Chapter 1-1

Fundamentals of Quantitative Design and Analysis

Topics in Chapter 1

1.1 Introduction
1.2 Classes of computers
1.3 Defining computer architecture and What's the task of computer design?
1.4 Trends in Technology
1.5 Trends in power in Integrated circuits
1.6 Trends in Cost
1.7 Dependability
1.8 Measuring, Reporting and summerizing Perf.
1.9 Quantitative Principles of computer Design
1.10 Putting it altogether

- What's CA?
- What's a CA designer's task ?

What's Computer Architecture

- Patterson's talk : "50 years of Computer Architecture"
  - https://www.bilibili.com/video/av46710093/

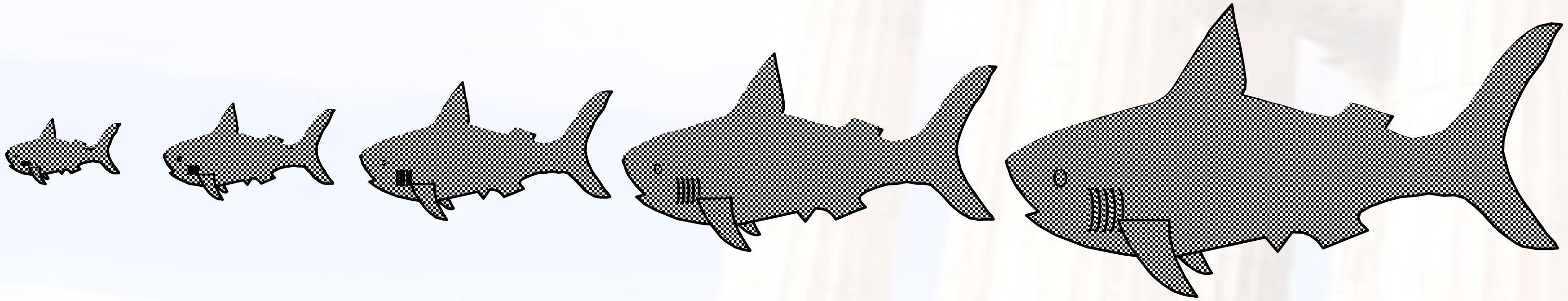
- The future of computing- a conversation with John Hennessy
  - https://www.bilibili.com/video/av23283946/

- **Technology**
  - A key factor in the long run of CPU performance improvement.

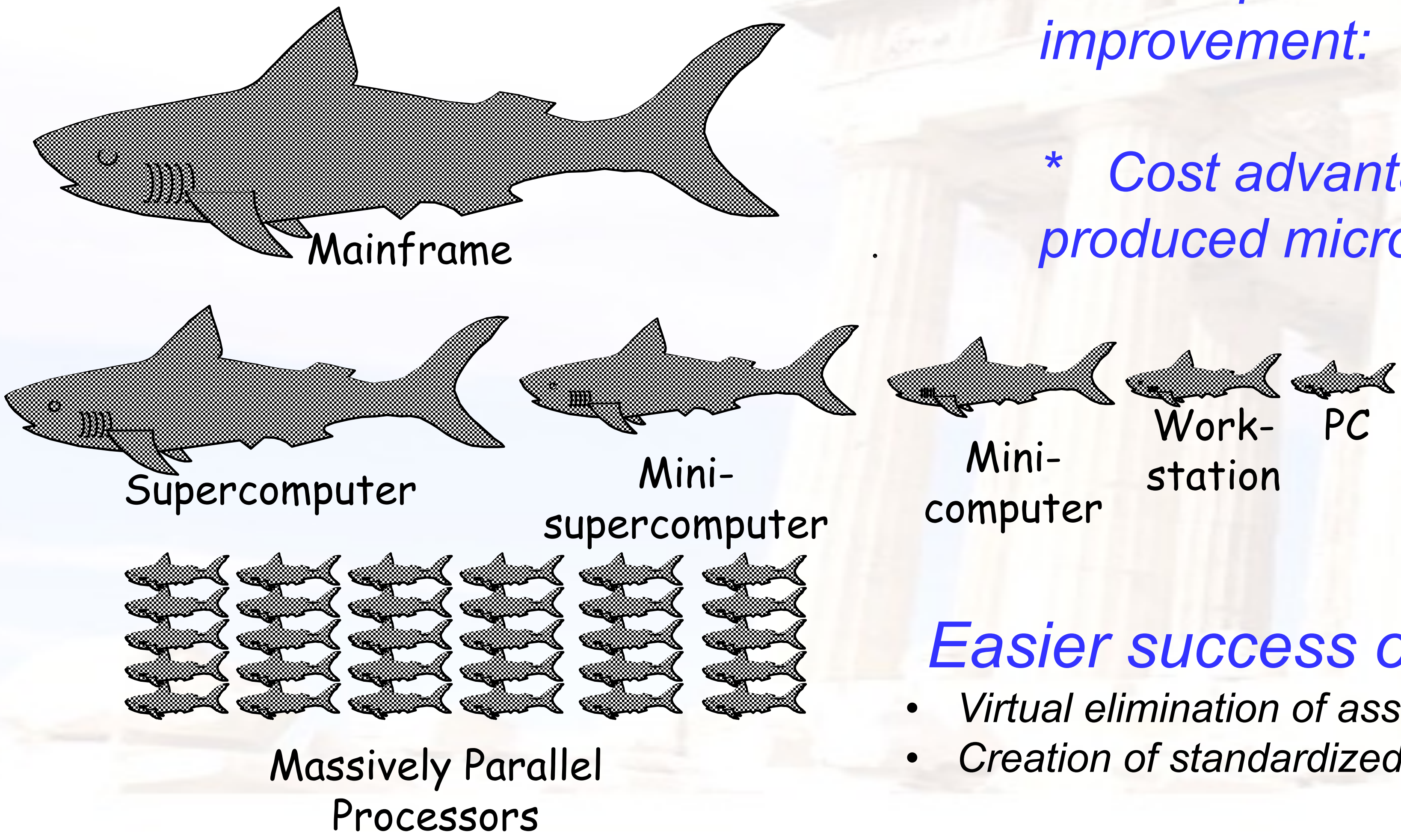
Evolution of computer market

- Original:

  Big Fishes Eating Little Fishes



Evolution of computer market



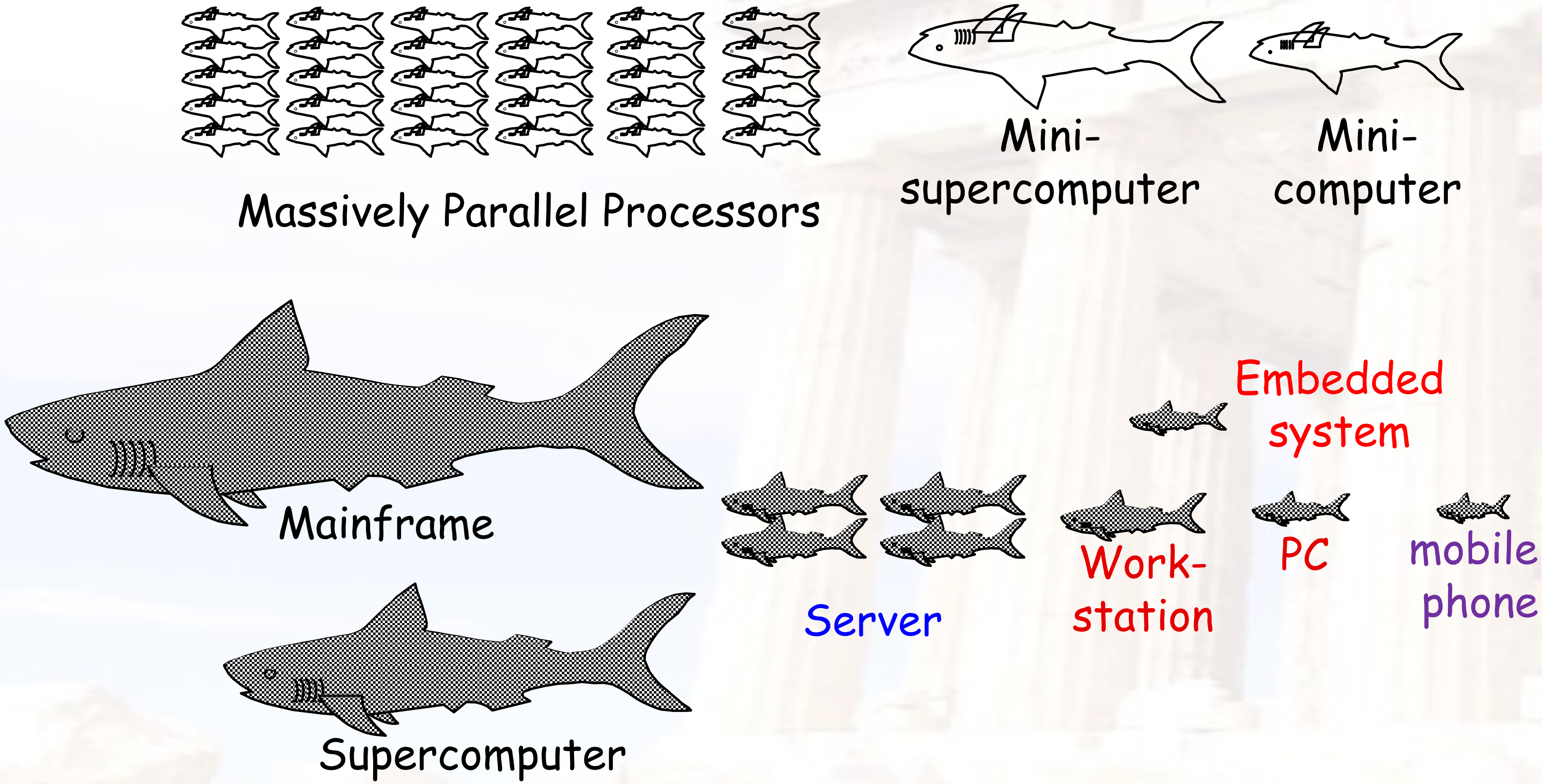
**   Microprocessor performance improvement: 35% yearly*

**   Cost advantages of a mass-produced microprocessor*

Easier success of new architecture:

- *Virtual elimination of assembly language programming*
- *Creation of standardized vendor-independent OS*

Evolution of computer market

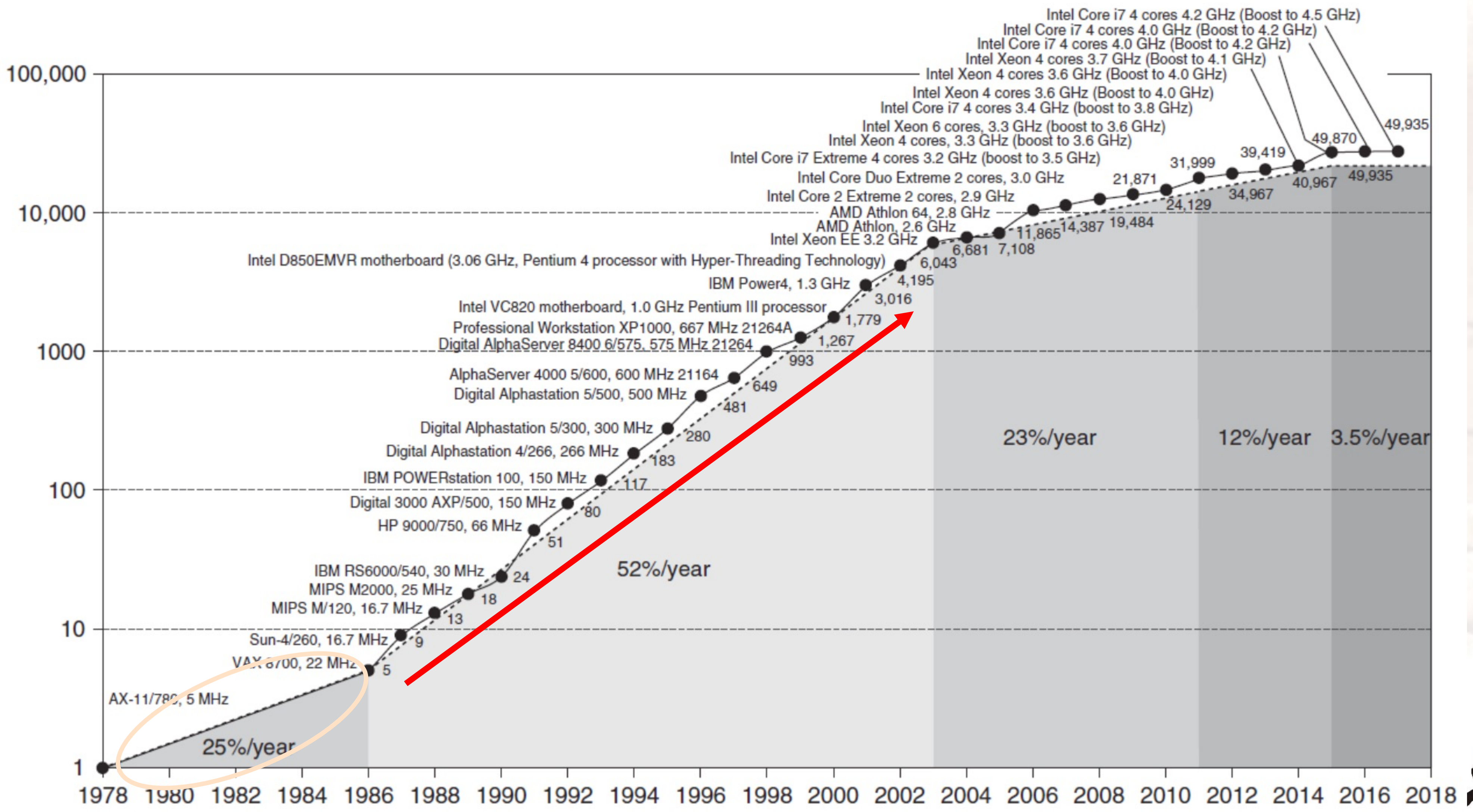


RISC-based computers raised performance bar: RISC replace CISC

In low-end application, power performance: ARM replace x86

Incredible CPU performance improvement

VAX : 25%/year 1978 to 1986； RISC+x86: 52%/year 1986 to 2002； RISC+x86: 22%/year after 2002



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What the figure tell us ?

- Performance improvements:

  25%: Technological improvements steadier than progress in computer architecture.

  - Feature size, clock speed

- 52%: After RISC emergence, computer design emphasized both architectural innovation and efficient use of technology improvements.
  - Computer Architecture plays an important role in performance improvement
  - **Pipeline, dynamic scheduling, ooo, branch prediction, speculation, superscalar（超标量）, VLIW, prediction instructions, ……**

Effect of dramatic growth rate during 20th centrury

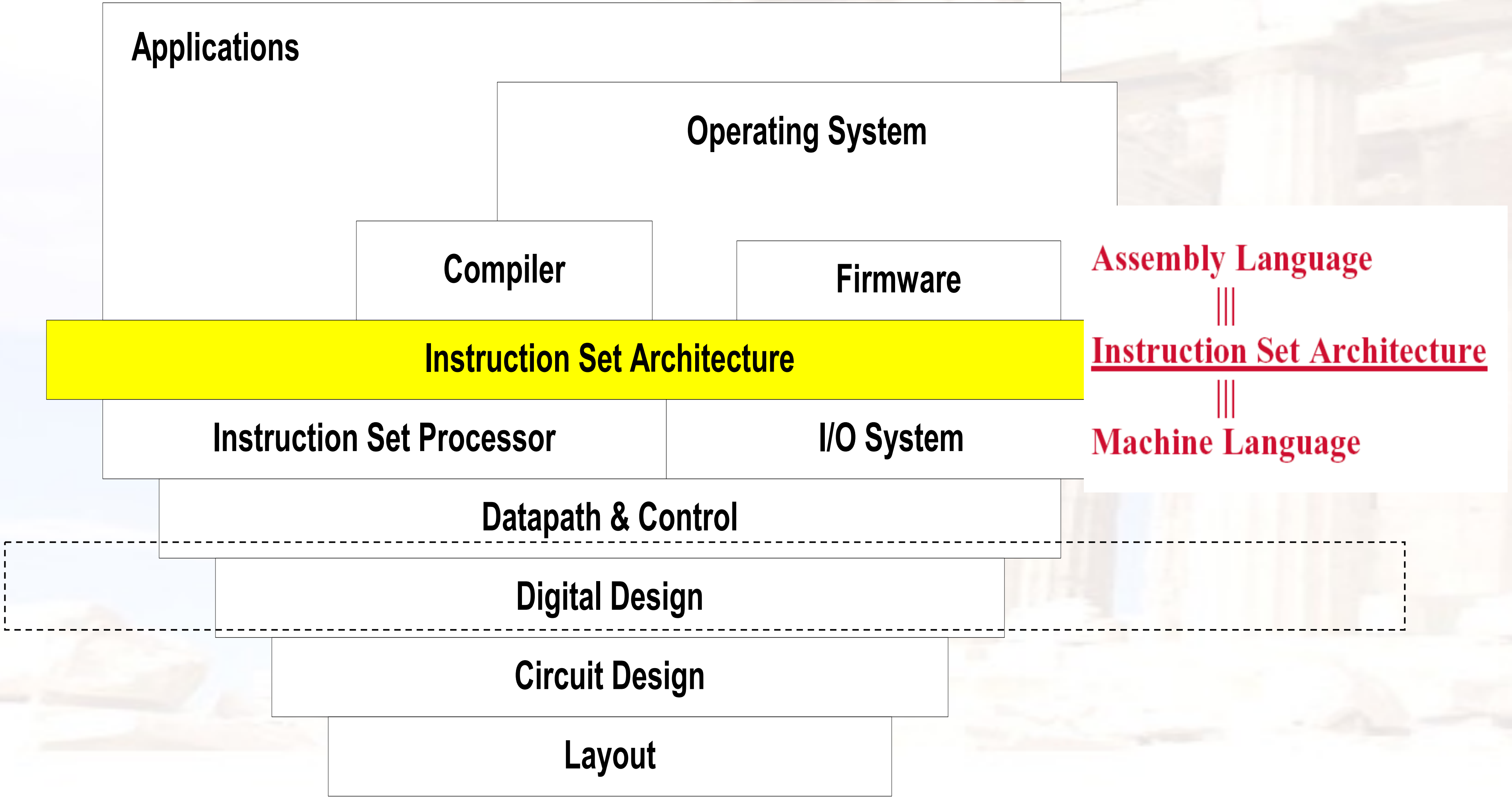
- Technology Advances
  - CMOS VLSI dominates older technologies (TTL, ECL) in cost AND performance
- Computer architecture advances
  - RISC, superscalar, OOO, Speculation, VLIW, RAID, …
- Enhanced the capability of computer users:
  - perfmicroprocessor > supercomputer 20 years ago
- New class of computer
  - PC, workstation→mobile phone, laptops access warehouse containing millions of servers
- Donimance of microprocessor-based computers across the computer design
  - Minicomputer→ server , mainframe, supercomputer → collections of microprocessor
- Change software
  - Trade performance for productivity c, c++ → java, scala, JavaScript, Python
  - Change nature of applications: scientific calculation→ speech, image, video

What's Computer Architecture

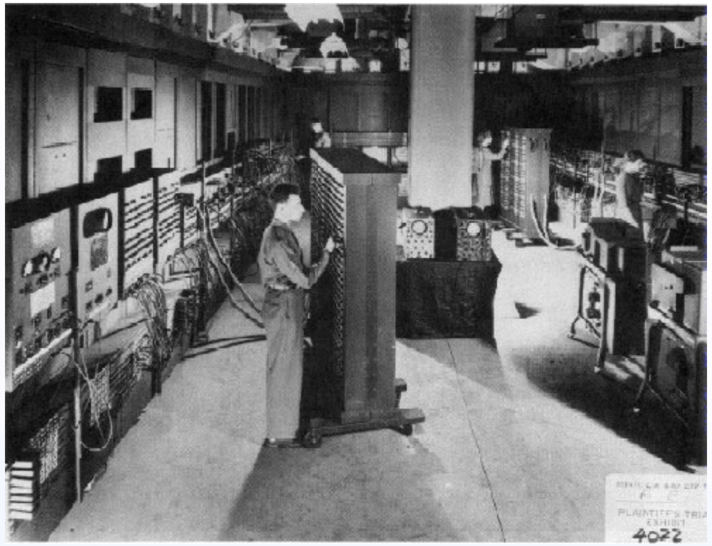
❑Concept Evolution

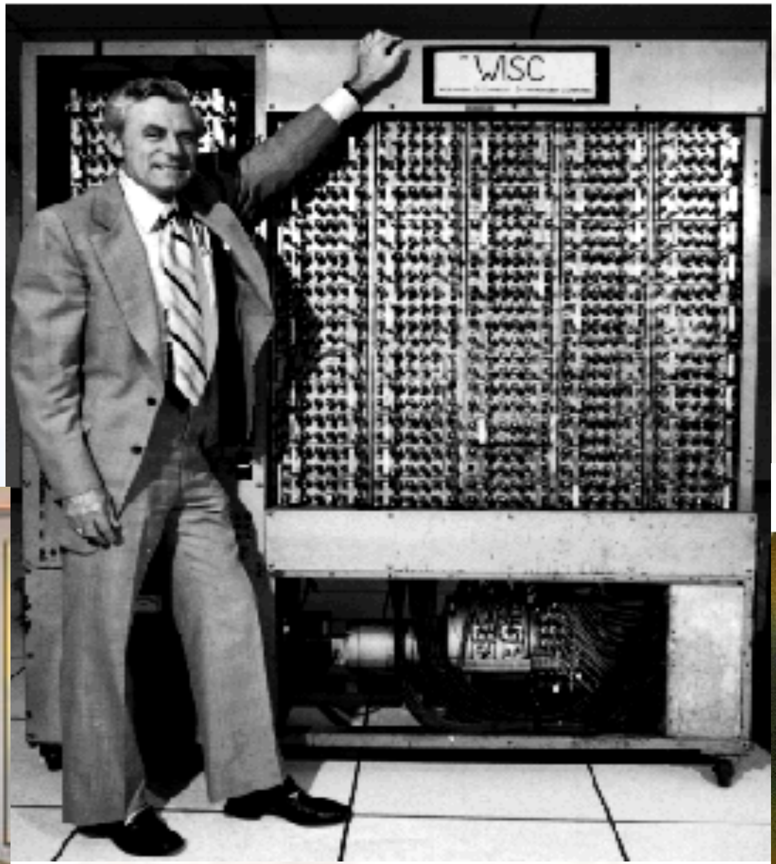
The attributes of a [computing] system as seen by the programmer, i.e., the conceptual structure and functional behavior, as distinct from the organization of the data flows and controls the logic design, and the physical implementation.

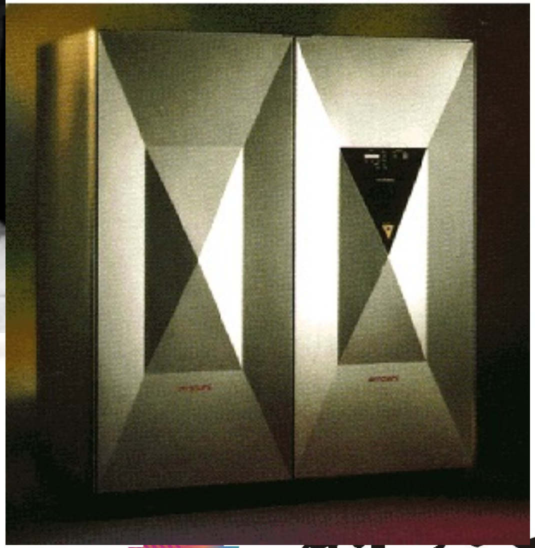
Amdahl, Blaaw, and Brooks, 1964


Applications
Operating System
Compiler
Firmware
Instruction Set Architecture
Instruction Set Processor
I/O System
Datapath & Control
Digital Design
Circuit Design
Layout
Assembly Language
|||
Instruction Set Architecture
|||
Machine Language

Very different appearance







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Very Different ISA

- PDP-11
- IBM 360
- VAX
- CRAY
- …

- LC3
- 80x86
- PowerPC
- MIPS
- ARM
- RISC V

New Concepts ?

Tradeoff

- *Computer Architecture* is the science and art of selecting and interconnecting hardware components to create computers that meet functional, performance, cost and power goals.

- It is a **blueprint** and functional description of requirements and design implementations for the various parts of a computer, focusing largely on the way by which the central processing unit (CPU) performs internally and accesses addresses in memory.

Computer architecture

- Computer architecture comprises at least three main subcategories:[1]
- ***Instruction set architecture***,
- ***Microarchitecture***, also known as ***Computer organization*** is a lower level, more concrete and detailed, description of the system that involves how the constituent parts of the system are interconnected and how they interoperate in order to implement the ISA.[
- ***System Design*** which includes all of the other hardware components within a computing system such as:

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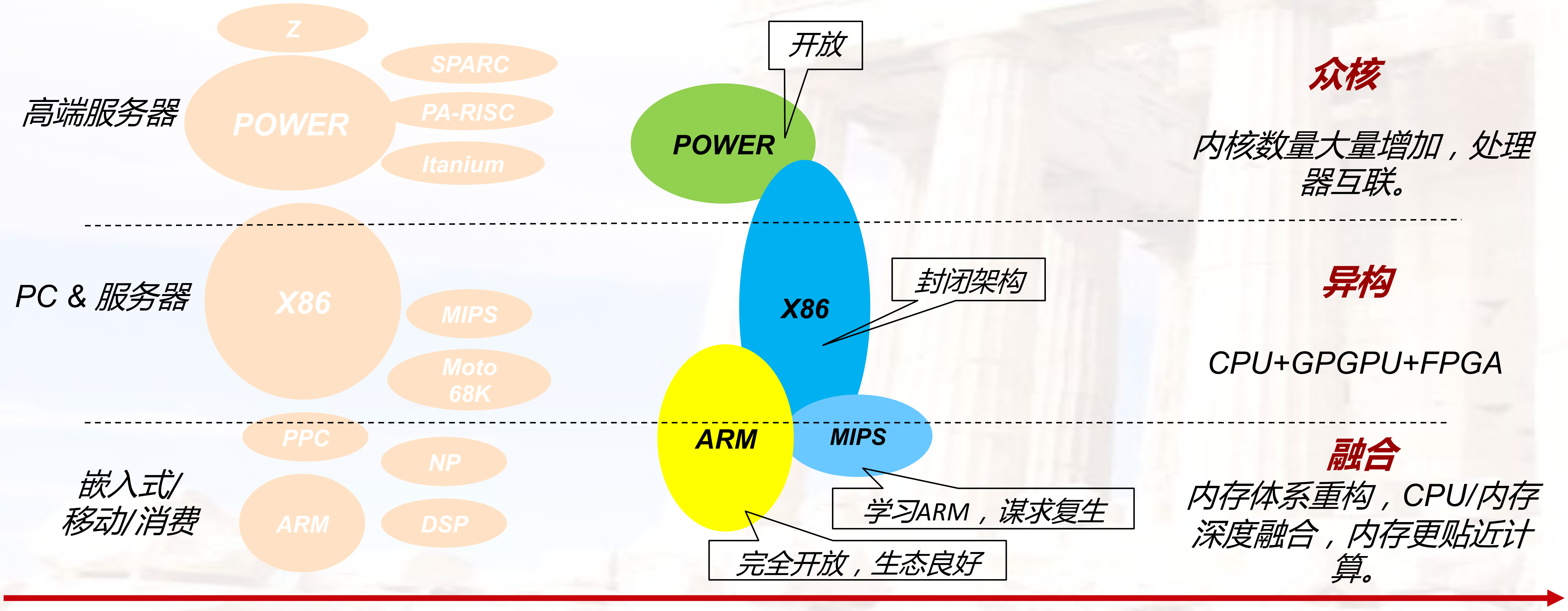
Seven dimensions of ISA

- Class of ISA
- Memory addressing
- Addressing modes
- Types and sizes of operands
- Operations
- Control flow instructions
- Encoding an ISA

ISA is most important interface in computer system where software meets hardware !



过去：架构众多，百花齐放　　**现在：生态成熟，架构垄断**　　**未来：摩尔定律失效，寻求多方向突破**

Computer Applications

- **Architects need to understand applications' behavior**
  - We say we design general purpose processors, but they really focus on specific sets of applications
  - Architecture can be tuned to applications
- **Types of applications today**
  - Scientific
    - Weather prediction, crash analysis, earthquake analysis, medical imaging, imaging of the earth (searching for oil)
  - Business
    - database, data mining, video
  - General purpose
    - Microsoft Word, Excel
  - Real-time
    - automated control systems,
  - Others: Games, Mobile, Internet of Things, 5G

The Task of Computer Design-2

- Determine the important attributes of a new machine to maximize performance while staying with constrains, such as cost, power, availability, etc.
  - instruction set architecture design
  - functional organization
    - High level aspects of computer design, i.e. memory system, bus architecture and internal CPU design.
  - logic design (hardware)
  - implementation (hardware)

Incredible CPU performance improvement

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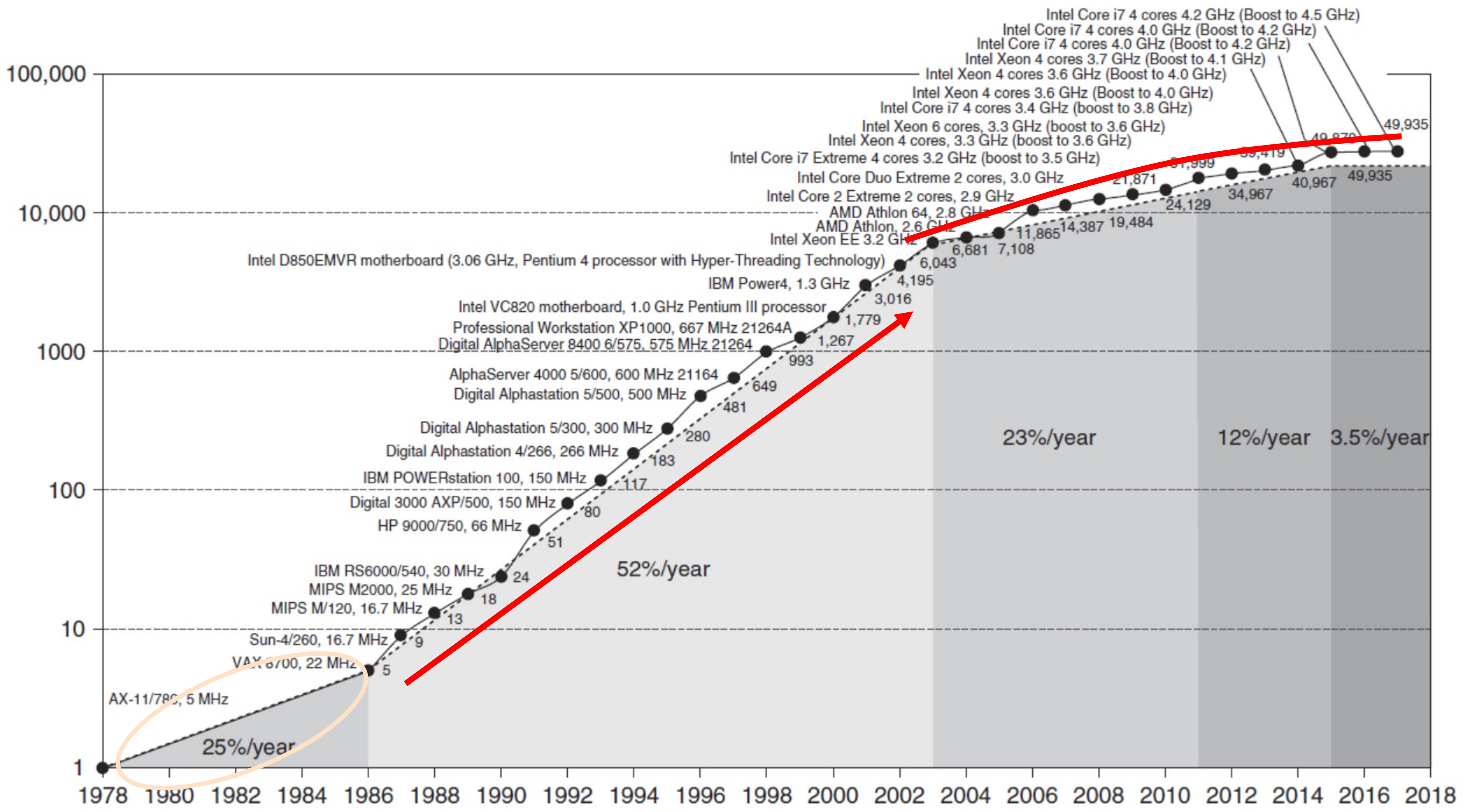

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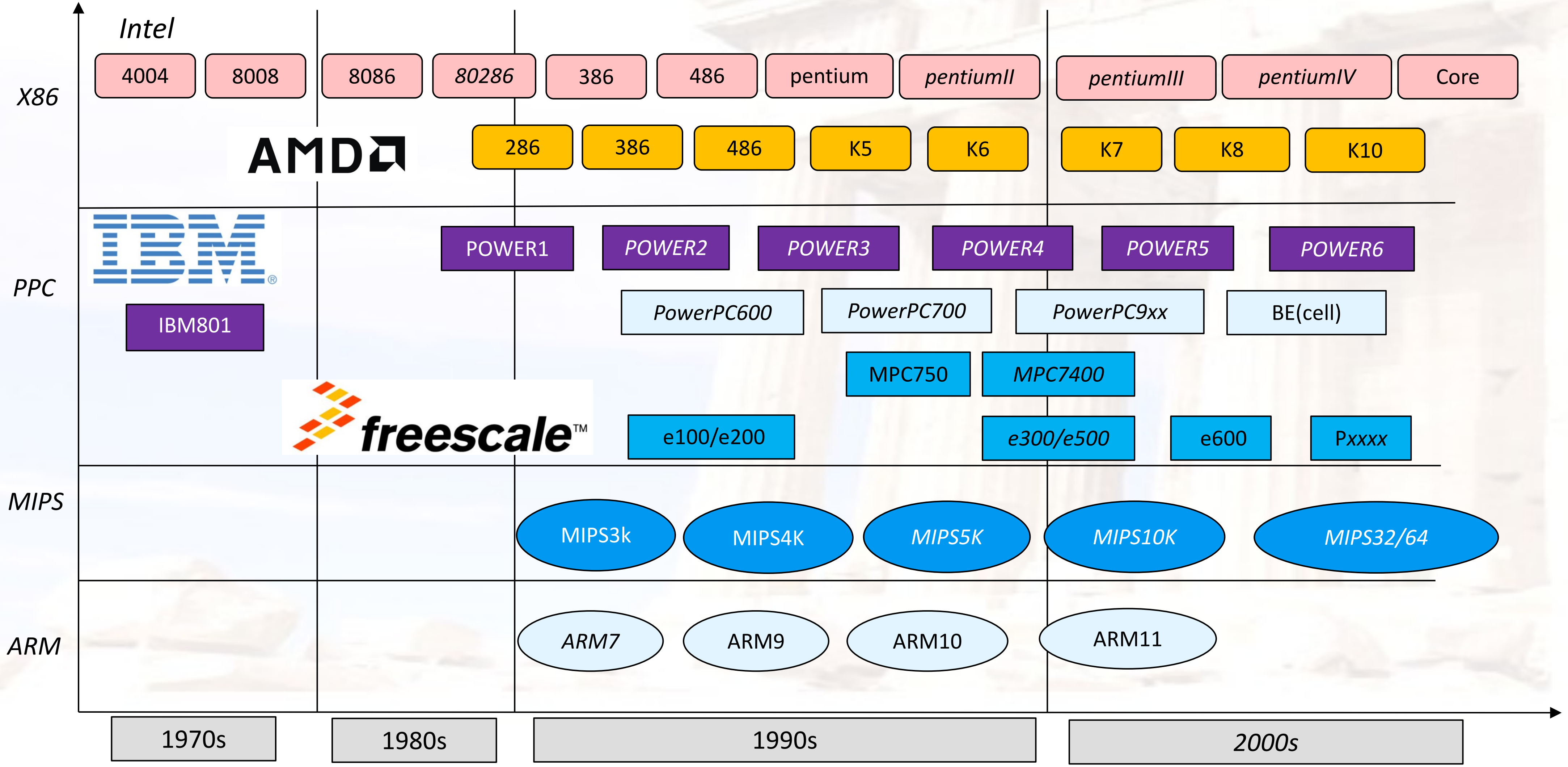
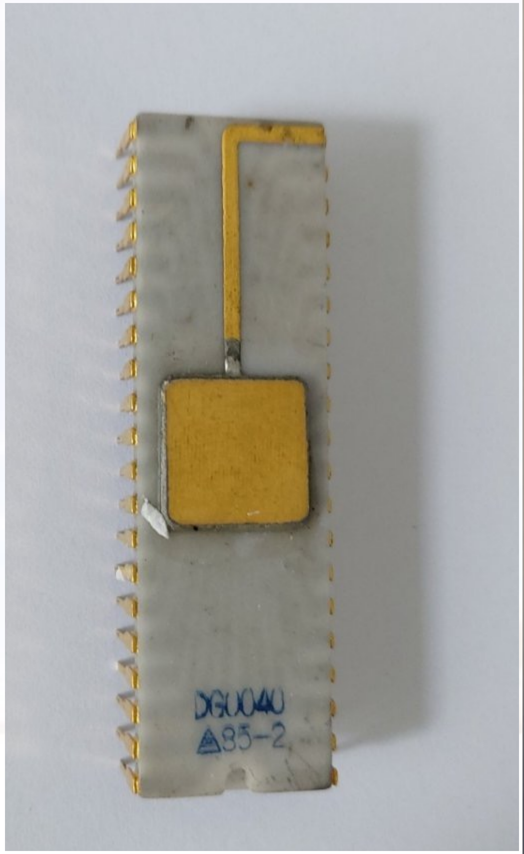
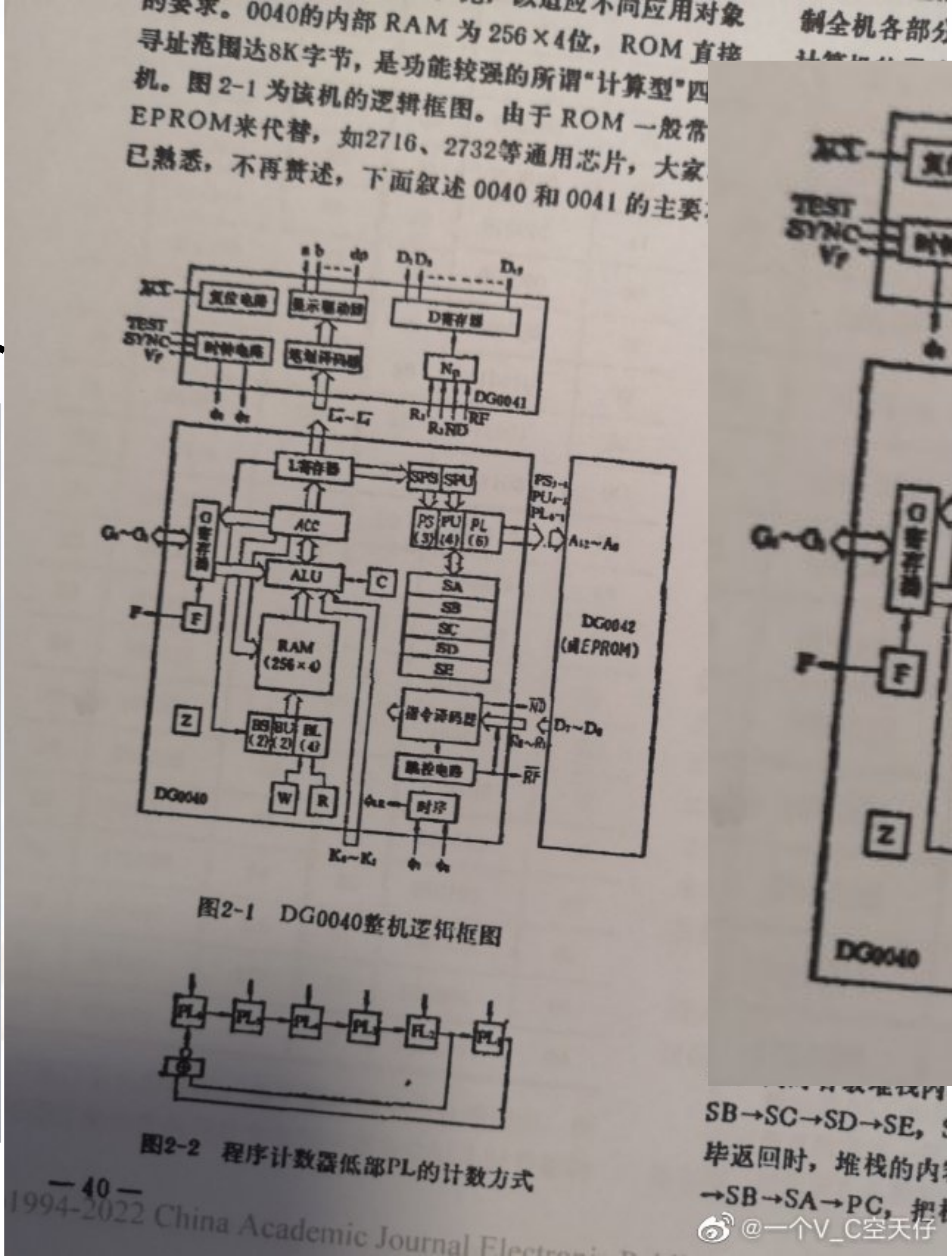
主流CPU发展路径



Intel
X86
4004
8008
8086
80286
386
486
pentium
pentiumII
pentiumIII
pentiumIV
Core
AMD
286
386
486
K5
K6
K7
K8
K10
IBM
PPC
IBM801
POWER1
POWER2
POWER3
POWER4
POWER5
POWER6
PowerPC600
PowerPC700
PowerPC9xx
BE(cell)
MPC750
MPC7400
freescale
e100/e200
e300/e500
e600
Pxxxx
MIPS
MIPS3k
MIPS4K
MIPS5K
MIPS10K
MIPS32/64
ARM
ARM7
ARM9
ARM10
ARM11
1970s
1980s
1990s
2000s

- DG0040
- 48条指令





……，以适应不同应用对象的要求。0040的内部 RAM 为 256×4位，ROM 直接寻址范围达8K字节，是功能较强的所谓"计算型"四……机。图 2-1 为该机的逻辑框图。由于 ROM 一般常……EPROM来代替，如2716、2732等通用芯片，大家……已熟悉，不再赘述，下面叙述 0040 和 0041 的主要……

制全机各部分……

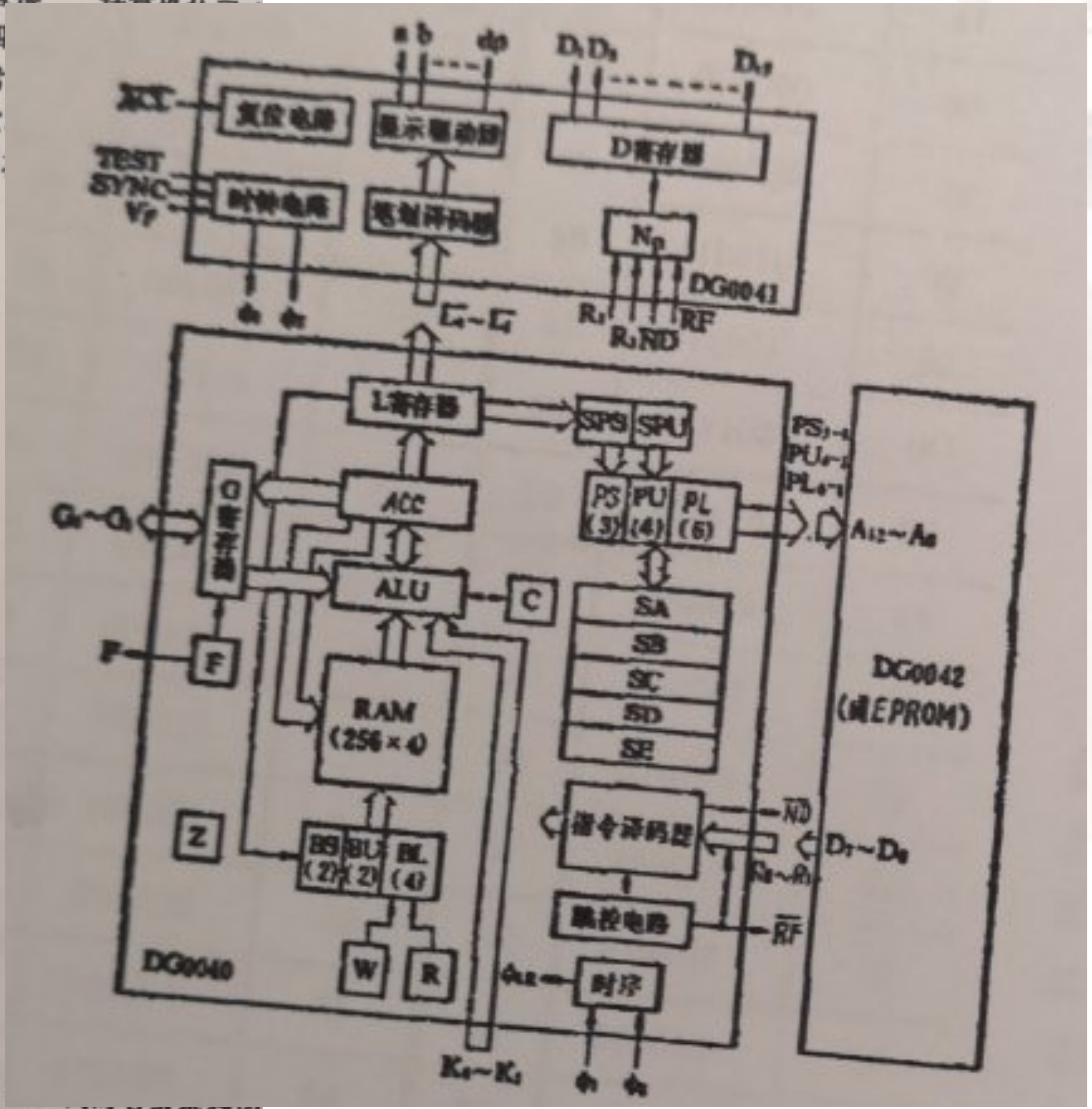
图2-1 DG0040整机逻辑框图

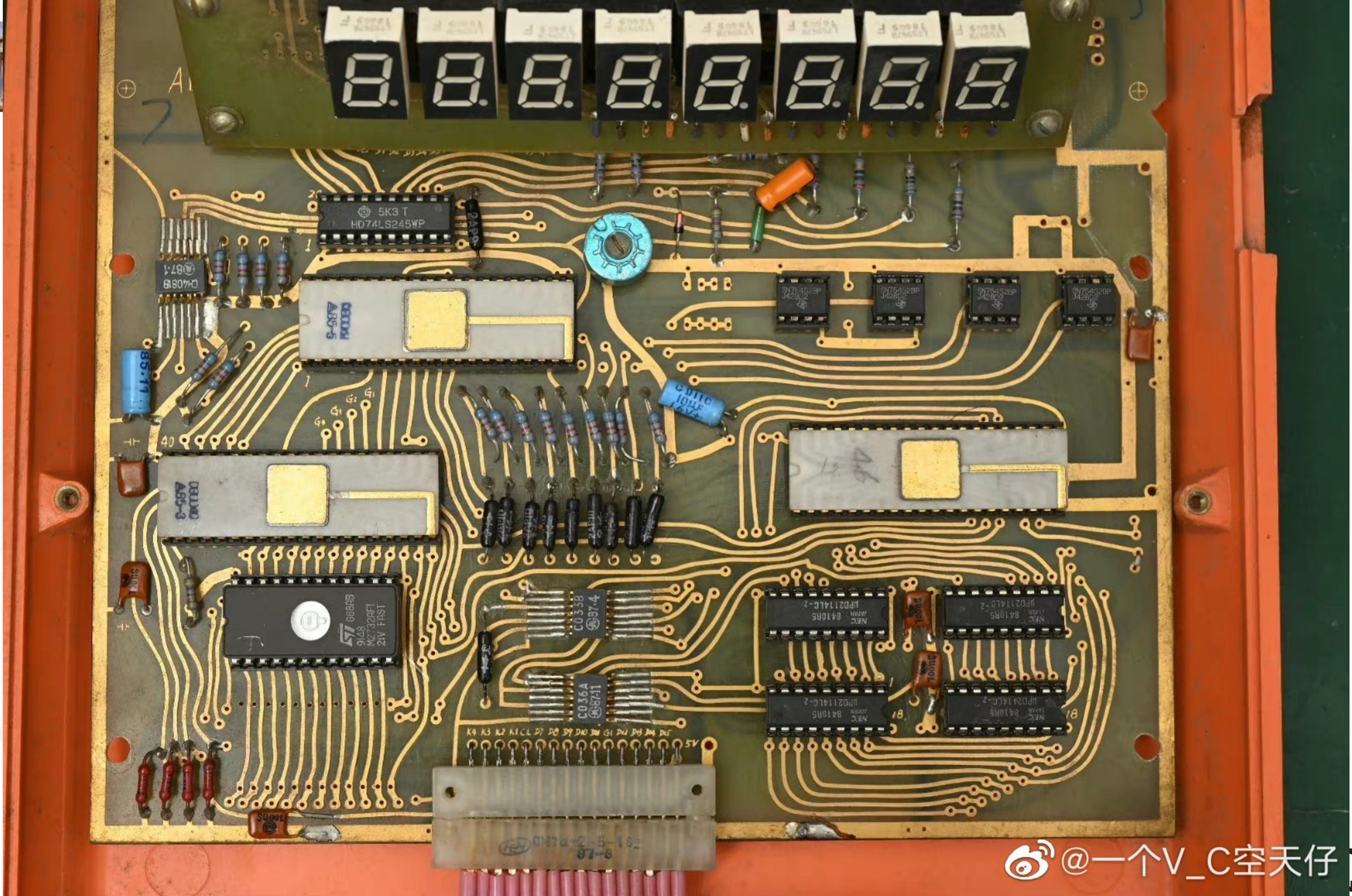
图2-2 程序计数器低部PL的计数方式

SB→SC→SD→SE，……

毕返回时，堆栈的内……

→SB→SA→PC，把……





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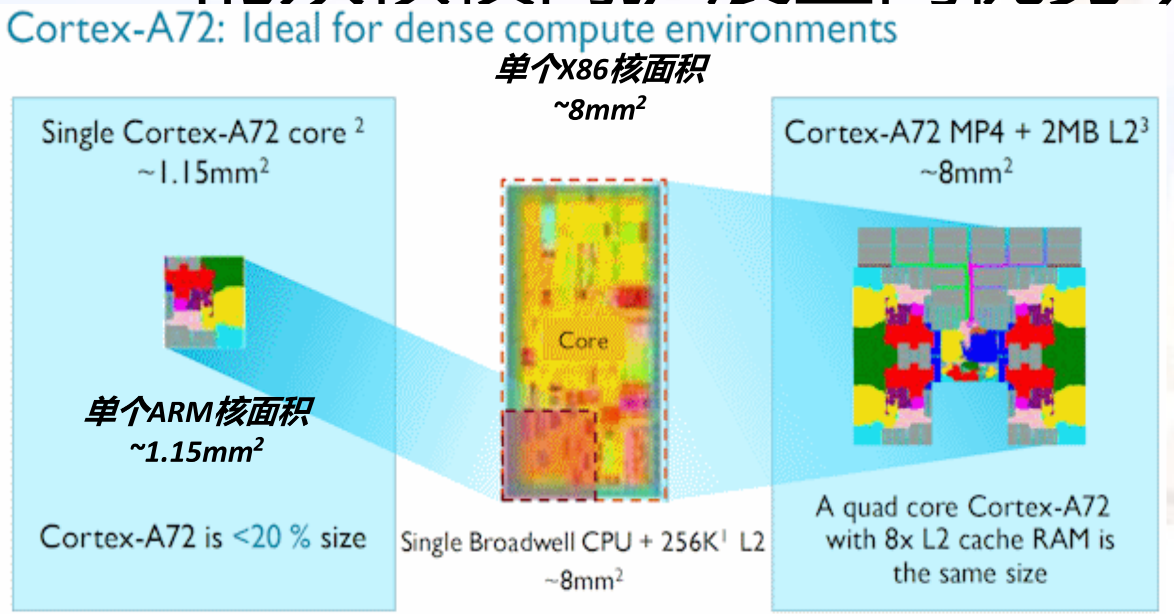
处理器芯片的发展趋势

- ❑工艺、主频遇到瓶颈后，开始通过增加核数的方式来提升性能；
- ❑芯片的物理尺寸有限制，不能无限制的增加；
- ❑ARM的众核横向扩展空间优势明显。



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ARM 服务器级别处理器一览

HISILICON	Hi1612	32C, 2.1GHz 16nm	Hi1616	32C,2.4GHz 16nm	Hi1620	48C,3.0GHz 7nm
CAVIUM	Thunder-X	48C,2.5GHz 28nm	Thunder-X2	32-54C,3.0GHz 14nm		
高通			2400	48Cores,2.2-2.6GHz 14nm		
AMPERE™					X-Gene3	32C, 3.3GHz 16nm
飞腾	FT1500	16 Cores,1.6GHz 28nm			FT2000+	64Cores,2.3GHz 16nm

横轴代表性能

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Open Interfaces work for software

Field	Open Standard	Free, Open Implement.	Proprietary Implement
Networking	Ethernet, TCP/IP	Many	Many
OS	Posix	Linux, FreeBSD	M/S Windows
Compilers	C	Gcc, LLVM	Intel icc, ARMcc
Databases	SQL	MySQL, PostgresSQL	Oracle 12C, M/S DB2
Graphics	OpenGL	Mesa3D	M/S DirectX
ISA	??????	--------	X86, ARM, IBM360, AMD

- Why not successful free & open standards and free & open implementations, like other fields ?

Proprietary ISA fortunes tied to business fortunes and whims.

Today, many ISAs on one SoC

- Application processor (usually ARM)
- Graphics processors
- Image processors
- Radio DSPs
- Audio DSPs
- Security processors
- Power-management processor
- > dozen ISAs on some SoCs – each with unique software stack

Why ?

- Apps processor ISA too big， inflexible for accelerators
- IP bought from different place， each proprietary ISA
- Engineers build home-grown ISA cores

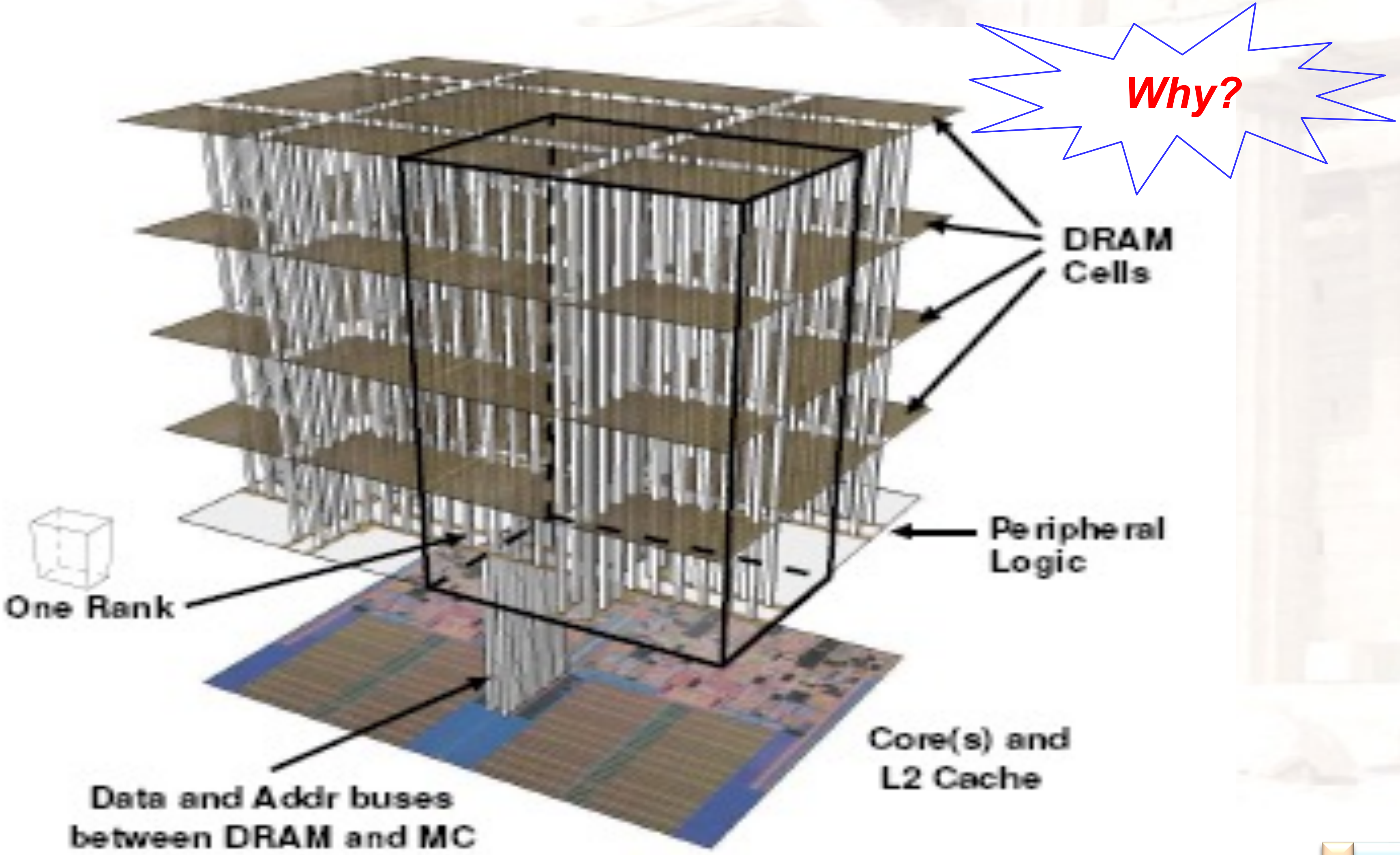
Why lower down after 2004 ?

- Power density was constant for a given area of silicon even as increase the number of transistors
  - voltage couldn't keep dropping and still maintain the dependability
  - Single inefficient processor → multiple efficient processors or cores
  - ILP → DLP, TLP, RLP(explicitly parallelism）
- Combination of
  - Transistors no longer etting much better due to Slowing of Moore's law
  - The unchanging power budgets for microprocessors
  - Replacement of the single power-hungry processor with several energy-efficient processors
  - The limits to multiprocessing to achieve Amdahl's Law

Challenges of “three walls”

- ILP Wall
  - diminishing returns on finding more ILP HW (Explicit thread and data parallelism must be exploited)
- Memory Wall
  - growing disparity of speed between CPU and memory outside the CPU chip. Memory latency would become an overwhelming bottleneck in computer performance.
- Power Wall
  - the trend of consuming double the power with each doubling of operating frequency

Trends of Computer Architecture



Computational RAM / PIM

- Processor in memory (PIM)
  - Processing in memory (PIM, sometimes called *processor in memory*) is the integration of a processor with RAM (random access memory) on a single chip. The result is sometimes known as a *PIM chip*.

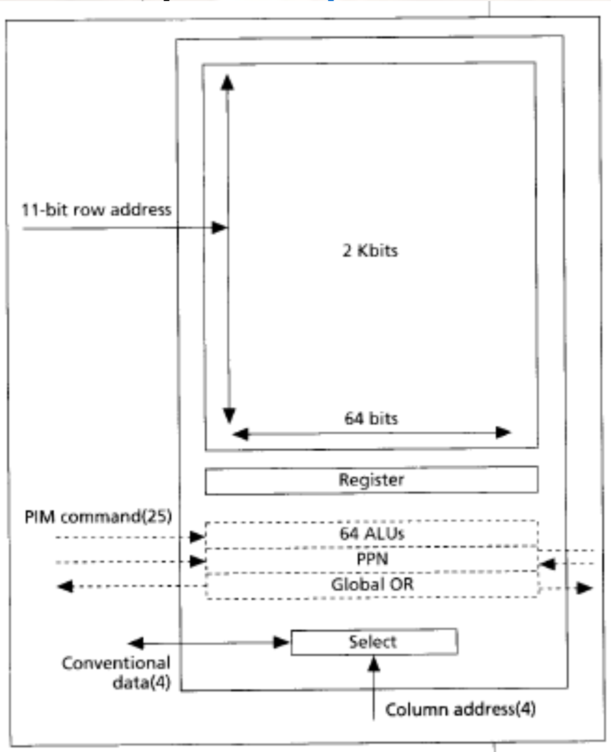
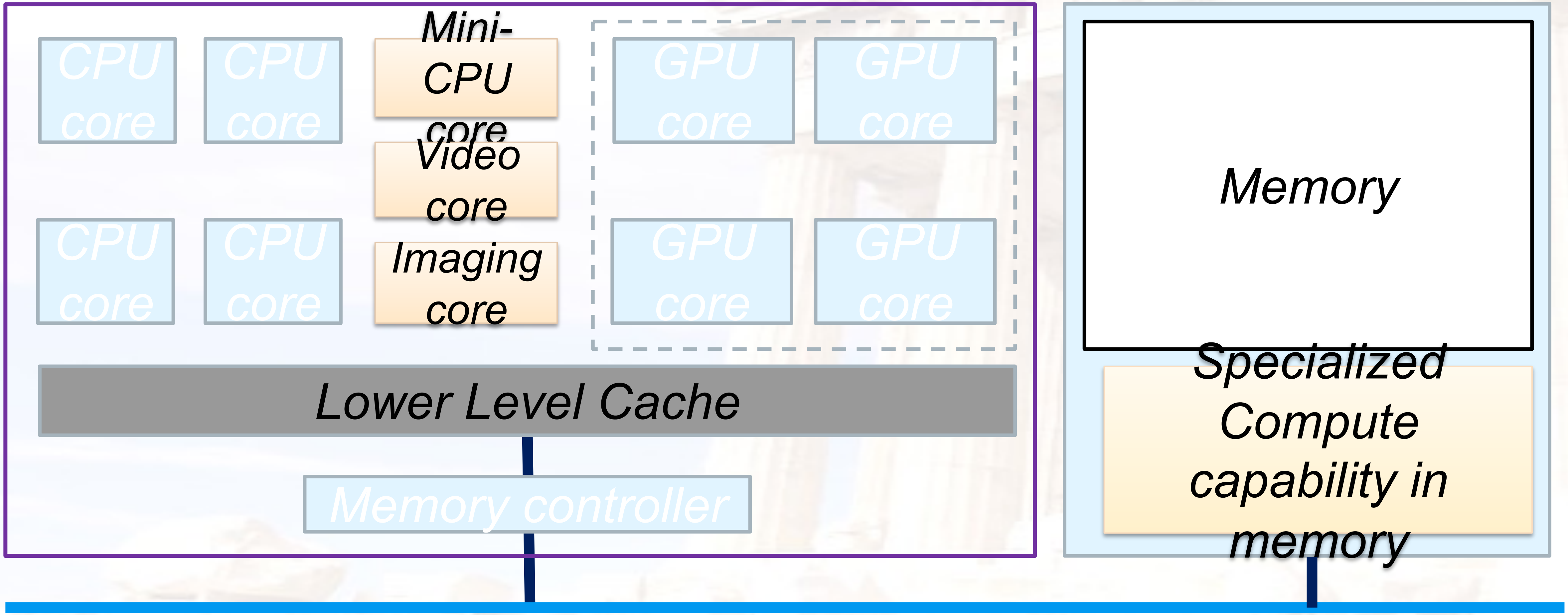


Figure 2. A processor-in-memory chip.

- 1995. 4 IEEE computer

  Processing in memory: the Terasys massively Parallel PIM Array.

Memory as an Accelerator



Bitwise Operation： In-DRAM copy， zero， and， or， not

Current Trends in Architecture

- Cannot continue to leverage Instruction-Level parallelism (ILP)
  - Single processor performance improvement ended in 2003

- New models for performance:
  - Data-level parallelism (DLP)
  - Thread-level parallelism (TLP)
  - Request-level parallelism (RLP)

- These require explicit restructuring of the application

Recent research fields

- Power-aware computer architecture
- Reconfigurable computer architecture
- Multicore, Manycore,
- HPS : P→T→ E-level computer
- PIM： Processor in Memory
- AI processor ------GPU & FPGA
- DSA： Domain Specific Architecture

- Hardware and Software Codesign

Why RISC V ? Open-source hardware ISA

- ❑What if there was one stable free and open ISA everyone could use for everything ?
- ❑In 2010， Archi group at UC Berkeley to choose ISA for next set of projects

  -x86 impossible –too complex，

  - ARM mostly impossible –complex， no 64-bit in 2010，
  - 2014， released frozen base user specification

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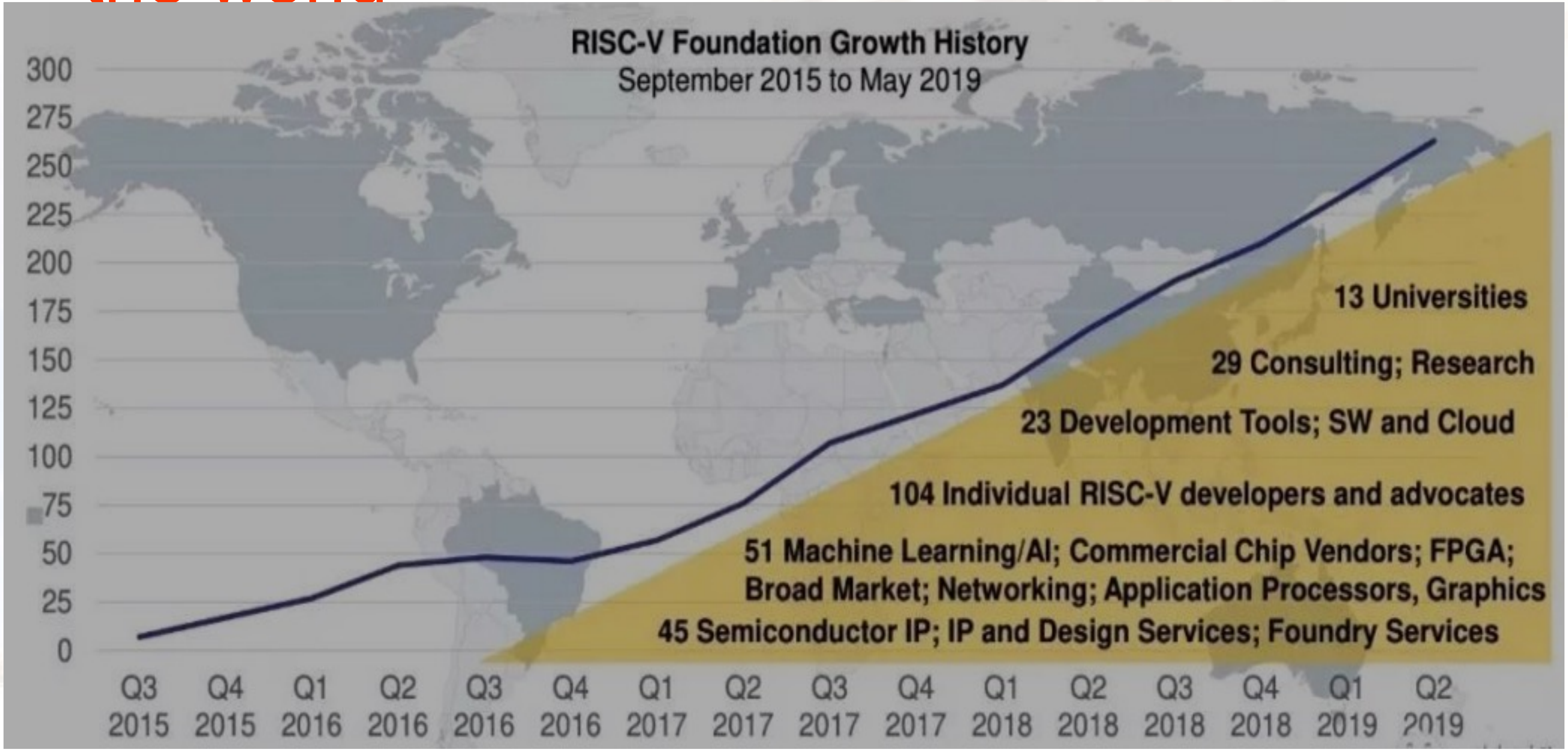
RISC-V Foundation （2015- ）

- RISC –V Foundation is a non-profit entity serving members and the industry, aims at accelerate RISC-V adoption with shared benefit to the entire community of stake holders.

- Drive progression of ratified specs, compliance suit, and other technical deliverables.
- Grow the overall ecosystem /membership, promoting diversity while preventing fragmentation
- Deepen community engagement and visibility

>250 RISC-V members in 28 countries in the world



Where to explore the parallelism ?

- Implicitly, compiler and hardware

  → Explicitly, programmer

So, YOU, programmers must know parallelism in hardware, and to explore parallelism when design Algorithm and programming !

application Algorithm Language Compiler Hardware

Hardware → Hardware and compiler → compiler and programmer

ILP, Loop-level Parallism → TLP, DLP

Something more about Computer Architecture

Fastest computer in China

- 2011 Tianhe-1A - MPP
- 2008 Dawning 5000A
  - 30720 node * AMD Opteron 1.9Ghz QC
  - Memory: 122.88TB, Infiniband, 180.6 TeraFLOPS
  - OS: Windows HPC 2008
  - Rank 10 in top 500 in Nov. 2008
- 2004 Dawning 4000A
  - 11 TeraFLOPS
  - rank 10 in top 500 in June, 2004
- 2003 ShenTeng6800
  - 5.324 TeraFLOPS
- 2002 ShenTeng1800
  - 2.04 TeraFLOPS
- 2000 YinHe IV
  - 1024个CPU
  - 1 TeraFLOPS

What are the fastest computers?

- http://top500.org/ June. 2011

1 K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect

2 Tianhe-1A - MPP, X5670 2.93Ghz 6C, NVIDIA GPU, FT-1000 8C

3 Jaguar - Cray XT5-HE Opteron 6-core 2.6 GHz

4 Nebulae - Dawning TC3600 Blade, Intel X5650, NVidia Tesla C2050 GPU

5 TSUBAME 2.0 - HP ProLiant SL390s G7 Xeon 6C X5670, Nvidia GPU, Linux/Windows

6 Cielo - Cray XE6 8-core 2.4 GHz

7 Pleiades - SGI Altix ICE 8200EX/8400EX, Xeon HT QC 3.0/Xeon 5570/5670 2.93 Ghz, Infiniband

8 Hopper - Cray XE6 12-core 2.1 GHz

9 Tera-100 - Bull bullx super-node S6010/S6030

10 Roadrunner - BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband

Fastest Supercomputer in the world

http://top500.org/ June. 2013

Rank	Site	System	Cores	Rmax (TFlop/s)	Tpeak (TFlop/s)	Power (kW)
1	National University of Defense Technology 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 USA	**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 USA	**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 USA	**Mira** - BlueGene/Q, Power BQC 16C 1.60GHz, Custom IBM	786,432	8,586.6	10,066.3	3,945
6	Texas Advanced Computing Center/Univ. of Texas USA	**Stampede** - PowerEdge C8220, Xeon E5-2680 8C 2.700GHz, Infiniband FDR, Intel Xeon Phi SE10P Dell	462,462	5,168.1	8,520.1	4,510
7	Forschungszentrum Juelich (FZJ) Germany	**JUQUEEN** - BlueGene/Q, Power BQC 16C 1.600GHz, Custom Interconnect IBM	458,752	5,008.9	5,872.0	2,301
8	DOE/NNSA/LLNL USA	**Vulcan** - BlueGene/Q, Power BQC 16C 1.600GHz, Custom Interconnect IBM	393,216	4,293.3	5,033.2	1,972
9	Leibniz Rechenzentrum Germany	**SuperMUC** - iDataPlex DX360M4, Xeon E5-2680 8C 2.70GHz, Infiniband FDR IBM	147,456	2,897.0	3,185.1	3,423
10	National Supercomputing Center in Tianjin China	**Tianhe-1A** - NUDT YH MPP, Xeon X5670 6C 2.93 GHz, NVIDIA 2050 NUDT	186,368	2,566.0	4,701.0	4,040

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Fastest Supercomputer in the world

from http://top500.org/ June， 2015

RANK	SITE	SYSTEM	CORES	(TFLOP/S)	(TFLOP/S)	(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	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
7	King Abdullah University of Science and Technology Saudi Arabia	**Shaheen II** - Cray XC40, Xeon E5-2698v3 16C 2.3GHz, Aries interconnect Cray Inc.	196,608	5,537.0	7,235.2	2,834
8	Texas Advanced Computing Center/Univ. of Texas United States	**Stampede** - PowerEdge C8220, Xeon E5-2680 8C 2.700GHz, Infiniband FDR, Intel Xeon Phi SE10P Dell	462,462	5,168.1	8,520.1	4,510
9	Forschungszentrum Juelich (FZJ) Germany	**JUQUEEN** - BlueGene/Q, Power BQC 16C 1.600GHz, Custom Interconnect IBM	458,752	5,008.9	5,872.0	2,301
10	DOE/NNSA/LLNL	**Vulcan** - BlueGene/Q, Power BQC 16C 1.600GHz,	393,216	4,293.3	5,033.2	1,972

Fastest Supercomputer in the world

from http://top500.org/ June. 2016

Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	National Supercomputing Center in Wuxi China	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway NRCPC	10,649,600	93,014.6	125,435.9	15,371
2	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
3	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
4	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
5	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
6	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
7	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	
8	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
9	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	
10	King Abdullah University of Science and Technology	**Shaheen II** - Cray XC40, Xeon E5-2698v3 16C 2.3GHz, Aries interconnect	196,608	5,537.0	7,235.2	2,834

Fastest Supercomputer in the world

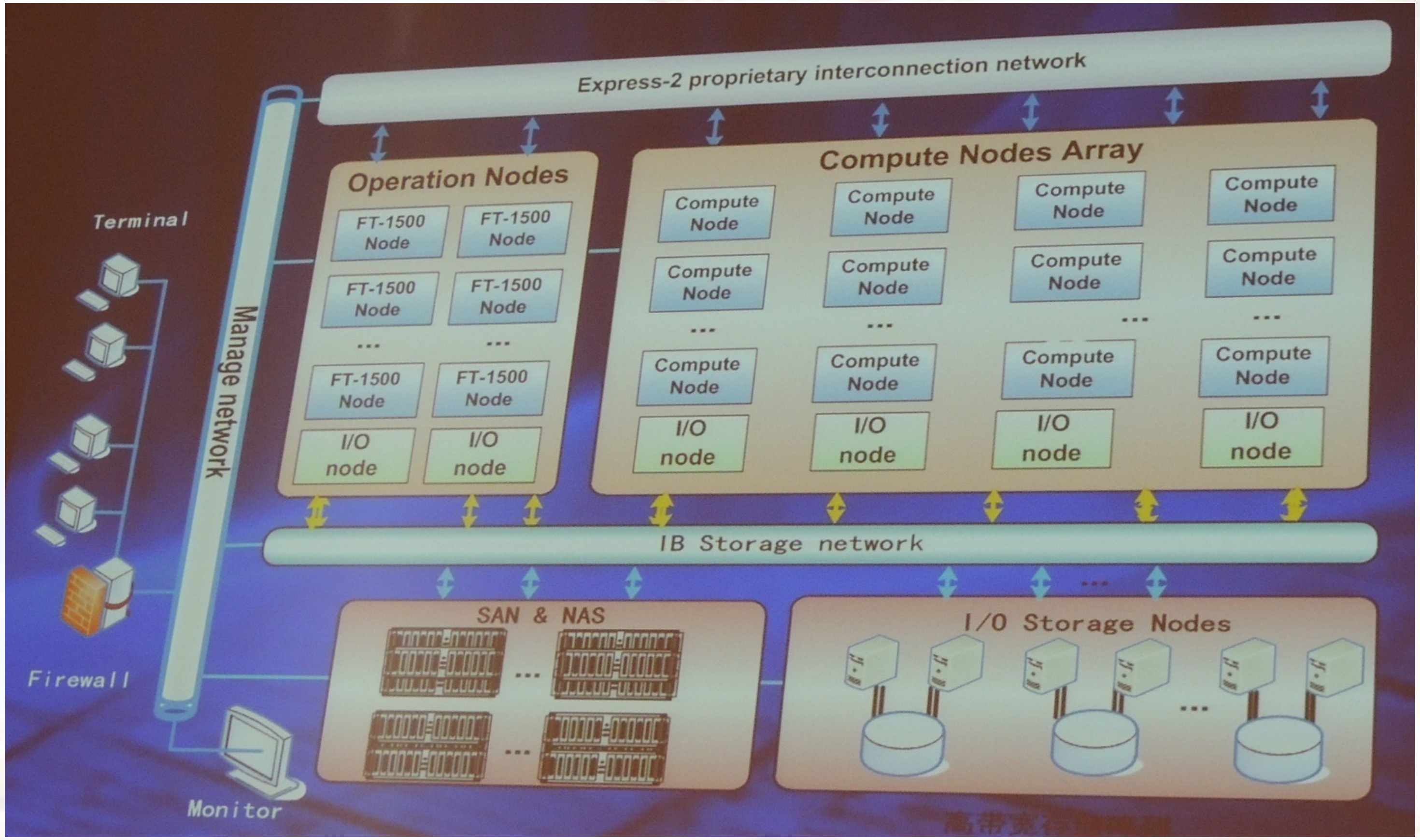
from http://top500.org/ June. 2017

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	**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
5	**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
6	**Cori** - Cray XC40, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect , Cray Inc. DOE/SC/LBNL/NERSC United States	622,336	14,014.7	27,880.7	3,939
7	**Oakforest-PACS** - PRIMERGY CX1640 M1, Intel Xeon Phi 7250 68C 1.4GHz, Intel Omni-Path , Fujitsu Joint Center for Advanced High Performance Computing Japan	556,104	13,554.6	24,913.5	2,719
8	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect , Fujitsu RIKEN Advanced Institute for Computational Science (AICS)	705,024	10,510.0	11,280.4	12,660

Overview of TH-2

Items	Configuration
Processors	32000 Intel Xeon CPUs + 48000 Xeon Phis + 4096 FT CPUs Peak performance is 54.9 Pflops, sustained performance 33.9PFlops
Interconnect	Proprietary high speed interconnection network TH Express-2
Memory	1.4PB in total
Storage	Global shared parallel storage system, 12.4 PB
Cabinets	125+13+24+8 = 170 Compute/Communication/Storage/Service Cabinets
Power	17.8MW
Cooling	Closed Air Cooling System

Hardware subsystem of TH-2



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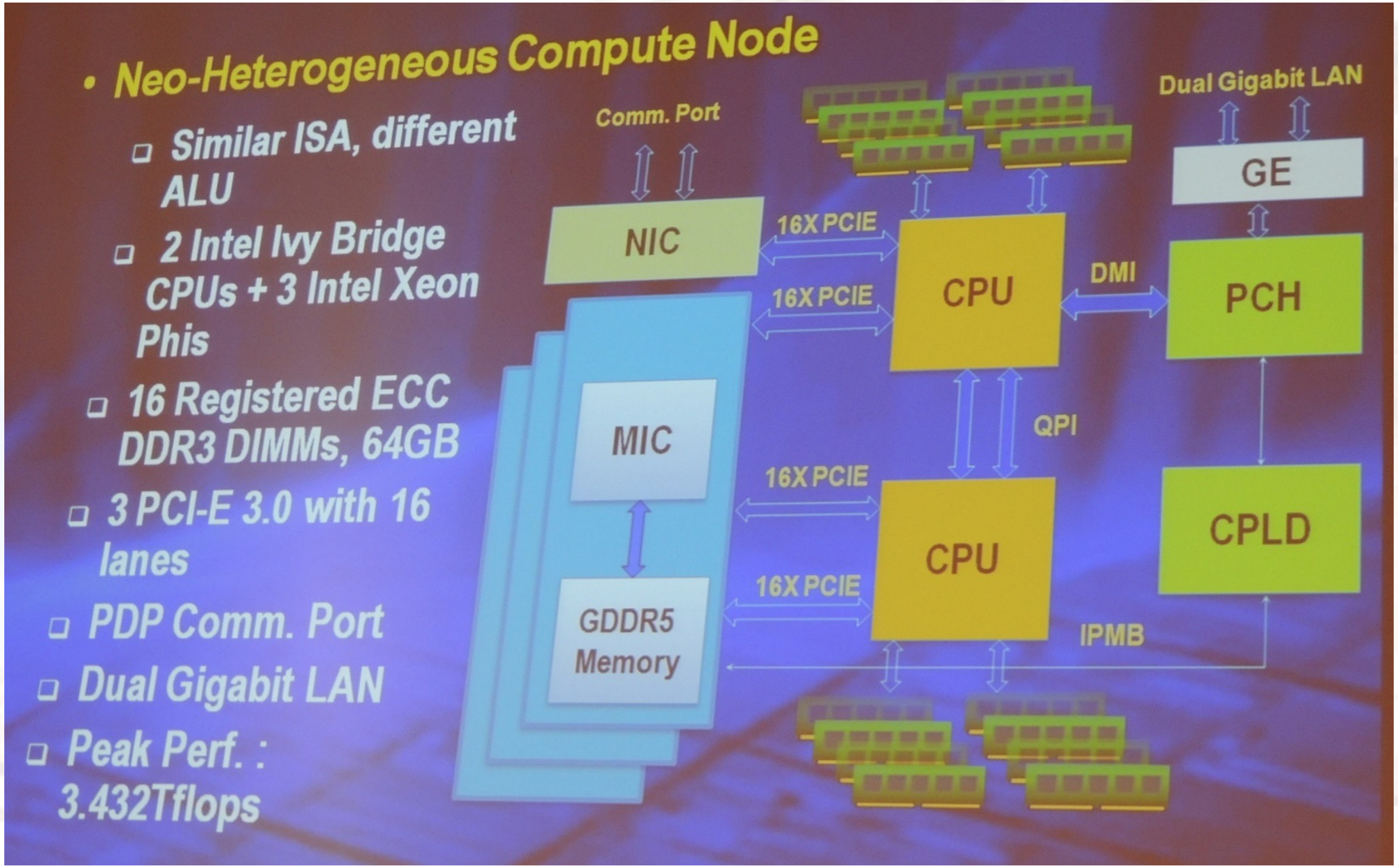
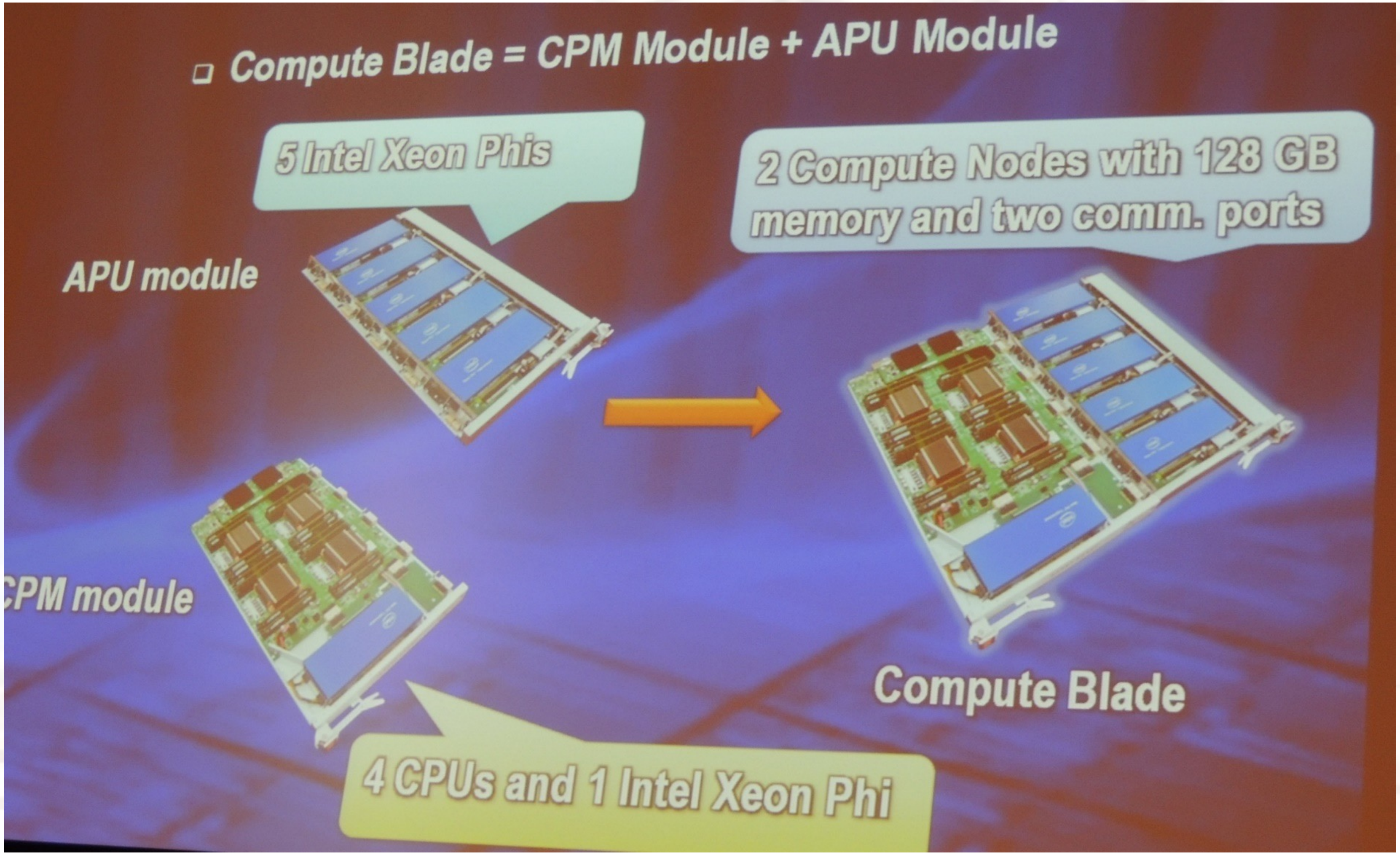
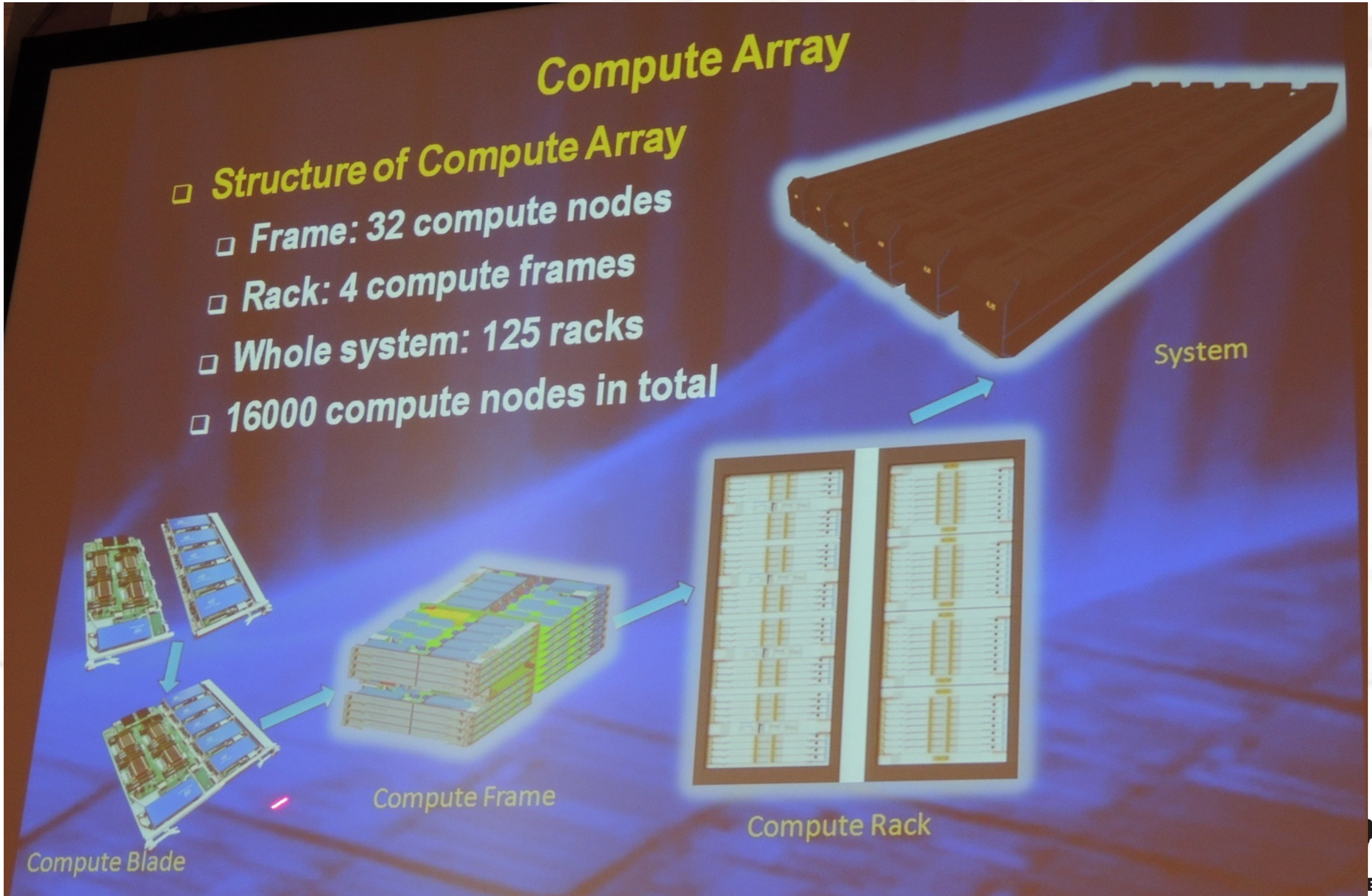
Comuter Node of TH-2



Comuter Node of TH-2



Computer Array of TH-2



- *40960 Chinese-designed SW26010 manycore 64-bit RISC processors*
  X (256 processing cores + 4 auxiliary cores) per SW26010
  = *10,649,600 CPU cores*
- *The processing cores feature 64 KB of scratchpad memory for data (and 16 KB for instructions) and communicate via a network on a chip,*
- ***OS:*** *Sunway RaiseOS 2.0.5 on linux with its its own customized implementation of OpenACC2.0*

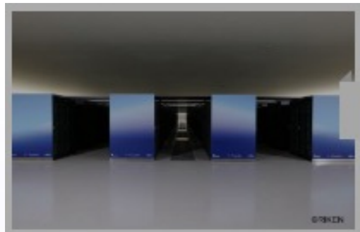
Fastest Supercomputer in the world

http://top500.org/ June. 2018

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	2,282,544	122,300.0	187,659.3	8,806
2	**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
3	**Sierra** - IBM Power System S922LC, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM DOE/NNSA/LLNL United States	1,572,480	71,610.0	119,193.6	
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	**AI Bridgi** Gold 614 National Japan			576.6	1,649
6	**Piz Daint** NVIDIA T Swiss Na Switzerl			326.3	2,272
7	**Titan** - C NVIDIA K20x , Cray Inc. DOE/SC/Oak Ridge National Laboratory United States			112.5	8,209
8	**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
9	**Trinity** - Cray XC40, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect , Cray Inc. DOE/NNSA/LANL/SNL United States	979,968	14,137.3	43,902.6	3,844
10	**Cori** - Cray XC40, Intel Xeon Phi 7250 68C 1.4GHz, Aries interconnect , Cray Inc.	622,336	14,014.7	27,880.7	3,939

Summit”的计算能力比神威·太湖之光要快60%，比前美国超级计算机“Titan（泰坦）”要快8倍。

Newest Top 10 June 2020



No.1 Fugaku(富岳)

日本 制造商：富士通

处理器核芯：7299072个；峰值(Rmax)：415530 TFlop/s

简介：

Fugaku超算原来被称为“Post K”，是曾经的世界第一K computer产品的第四代，采用ARM架构的富士通A64FX处理器，性能为第二名Summit的2.8倍。

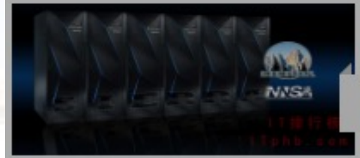
No.2 Summit（美国）

美国 制造商：IBM

处理器核芯：2414592个；峰值(Rmax)：148600 TFlop/s

简介：

顶点Summit是IBM和美国能源部橡树岭国家实验室（ORNL）推出的新超级计算机，Summit 要比神威·太湖之光快 60%，比同在橡树岭实验室的Titan——前美国超算记录保持者要快接近 8 倍。而在其之下，近 28,000 块英伟达 Volta GPU 提供了 95% 的算力。



No.3 Sierra（美国）

美国 制造商：IBM

处理器核芯：1572480个；峰值(Rmax)：94640 TFlop/s

简介：

Sierra超级计算机美国国家能源局橡树岭国家实验室已经给它定下来要做的事情，助力科学家在高能物理、材料发现、医疗保健等领域的研究探索。其中在癌症研究方面将用于名为“CANcer分布式学习环境（CANDLE）”的项目。

No.4 神威 太湖之光（Sunway TaihuLight）中国

中国 制造商：国家并行计算机工程技术研究中心

处理器核芯：10649600个；峰值(Rmax)：93015 TFlop/s

简介：

我国的神威 “太湖之光”超级计算机曾连续获得top500四届冠军，该系统全部使用中国自主知识产权的处理器芯片。

No.5 TH—2 天河二号（中国）

中国 制造商：国防科大

处理器核芯：4981760个；峰值(Rmax)：61445 TFlop/s

简介：

天河二号曾经6次蝉联冠军，采用麒麟操作系统，目前使用英特尔处理器，将来计划用国产处理器替换，不仅应用于助力探月工程、载人航天等政府科研项目，还在石油勘探、汽车飞机的设计制造、基因测序等民用方面大展身手。

No.6 HPC5（意大利）

意大利 制造商：DELL EMC

处理器核芯：669760个；峰值(Rmax)：35450 TFlop/s

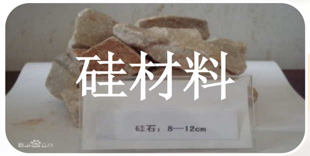
简介：

由DELL EMC公司为Eni能源公司打造的世界上功能最强大的工业用超级计算机，它的混合体系结构使分子模拟算法特别有效。

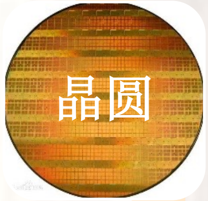
ZHEJIANG UNIVERSITY

Chip technology

高纯硅要求99.999999999%,几乎全赖进口，传统霸主依然是德国Wacker和美国Hemlock(美日合资)



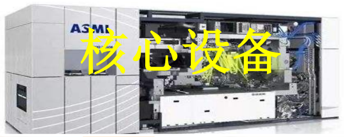
一块300mm直径的晶圆，16nm工艺可以做出100块芯片，10nm工艺可以做出210块芯片，价格可便宜了一半



美英特尔、韩三星、日东芝、意法半导体；台湾的：旺宏电子；中国华润微电子等。但中国高端芯片几乎空白

晶圆代工厂：台积电，中芯国际

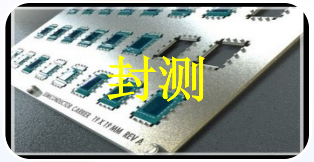
高通、博通、AMD，中国台湾的联发科，大陆的华为海思



光刻机，荷兰阿斯麦公司(ASML)唯一高端光刻机生产商（12，24，40台/年）

刻蚀机，中国的状况要好很多，16nm已经量产，7-10nm也在上

离子注入机70%的市场份额是美国应用材料公司



台湾的天下，排名世界第一的日月光，还跟着一堆实力不俗的小弟：矽品、力成、南茂、欣邦、京元电子。

大陆的三大封测巨头：长电科技、华天科技、通富微电

Chip technology

中国芯片的总体水平差不多处在刚刚实现零突破的阶段，虽然市场份额微乎其微，但每个领域都参了一脚，前景还是可期待的。

大陆半导体产业链市占率整体偏低

产业环节	细分方向	大陆企业全球市占率	国内相关公司
设计&IDM	存储芯片	1%	长江存储、合肥长鑫、福建晋华
	CPU\MPU	1%	龙芯、兆芯、飞腾、申威等
	AP\BP	12%	华为海思、紫光展讯
	传感器执行器	1%	士兰微
	逻辑芯片	6%	兆易创新、中颖电子、矩力、华润微电子、华大半导体等
	模拟芯片	1%	圣邦股份、韦尔股份
	FPGA\CPLD	1%	京微雅格、高云 FPGA、同方国芯、上海安路、西安智多晶等
	分立器件	17%	扬杰科技、捷捷微电
制造	28nm 及以下先进工艺	1%	中芯国际
	28nm 以上成熟工艺	16%	中芯国际、华力微
	8 寸硅基工艺	11%	华宏半导体
	化合物半导体	1%	三安光电
	特殊模拟工艺	1%	
封装测试		25%	长电科技
设备	前道高端设备	0%	
	前道成熟设备	2%	中微半导体、北方华创、上海微电子
	后道设备	4%	长川科技
制造材料		1%	江丰电子、上海新阳
设计核心 IP		1%	\
EDA		1%	\

资料来源：芯谋研究 IC Wise 2018.4；注：1%为估测值，指市占率较小；光大证券研究所整理

What are the Big Bananas ?

- **Eckert-Mauchly Award**
  - http://www.computer.org/portal/web/awards/eckert
  - **Administered jointly by ACM and IEEE Computer Society. The award of $5000 is given for contributions to computer and digital systems architecture where the field of computer architecture is considered at present to encompass the combined hardware-software design and analysis of computing and digital systems.**

Eckert-Mauchly Award Recipients

2018 Susan Eggers,
2017 Charles P. Thacker
2016 Uri Weiser
2015 Norman P. Jouppi
2014 Trevor Mudge
2013 James R. Goodman
2012 Algirdas Avizienis
2011 Gurindar (Guri) S. Sohi
2010 William J. Dally
2009 Joel S. Emer
2008 **Patterson, David**
2007 Valero, Mateo
2006 Pomerene, James H
2005 Colwell, Robert P.
2004 Brooks, Frederick P.
2003 Fisher, Joseph A. (Josh)
2002 Rau, B. Ramakrishna (Bob)
2001 **Hennessy, John**
2000 Davidson, Edward
1999 Smith, James E.

1998 Watanabe, T.
1997 **Tomasulo, Robert**
1996 **Patt, Yale**
1995 Crawford, John
1994 Thornton, James E.
1993 Kuck, David J
1992 **Flynn, Michael J.**
1991 Smith, Burton J.
1990 Batcher, Kenneth E.
1989 **Cray, Seymour**
1988 Siewiorek, Daniel P.
1987 **Amdahl, Gene M.**
1986 Cragon, Harvey G
1985 **Cocke, John**
1984 Dennis, Jack B.
1983 Kilburn, Tom
1982 **Bell, C. Gordon**
1981 Clark, Wesley A.
1980 Wilkes, Maurice V.
1979 Barton, Robert S.

浙江大學
ZHEJIANG UNIVERSITY

Big Men in Architecture(1)

- **2007Mateo Valero**

  http://personals.ac.upc.edu/mateo/

  For important contributions to instruction level parallelism and superscalar processor design.

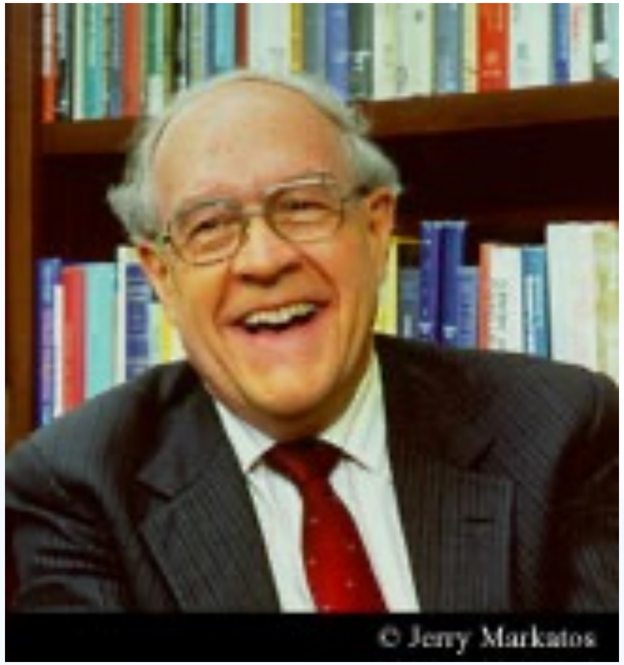
ZHEJIANG UNIVERSITY

Big Men in Architecture(2)

- **2001 Hennessy, John**

  For being the founder and chief architect of the MIPS Computer Systems and contributing to the development of the landmark MIPS R2000 microprocessor.

Big Men in Architecture(3)



Frederick P. Brooks

http://www.cs.unc.edu/~brooks/

2004 Eckert-Mauchly Award

"For the definition of computer architecture and contributions to the concept of computer families and to the principles of instruction set design; for seminal contributions in instruction sequencing, including interrupt systems and execute instructions; and for contributions to the IBM 360 instruction set architecture."

- **1999 ACM Turing Award**

  landmark contributions to computer architecture, operating systems, and software engineering."

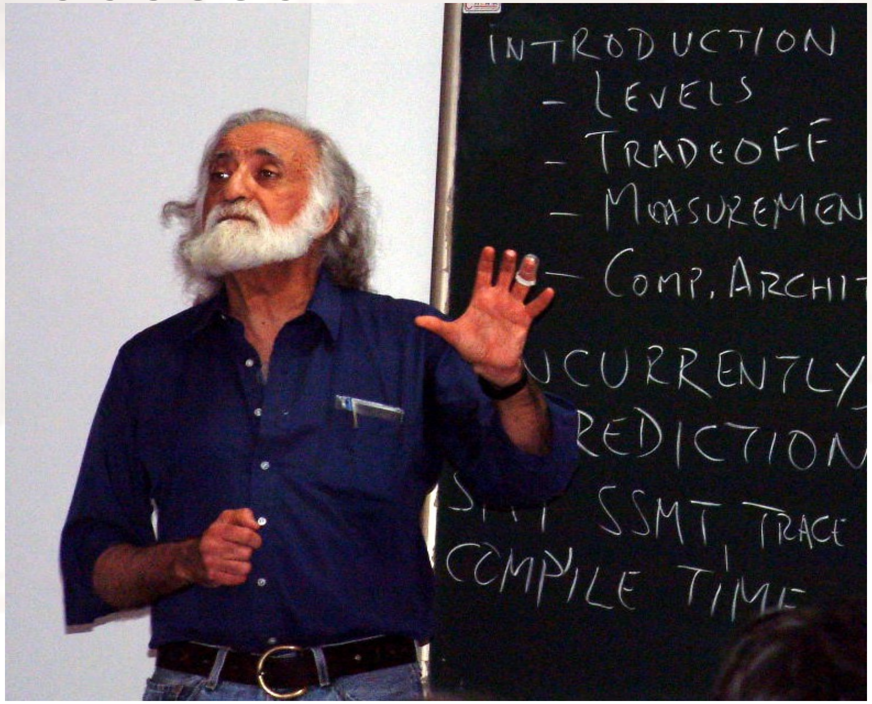
Big Men in Architecture(5)

- 1996 Yale Patt

  For important contributions to instruction level parallelism and superscalar processor design.

- Introduction to computing systems

  （2013-2017, 2019）



Big Men in Architecture(6)

- 1992 **Michael J. Flynn**

  http://www.cpe.calpoly.edu/IAB/flynn.html

- For his important and seminal contributions to processor organization and classification, computer arithmetic and performance evaluation.

Big Men in Architecture(7)

- 1989 Cray, Seymour
- For a career of achievements that have advanced supercomputing design.

Big Men in Architecture(8)

From Computer Desktop Encyclopedia
Reproduced with permission.
© 1999 Dr. Gene M. Amdahl

In 1975, Dr. Amdahl stands beside the Wisconsin Integrally Synchronized Computer (WISC), which he designed in 1950. It was built in 1952. (Image courtesy of Dr. Gene M. Amdahl.)

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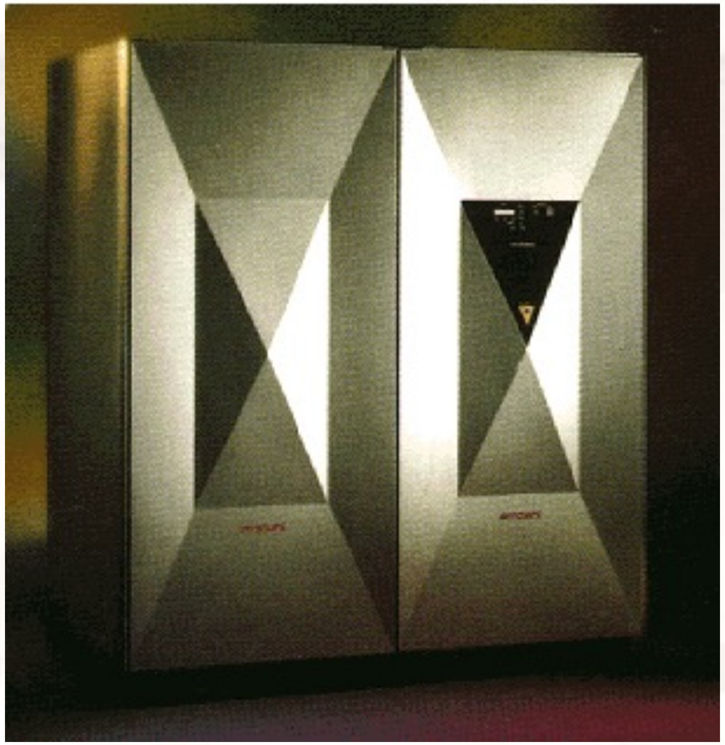


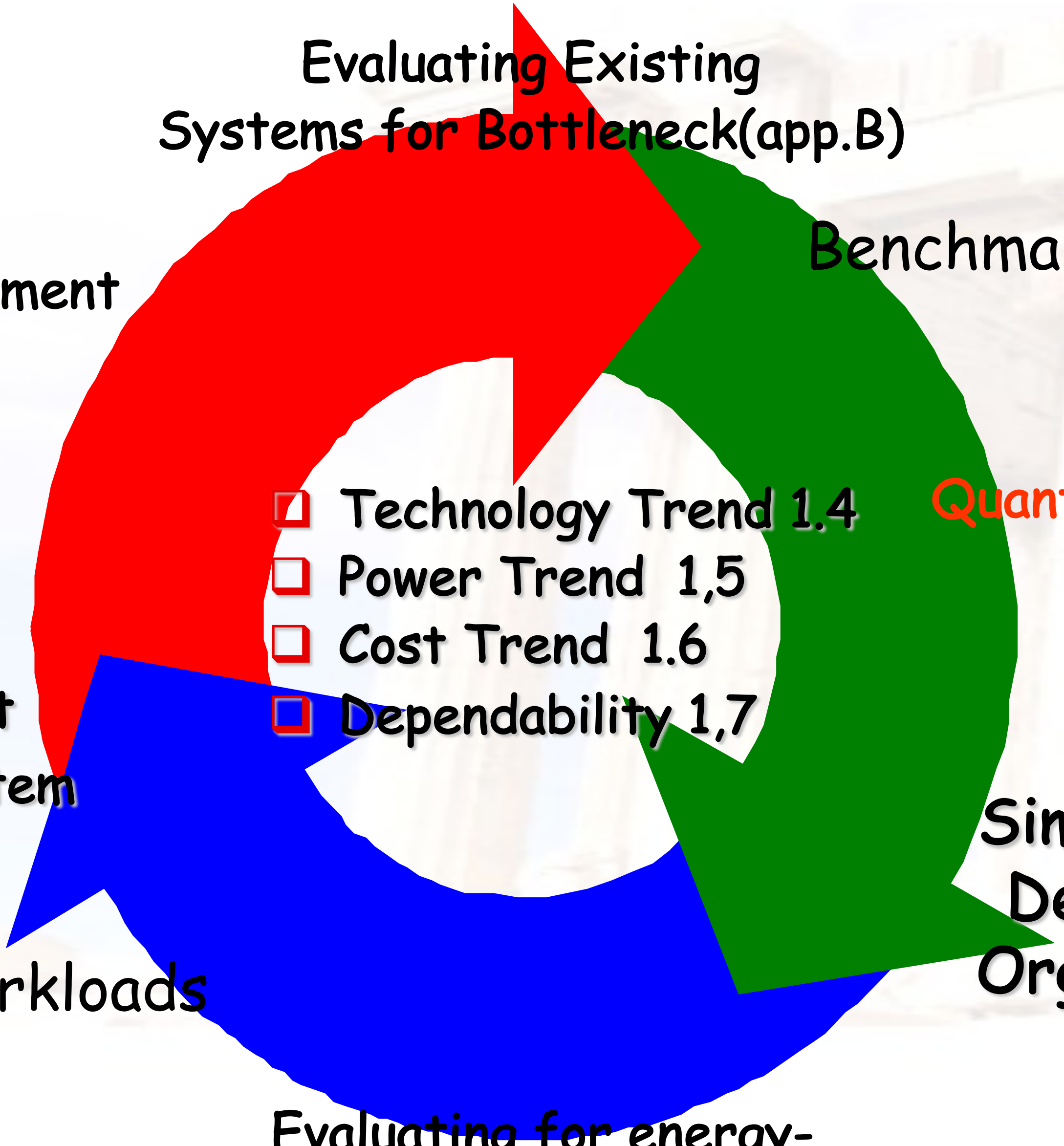
in computer architecture,
ion look-ahead, and

Top conferences and Journals

- Top conference:
  - ISCA
  - MICRO,
  - …
- Top journals:
  - IEEE Tran. on Computers IF 3.131
  - ACM Tran. on Computer Systems IF 1.917
  - IEEE Tran. on Parallel and Distributed Systems. IF 3.402

- What’s a CA designer’s task ?

Computer Design Engineering life cycle



Topics in Chapter 1

1.1 Introduction
1.2 Classes of computers
1.3 Defining computer architecture and What's the task of computer design?
1.4 Trends in Technology
1.5 Trends in power in Integrated circuits
1.6 Trends in Cost
1.7 Dependability
1.8 Measuring, Reporting and summerizing Perf.
1.9 Quantitative Principles of computer Design
1.10 Putting it altogether

Summary: Task of computer design

- **Considerations:**
  - functional and non functional requirements
  - implementation complexity
    - Complex designs take longer to complete
    - Complex designs must provide higher performance to be competitive
  - **Technology trends**
    - Not only what's available today, but also what will be available when the system is ready to ship. (more on this later)
  - **Trends in Power in IC**
  - **Trends in cost**
- **Arguments**
  - Evaluate Existing Systems for Bottlenecks
- **Quantitative Principles**

Reading Assignments

- Chapter 1， Chapter 2.
- Homework1 for chapter 1 will be loaded on website