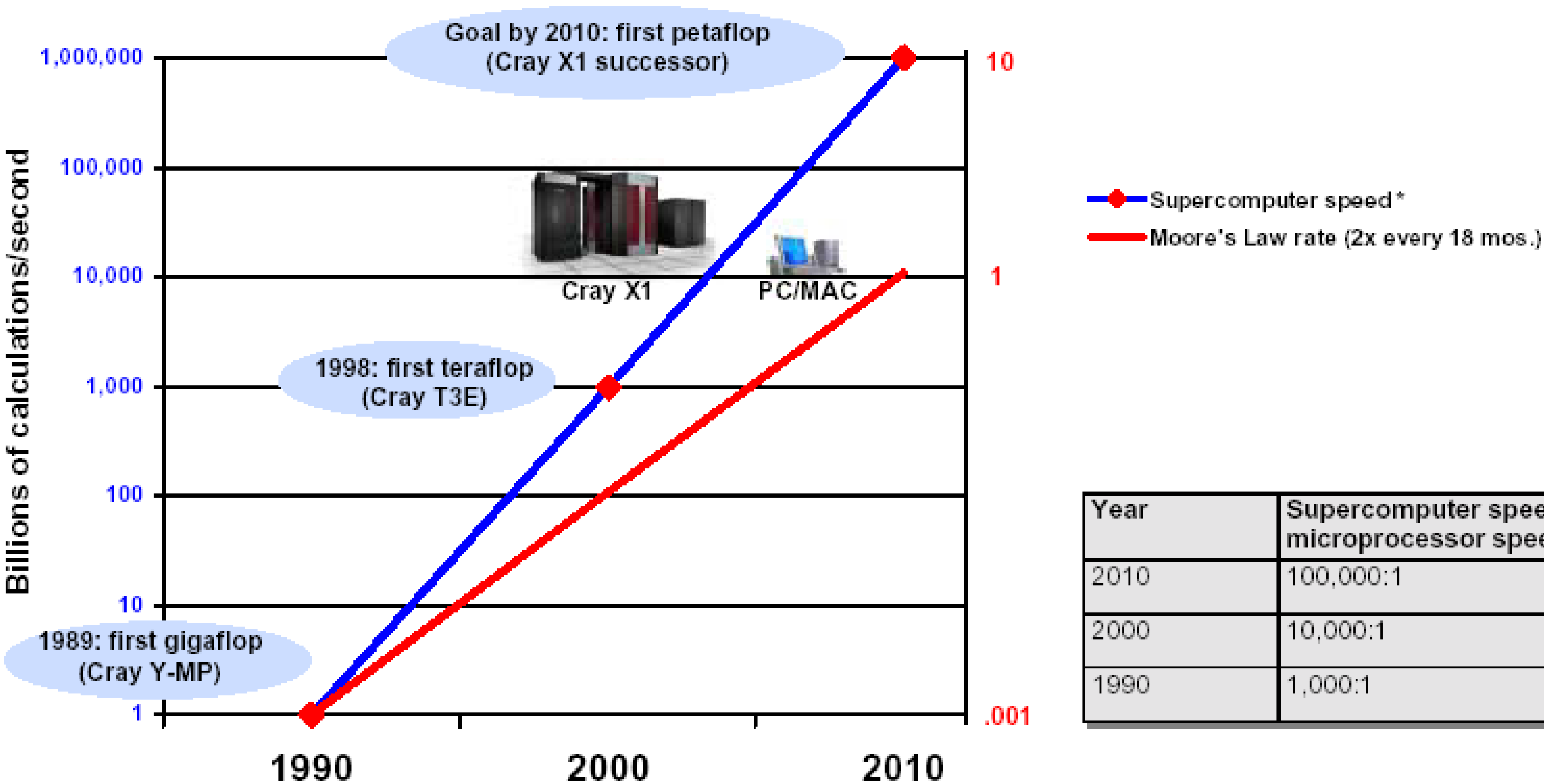
TOP 10 Sites for November 2017

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

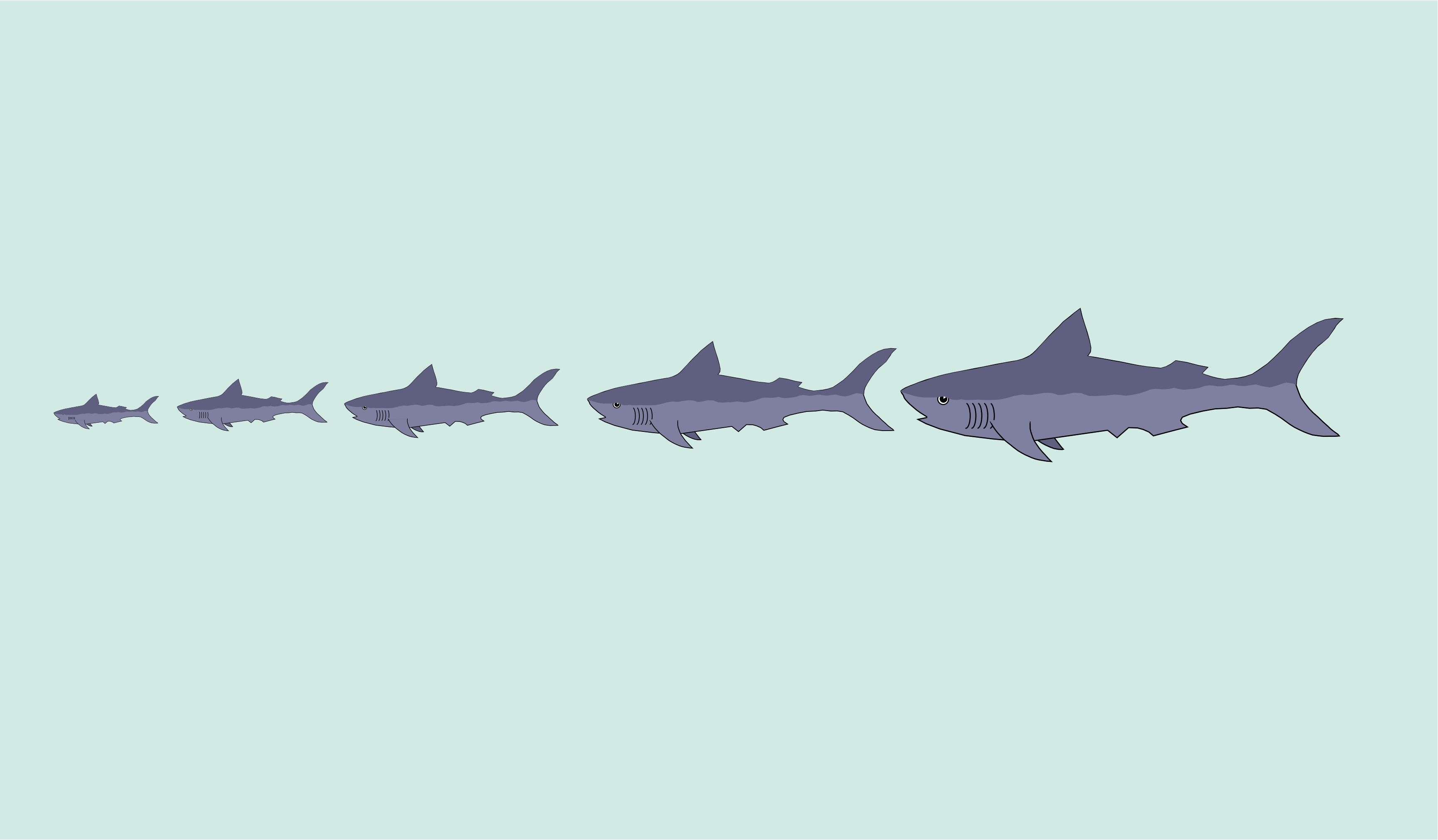
超级计算机的增长速度——超过摩尔定律100倍



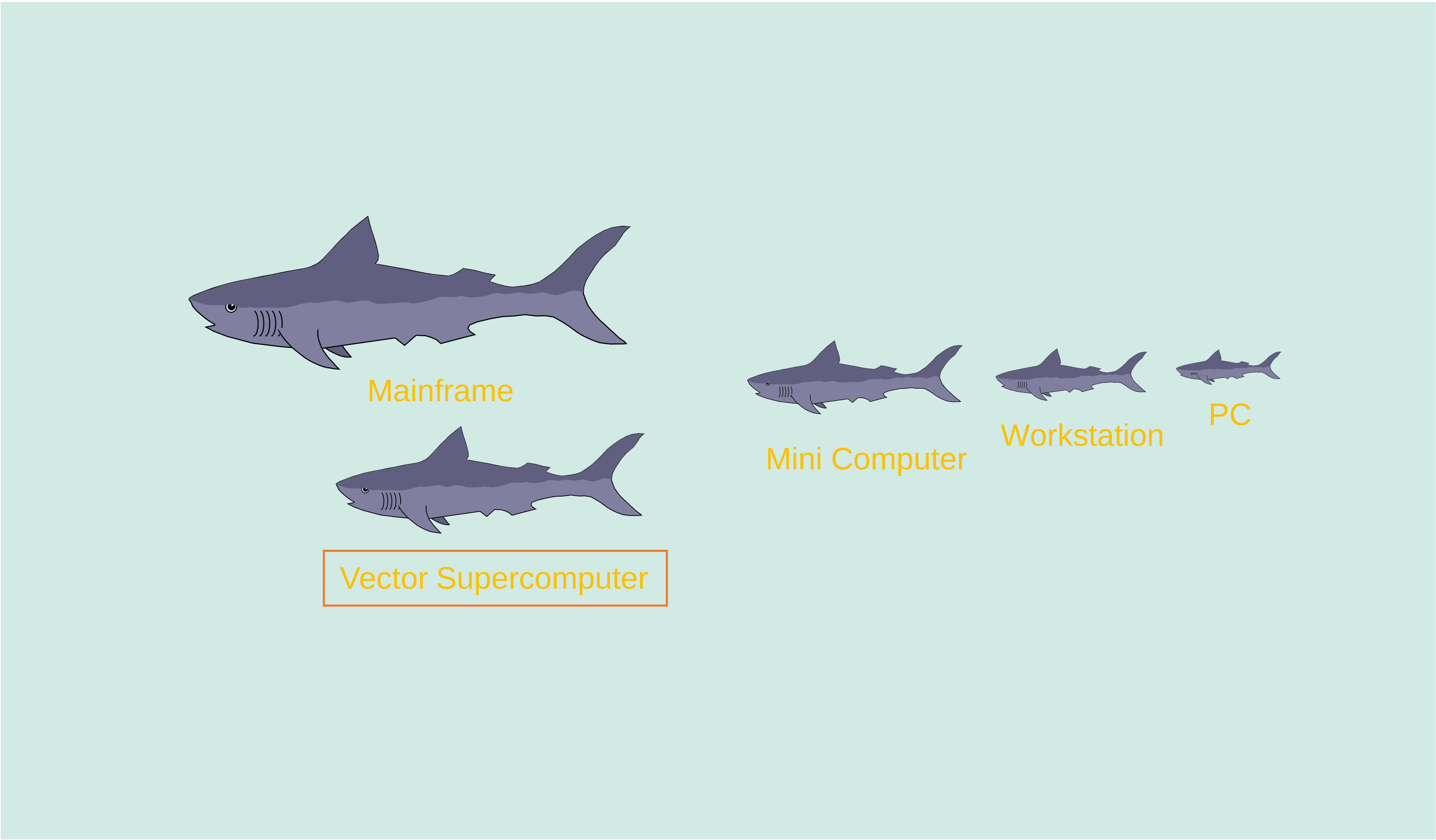
Year	Supercomputer speed: microprocessor speed
2010	100,000:1
2000	10,000:1
1990	1,000:1

Cite from CRAY Inc.

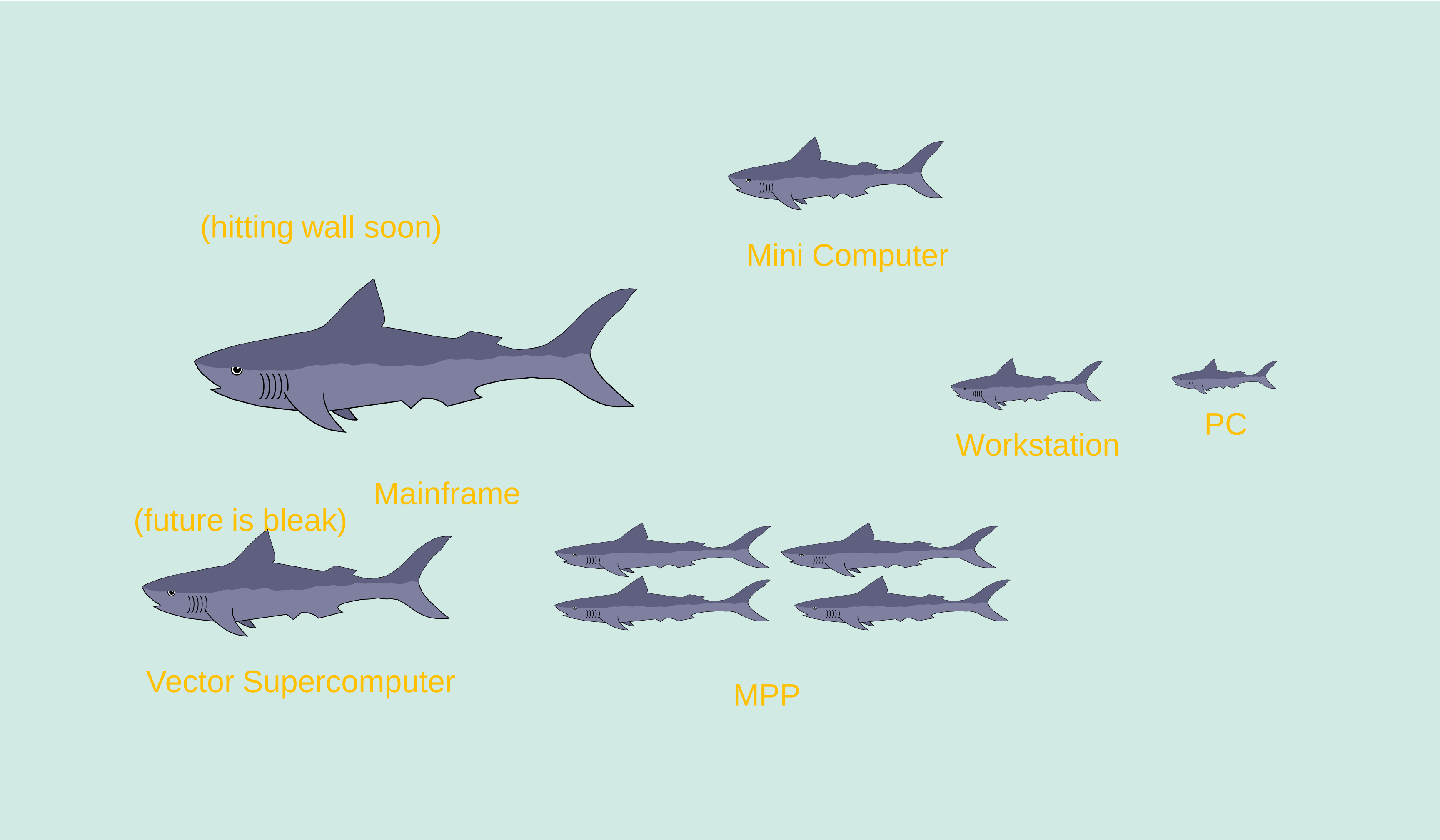
Trends？ - 动物食物链



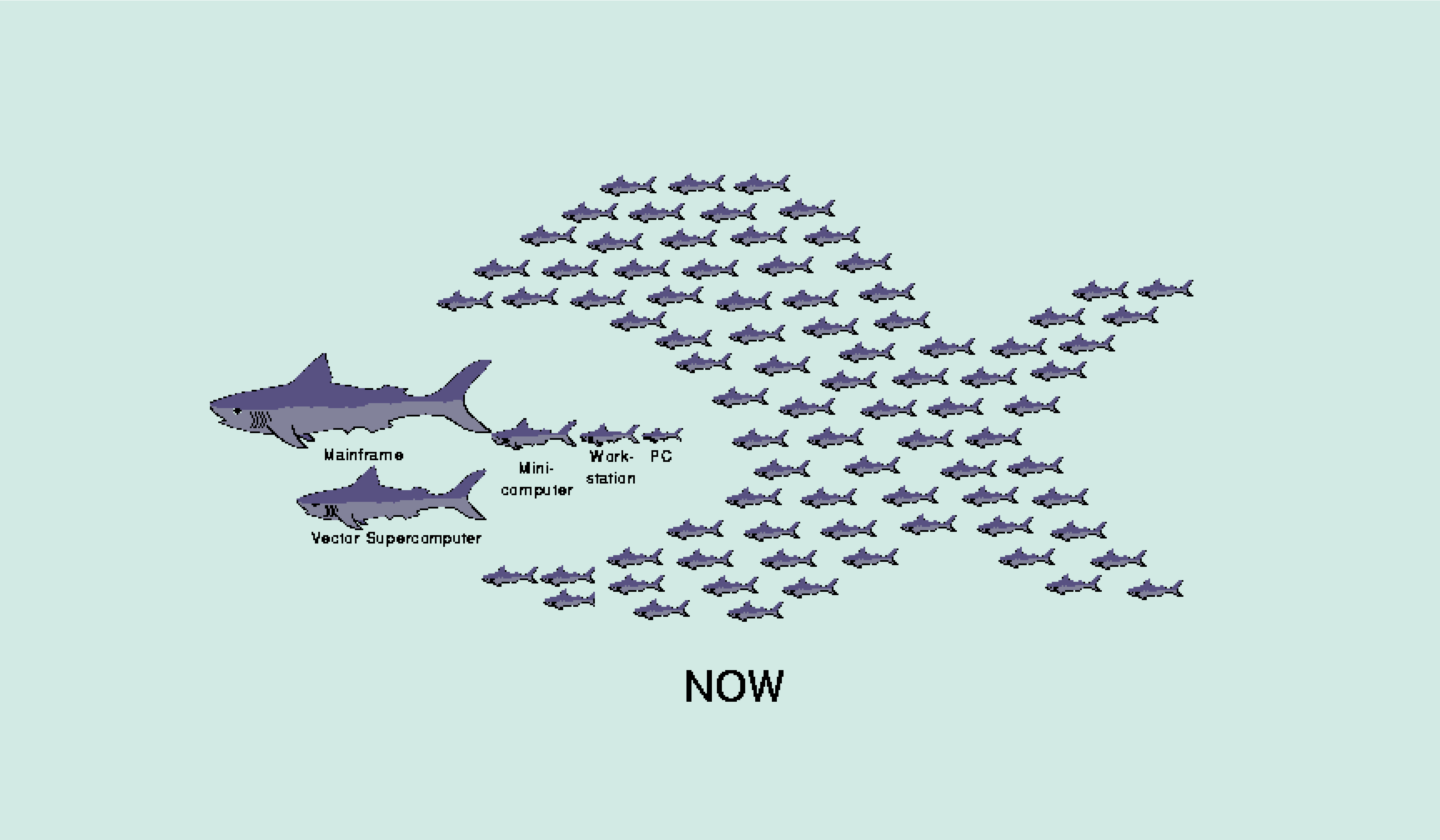
Trends？ - 1984计算机食物链



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 01

- 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？