ARM Processor Evolution: Bringing High Performance to Mobile Devices

Simon Segars EVP & GM, ARM
August 18th, 2011
1980’s mobile computing
HotChips 1981

- 4MHz Z80 Processor
- 64KB memory
- Floppy drives
- 5” screen
- 24.5 lbs
- $1,795
- 11,000 units sold

Osbourne 1 image courtesy of www.oldcomputers.net
Hot Chips 1983

- Motorola DynaTAC
- $3995
- 30 minutes talk time
- 10 hours charge time
- No texting or Bluetooth
30 Years later...

- MacBook Air
- 1.7GHz Processor
- 8GB memory
- 256GB storage
- 13” screen
- 2.96 lbs
- $1,599
Your phone is a lot more useful too

- Samsung Galaxy S-II
- Android 2.3
- 4.3” screen
- 32GB memory
- Web, weather, Angry Birds
- ~\(\frac{1}{20}\) the DynaTAC cost
Connectivity driving computing

Computing Growth Drivers Over Time, 1960-2020E

Source: Morgan Stanley, 2009
Evolutionary Pressures

- Functionality
- Cost
- Form Factor
- Competition
1990-2011
A long time ago in a village far away....

- Acorn, Apple and VLSI formed a joint venture
  - 13 engineers and a CEO

- ARM the company was born
  - 21 years old in November

- Goal to design low power *embedded* 32b processors

- But *never* to manufacture them
1993: An early mobile computer

- 1.4lb
- Personal Applications
- Expansion socket
- Stylus interface
1992: ARM7TDMI – ‘thumb’

- A small, low power 32 bit core for wireless baseband
- 74,000 transistors, 40MHz, 4.2mm² on 0.5µm
Early GSM phone

- 1 week battery life
- Contact list
- Calculator
- SMS
- Snake…
- Not exactly a mobile computer
Evolution
Moore’s law has helped a lot

- **Cortex-M0 Subsystem**
  - Dec 2010
  - Cortex-M0
  - 20nm 8k gates
  - 0.07mm x 0.07mm

- **1985 ARM1**
  - 3μ 6k gates
  - 7mm x 7mm

- **Cortex-A9 SOC**
  - 40nm 100M gates
  - 7.4mm x 6.9mm

- **Mali-400 Dual Cortex-A9 System**
  - IO

**1/10,000th size**
The next decade

There may be trouble ahead....
First the good news

- In 2010 280M smartphones were shipped
- Over 4 Billion people connected via mobile phones
- LTE Deployment starting
- During the 2010 Holiday period $230M was spent on eBay using smartphones
- Over 13 Billion smartphone apps downloaded in 2.5 years
- Smartphones will leapfrog over the PC in the developing world
- Smartphone data traffic will exceed PC traffic in 2014
Smartphone growing and growing

Phase 1
- ARM 926 100 MHz

Phase 2
- ARM 926 200 MHz
- ARM 11 500 MHz

Phase 3
- Cortex-A8 650 MHz
- 2x Cortex-A9 1 GHz
- 4x Cortex-A9 1 GHz
- 2x Cortex-A15 1.5 GHz

Source: Gartner Q4 2010 Forecast

The Architecture for the Digital World®
The “Superphone” for 2013

**Device Vision**
- Your primary internet access device
  - Always connected broadband
- Enough compute power to replace your laptop
- Your content with you
  - From HD to MP3 with cloud access

**Enabling Technology**
- Multi-core processor
- Multi-core graphics processor
- Multi-core coherency
- 28nm implementation
- Security solution

**Visual Experience**
- 12+MP Camera
- 1080p playback and capture
- 128 Gbyte of storage
  - 45 hours of 1080p video
- HDMI video out

**Applications**
- Full browser with HTML v5 & Flash Player
- New UI paradigms
  - Voice, gestures, Augmented Reality supported by OpenCL
- Full ‘office’ support
- Vibrant applications market
- HD Gaming on device or screen
Another 1Bn sub $100 Computers

1+ Billion Opportunity

- Consumers, OEMs & MNO all want smartphones
- Emerging markets to bypass the PC
- Full internet connectivity
- Growth controlled by retail price, target $100-$200
- Requirement beyond ARM11™ performance

Device Features

- Full Android™ OS
- Access to full range of apps in Google Marketplace
- Full browser
- Flash Player 10 support
- Full HTML 5 support
- 3D UI accelerated with OpenGL® ES 2.0

Access to full range of apps in Android Marketplace
A whole lot of software

Application diversity delivers the personalized compute experience

- Apps & App Stores
  - 100,000’s of Apps
  - 15+ Billion Downloads

Full connectivity to the Internet and the Cloud

- Web Technology support for all standards
  - Flash Player 10
  - AIR
  - <HTML> v5
  - Webkit
  - Internet Explorer
  - Google Chrome
  - Mozilla Firefox

Diversity and rapid mobile OS innovation

- Operating Systems innovating on a 6-12 month period
  - BlackBerry
  - Palm webOS
  - Windows Phone
  - LiMo Foundation
The center of your world
TrustZone in 3 Steps

1. Define secure hardware architecture
   - Two separate domains: - normal and secure
   - Extends across system:
     \[\text{Processor, display, keypad, memory, clock, radios}\]

2. Implement in silicon system on chip (SoC)
   - Physically enforcing secure/normal separation

3. Combine SoC with Secure OS
   - Separate but connected to main operating system

Result: A Trusted Execution Environment
   - Ready to develop and deploy trusted services
But there are challenges

- Modems
- Implementation
- Battery scaling
- Transistor scaling
Modem relative performance

- 4G modem ~500x more complex than 2G
  - Control processor
  - Dedicated data processing engines
  - More silicon area
  - More power consumed
Batteries haven’t helped

- Historical 11% capacity growth
  - Not well matched to Moore's Law
- Continued innovation required just to maintain 11%
  - New Si alloy materials or anode Carbon Nano Tubes may help

Assuming 12 hours of use per day

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<td>3-day life</td>
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Assuming 12 hours of use per day
Challenge: Implementation Complexity

- **ARM7TDMI**
  - 74K transistors
  - 4.2 mm² in 0.5µm technology
  - Largely hand-designed
  - 3 corners, 1 voltage domain

- **Cortex-A9 MP Dual Core**
  - >20M transistors
  - 3.4 mm² in 28nm technology
  - Complex timing sign-off
  - 12+ corners, 3 voltage domains
  - DFM, Variation modeling, …
Disaggregation – pros and cons

- **1970s**: Fully Vertically Integrated
  - Vertical Suppliers
  - System Manufacturer
  - ASIC Vendor

- **1980s**: ASIC Vendors
  - Design & Distribution

- **1990s**: Fabless Semis
  - EDA
  - Manufacture

- **Today**: IP Driven Design
  - Design
  - IP
  - EDA
  - Manufacture
  - Foundry

The Architecture for the Digital World®
Fabs: not as popular as they used to be

Altis Semiconductor
Dongbu Hitek
Freescale
Fujitsu
Globalfoundries
Grace Semiconductor
IBM
Infineon
Intel
Panasonic
Renesas (NEC)
Samsung
Seiko Epson
SMIC
Sony
ST Microelectronics
Texas Instruments
Toshiba
TSMC
UMC

130nm
90nm
65nm/55nm
45/40nm
32/28nm
22/20nm
Device Scaling

65nm

40nm

Strain

High-K

32nm

28nm

20nm

2x Patterning

14nm

3x Patterning?

10nm

EUV??

8nm

???

?nm
Think different!

- Web
- Video
- Audio
- 5G
- WiFi

Multi-Gx
Multi-CPU
Hardware
CPU-Audio
Modem
Modem

Application
Kernel

Platform
Runtime
Object
Compiler
Advanced Processing

Cortex-A15 for High-end, power-efficient processing

- 15-Stage Integer Pipeline
- 2 extra cycles for multiply, load/store
- 2-10 extra cycles for complex media instructions

Integer pipeline

Fetch  Decode Rename Dispatch

5 stages  7 stages
Cortex-A15 System Scalability

Introduces Cache Coherent Interconnect

- Processor to Processor Coherency and I/O coherency
- Memory and synchronization barriers
- Virtualization support with distributed virtual memory signaling

Quad Cortex-A15 MPCore

A15 A15 A15 A15

Processor Coherency (SCU)
Up to 4MB L2 cache

128-bit AMBA 4

CoreLink CCI-400 Cache Coherent Interconnect

Quad Cortex-A15 MPCore

A15 A15 A15 A15

Processor Coherency (SCU)
Up to 4MB L2 cache

128-bit AMBA 4

GIC-400

IO coherent devices

MMU-400

System MMU
**Fully coherent SoCs**

### 2011 Devices
- Full coherency within CPU cluster
- Limited I/O coherency
- Software managed coherency for SoC

### 2013 Devices
- Full coherency for multiple CPU clusters
- I/O coherency with graphics and other
- Simpler software programming model

### 2015 Devices
- Full coherency on CPU, GPU and other
- True General Purpose Compute

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**2011 Devices**

- **Applications Processor**: 2x or 4x Cortex-A9
- **Graphics and Video**: Mali-400 Video
  - Fully Coherent
  - Non-coherent or Software Managed

**2013 Devices**

- **Applications Processor**: >4x Cortex-A15
- **Graphics and Video**: Mali-T604 Video
  - Fully Coherent
  - I/O Coherent

**2015 Devices**

- **Applications Processor**: Next generation Compute cluster
- **Graphics and Video**: Next Gen Video
  - Fully Coherent
The holistic SoC Designer

Architecture

Implementation

IP Driven Design
Design
IP
EDA
Manufacture
Foundry
Conclusion

- 30 years have delivered incredible gains
  - Mobile computing now ubiquitous
  - Smartphones, Superphones, Tablets

- Silicon scaling has driven PPA gains
  - But it has to end somewhere, so get ready!

- The future is Heterogeneous
  - Multi-core CPU, multi-CPU, dedicated engines

- A new battery would help too!
Thank you.