



并行计算概述

于策

2011-03-02

<http://ics.tsinghua.edu.cn/orgs/hpclab/>



Outline

- 并行计算基本概念
 - 应用需求
 - 并行计算硬件
 - 并行程序设计
- 并行化方法
 - 域分解 (Domain decomposition)
 - 任务分解 (Task decomposition)
 - 流水线 (Pipelining)

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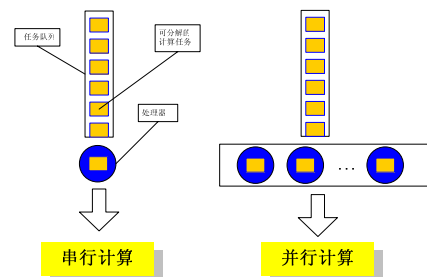
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并行计算



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为什么需要并行计算？

- 为满足不断增长的计算力需求
 - 用速度更快的硬件，也就是减少每一条指令所需时间
 - 优化算法（或者优化编译）
 - 用多个处理机(器)同时解决一个问题
 - 并行计算
- 计算机硬件及网络技术的发展
 - 集群的广泛应用
 - 多核处理器技术的驱动
 - 并行计算环境无处不在，应用程序必须能够支持并行执行才能够充分利用计算能力

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应用需求的推动

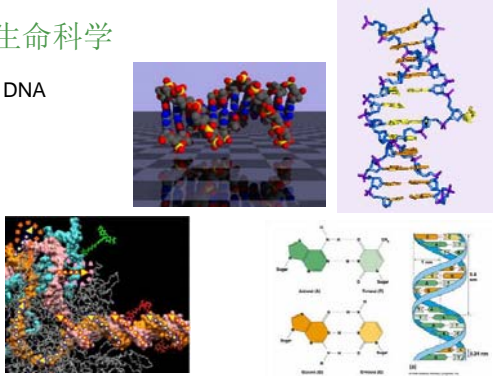
- 生命科学
- 天气预报/气候模拟
- 天文学/地球科学
- 计算金融
- CAD/CAM
- 航空航天
- 遥感
- 军事
- 信息检索
- 影视/游戏
- 计算流体力学
- 空气动力学模拟
- 数据加密/解密
- 土木工程
- 药物设计
-

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生命科学

- DNA

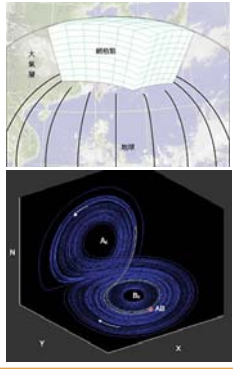


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天气预报

- 由连续方程、热力学方程、水汽方程、状态方程和3个运动方程(大气动力方程)共7个方程所构成的方程组。
- 网格点尺度决定预报精度
 - 精度提高一倍, 计算量提高16倍



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天文学

- 中国国家大科学工程
 - LAMOST
 - AST3
 - FAST



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LAMOST

- 同时观测4000个天体
- 3-5GB/天, 1-2TB/年

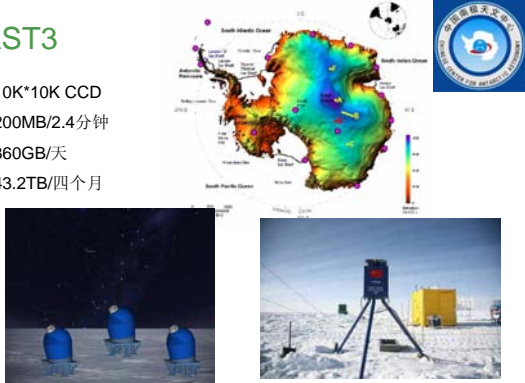


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AST3

- 10K*10K CCD
- 200MB/2.4分钟
- 360GB/天
- 43.2TB/四个月



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FAST

- 2007年立项（国家大科学工程）
- 建设周期5年半，投资6.72亿元。

图1 传统射电望远镜。

图2 FAST 总体方案。

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并行计算硬件发展

- 超级计算机
 - 天河一号（国家超级计算天津中心）
 - Top500排名
- 多核处理器
 - IBM、SUN、Intel、AMD。
- GPU/Cell BE
 - Nvidia、AMD（ATI）、IBM

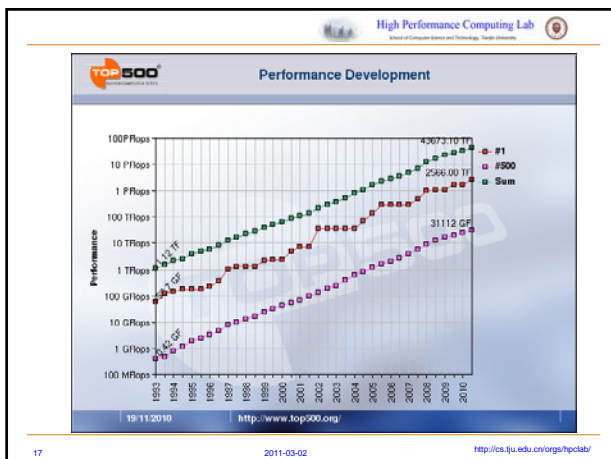
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Top500, 2010.11

Rank	Site	Computer
1	National Supercomputing Center in Tianjin, China	Tianhe-1A - 160 TF1.1 MPP, X8670 2.33GHz EC, NVIDIA GPU, PT-10000, NICOT
2	DOE/SC/Argonne National Laboratory, United States	Jaguar - Cray XT5-HE Opteron 6-core 2.6 GHz
3	National Supercomputing Centre in Shenzhen, China	Nasuter - Dawning TC3600 Blade, Intel X5550, NVIDIA Tesla, 2008 Planning
4	OSU Center, Tokyo Institute of Technology, Japan	TSUBAME 2.0 - HP ProLiant SL380s G7, Intel X5570, NVIDIA GPU, Linux/Windows
5	DOE/SC/LLNL/NERSC, United States	Hopper - Cray XE6 12-core 2.6 GHz
6	Commissariat à l'Energie Atomique (CEA), France	Tera-100 - Bull bull super-node 5801055030 Bull SA
7	DOE/NS/SLAC, United States	Redstorm - BladeCenter G223L21 Cluster, PowerCell B 3.2 G2 / Opteron DC 1.8 GHz, VMware Infrastructure
8	National Institute for Computational Sciences/University of Tennessee, United States	Kraken XT5 - Cray XT5-HE Opteron 6-core 2.6 GHz
9	Forschungszentrum Juelich (FZJ), Germany	JUQUENE - Blue Gene/P Solution
10	DOE/NS/SLAC, United States	Cielo - Cray XE6 8-core 2.4 GHz

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Top100 China, 2010									
排名	厂商	型号	实施地点	年份	应用领域	处理器	Linpack (Gflops)	峰值	效率
1	国防科大	天河一号A (2.16Peta) Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	国家超级计算天津中心	2010	科学计算	Intel Xeon X5670 2.93GHz	2347000.00	Q	4701000.00 0.533
2	曙光	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	曙光天津产业基地	2010	科学计算	Intel Xeon X5670 2.93GHz	120040	C	2984300.00 0.426
3	中科院过程所	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	中科院过程所天津中心	2010	科学计算	Intel Xeon X5670 2.93GHz	11120	Q	1118440.00 0.182
4	曙光	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	曙光天津产业基地	2010	科学计算	Intel Xeon X5670 2.93GHz	10720	C	211472.00 0.174
5	曙光	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	曙光天津产业基地	2010	科学计算	Intel Xeon X5670 2.93GHz	11740	C	141391.00 0.173
6	曙光	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	曙光天津产业基地	2010	科学计算	Intel Xeon X5670 2.93GHz	1720	C	141189.00 0.140
7	曙光	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	曙光天津产业基地	2010	科学计算	Intel Xeon X5670 2.93GHz	4160	C	310328.00 0.140
8	曙光	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	曙光天津产业基地	2010	科学计算	Intel Xeon X5670 2.93GHz	8060	C	90480.00 0.140
9	曙光	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	曙光天津产业基地	2010	科学计算	Intel Xeon X5670 2.93GHz	7840	C	79420.00 0.137
10	曙光	曙光星云 C2000-GPQ Intel Xeon X5670 2.93GHz + 7168 Nvidia Tesla M2050 2.15GHz + 1024 Intel Xeon Core E7-1000 2.13GHz + 2.13GHz + 2.13GHz	曙光天津产业基地	2010	科学计算	Intel Xeon X5670 2.93GHz	7140	C	72140.00 0.130

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制造商

	厂商	系统	份额	Rmax [TF/s]	Rpeak [TF/s]	平均效率 (%)	处理量
国产 机器	曙光		34.34%	2028.19	4218.89	61.07%	233436
	浪潮		5.5%	92.11	115.38	78.30%	10360
	联想		3.3%	126.69	182.27	50.83%	16128
	神州		3.3%	50.74	64.49	80.23%	6096
	宝德		2.2%	40.38	51.20	79.00%	4320
	国防科大		1.1%	2507.00	4701.00	53.30%	202752
	中科院过程所		1.1%	207.30	1138.44	18.20%	33120
国产小计			49.49%	5052.41	10471.67	60.13%	506212
引进 机器	IBM		28.28%	753.01	1328.21	58.13%	133008
	HP		19.19%	367.46	629.12	60.93%	65508
	Dell		3.3%	47.83	74.60	72.43%	6880
	SUN		1.1%	10.46	13.58	66.00%	1200
	引进小计		51.51%	1178.76	2045.51	64.37%	206588
总计			100.00%	6231.17	12513.58	63.09%	712800

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我国的超级计算机

- 天河一号
 - 国防科大
 - 国家超级计算天津中心（部署完成）
- 星云
 - 曙光
 - 国家超级计算深圳中心（部署中）

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天河一号

- 一期系统于2009年9月研制成功，峰值性能为每秒1206万亿次双精度浮点运算（TFlops），持续性能为563.1TFlops（LINPACK实测值），2009年11月TOP 500排名，位列亚洲第一、世界第五。
- 二期系统于2010年8月在国家超级计算天津中心升级完成，峰值性能提升为4700TFlops，持续性能提升为2507TFlops（LINPACK实测值），部分采用了自主研发的飞腾—1000中央处理器，2010年11月TOP 500排名世界第1。

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天河一号

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天河一号计算系统

- 计算处理系统：包含**7168**个计算结点和**1024**个服务结点。
 - 每个计算结点包含**2路Intel CPU**和**1路NVIDIA GPU**
 - 每个服务结点包含**2路飞腾CPU**。
- 全系统共计**23552**个微处理器，CPU核共计**102400**个，GPU核共计**100352**个。
 - Intel XEON X5670 CPU（2.93GHz、6核）**14336**个
 - 飞腾—1000 CPU（1.0GHz、8核）**2048**个
 - NVIDIA M2050 GPU（1.15GHz、14核/448个CUDA核）**7168**个

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天河：自主研发

- 芯片：飞腾—1000 CPU，高阶路由芯片NRC，高速网络接口芯片NIC
- 结点：计算、服务、I/O管理、I/O存储
- 网络：互联通信网、维护诊断网
- PCB板：15种



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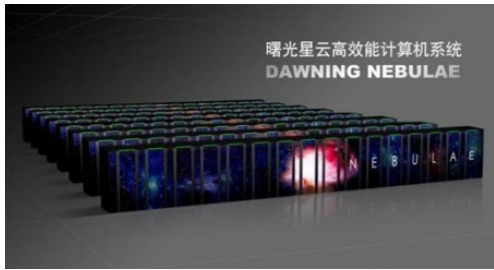
技术亮点：基于高阶路由的高速互连通信

- 突破了片上高阶网络体系结构技术
- 自主设计了高效通信协议、高阶瓦片式（Tile）片上交换网络和高密度片间互连网络
- 链路双向通信带宽达到160Gbps、单背板交换密度达到61.44Tbps，
- 分别为当前国际主流商用互连IB QDR的2倍和2.37倍。

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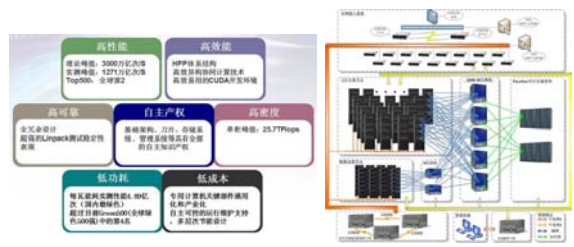
星云



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星云

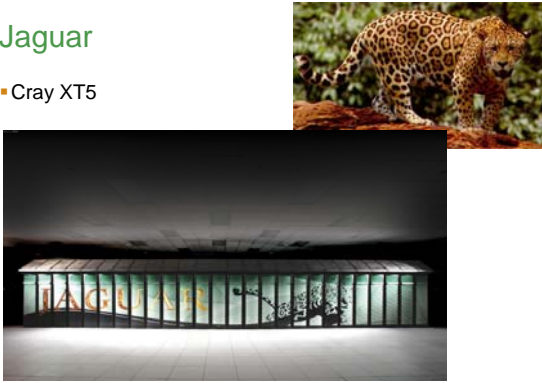


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Jaguar

- Cray XT5



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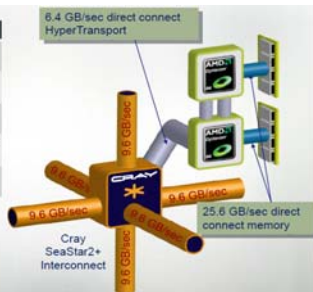
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- XT5, XT6
 - 采用AMD处理器、Linux操作系统
 - 采用Cray SeaStar2+专有连接设备组成的3维环网结构
 - 面向**高端市场**：大规模、超大规模并行处理（6000至240000处理器核）的领域如气象、天文等
- XT5m, XT6m
 - 采用AMD处理器、Linux操作系统
 - 采用Cray SeaStar2+专有连接设备组成的2维环网结构
 - 面向**中端市场**：中等规模、大规模并行处理（600至6000处理器核）的领域如气象、天文等

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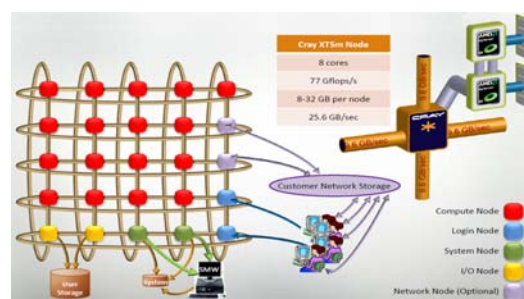
Cray SeaStar

Characteristics	
Number of Cores	8 or 12
Peak Performance Shanghai (2.7)	86 Gflops/sec
Peak Performance Istanbul (2.6)	124 Gflops/sec
Memory Size	8-32 GB per node
Memory Bandwidth	25.6 GB/sec



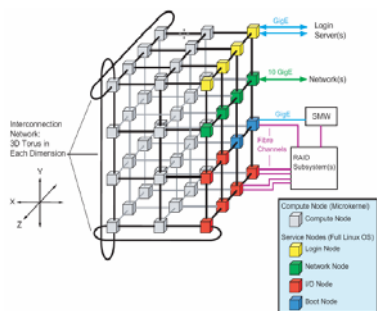
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Cray XT5m



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CrayXT5



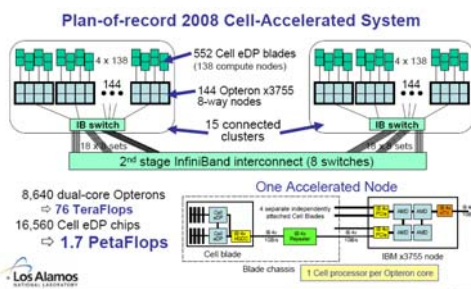
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Roadrunner



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Roadrunner体系结构



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超级计算机面临的主要问题

- 应用与研发
 - 并行程序编制、调试过于复杂
 - 同步
 - 数据交换
 - GPU加速模式
 -
 - 工具及集成开发环境的支持不足
 - 商业软件价格昂贵
- 能源消耗

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并行程序设计

Applications

1. What are the applications?
2. What are common kernels of the applications?

Hardware

3. What are the hardware building blocks?
4. How to connect them?

Programming Models

5. How to describe applications and kernels?
6. How to program the hardware?

Evaluation:

7. How to measure success?

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.)

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域分解

- 首先，确定数据如何划分到各个处理器
- 然后，确定每个处理器所需要做的事情
- 示例：求数组中的最大值

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域分解

查找数组中的最大值


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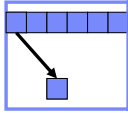
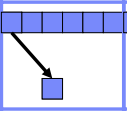
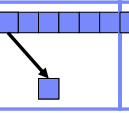
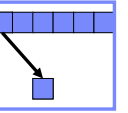
域分解

查找数组中的最大值

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<http://ics.sjtu.edu.cn/orgs/hpctab/>

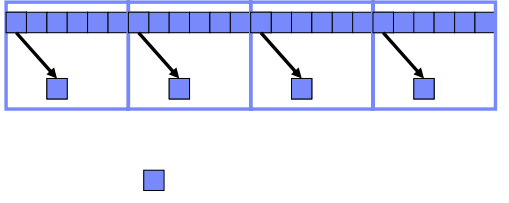


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查找数组中的最大值



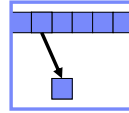
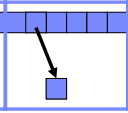
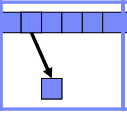
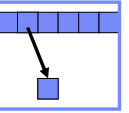
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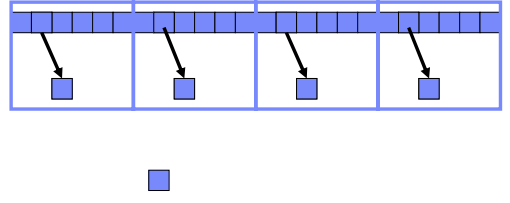


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查找数组中的最大值



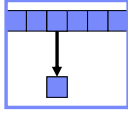
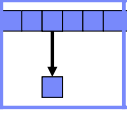
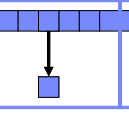
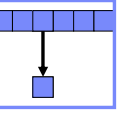
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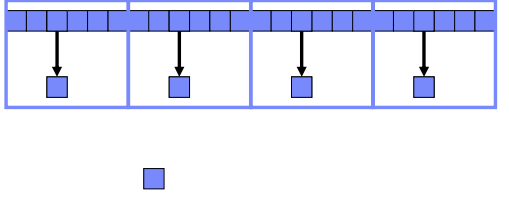


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查找数组中的最大值



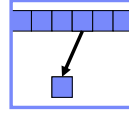
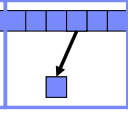
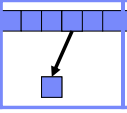
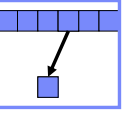
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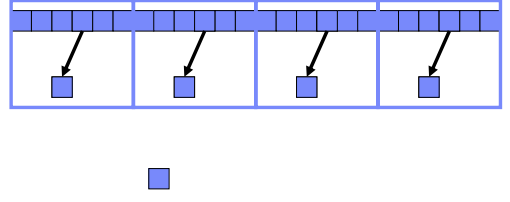


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域分解


查找数组中的最大值



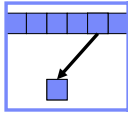
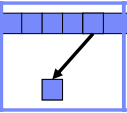
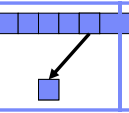
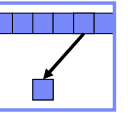
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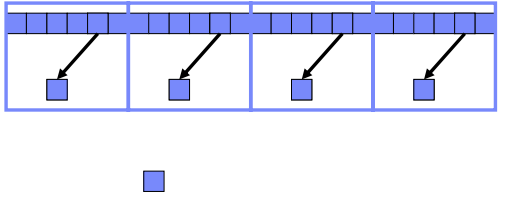


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查找数组中的最大值



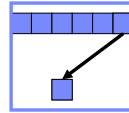
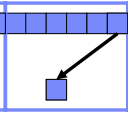
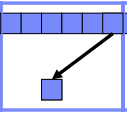
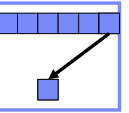
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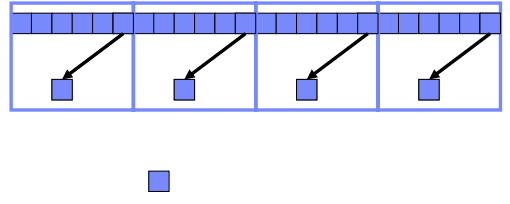


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域分解

查找数组中的最大值



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域分解

查找数组中的最大值

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域分解

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Outline

- 并行计算基本概念
 - 应用需求
 - 并行计算硬件
 - 并行程序设计
- 并行化方法
 - 域分解 (Domain decomposition)
 - 任务分解 (Task decomposition)**
 - 流水线 (Pipelining)

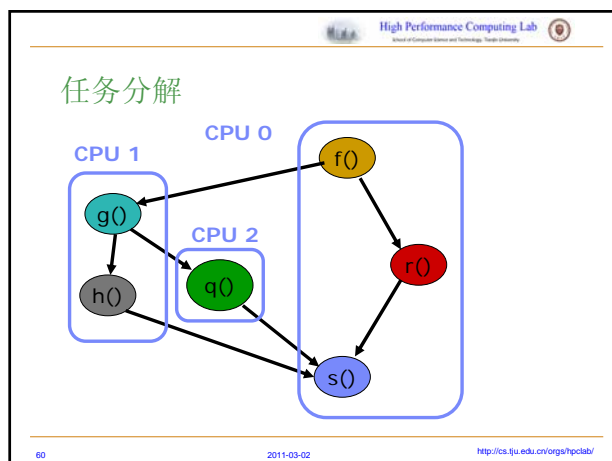
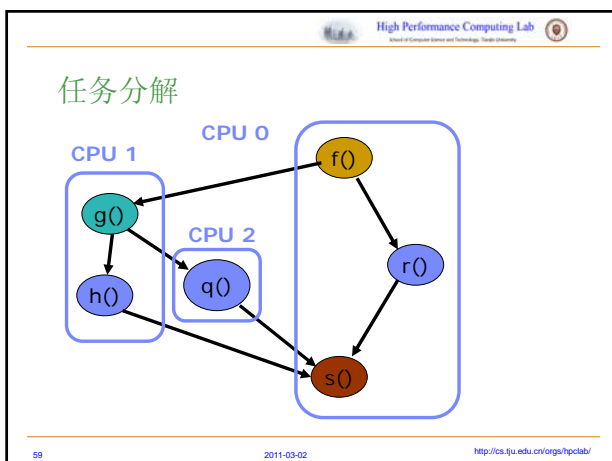
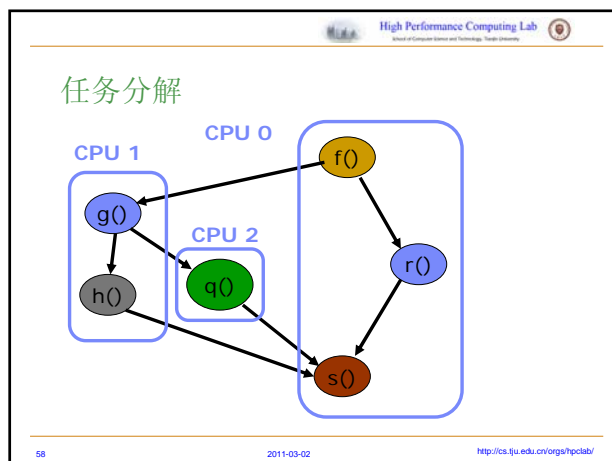
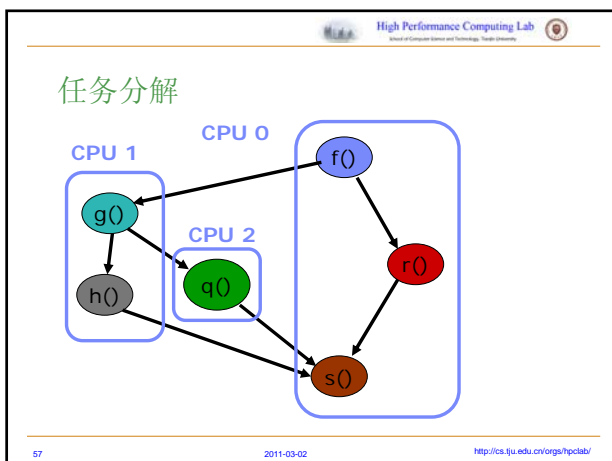
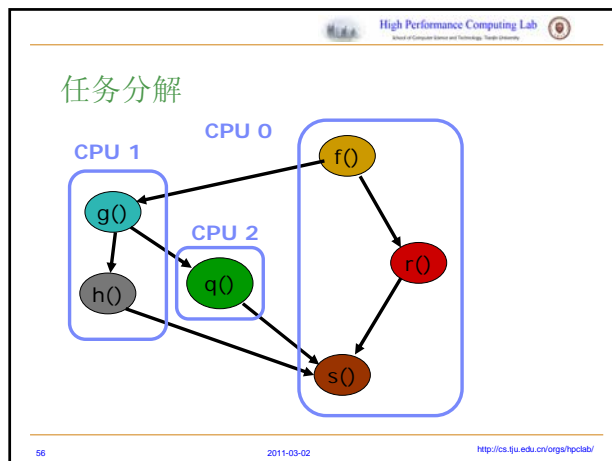
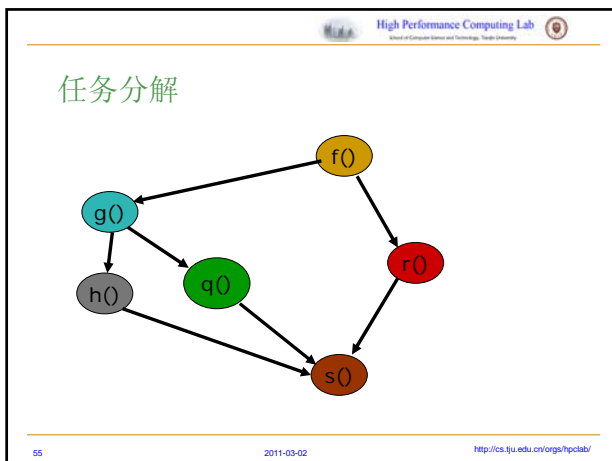
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任务 (功能) 分解

- 首先, 将任务划分到各个处理器
- 然后, 确定各个处理器需要处理的数据
- Example: Event-handler for GUI

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Outline

- 并行计算基本概念

- 应用需求
- 并行计算硬件
- 并行程序设计

- 并行化方法

- 域分解 (Domain decomposition)
- 任务分解 (Task decomposition)
- 流水线 (Pipelining)

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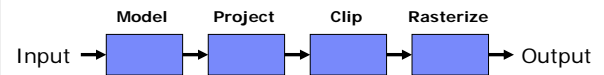
<http://ics.fju.edu.cn/orgs/hpctlab/>

流水线

- 一类特殊的任务分解方式

- “Assembly line” parallelism

- Example: 3D rendering in computer graphics

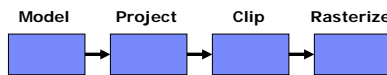


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Processing One Data Set (Step 1)

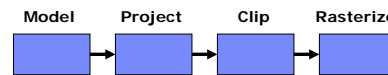


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Processing One Data Set (Step 2)

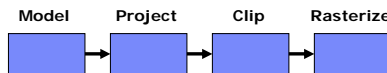


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Processing One Data Set (Step 3)

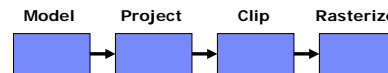


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Processing One Data Set (Step 4)

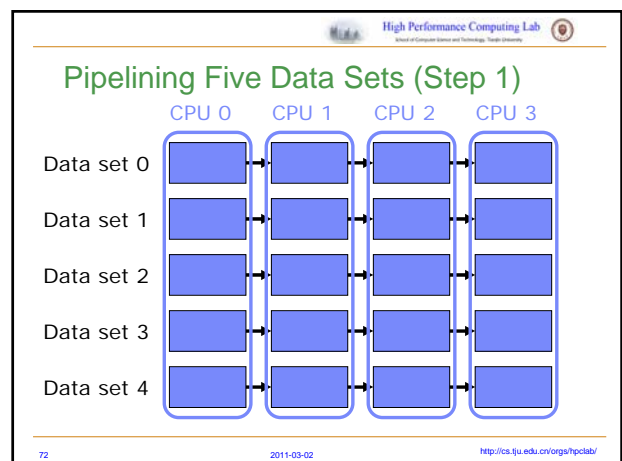
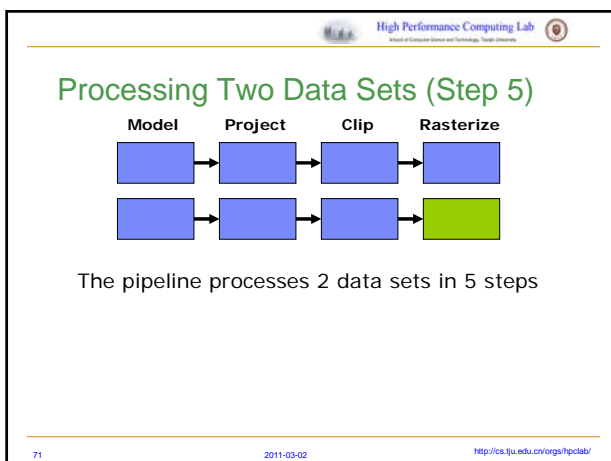
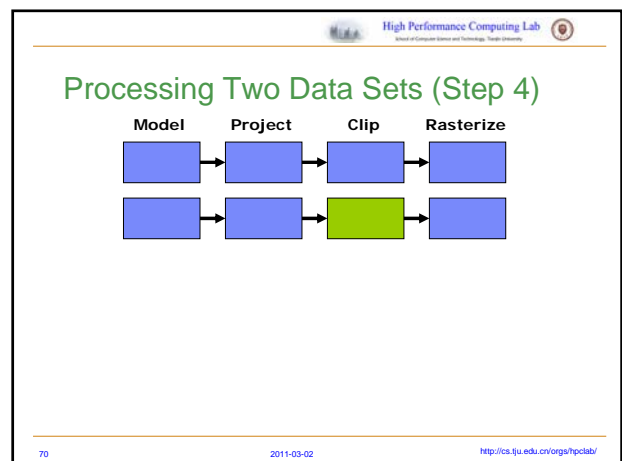
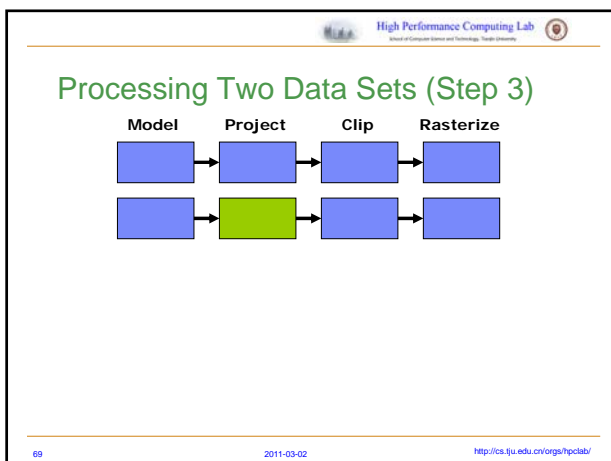
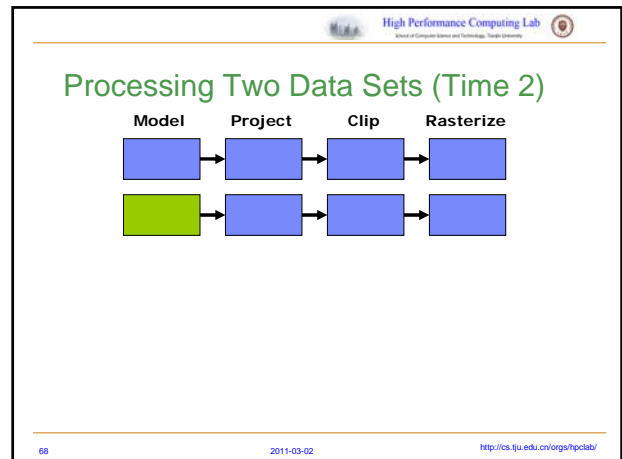
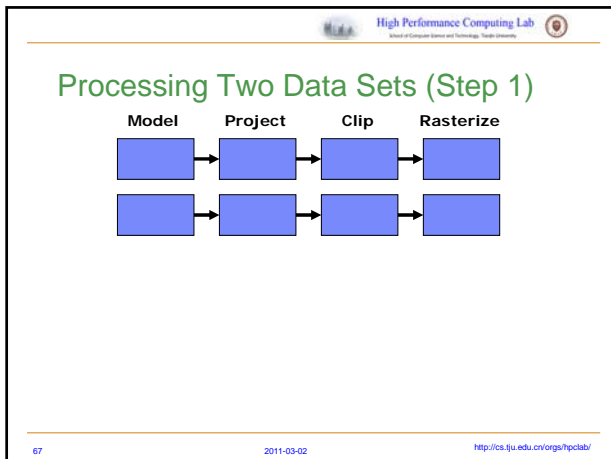


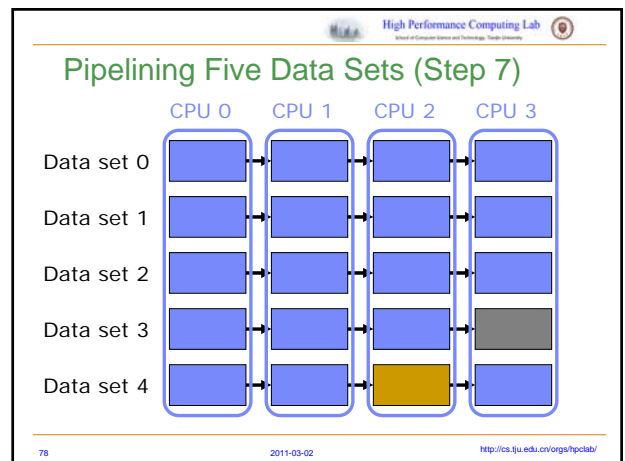
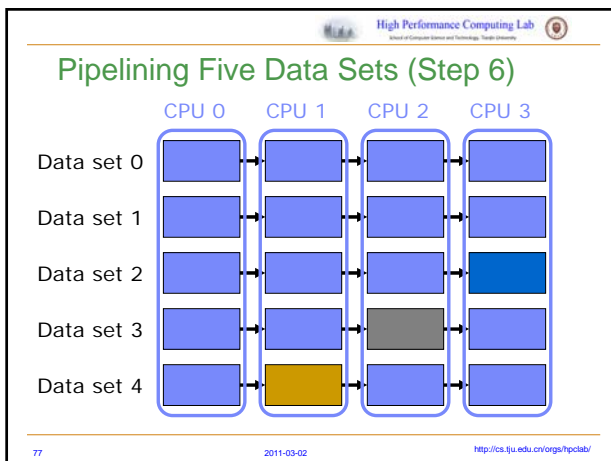
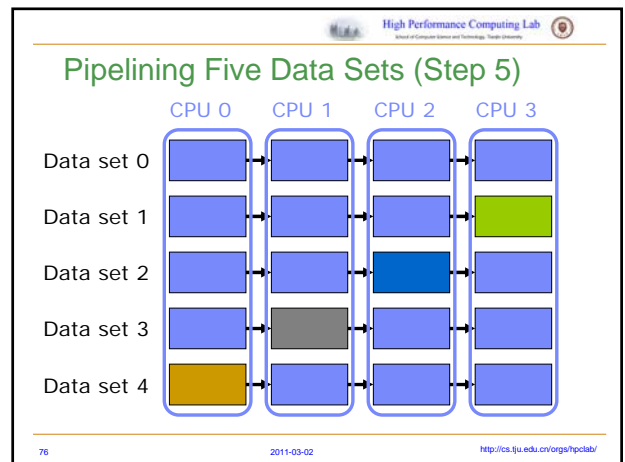
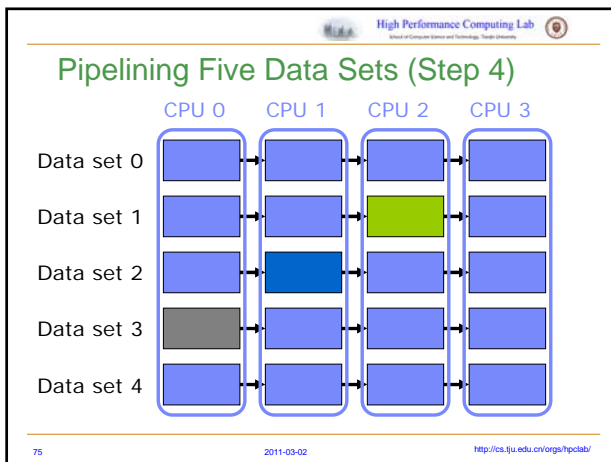
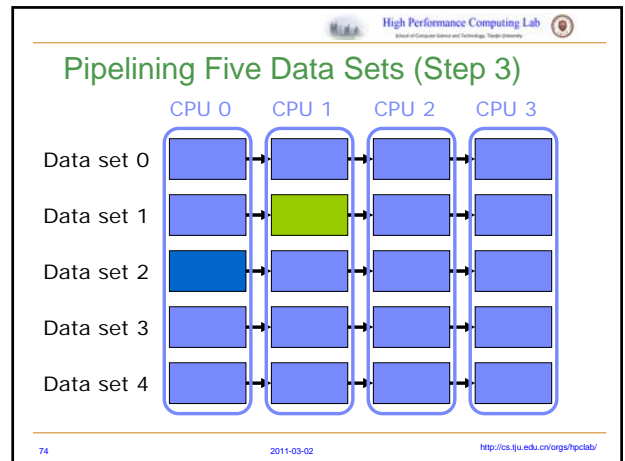
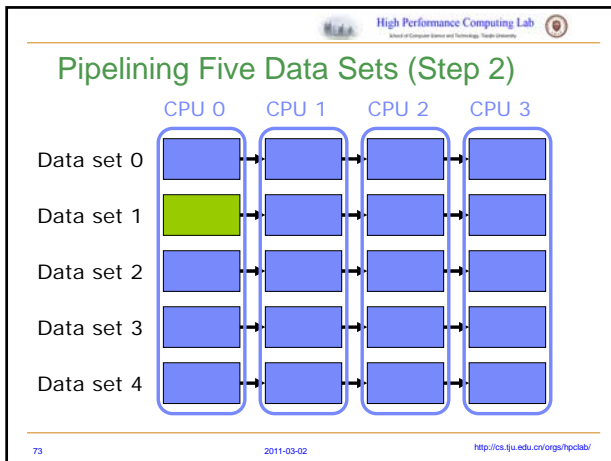
The pipeline processes 1 data set in 4 steps

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Pipelining Five Data Sets (Step 8)

