## 计算机系统结构

# Computer Systems and Architecture 

李峰<br>fli＠sdu．edu．cn<br>https：／／funglee．github．io

## Short Bio

－Feng Li（李峰）
－Education
－ 2010 －2015，Ph．D．，Nanyang Technological University，Singapore．
－ 2007 －2010，M．S．，Shandong University，China．
－ 2003 －2007，B．S．，Shandong Normal University，China．
－Employment
－Sep 2015 －Present，Associate Professor，Shandong University，China
－Nov 2015 －Aug 2018，Assistant Professor，Shandong University，China．
－Dec 2014 －Nov 2015，Research Fellow，National University of Singapore，Singapore
－Research Interests

- Distributed Algorithms and Systems（分布式算法及系统）
- Wireless Networking（无线网络）
- Mobile Sensing and Computing（移动感知及计算）
- Internet of Things（物联网）


## 课程介绍

## 1．课程名称

－Computer Architecture

- 计算机系统结构，计算机体系结构
- 建筑物的设计或式样，通常指一个系统的外貌

2．研究内容

- 从外部来研究计算机系统
- 使用者所看到的物理计算机的抽象
- 编写出能够在机器上正确运行的程序所必须了解到的计算机属性

3．学习目的

- 建立计算机系统的完整概念
- 学习计算机系统的分析方法和设计方法
- 了解计算机系统的最新研究成果

4．课程安排

- 课内：48学时；实验：16学时
- 成绩 $=$ 考试成绩 $* 80 \%+$ 平时成绩（包括实验及作业）$* 20 \%$

5．参考书：
1）David A．Patterson and John L．Hennessy，Computer Architecture：A Quantitative Approach

2）David A．Patterson and John L．Hennessy，Computer Organization and Design：The Hardware／Software Interface

3）郑纬民，汤志忠，计算机系统结构
6．课程网站：https：／／funglee．github．io／csa／csa．html

## 7．课程大纲

- 基本概念（Basic Concepts）
- 指令系统（Instruction Systems）
- 存储体系（Memory Architecture）
- I／O系统（I／O Systems）
- 标量处理机（Scalar Processors）
- 向量处理机（Vector Supercomputer）
- 多处理机系统（Multiprocessor Systems）


## 8．相关课程



## 计算机体系结构是什么？



## 摩尔定律（Moore＇s law）

－The number of transistors in a dense integrated circuit doubles approximately every two years（by Gordon E．Moore，1975）
－The capabilities of many digital electronic devices are strongly related to Moore＇s law：processing speed，memory capacity， sensors and even the number and size of pixels in digital cameras

## Microprocessor Transistor Counts 1971-2011 \& Moore's Law



## 1950s: Early Designs

- CPUs were customized and used as part of a larger computer
- Uniqueness
- Poor compatibility



## 1960s: The Computer Evolution and CISC

- Price and Performance is the main concern
- A family of computers which can run the same software but with different performance
- CISC (Complex Instruction Set Computing) is a processor design where single instructions can execute several lowlevel operations or are capable of multi-step operations or addressing modes within single instructions
- Examples: PDP-11, Motorola 68000


## 1970s: Large-Scale Integration

- Intel 4004 in 1970
- 740 kHz, 4-bit BCD-oriented, 10um, 2300 transistors
- Intel 8008 in 1972
- 0.2-0.8 MHz, 8-bit, 10um, 3500 transistors
- MOS Technology 6502 in 1975
- 1-2 MHz, 8-bit,
- VAX-11/780 in 1977
- $5 \mathrm{MHz}, 32$-bit,
- Intel 8086 and Intel 8088 in 1978 (the first x86 chips)
- 5 -10MHz, 16-bit, 3um, >20000 transistors


## Early 1980s: the lesson of RISC

- However, only a small set of these complex instructions were used frequently by most computer language compilers and interpreters.
- There, RISC (Reduced Instruction Set Computing) was emerged in the early 1980s, where a simplified instruction set is adopted.
- Examples: DEC Alpha, AMD Am29000, ARC, ARM, Atmel AVR, Intel i860 and i960, MIPS, Motorola 88000, Power,


## Mid-to-late 1980s: Exploiting Instruction Level Parallelism

- Instruction pipelining is a technique that implements a form of parallelism called instruction-level parallelism within a single processor. It results in much faster CPU throughput
- Unfortunately, this architecture increases hardware complexity, resulting in higher cost, larger circuits, higher power consumption.
- Examples: Intel 80386, 80486


The exposed die of an Intel 80486DX2 microprocessor
Produced From 1989 to 2007
Common Intel, IBM, AMD, Texas
manufacturer(s) Instruments, Harris
Semiconductor, UMC, SGS
Thomson
Max. CPU clock 16 MHz to 150 MHz rate
FSB speeds $\quad 16 \mathrm{MHz}$ to 50 MHz Min. feature $\quad 1 \mu \mathrm{~m}$ to $0.6 \mu \mathrm{~m}$ size

## 1990 to today

- VLIM (Very Long Instruction Word)
- Scheduling instructions is performed by compilers and programs rather than hardware.
- Complicated compiler but simpler hardware
- EPIC (Explicitly Parallel Instruction Computing)
- Highly improve VLIM by increasing instruction throughput
- Indicate the dependency between the "bundles" of instructions
- Multi-threading
- Multi-core
- Open source processors
- Asynchronous CPUs (clockless CPU)
- Optical processors


## Ivy Bridge

- It is the codename for a line of processors based on the 22 nm manufacturing process developed by Intel in 2011
- Examples: 15-core Xeon Ivey Bridge-EX, 4-core Core i7 Ivy

- Around 4,310,000,000 transistors
- 22 nm Tri-gate transistor

History of Computing and Computers


## The First Electronic General-Purpose Computer

ENIAC (Electronic Numerical Integrator and Computer)

- Designed and built by Eckert and Mauchly at the University of Pennsylvania during 1943-45.
- It was Turing-complete, digital, and could solve "a large class of numerical problems" through reprogramming.
- 30 tons, 72 square meters, 200KW
- Read in 120 cards per minute
- Addition took 20us, division 6 ms

- 1000 times faster than electromechanical machines
- Applications: ballistic calculations


## Von Neumann Architecture

- Proposed by John von Neumann in 1945



## The First Commercial Computer

- UNIVAC I (UNIVersal Automatic Computer I) designed by J. Presper Eckert and John Mauchly in 1951
- 5200 vacuum tubes
- 29000 pounds (13 tons)
- 125W
- 1905 operations per second
- 2.25 MHz clock
- $4.3 m \times 2.4 m \times 2.6 m$



## More

- More computer firsts:
- 1947 : The invention of the transistor;
- 1958 : The invention of the integrated circuit;
- 1971 : A young company called Intel produced the very first microprocessor:
- Intel 4004 and contained around 2300 transistors on a single chip;
- Chip technology is now so advanced that we are close to having one billion transistors on a single chip.
- 1981 : The first Personal Computer.
- Now:
- Desktop, laptop, supercomputer, smart phones, smart watches, smart glass,
- ... ...


## The TOP500 project ranks and details the 5000 most powerful (non-distributed) computer systems in the world.

| Rank . | Rmax Rpeak . (PFLOPS) | Name - | Computer design <br> Processor type, interconnect | Vendor - | Site <br> Country, year | Operating system * |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $\begin{aligned} & 33.863 \\ & 54.902 \end{aligned}$ | Tianhe-2 | NUDT <br> Xeon E5-2692 + Xeon Phi 31S1P, TH Express-2 | NUDT | National Supercomputing Center in Guangzhou China, 2013 | Linux (Kylin) |
| 2 | $\begin{aligned} & 17.590 \\ & 27.113 \end{aligned}$ | Titan | Cray XK7 <br> Opteron 6274 + Tesla K20X, Cray Gemini Interconnect | Cray Inc. | $\begin{aligned} & \text { Oak Ridge National Laboratory } \\ & \text { United States, } 2012 \end{aligned}$ | Linux (CLE, SLES based) |
| 3 | $\begin{aligned} & 17.173 \\ & 20.133 \end{aligned}$ | Sequoia | Blue Gene/Q <br> PowerPC A2, Custom | IBM | Lawrence Livermore National Laboratory United States, 2013 | Linux (RHEL and CNK) |
| 4 | $\begin{aligned} & 10.510 \\ & 11.280 \end{aligned}$ | $K$ <br> computer | RIKEN <br> SPARC64 VIIIfx, Tofu | Fujitsu | RIKEN <br> - Japan, 2011 | Linux |
| 5 | $\begin{gathered} 8.586 \\ 10.066 \end{gathered}$ | Mira | Blue Gene/Q <br> PowerPC A2, Custom | IBM | Argonne National Laboratory <br> United States, 2013 | Linux (RHEL and CNK) |
| 6 | $\begin{gathered} 8.101 \\ 11.079 \end{gathered}$ | Trinity | Cray XC40 <br> Xeon E5-2698v3, Cray Aries Interconnect | Cray Inc. | DOE/NNSA/LANL/SNL $\text { 프 United States, } 2015$ | Linux (CLE) |
| 7 | $\begin{aligned} & 6.271 \\ & 7.779 \end{aligned}$ | Piz Daint | Cray XC30 <br> Xeon E5-2670 + Tesla K20X, Aries | Cray Inc. | Swiss National Supercomputing Centre Switzerland, 2013 | Linux (CLE) |
| 8 | $\begin{aligned} & 5.640 \\ & 7.404 \end{aligned}$ | Hazel Hen | Cray XC40 <br> Xeon E5-2680v3, Cray Aries Interconnect | Cray Inc. | HLRS - Höchstleistungsrechenzentrum, <br> Stuttgart <br> Germany, 2015 | Linux (CLE) |
| 9 | $\begin{aligned} & 5.537 \\ & 7.235 \end{aligned}$ | Shaheen <br> II | Cray XC40 <br> Xeon E5-2698v3, Aries | Cray Inc. | King Abdullah University of Science and Technology <br> Saudi Arabia, 2015 | Linux (CLE) |
| 10 | $\begin{aligned} & 5.168 \\ & 8.520 \end{aligned}$ | Stampede | PowerEdge C8220 <br> Xeon E5-2680 + Xeon Phi, Infiniband | Dell | Texas Advanced Computing Center E United States, 2013 | Linux (CentOS) ${ }^{[13]}$ |

FLOPS (Floating-point operations per second), PFLOPS $=10^{15}$ FLOPS

## Tianhe-2

- 16000 computer nodes, each comprising two Intel Ivy Bridge Xeon processors and three Xeon Phi coprocessor chips.
- Each node is equipped with memory of 88 GiB
- HD array 12.4 PiB
- Price: 3.9 million US\$
- Applications: scientific computing



## Cloud Computing

- Everyone is talking about Cloud Computing, but what is it?
- Computing service is managed, scheduled, and delivered to users over Internet.
- For example
- Google Drive
- One Drive
- Hotmail
- Gmail



## Characteristics

- On demand self-service
- Access to networks anywhere, anytime, on any devices
- Location independent resource pooling
- Deployment flexibility
- Pay as you go



## Infrastructures for Cloud Computing

- Development of computing capability
- Virtualization technology
- Distributed Storage
- Fast internet access



## Services of Cloud Computing

- SaaS: Software as a Service
- Gmail, Hotmail, Flickr, OfficeLive
- PaaS: Platform as a Service
- Amazon EC2, Microsoft Azure
- laaS: Infrastructure as a Service
- AT\&T Hosting and Storage
- Amazon EC2


## Internet of Things (IoT)

- Smart + X
- Smart City
- Smart Traffic
- Smart Building
- Smart ...
- Wireless Sensor Networks

- Sensor Motes
- Mobile Phones
- RFID Systems


## IoT Systems include...

- Sensors
- We look at the world through sensors, e.g., light sensors, cameras, microphones, motion sensors, accelerators, gyroscopes, magnetic sensors, barometers, GPS.
- Networks and communications
- The sensed data are transmitted, stored and processed in a networked fashion, e.g., WAN, MAN, LAN, PAN.
- Various communication techniques are combined in the systems, e.g., 3G, 4G, Bluetooth, WiFi, ZigBee, RFID.
- Applications, people and processes
- All the data are fed back to applications, people and processes for further process and analysis, and finally are sued to make better decision, e.g., remote monitoring, mobile apps, security, supply chain management, locating and tracking, control and automation.


## Libelium Smart World



Thanks!

