# The 2015 International Symposium on Highly Efficient Accelerators and Reconfigurable Technologies

Boston, MA, 1-2 June 2015

## Keynote: Computing in the IoT Era, Opportunities and Challenges

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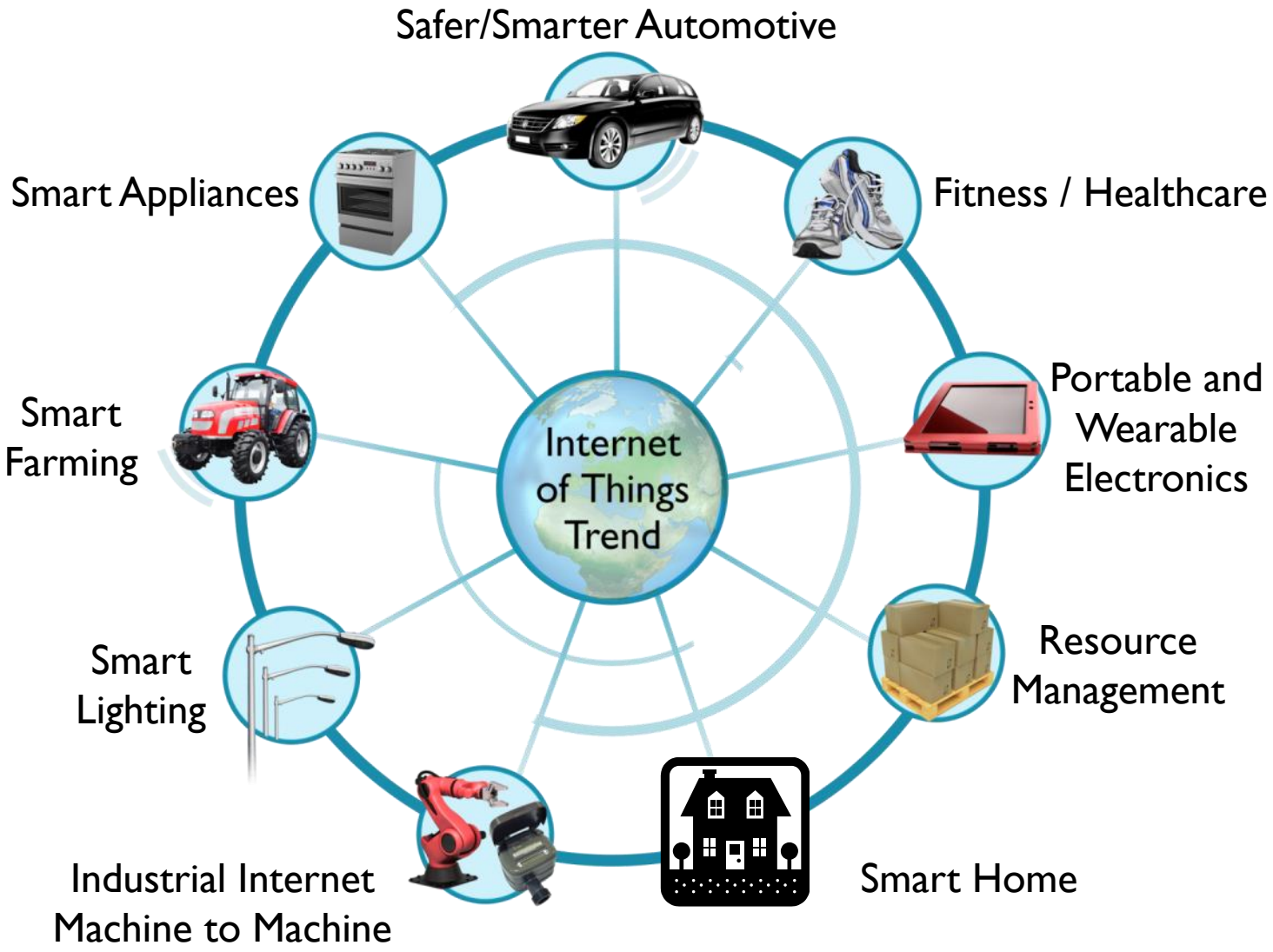
# Outline

- Introduction to IoT
- Architectures and Technologies, Challenges and Opportunities
  - Hardware, Software, Tools
- The ARM Ecosystem Contribution
  - Hardware, Software, Tools, Education
- Conclusions

# Introduction to the Internet of Things (IoT)

# Internet of Things (IoT)

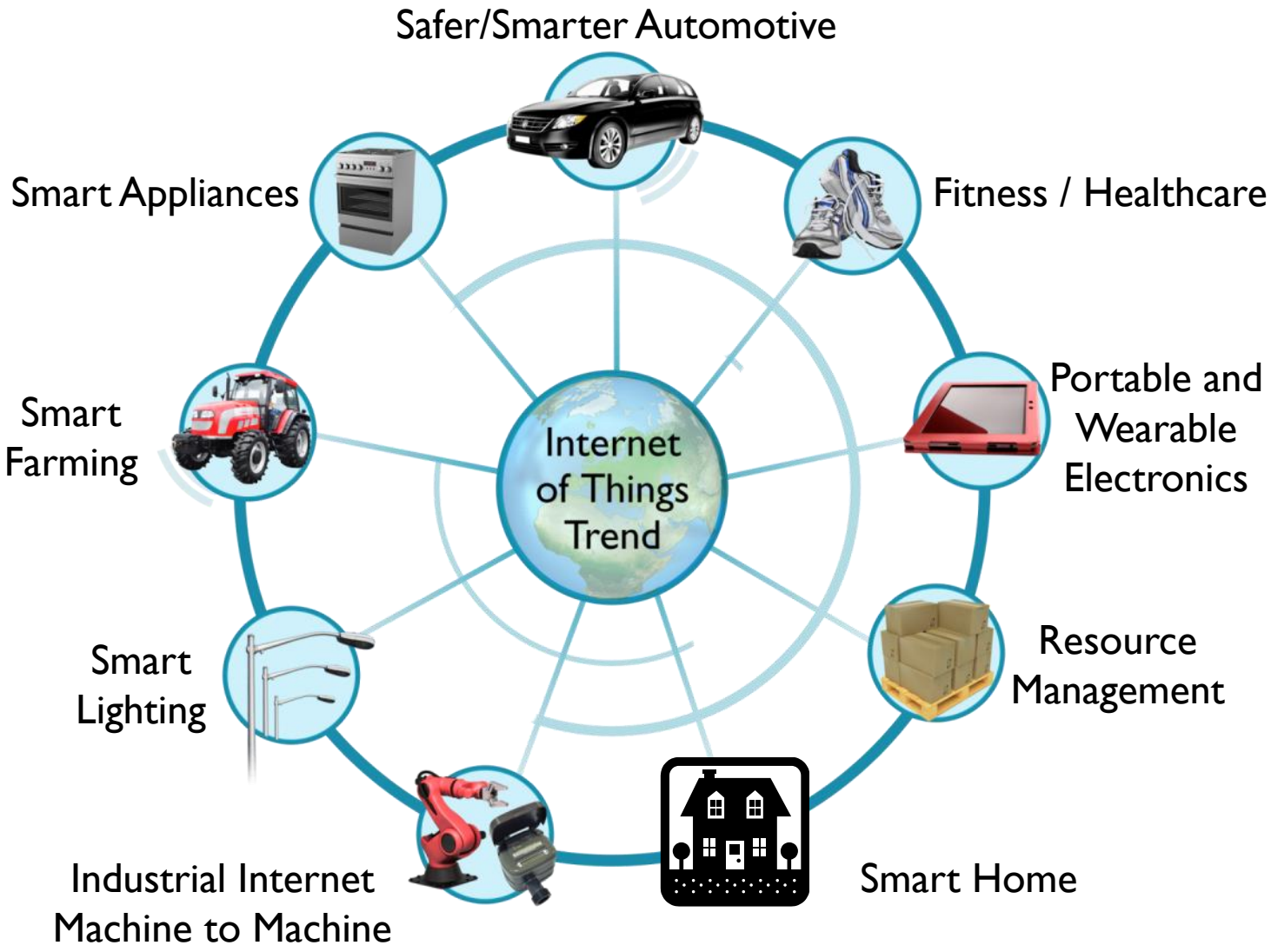



## What is it?

- "*The Internet of Things (IoT) is the interconnection of uniquely identifiable embedded computing devices within the existing Internet infrastructure.*" wikipedia.org

- Buzzword, trend, convenient categorisation, industrial and consumer

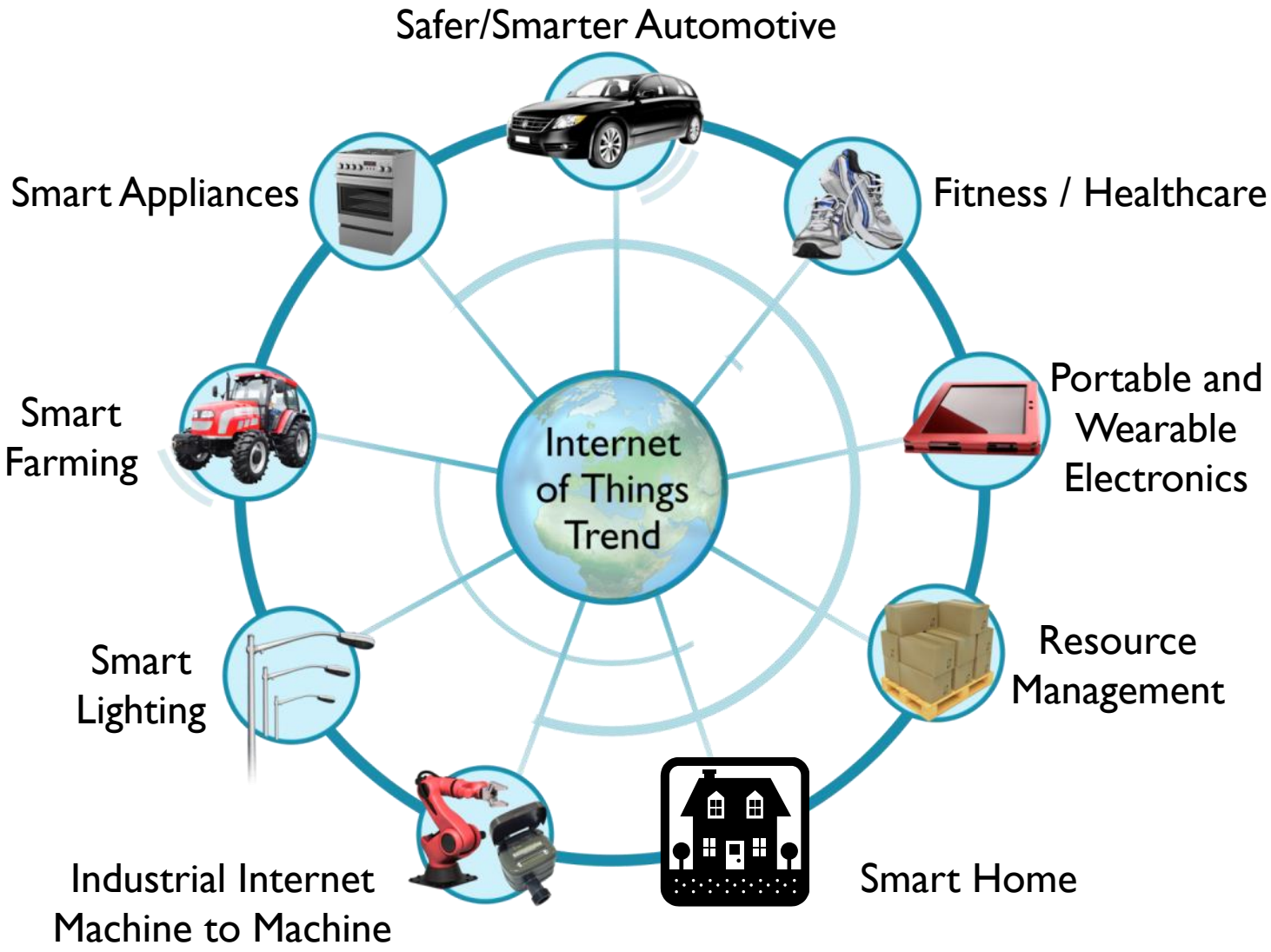
# Internet of Things (IoT)




## Why Now?

- Embedded chips are becoming:
  - Cheaper (<50c)
  - Smaller (<1mm$^2$)
  - Lower power (µW)
  - Commoditised HW and SW
- Communication is growing faster (broadband)
- New socio-economic demands (globalisation, competition, mobility)

# Internet of Things (IoT)




## Socio-Economic Benefits

- Automation (higher productivity)
- Smart monitoring, control and maintenance (higher efficiency, lower cost, higher quality, better optimisation/outcomes)
- Better safety (early warning)
- Higher responsiveness (dynamic response to varying demands)
- Huge and varied applications in industry, agriculture, health, transport, infrastructure, smart living, consumer etc.

# Architectures and Technologies, Challenges and Opportunities

# Things, the Internet and Cloud Services


People Things

- Integrated sensors, memory and processing
- Low power systems
- Little Data

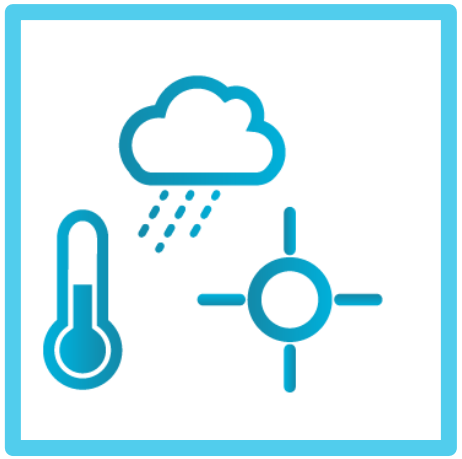
The Network

- High throughput networks
- Low power wireless networks

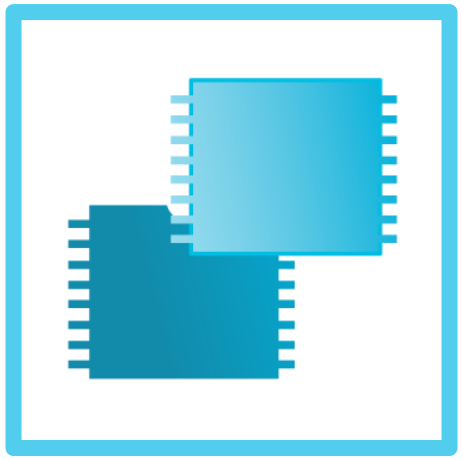
The Cloud

- High performance efficient servers
- High capacity storage
- Software as a service
- Big Data

# Things: Basic Building Functional Blocks



Sense



Compute

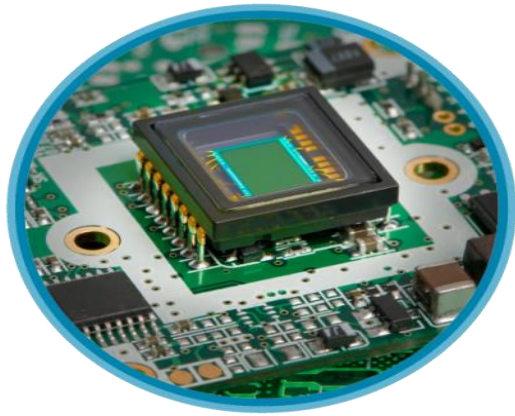
Control


Store

Communicate

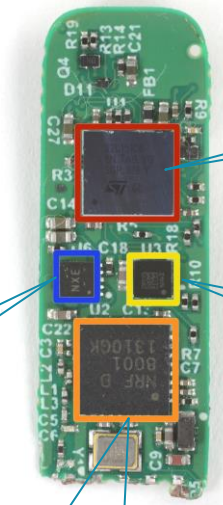
# Things: Technologies

- Sensor(s) e.g. MEMS-based accelerometers or pressure sensors
- Micro-control/processing: sleep, wake up occasionally e.g. in response to interrupts, do some task, sleep again:
  - Minimize energy
  - Efficient power down and wake-up modes
  - Interrupt based processing,  long standby
- Memory / Storage
  - SRAM, Embedded Flash
- Communicate
  - via RF e.g. WiFi, 6LoWPAN, Zigbee, BLE → RF/Analog + baseband modem
  - Wired comms e.g. IPv4/6 → Analog + baseband modem
- Software stack
  - Might involve an operating system
  - Standards for higher Interoperability
  - Code reuse for higher productivity
  - Maintenance of software after deployment e.g. field upgrades (OTA)
  - Security



Leaf Nodes

# Things Today: Example



Host MCU
(inc. Flash, RAM, ADC)

MEMS Sensor
(Accelerometer)

Charger

Radio (inc. CPU)

# Things: Challenges

- Limited Energy Budget
  - Long battery life is a must: can be as long as years (instead of days or hours)
  - Delivery (battery, harvesters)
- Cost (NRE, Volume)
  - Cost matters – critical to market size which in turn impacts cost
- Security – protect against hacking
- Privacy – who's data is it?
- Seamless – standards to create/support an ecosystem and interoperability
- Simple – easy to install by "ordinary" members of the public
- E-waste management

# Things: The Energy/Power Challenge


2600mAh

~5W

12 hours


300mAh

~50mW

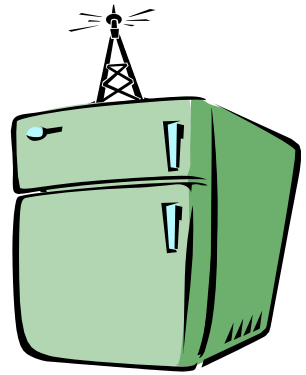
1 Week

14X Battery life!

# Things: The Security Challenge

- A serious security breach could limit market growth
  - Published examples of simple hacks to security cameras
  - "Weakest link" approach
  - With internet, a few lions can do a lot of damage…
- Vulnerability to attack means even simple devices will need to be protected
- Minimal requirements
  - Encryption capability
  - Trust management
  - Secure design practice

# Things: The Privacy Challenge – Data Ownership



My Data

Their Data

Me

Gym

Life Insurance

Coupon Companies

X

X

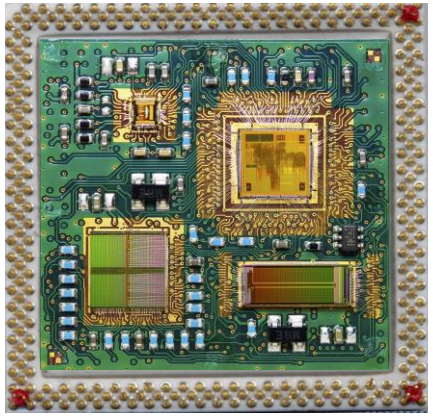
!

!!

**What about Government?**

# Things in the Future: Integration and heterogeneity

- IoT Processor die
  - Multiple CPU sub-systems (apps intelligence, sensor hub, comms protocols)
  - eNVM, RAM (universal memory?)
  - ADC, DAC, various I/Os, power regulation, energy harvesting
- MEMS-based sensors - die or chip
- Radio die
  - CPU for baseband modem plus RF/Analog, multi-standard, SDR
- Other discrete components
- Many design variations



# The Network and the Cloud

# Data - Trends

18x

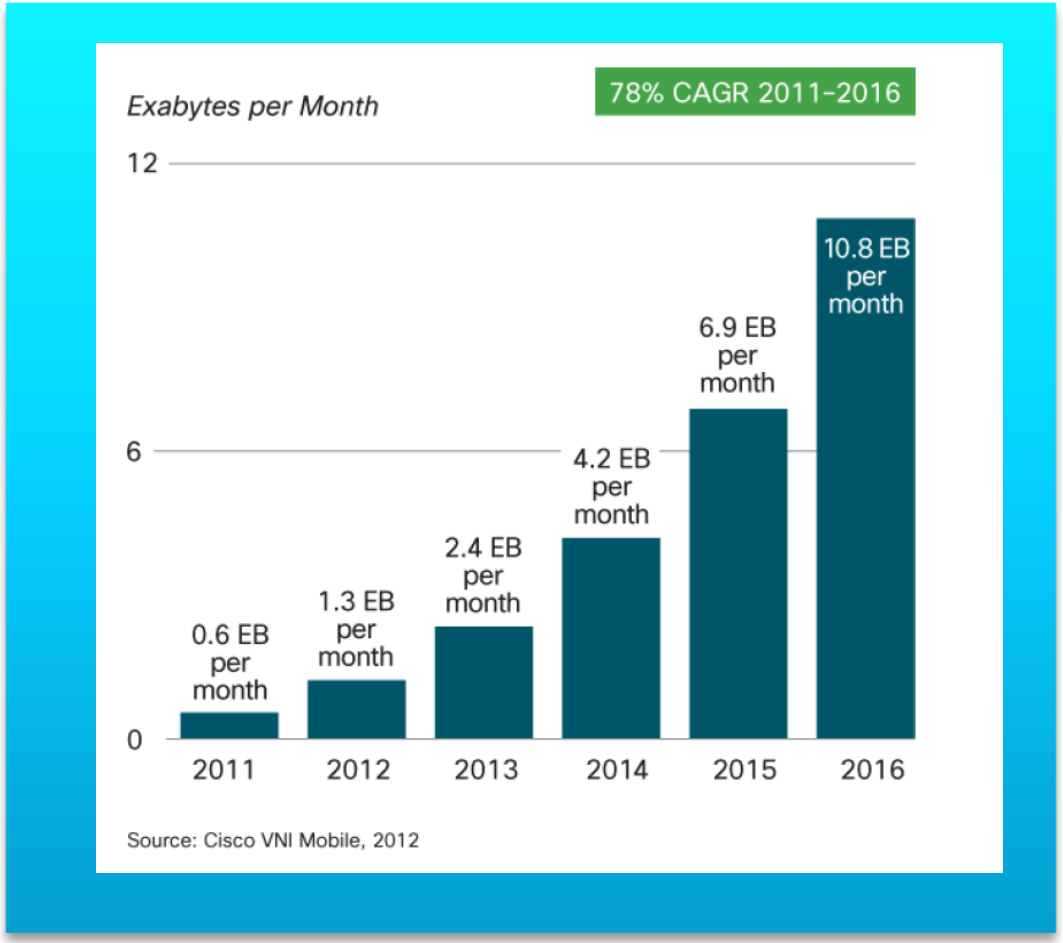
Data traffic increase on mobile networks 2011-2016

107% — LTE Capex CAGR 2010-2014

86% — Operator energy budget used by the network

60-80% — Network energy consumption attributable to base stations

Cisco Systems, ISuppli, NSN, IEEE



# Infrastructure Trends

Macro

4G
2016

Micro

3G

Small cell

- Heterogeneous form factors
- Rapid deployment of new services
- Server capacity at edge
- Scalable processing
- Open software platforms
- 3m small cells forecast (2016)

# Cloud growth

**Majority of IT decision makers plan to move Storage, Web/Email to the cloud ***

**End User spending on public cloud in 2015 $150 B ****

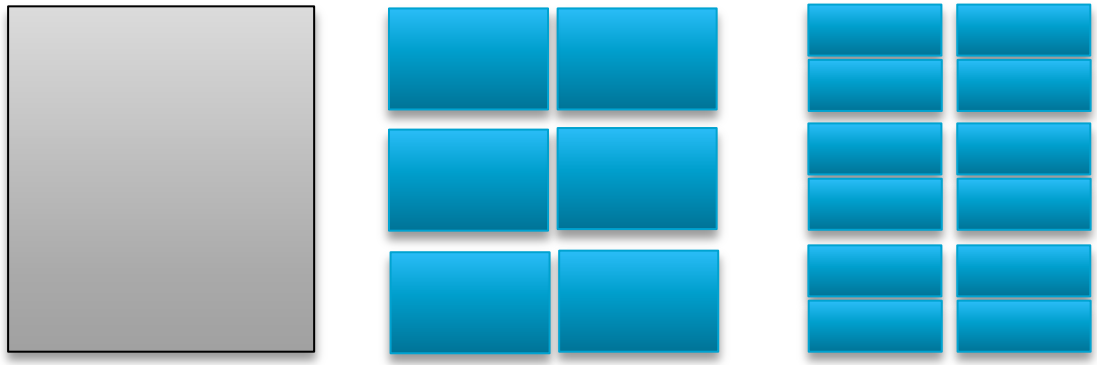
**Cloud Equipment spend in 2018 $79.1 B *****

*Source: Cisco Global Cloud Networking Survey 2012
**Source: Gartner as published in information Week July 2013
***Source : Seagate as published in Silicon Angle June 2013

# Data Center Workload Characteristics are Evolving




Data center workload characteristics are scaling out

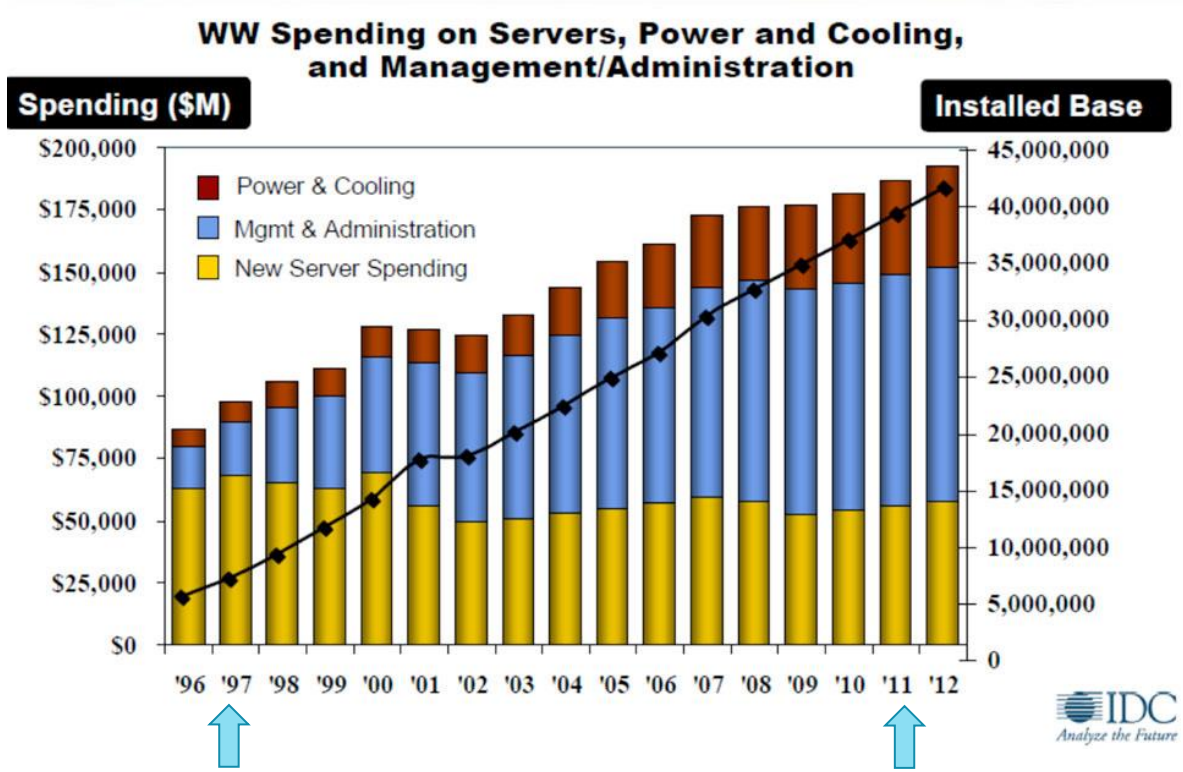


Throughput

Workload optimized

Total cost of ownership

# Trends in Power and Cost of Data Centers




P&C cost % of initial capex = 10%

P&C cost % of initial capex = 75%

# Enterprise Trends

- IT is the business
- Estimated 20x increase in network traffic
- Density, power and cost over raw perf.
- One size no longer fits all - heterogeneity
- Optimized highly integrated SoCs
- Open source and end user S/W

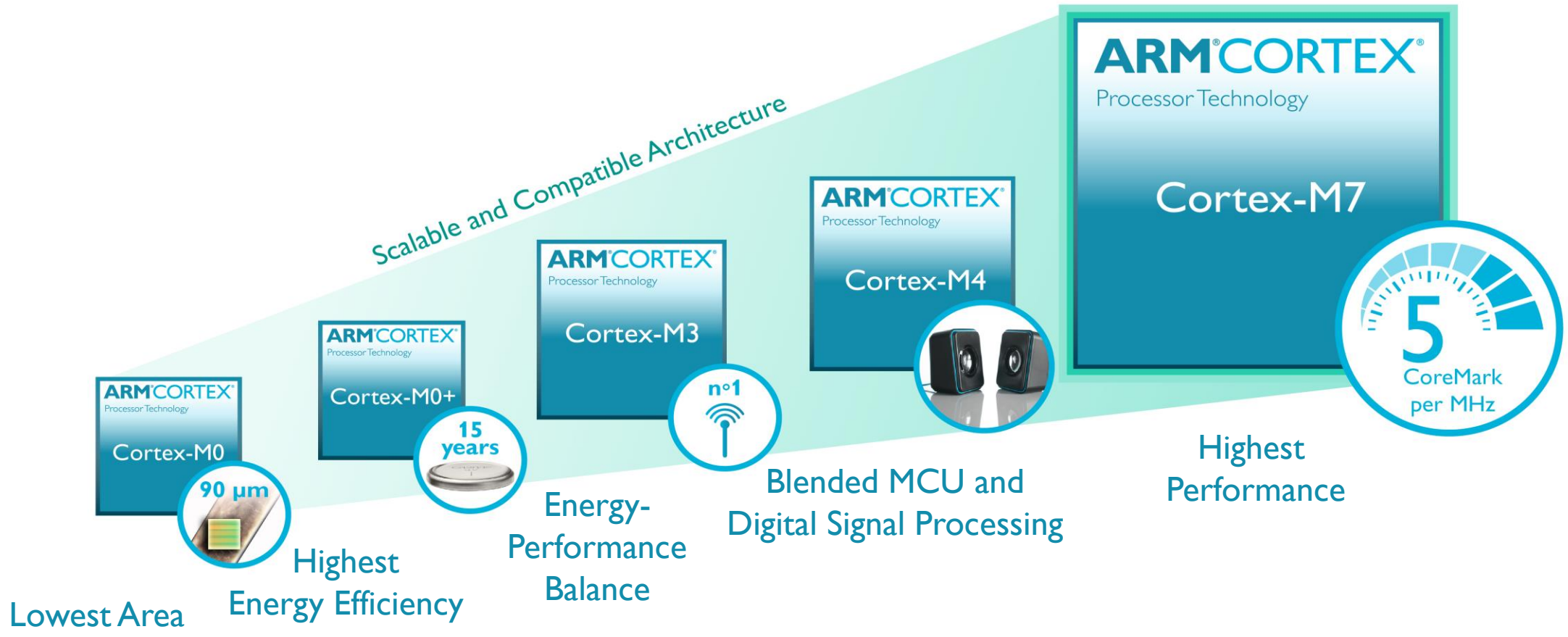
# The ARM Eco-System Contribution

# ARM in Embedded Intelligence

# ARM Cortex-M0/M0+

- The ARM Cortex-M0 processor is the smallest and more power efficient ARM processor (12 K gates in its smallest configuration)
- Yet it is a 32 bit processor capable of over 1 DMIPS per MHz performance
- Cortex-M0 based microcontrollers are manufactured by many ARM licensees e.g. STMicroelectronics, NXP, Freescale
- Development boards are available at low prices (as low as ~$10 USD)
- The Cortex-M0 DesignStart is a synthesizable softcore IP delivered as a gate-level Verilog model of the ARM Cortex™-M0 processor (can be used for FPGA and ASIC prototypes)

# Taking Embedded Intelligence to the Next Level : Scalable and Compatible Architecture



# ARM® mbed™

mbed.org

**100,000+**
developers

**8+ years**
of IoT server and 6LowPan products


**1,000,000+**
project builds last year

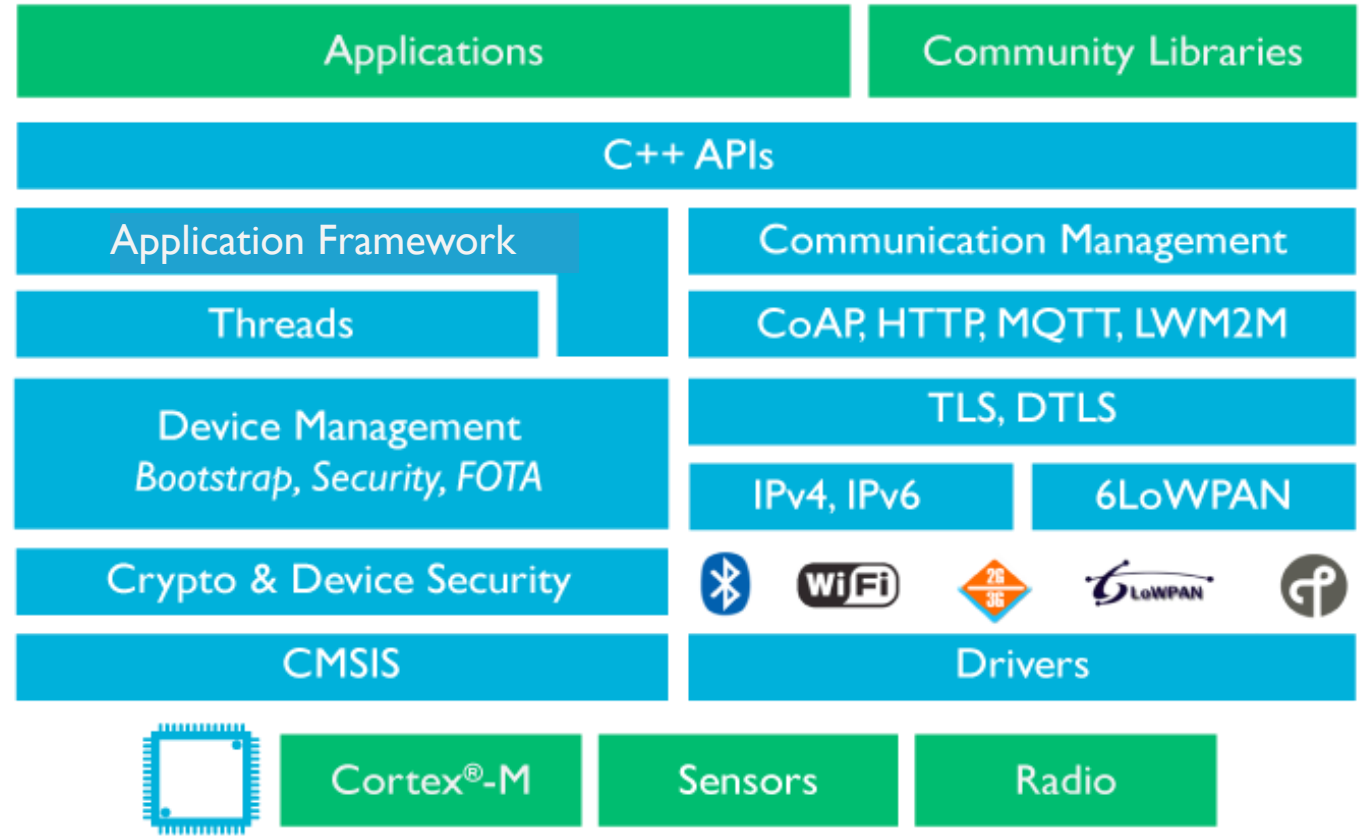
**30+**
official boards

**9,000+**
published projects

**5+ years 24/7**
service operation

# mbed OS

- Minimize time-to-market
- Low-power by design
- Complete security solution
- Top connectivity standards
- Built-in device management

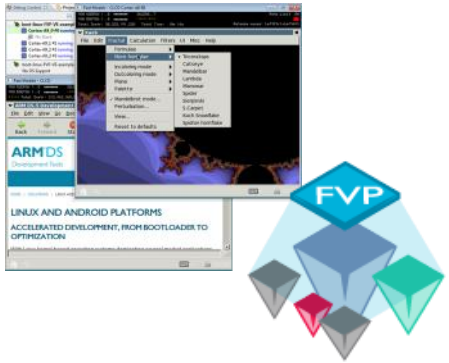


# Developers & Development Tools

RTOS | Network | USB Host | File System | USB Device | Graphics

## Middleware

Software Building Blocks



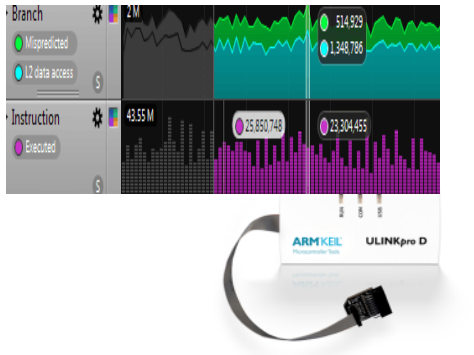

## Fast Models

Fixed Virtual Platforms
Fast Models

TÜV SÜD ISO 9001

## Compiler

Best in Class Technology
Qualification Kit
Roadmap for LLVM
Embedded




## Debug

Performance Analysis
Streaming Trace
Code Coverage

ARM® KEIL®
Microcontroller Tools

ARM® DS
Development Tools

# Ecosystem and Tools for Embedded Market

- 30+ Real-time Operating Systems
- 13+ IDEs and C/C++ compilers
- 21+ Debug systems

- Graphics & UI
- DSP and Security
- Media processing

**16 Billion**
Units Shipped to date

**230+**
Licences

**3000+**
Parts

# ARM in Mobile

# Trends Driving the Growth in Mobile

- Fast migration of features across smartphone segments
- Higher performance in power and thermal envelopes
- Partnership addressing system and software complexity
- Heterogeneous Computing (App  processors + GPUs)

# ARM® Cortex®-A Current Portfolio

2H 2014


A


ARMv7-A
High performance
32-bit CPU with
enterprise class
feature set


ARMv7-A
High performance
32-bit CPU with
lower power and
smaller area


ARMv8-A
Highest performance
64/32-bit CPU

High Performance


ARMv7-A
Smallest and
lowest power CPU


ARMv7-A
High efficiency
32-bit CPU
big.LITTLE™ compatible


ARMv8-A
High efficiency
64/32-bit CPU
big.LITTLE compatible

High Efficiency

# Driving Power Savings and Performance with big.LITTLE™ MP

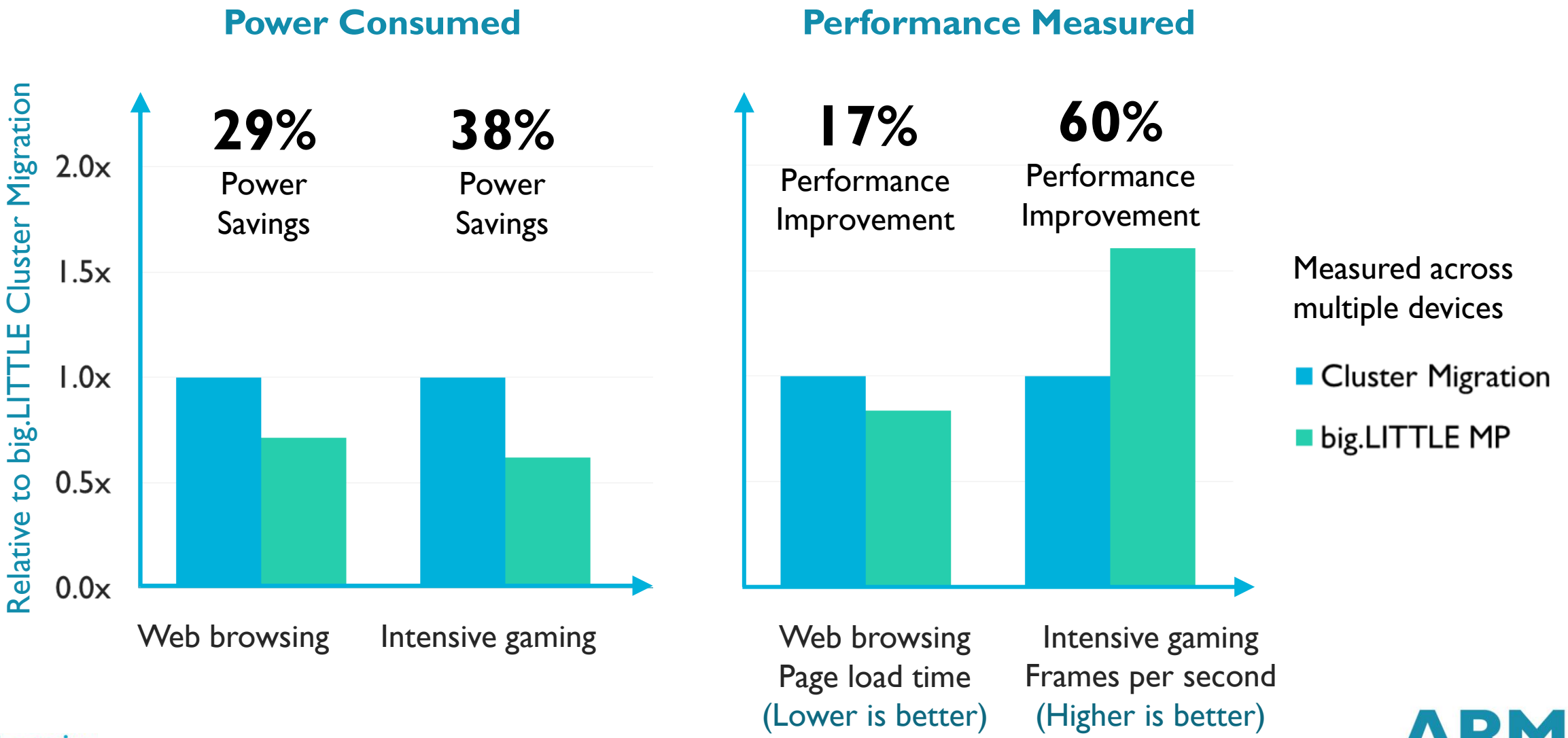
2013

big.LITTLE Cluster Migration

2014

big.LITTLE MP

# Increasing Power Savings and Performance with big.LITTLE MP



# Extending big.LITTLE MP for Thermal Management

## Traditional Thermal Control

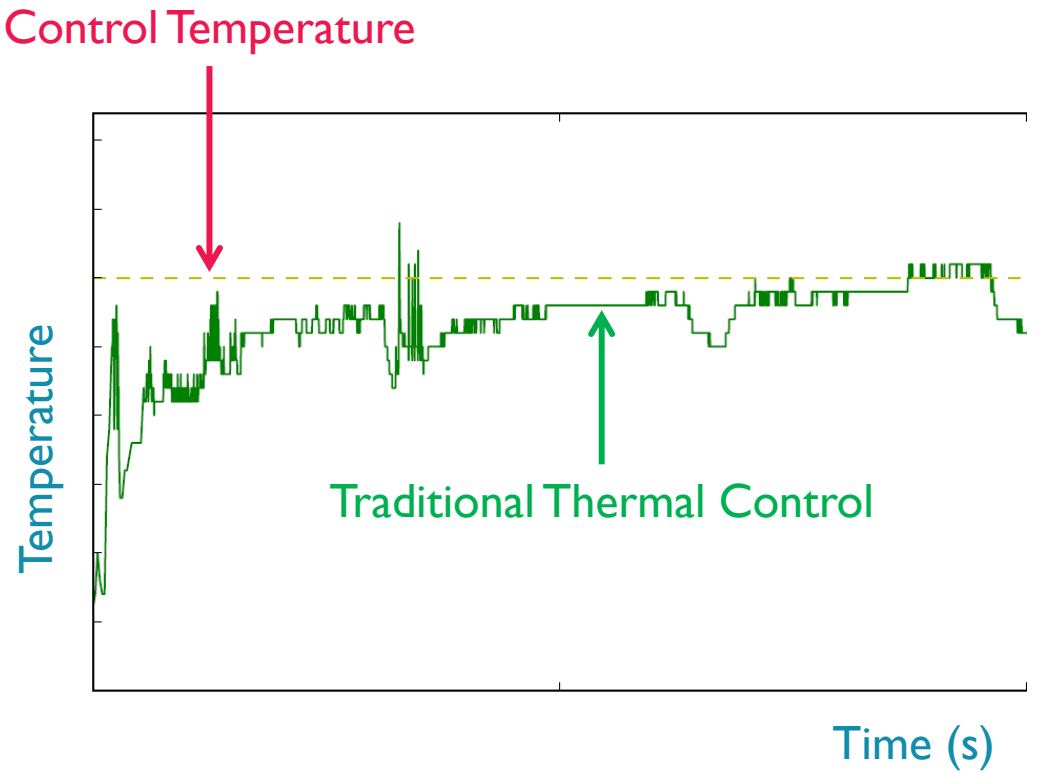
Linux Kernel Scheduler

Performance Monitor

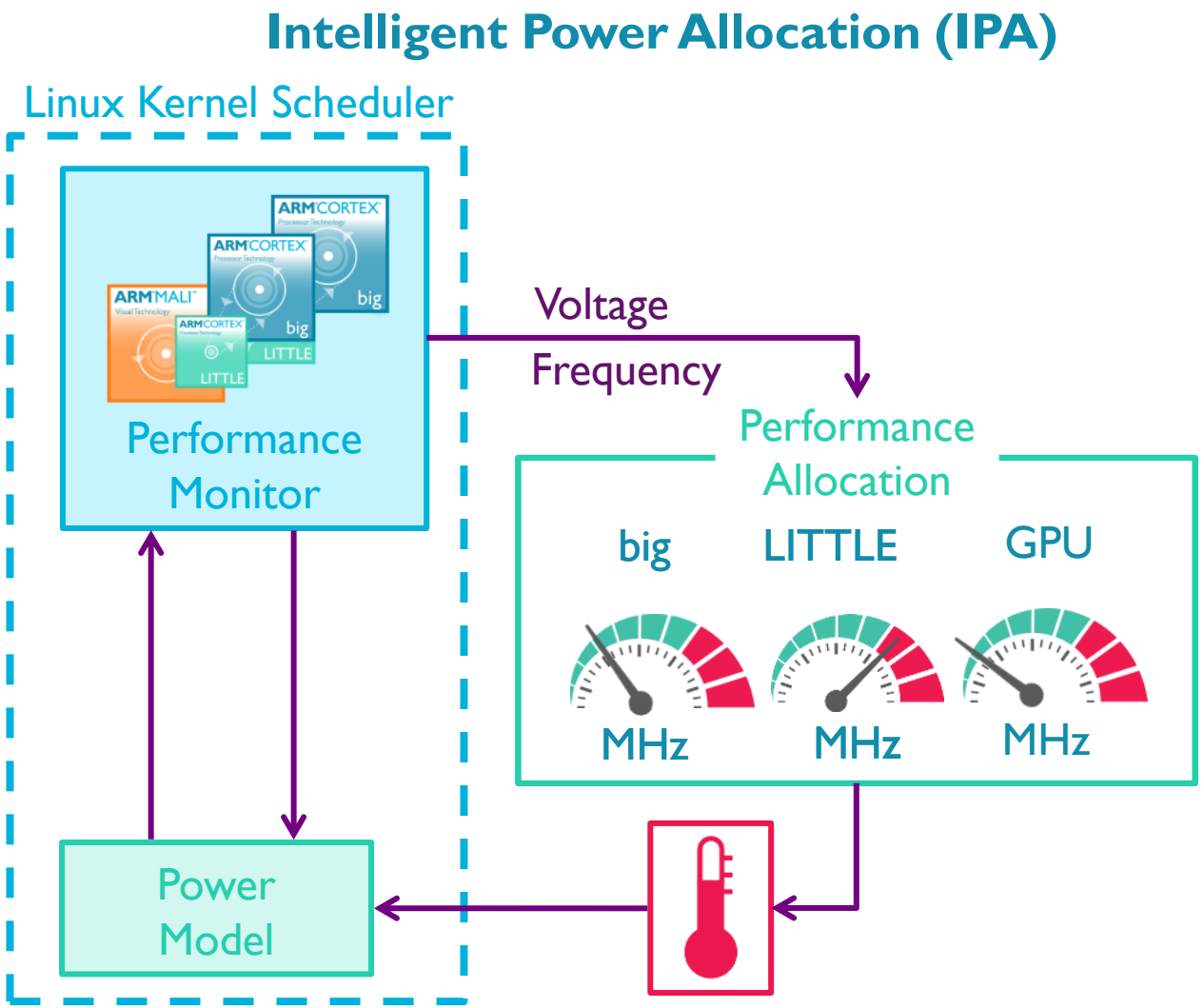
Performance Allocation

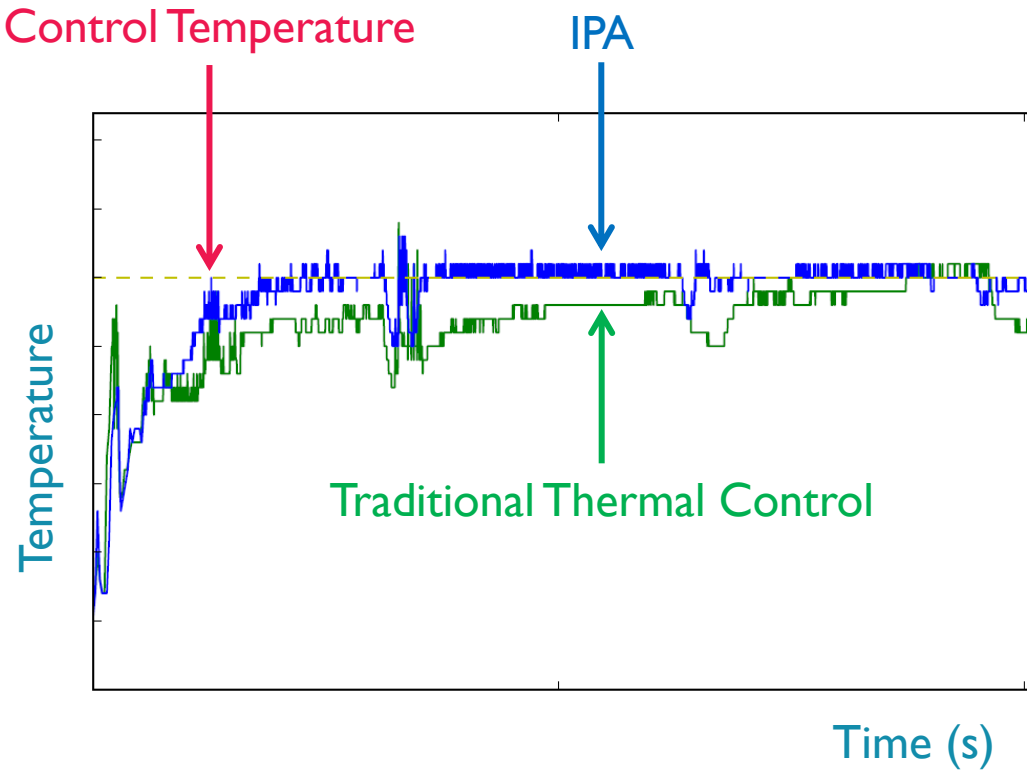
big LITTLE

MHz MHz



# Extending big.LITTLE MP for Thermal Management

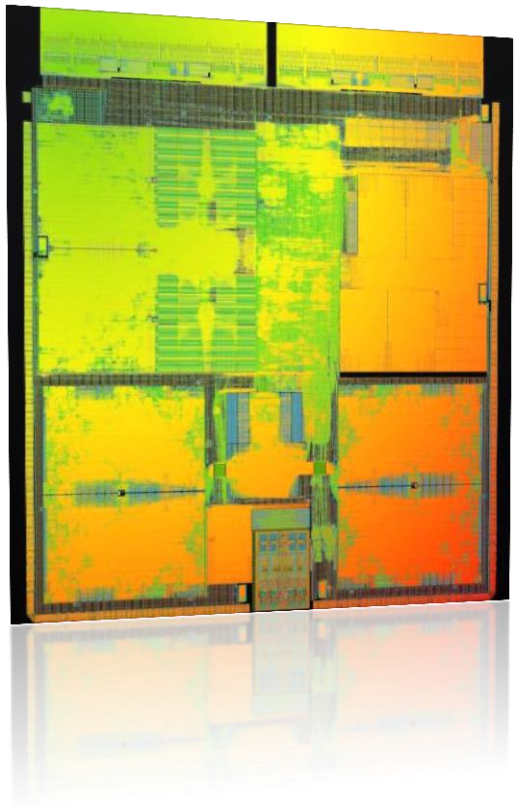


# Juno – The First ARMv8-A 64-bit Software Development Target

**Juno**
Premium ARMv8-A software target platform

Integrated and fully validated ARMv8-A IP



32-bit Apps

64-bit Apps

Android L (developer preview) release with Android Open Source Project

Mali Drivers

Linux Kernel + big.LITTLE MP + IPA

ARM Trusted Firmware

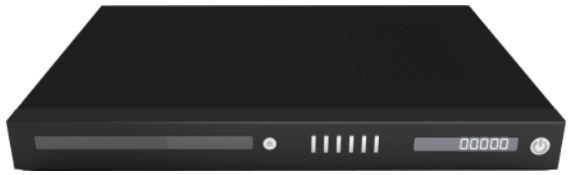
Cortex-A57 MP2
Cortex-A53 MP4

Mali-T624 MP4

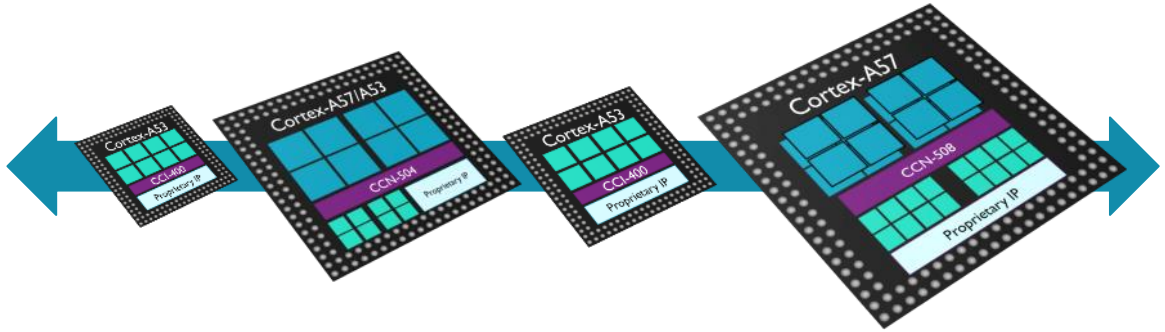
# ARM in Networking and Servers

# Content in the Cloud Drives Intelligence in the Network

Wide range of network performance and intelligence behaviors



STB



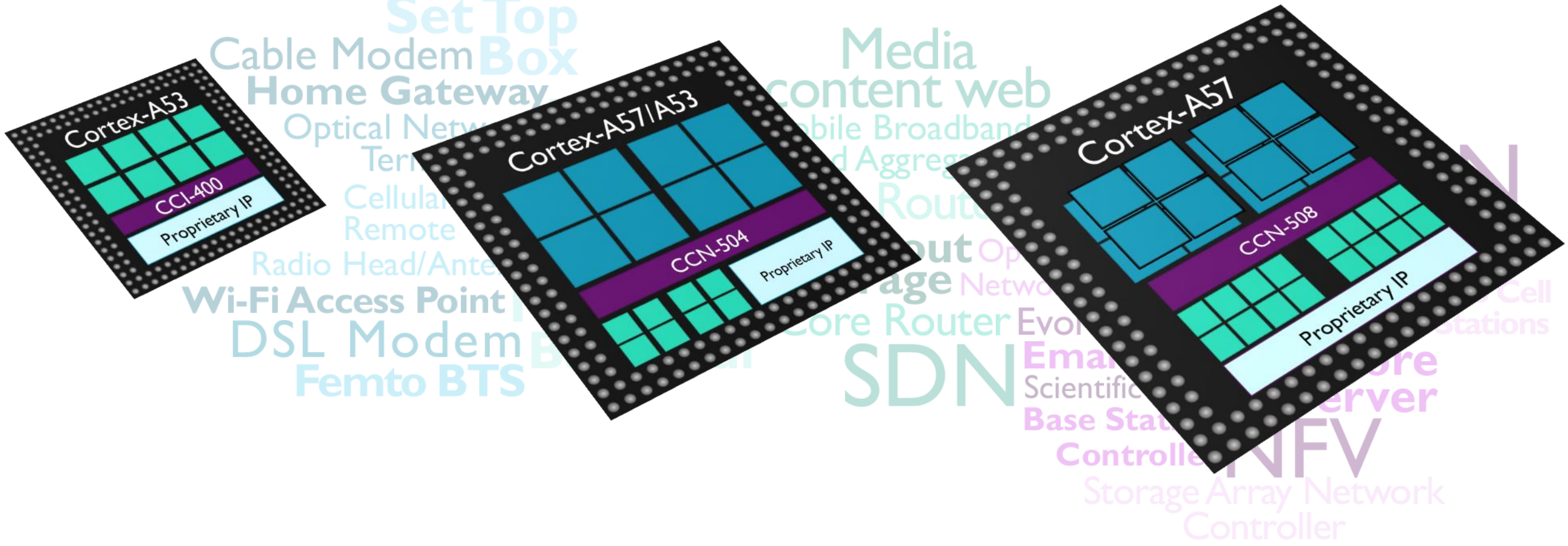


Display Clients

Rendering moving into network
for greater UI possibilities

Content moving closer to user for better performance

# Scalable Platform for Diverse Processing Needs



# HPC using ARM Cortex-A Processors

- Mobile processors have qualities that make them interesting for HPC
  - FP64 capability
  - Performance increasing rapidly
  - Large market, many providers, competition, low cost
  - Embedded GPU accelerator

- ARM-based servers are now a reality, not a concept or dream
  - ARMv7 (32bit) based systems shipping
  - ARMv8 (64bit) based systems also shipping e.g. HP Moonshot
  - ARM-based SoCs optimized for specific workloads
  - Rapidly growing eco-system

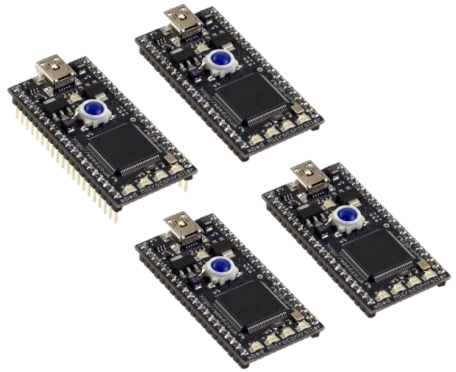


# Education

# Education : The ARM University Programme

## Flagship Product: The ARM Lab-in-a-Box

**HARDWARE + SOFTWARE (MDK Pro or DS5 Pro) – 100 floating licenses + TEACHING MATERIAL**




ARM DS
Development Tools

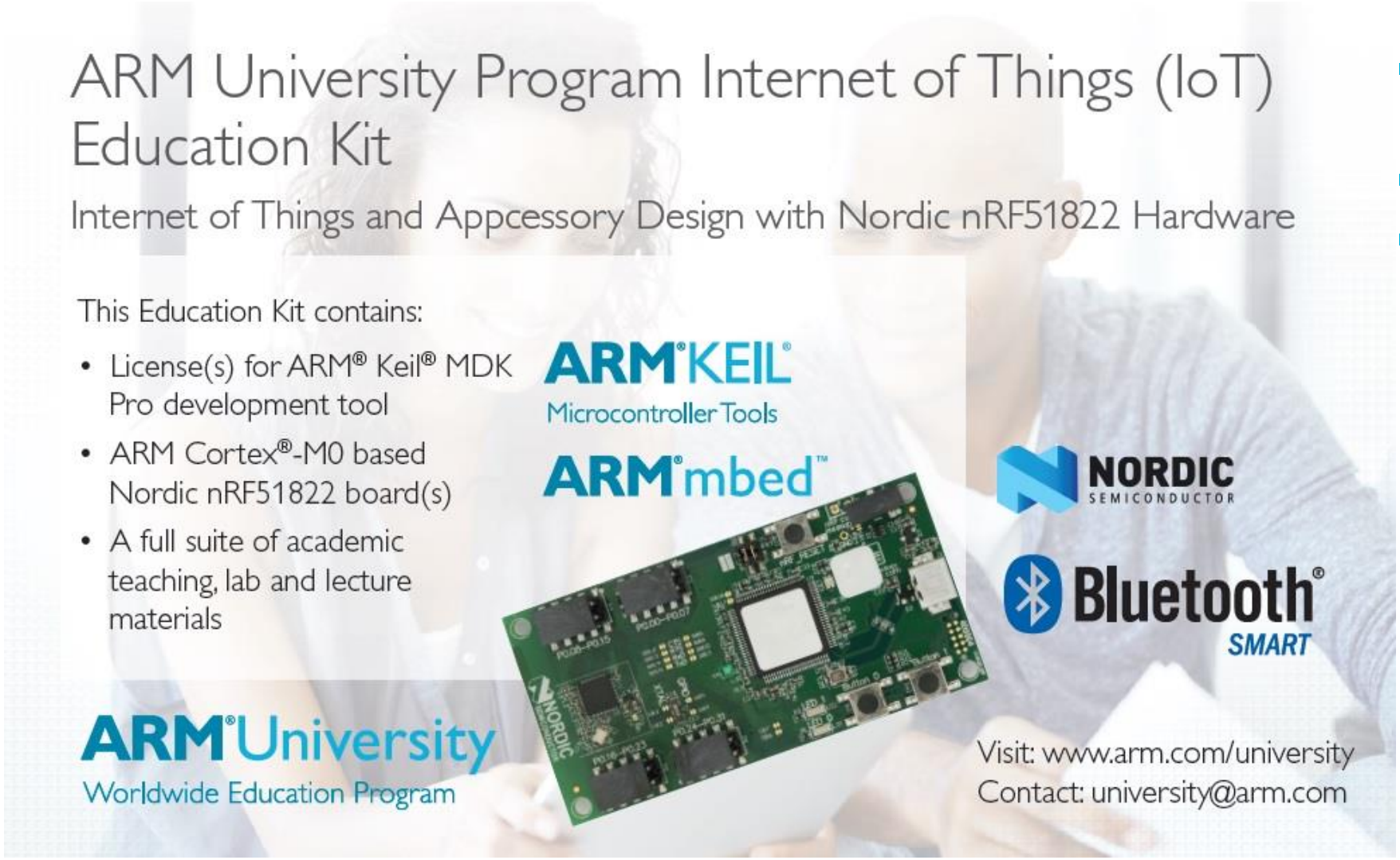
+ 1-day Professor workshops

**All Free of charge to Academia worldwide**

# Guiding Principles

- Cost of ownership of necessary hardware and software to students less than the typical cost of a textbook (<£50 in EU/US)
- Convenient access (harness the internet for deployment)
- Make the material fun and interactive e.g. use games, multimedia
- Deep learning - link theory to practice
- Offer solutions to problems/labs only to professors (only a subset is available directly to students).
- Train professors and help them tailor material to their own needs e.g. through Professor workshops
- Reuse the same hardware for as many courses as possible –> Full Education Kit

# Internet-of-Things (IoT) Lab-in-a-Box or Education Kit, with Nordic Semiconductor's nRF51822 board




- Smartphone App development
- Bluetooth LE connectivity
- Cortex-M0 based nRF51822 board from Nordic Semiconductor with
  - 256kB/128kB flash + 32kB/16kB RAM.
  - Embedded 2.4GHz transceiver supports both Bluetooth LE and the Nordic Gazell 2.4 GHz protocol stack

# Internet of Things (IoT) Lab-in-a-Box

| Segment | Module | Lecture Note | Lab Exercise | Lab Code | Code Solution |
|---|---|---|---|---|---|
| Introduction | 1. Introduction to Internet of Things | Presentation | | | |
| | 2. ARM-based Embedded System Design | Presentation | | | |
| Embedded Programming | 3. ARM Cortex-M0 Processor –Part1 | Presentation | Getting Started with Keil MDK<br>Programming Cortex-M0 in Assembly using Keil MDK | Lab Code - Square Root | Code Solution - Square Root |
| | 4. ARM Cortex-M0 Processor – Part2 | Presentation | Programming Cortex-M0 in C using Keil MDK | Lab Code - LED | Code Solution - LED |
| | 5. Interrupt and Power Consumption | Presentation | | | |
| | 6. ARMv7 Architecture | Presentation | | | |
| Mobile Computing | 7. ARM Cortex-A9 processors | Presentation | Getting Started with ARM DS-5<br>Simple Cortex-A9 Programming using DS-5 | | Code Solution - DS5 |
| | 8. Smartphones and Appcessory Programming | Presentation | Design a Basic Mobile Appcessory | Lab Code - Android | Code Solution - Android |

# Internet of Things (IoT) Lab-in-a-Box

| Segment | Module | Lecture Note | Lab Exercise | Lab Code | Code Solution |
|---|---|---|---|---|---|
| Network Connectivity | 9. Bluetooth Smart Connectivity | Presentation | Design an Bluetooth Smart App to Connect to a Heart Rate Sensor | Lab Code - Android | Code Solution - Android |
| | 10. RF Design Basics | Presentation | | | |
| | 11. nRF51-series SoC Architecture | Presentation | | | |
| | 12. Embedded Programing using mbed | Presentation | Blinking LED using mbed SDK | Lab Code - Blinking LED<br>Lab Code - Interrupt | Code Solution - Blinking LED<br>Code Solution - Interrupt |
| Community based Development and Demonstrations | 13. High-level Programming using mbed SDK | Presentation | Bluetooth Smart Design and Programming | Lab Code - Basic BLE Device<br>Lab Code - Temperature Sensor | Code Solution - Basic BLE Device<br>Code Solution - Temperature Sensor |
| | 14. System Integration Project - App Controlled Robot | | Design an App Controlled Robot | Lab Code - Android<br>Lab Code - mbed | Code Solution - Android<br>Code Solution - mbed |

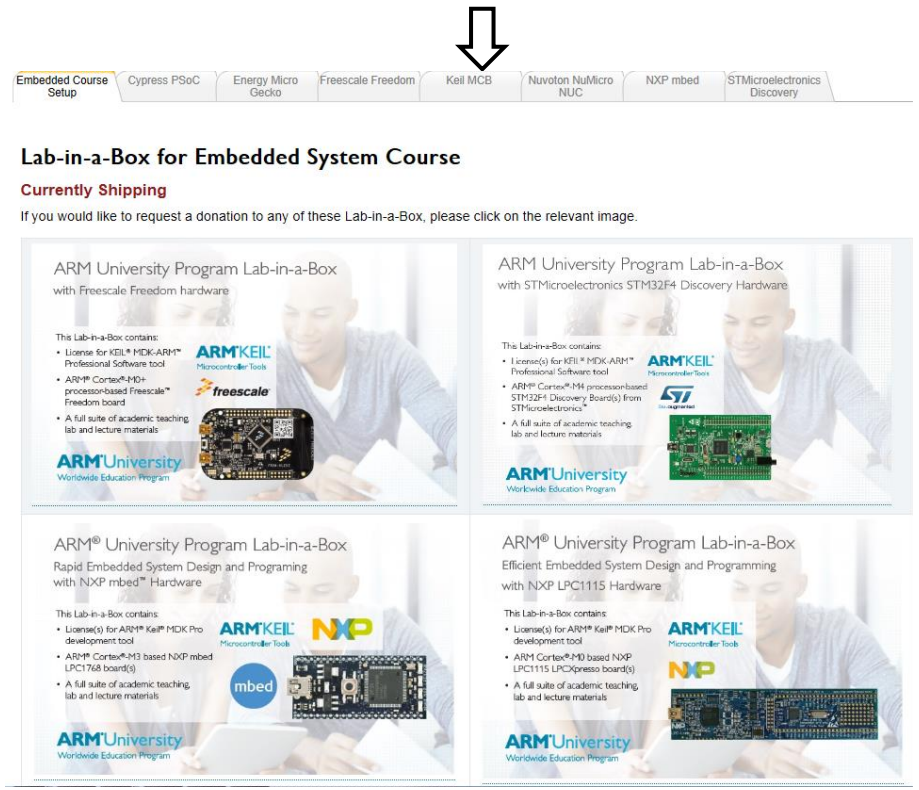
# ARM University Programme Current Partners






# Easy Online Access (www.arm.com/university)

:Researcher
:Student
:Educator

# Conclusions

# Conclusions (1/2)

- IoT is perhaps a buzzword but we are truly embarking on a new era of embedded and distributed computing
- Old paradigms need to be revised:
  - Secure/safe, seamless, simple operation: IoT is for everyone and everything!
  - Need standards for interoperability and economies of scale/scope
  - Distributed computing is the default
  - Higher computing & power density: low power is no longer secondary, it is essential
  - Low cost is key – at an even lower scale
  - Increased integration: RF/Analog, Memory, processor, MEMS
  - No one-size-fits-all, increased heterogeneity (design, implementation and programming problems)
  - Need for a new education paradigm

# Conclusions (2/2)

- For true connected intelligence, we need to first assemble the essential ingredients of intelligence:
  - **Processing Power**: ability to manipulate data/information to generate new ones. IoT provides increased processing power in the node, network and cloud.
  - **Communication**: Proper ability to communicate information (throughput and latency). IoT networks offer this.
  - **Self-reflection**: ability to self-reflect and evolve. With **sensing** and **memory**, as well as processing power, and communication, IoT has the basic building blocks for this. Self-reflection/awareness/ consciousness is increasingly seen as a consequence of large scale network effects in the human brain (coupled with sensing).
- IoT has all necessary ingredients for true intelligence.
- **What about reproduction e.g. self-replication? a new artificial life?**

# Thank You For Your Attention

## Questions?