Computer Organization and Architecture

Designing for Performance

Eighth Edition

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CONTENTS

ONLINE CHAPTERS

WilliamStallings.com/COA/COA8e.html

ONLINE APPENDICES

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the computers: processor, I/O, memory, peripheral devices. Part Two examines these components and looks in some detail at each component except the processor. This approach allows us to see the external functional requirements that drive the processor design, setting the stage for Part Three. In Part Three, we examine the processor in great detail. Because we have the context provided by Part Two, we are able, in Part Three, to see the design decisions that must be made so that the processor supports the overall function of the computer system. Next, in Part Four, we look at the control unit, which is at the heart of the processor. Again, the design of the control unit can best be explained in the context of the function it performs within the context of the processor. Finally, Part Five examines systems with multiple processors, including clusters, multiprocessor computers, and multicore computers.

0.3 WHY STUDY COMPUTER ORGANIZATION AND ARCHITECTURE?

The *IEEE/ACM Computer Curricula 2001,* prepared by the Joint Task Force on Computing Curricula of the IEEE (Institute of Electrical and Electronics Engineers) Computer Society and ACM (Association for Computing Machinery), lists computer architecture as one of the core subjects that should be in the curriculum of all students in computer science and computer engineering. The report says the following:

> The computer lies at the heart of computing. Without it most of the computing disciplines today would be a branch of theoretical mathematics. To be a professional in any field of computing today, one should not regard the computer as just a black box that executes programs by magic. All students of computing should acquire some understanding and appreciation of a computer system's functional components, their characteristics, their performance, and their interactions. There are practical implications as well. Students need to understand computer architecture in order to structure a program so that it runs more efficiently on a real machine. In selecting a system to use, they should be able to understand the tradeoff among various components, such as CPU clock speed vs. memory size.

A more recent publication of the task force, *Computer Engineering 2004 Curriculum Guidelines,* emphasized the importance of Computer Architecture and Organization as follows:

> Computer architecture is a key component of computer engineering and the practicing computer engineer should have a practical understanding of this topic. It is concerned with all aspects of the design and organization of the central processing unit and the integration of the CPU into the computer system itself. Architecture extends upward into computer software because a processor's

> architecture must cooperate with the operating system and system software. It is difficult to design an operating system well without knowledge of the underlying architecture. Moreover, the computer designer must have an understanding of software in order to implement the optimum architecture.
>
> The computer architecture curriculum has to achieve multiple objectives. It must provide an overview of computer architecture and teach students the operation of a typical computing machine. It must cover basic principles, while acknowledging the complexity of existing commercial systems. Ideally, it should reinforce topics that are common to other areas of computer engineering; for example, teaching register indirect addressing reinforces the concept of pointers in C. Finally, students must understand how various peripheral devices interact with, and how they are interfaced to a CPU.

[CLEM00] gives the following examples as reasons for studying computer architecture:

1. Suppose a graduate enters the industry and is asked to select the most cost-effective computer for use throughout a large organization. An understanding of the implications of spending more for various alternatives, such as a larger cache or a higher processor clock rate, is essential to making the decision.
2. Many processors are not used in PCs or servers but in embedded systems. A designer may program a processor in C that is embedded in some real-time or larger system, such as an intelligent automobile electronics controller. Debugging the system may require the use of a logic analyzer that displays the relationship between interrupt requests from engine sensors and machine-level code.
3. Concepts used in computer architecture find application in other courses. In particular, the way in which the computer provides architectural support for programming languages and operating system facilities reinforces concepts from those areas.

As can be seen by perusing the table of contents of this book, computer organization and architecture encompasses a broad range of design issues and concepts. A good overall understanding of these concepts will be useful both in other areas of study and in future work after graduation.

0.4 INTERNET AND WEB RESOURCES

There are a number of resources available on the Internet and the Web that support this book and help readers keep up with developments in this field.

Web Sites for This Book

There is a Web page for this book at **WilliamStallings.com/COA/COA8e.html**. See the layout at the beginning of this book for a detailed description of that site.

CPU-Z

CPU | Caches | Mainboard | Memory | SPD | Graphics | Bench | About

Memory Slot Selection

Slot #2 — DDR3

Module Size	4096 MBytes	Correction	
Max Bandwidth	PC3-12800 (800 MHz)	Registered	
Manufacturer	Hyundai Electronics	Ranks	Single
Part Number	HMT451S6BFR8A-PB	SPD Ext.	
Serial Number	0B39E329	Week/Year	52 / 15

Timings Table

	JEDEC #4	JEDEC #5	JEDEC #6	JEDEC #7
Frequency	609 MHz	685 MHz	761 MHz	800 MHz
CAS# Latency	8.0	9.0	10.0	11.0
RAS# to CAS#	8	9	10	11
RAS# Precharge	8	9	10	11
tRAS	22	24	27	28
tRC	30	33	37	39
Command Rate				
Voltage	1.35 V	1.35 V	1.35 V	1.35 V

CPU-Z Ver. 1.85.0.x64 — Tools | Validate | Close

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File Edit Software Hardware Network Tools Help

Network Information

- Browser Helper Objects
- Scheduled Tasks
- Databases
- Audio and Video Codecs
- Shared DLLs
- ActiveX
- Shell Extensions
- Event Viewer
- Certificates
- **Hardware**
  - System Summary
  - Motherboard
  - BIOS
  - CPU
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  - System Slots
  - Network Adapters
  - Video
  - Sound Devices
  - Storage Devices
  - Logical Disks
  - Ports
  - Power Policy
  - Battery
  - Printers
  - Resources
  - Performance
- **Network**
  - Network Information
  - Network Connections
  - Shares
  - Active Directory
  - Groups and Users
  - Neighborhood Scan
  - Open Ports
  - Network
  - Search Network Neighborhood

Property	Value
Network Information	
Network	
Computer Name	[redacted]
Workgroup Name	WORKGROUP
Logon Server	[redacted]
Windows Sockets	
Socket Version	2.0
Highest Version	2.2
Description	WinSock 2.0
System Status	Running
Network Interface 1	
Friendly name	Local Area Connection
Model	TAP-Win32 Adapter V9
Manufacturer	Not Available
Description	TAP-Win32 Adapter V9
Type	Ethernet Adapter
MAC Address	00:FF:3F:9F:99:F5
MTU	1500 Bytes
Operational Status	Down
Network Interface 2	
Friendly name	Ethernet
Model	Realtek PCIe GBE Family Controller
Manufacturer	Not Available
Description	Realtek PCIe GBE Family Controller
Type	Wired 802.3
MAC Address	08:60:6E:E5:68:A0
MTU	1500 Bytes
Operational Status	Up
TransmitLinkSpeed	100 Mbps
ReceiveLinkSpeed	100 Mbps
IPv4 Address	192.168.1.34 [thedarknut]
IPv4 Default Gateway	192.168.1.1
IPv4 DHCP Enabled	Yes
IPv4 DNS Server	192.168.1.1
WINS Enabled	No
IPv4 Multicast Address	224.0.0.1 [all-systems.mcast.net]
IPv6 Address	fe80::34da:809d:3cc:ab15%3
Flags	DDNS_ENABLED, DHCP_ENABLED, OTHER_STATEFUL_CONFIG
Zone Info	if 3, link 3, subnet 3, admin 1, site 1, org 1, global 0

NUM

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File Edit Software Hardware Network Tools Help

System Summary

- Software
  - Operating System
  - System Directories
  - System Files
  - Installed Programs
  - Applications
  - Security
  - Licenses
  - Passwords
  - Accessibility
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  - Regional Settings
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  - PCI
  - System Slots
  - Network Adapters
  - Video
  - Sound Devices

Property	Value
System Summary	
Computer	
Manufacturer	Chassis Manufacture
Family	Not Available
Product Name	Not Available
Model	Not Available
Version	Not Available
Serial Number	Chassis Serial Number
SMBIOS Asset Tag	Asset-1234567890
SKU Number	SKU
Chassis	Not Available
PC System Type	Desktop
Machine Type	AT/AT COMPATIBLE
Firmware Type	BIOS
Infrared (IR) Supported	No
UUID	A0ECE01E-DAD7DD11-B08F0860-6EE568A0
Disk Space	
Disk C:	72 GB Available, 150 GB Total, 72 GB Free
Disk D:	73 GB Available, 150 GB Total, 73 GB Free
Disk E:	14 GB Available, 164 GB Total, 14 GB Free
Disk H:	Not Available
Disk \:	59 MB Available, 99 MB Total, 59 MB Free
Memory	
Memory	8144 MB Total, 4540 MB Free
Memory Load	44%
Virtual Memory	16336 MB Total, 11513 MB Free
Pagefile	
PageFile Name	C:\pagefile.sys
PageFile Size	8192 MB
In use	158 MB
Max used	284 MB
Registry Size	
Current Size	94 MB
Maximum Size	0 MB
The system clock interval	15 ms

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File Edit Software Hardware Network Tools Help

Operating System

- Software
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Property	Value
Operating System	
Windows 8.1 Pro	
Name	Windows 8.1 (Update) Pro x64
Features	Terminal Services in Remote Admin Mode, 64 Bit Edition, Multiprocessor Free
Edition Type	Professional
Edition ID	[Blue]X18-95588
Key Type	Volume:GVLK
EULA	Volume
SKU	48 [0x30]
Language	English
Safe Mode	No
Activation Status	Activated
License Status	Licensed [Windows(R) Operating System, VOLUME_KMSCLIENT channel]
Genuine	Yes
Remaining Grace Period	23 (169 Days, 23 Hours, 23 Minutes)
Checked Build	No
UAC Enabled	Yes
OS Root	C:\Windows\
Boot Device	\Device\HarddiskVolume1
System Device	\Device\HarddiskVolume2
Kernel Version	6.3.9600.17056
Build Lab	9600.winblue_r3.140827-1500
Build Lab Ex	9600.17328.amd64fre.winblue_r3.140827-1500
Security	256 bits
MMC Version	3.0
Hardware DEP Available	Yes
Automatic Updates	Enabled
Automatic Updates	Enabled
Registration	
Windows To Go	No
Installation Time	2014-12-08 01:31:33
Boot Time	2014-12-18 01:38:45
Up Time	10 Hours 59 Minutes 8 seconds
System Restore	Enabled

NUM

samsung Galaxy Note 10+
SM-N975F

Device	samsung SM-N975F
Model name	Galaxy Note 10+
Resolution	1440x2560
Platform	exynos9825
Android	12
Kernel	4.14.113-24230781 #1 SMP PREEMPT Wed Jun 22 15:32:47 KST 2022
Touchscreen	sec_ts
Accelerometer	LSM6DSO
Als/ps	TMD4910 Palm
Magnetometer	AK09918C
Gyroscope	LSM6DSO
Barometer	LPS22H
Lens AF	AK737X AK737X
Charger	mfc-charger pca9468-charger
PMIC	s2mpb03-regulator max77705
NFC	sec-nfc
Audio	cs35l41 cs40l2x cs35l41 madera
Fingerprint	qbt2000
Wi-Fi	BCM4375B1
RAM	12 GB LPDDR4X

Exynos 9825

CPU	**Exynos 9825**
Vendor	Samsung
Cores	8
big.LITTLE	3 clusters
Clusters	2 x 2.73 GHz 2 x 2.40 GHz 4 x 1.95 GHz
Family	Mongoose-M4 Cortex-A75 Cortex-A55
Mode	64-bit
Machine	aarch64
ABI	arm64-v8a
Instructions	fp asimd evtstrm aes pmull sha1 sha2 crc32 atomics fphp asimdhp cpuid asimdrdm dcpop
Process technology	7 nm
Revision	r1p0 r2p1 r1p0
Clock speed	442 - 2730 MHz
Governor	schedutil
Supported ABI	arm64-v8a armeabi-v7a armeabi
GPU	**Mali-G76**
Vendor	ARM
OpenGL ES	3.2 v1.r32p1-01bet2-mbs2v39_0.131801e953429f661ecce1d5e1d2b3ef
Vulkan	1.1
Extensions	102
Clock speed	325 - 754 MHz

Snapdragon 8 Gen 1

CPU	**sm8450**
Vendor	Qualcomm
Cores	8
big.LITTLE	3 clusters
Clusters	1 x 3.00 GHz 3 x 2.50 GHz 4 x 1.78 GHz
Family	Cortex-X2 Cortex-A710 Cortex-A510
Mode	64-bit
Machine	aarch64
ABI	arm64-v8a
Instructions	fp asimd evtstrm aes pmull sha1 sha2 crc32 atomics fphp asimdhp cpuid asimdrdm jscvt fcma lrcpc dcpop sha3 sm3 sm4 asimddp sha512 sve asimdfhm dit uscat ilrcpc flagm ssbs sb paca pacg dcpodp flagm2 frint i8mm bf16 bti
Process technology	4 nm
Revision	r2p0 r0p2
Clock speed	307 - 2995 MHz
Governor	walt
Supported ABI	arm64-v8a armeabi-v7a armeabi
GPU	**Adreno (TM) 730**
Vendor	Qualcomm
OpenGL ES	3.2 V@0613.0 (GIT@fa3b9353c9, Ib62fda793a, 1647348410) (Date:03/15/22)
Vulkan	1.1
Extensions	104
Clock speed	124 - 818 MHz
Governor	msm-adreno-tz