The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2057-6

First Workshop on Open Source and Internet Technology for Scientific Environment: with case studies from Environmental Monitoring

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Embedded Systems

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Embedded Systems in Distributed Environment

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Objectives

- Brief history of hardware in embedded systems
- To introduce embedded system hardware
  - Small systems ($1-10)
  - Mid-range systems ($10-100)
  - Large systems ($100-1000)

Introduction

- Myself
- History of hardware and computing
  - From ENIAC to Computing for the Future of the Planet
    - ENIAC http://en.wikipedia.org/wiki/ENIAC
    - Future http://www.cl.cam.ac.uk/research/dtg/research/wiki/CFTFP
- History of hardware in this workshop series
  - Origin of this long running workshop
  - Microprocessor – Real-time OS – Distributed Systems – Open Source Systems

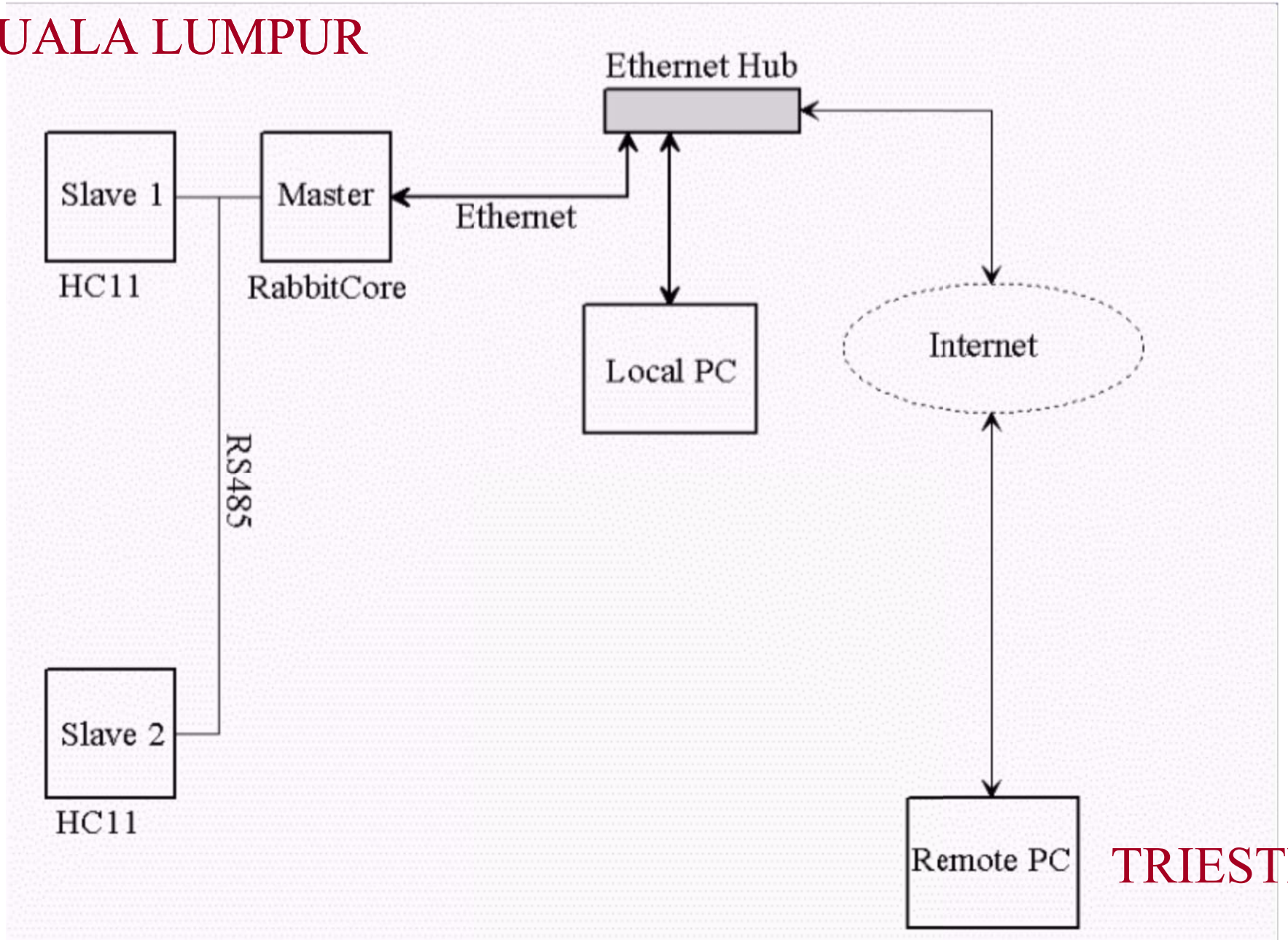
Free and Open Source

- Free and Open Source Software
  - http://en.wikipedia.org/wiki/Free_and_Open_Source_Software
  - Richard Stallman's Free Software Foundation http://en.wikipedia.org/wiki/Free_Software_Foundation
  - Open Source Initiative
  - Bruce Perens, Eric Raymond
    - http://en.wikipedia.org/wiki/The_Cathedral_and_the_Bazaar
  - http://en.wikipedia.org/wiki/Open_Source_Initiative
- Open Source Hardware
  - http://en.wikipedia.org/wiki/Open_Source_Hardware
  - Has been around for longer
  - Engineering practice

Real-time Internet Remote Access

- Webcams: http://219.94.127.11/webcam.htm
- Remote Control: http://219.94.127.14
- KL Temperatures: http://219.94.127.12

Demo of a Distributed ES since 2003



Early Example

- 1991 Cambridge Trojan Room coffee pot webcam
  - http://www.cl.cam.ac.uk/coffee/coffee.html
  - Server gets data (video frame) ready
  - Client (web browser) accesses via network
- Server side effort is relatively simple
  - HTML with SSI
- Client more complicated
  - Done by browser

Paradigm Shift in Hardware

- Prehistory – 1970s and earlier!
  - Mostly analogue design
  - Mostly self designed
  - Unless you are rich
    - Then buy HP, Keithley, Tektronics, etc.

Paradigm Shift in Hardware

- Microprocessor Era – 1980s
  - Thrill of learning digital computer albeit 8-bit
    - Everyone learned assembly language
    - Everyone learned 8-bit architecture
    - Everyone designed uP boards
  - Laboratory applications proliferate
  - Mostly self designed
    - Relatively simple
    - No standardization
    - No cheap products

Paradigm Shift in Hardware

- Warring States Era – 1990s
  - Transition from 8 bits to 32 bits
  - Many attempts by many people
    - Enhancing 8-bit power with large memory
      - Rabbit Semiconductor
    - Riding on Java success
      - TINI sub-module (8-bit)
    - Tapping on large scale integration
      - AXIS ETRAX System-on-chip (32-bit)
    - Building single board PC
      - ICOP SBC

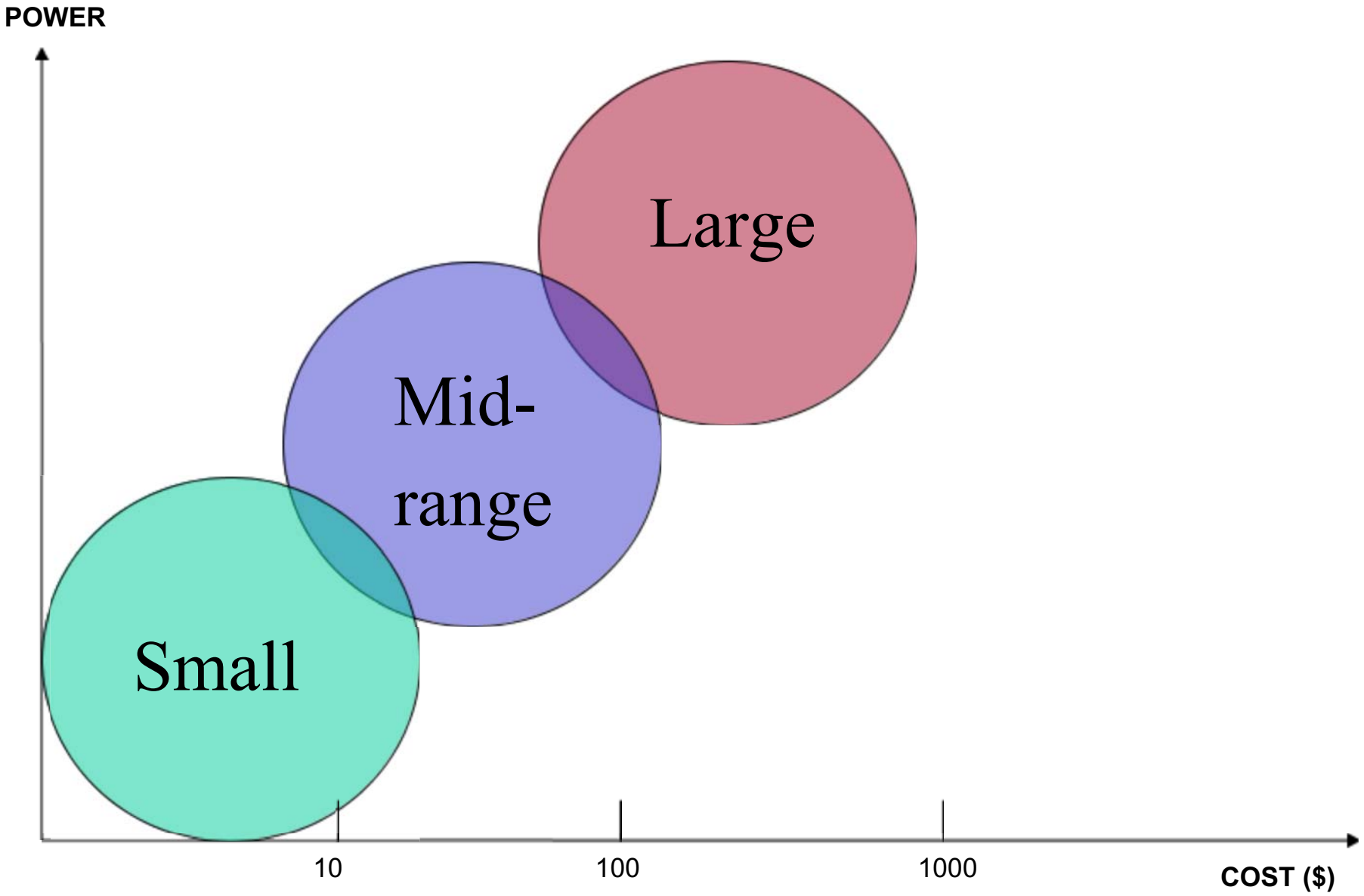
Paradigm Shift in Hardware

- 32-bit Era – 2000s
  - PC becomes embedded system workhorse
    - Large memory & storage and raw processing power
    - Networking
    - High resolution display with powerful image processors
    - Wireless
  - Embedded hardware design becomes
    - Either very simple (8-bit)
    - Or very complex (32-bit)

Paradigm Shift in Hardware

- Now – 2009 *(Ang's suggestion)*
  - Three types of hardware
  - For most small or real-time jobs
    - Design with 8-bit MCU, *aka* PIC
    - Design your hardware because no one else knows what you want
  - For others with space constraints
    - Buy 32-bit SBC, *aka* ARM9
    - Buy because it is cheaper to do so
  - For the remaining
    - Buy PC, *aka* Intel Atom netbook
    - Because everyone is doing so

Small to Large Embedded Systems



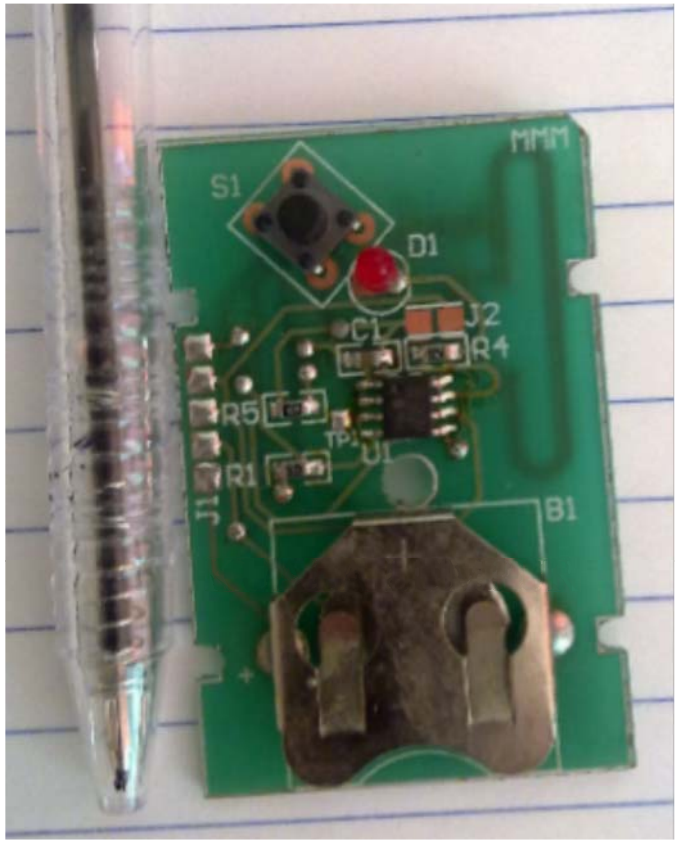
Embedded Processors

- $1 - $10
  - Microcontrollers
- $10 - $100
  - 32-bit Embedded Systems
- $100 - $1000
  - PC

Microcontrollers

- Small applications
  - As low as $1
- Powerful despite its size and cost
  - Web server for <$5
  - Good for distributed applications
- About the power of the hardware used in early microprocessor colleges here
- Very popular uC- PIC

PIC and Application



Microchip Technology shipped the 6 billionth chip by February 2008.

World population is 6.8 billion in 2009.

Microcontroller Applications

- Good for large range of lab applications
  - Parallel & serial I/O
  - ADC/DAC
  - Timer/Counting
- Good for real-time applications
  - By partitioning tasks to small sub-systems
  - Like encapsulation in OOP
- Real-time tasks easily implemented
  - Crystal oscillator
  - $10^{5 \sim 7}$ stability e.g. 10 s measurements in 1 s possible

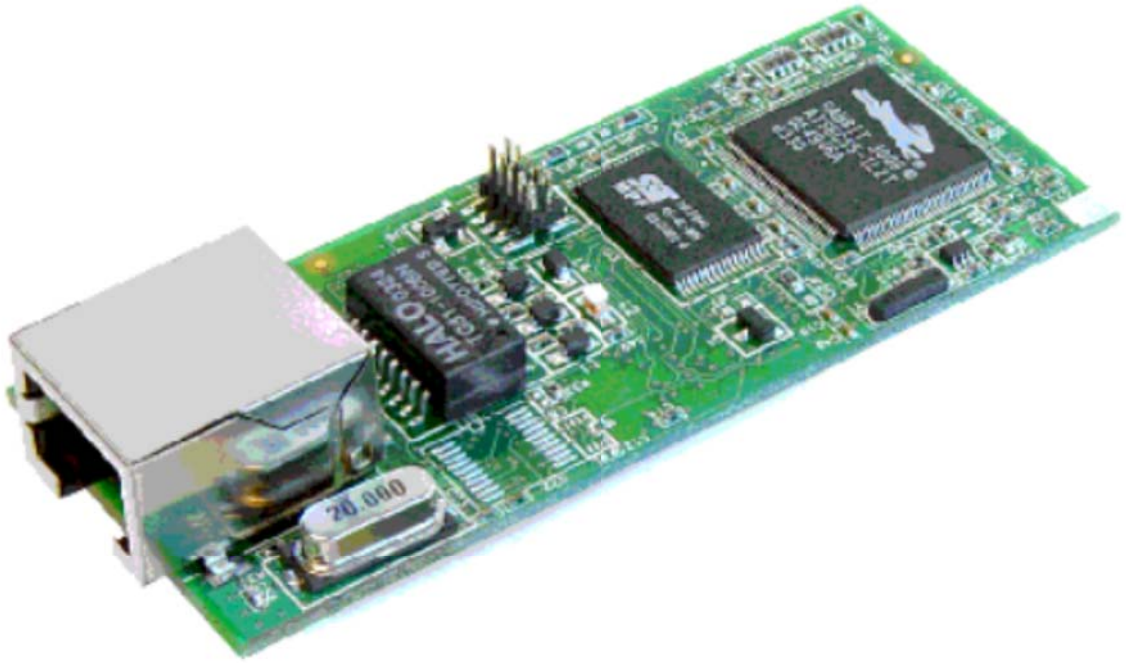
EP Module - TINI

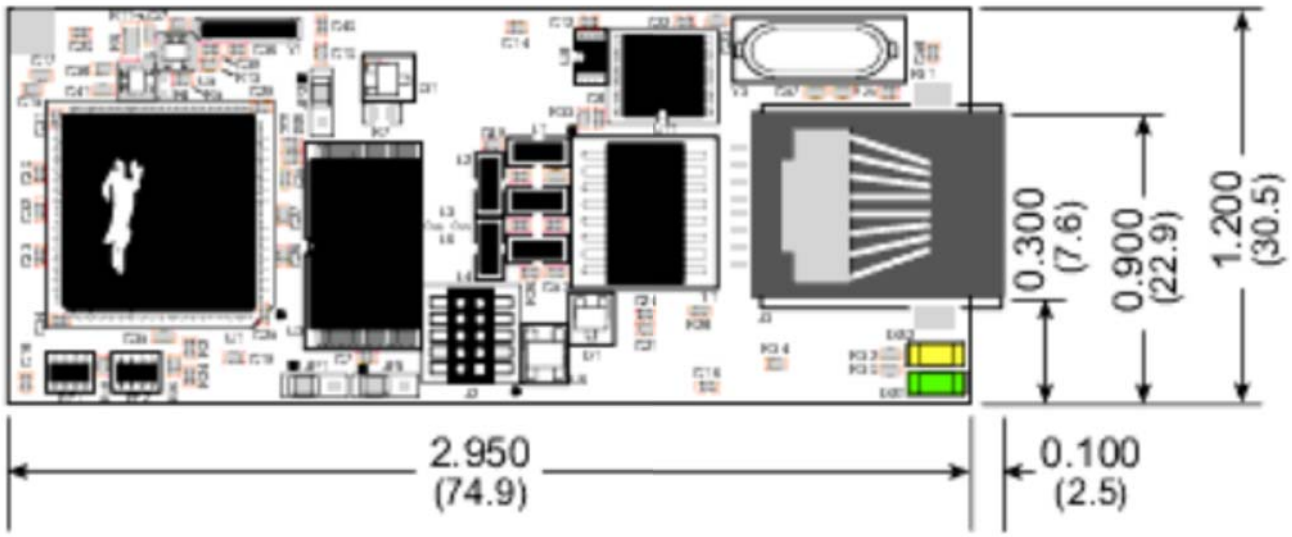
- Tiny Internet Interface
  - Dallas Semiconductor (Maxim Integrated Products since 2001)
- Java runtime environment
  - Used in this Workshop
- Mid range EP Module
- Category of $50 - $100
- Used in our Lab

EP Module - Rabbit Cores

- Rabbit Semiconductor
- Same category as TINI
  - $50 - $100
- Very popular now
  - Earlier market entry than TINI
  - Extensive range of modules
  - Good candidate for interfacing to legacy devices
  - Powerful EP by itself
  - Small hard real-time controller

RCM3700





System-on-Chip

- Complete system on a chip
  - Processor, memories & peripheral
- ETRAX 100LX Multi Chip Module (MCM)
  - By Axis Communications
- Runs Linux & OS of similar complexity
- $70
- Good candidate for complex RTS in distributed environment

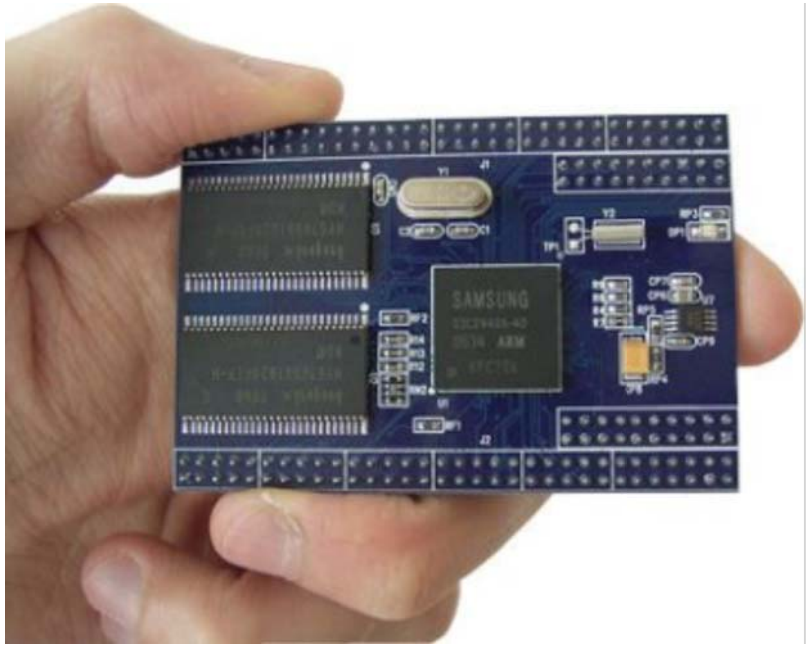
32-bit RISC Microcontrollers

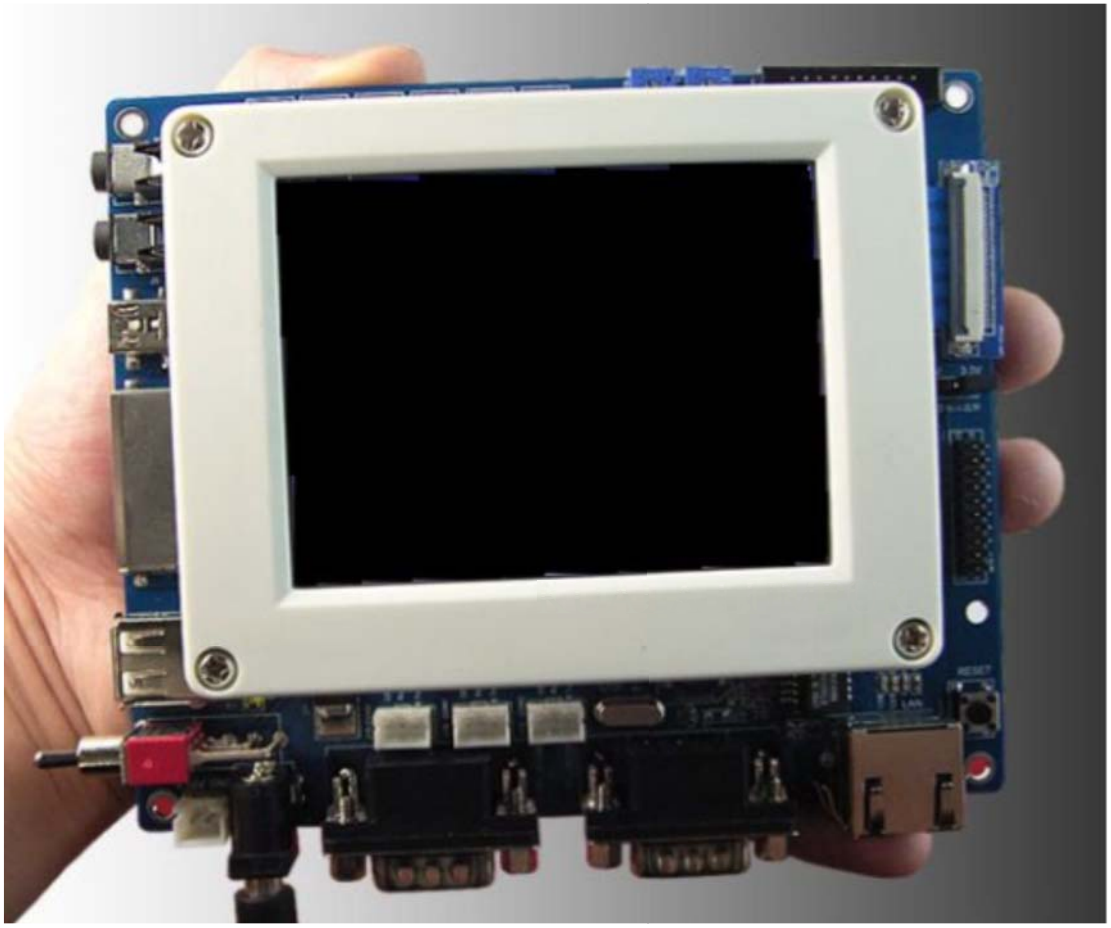
- Chips with ARM core
  - 32-bit Processor, memories & peripherals
- 80% of EP market
- Runs Linux & OS of similar complexity
- $5 ~ $20
- Powerful, low power consumption

SBC & Mini PCs

- Cheapest hardware not necessary wise choice
- SBCs are more cost effective in many situations
- Many standards & form factors available
  - STB Bus, PC/104, EBX, Half-size SBC, 3.5”
  - Mini ITX
- Standard PC functions at $100 available now

Samsung S3C2440-based Boards





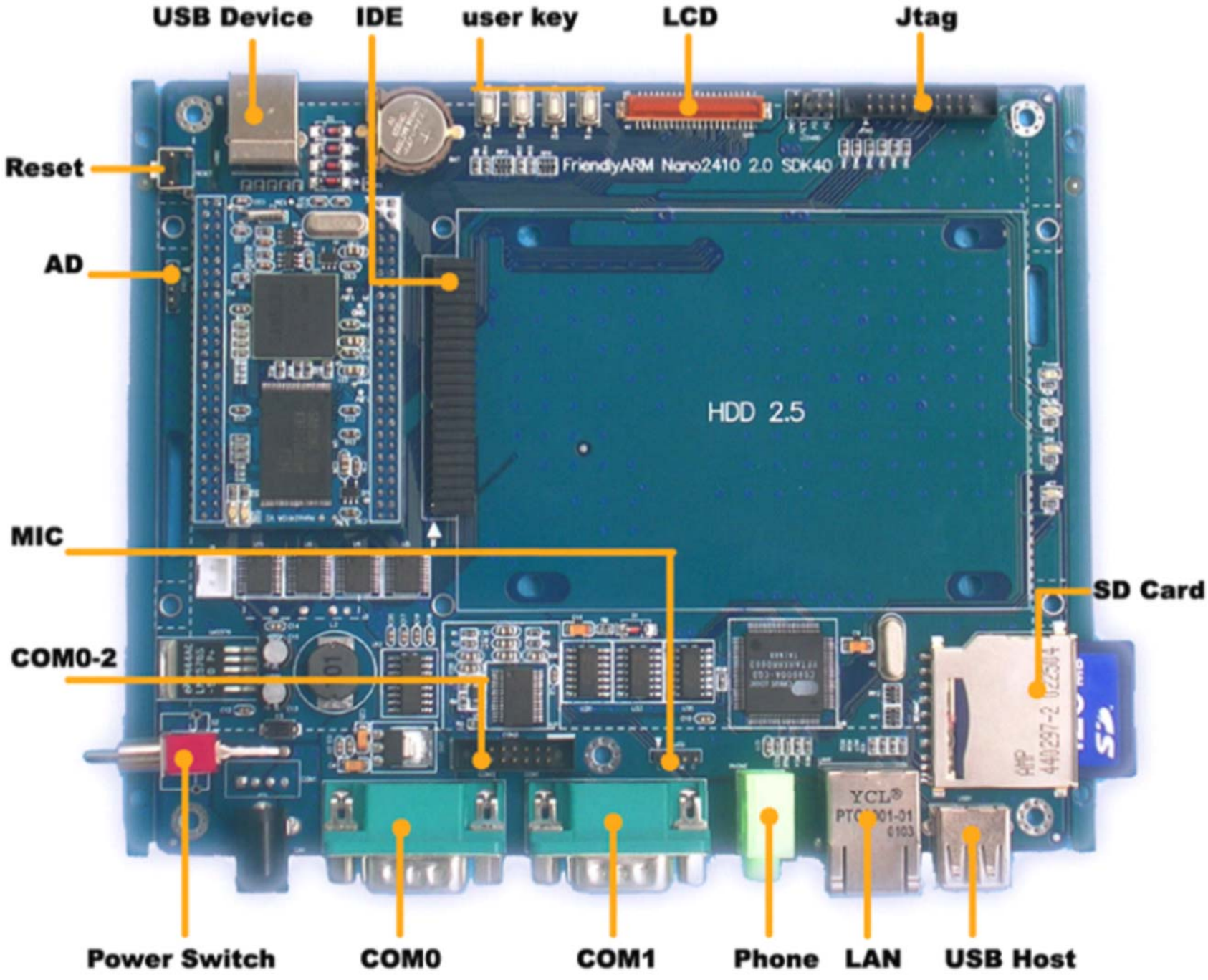
At $50~100,
the day of building your own is over?
Ssh! Don't tell Uli.

Other ARM9-based Boards

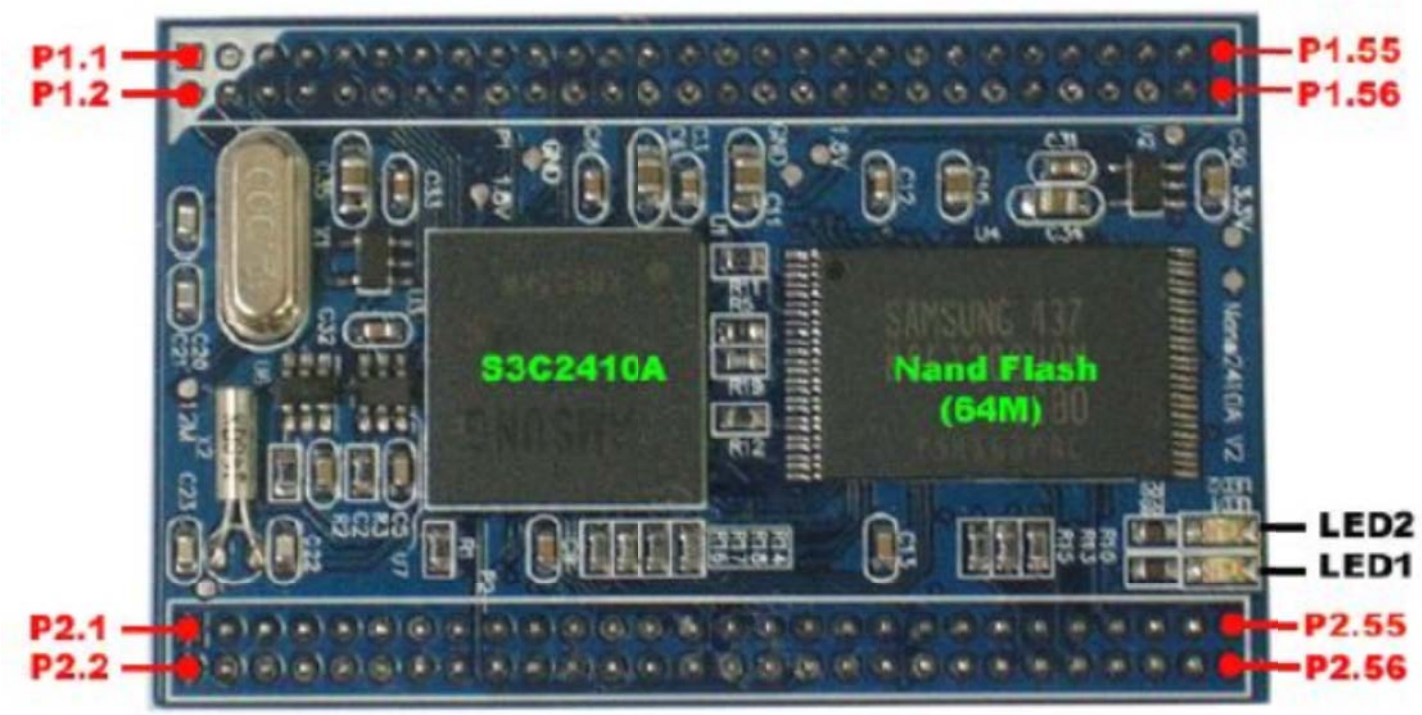
Samsung's S3C

Marwell's XScale

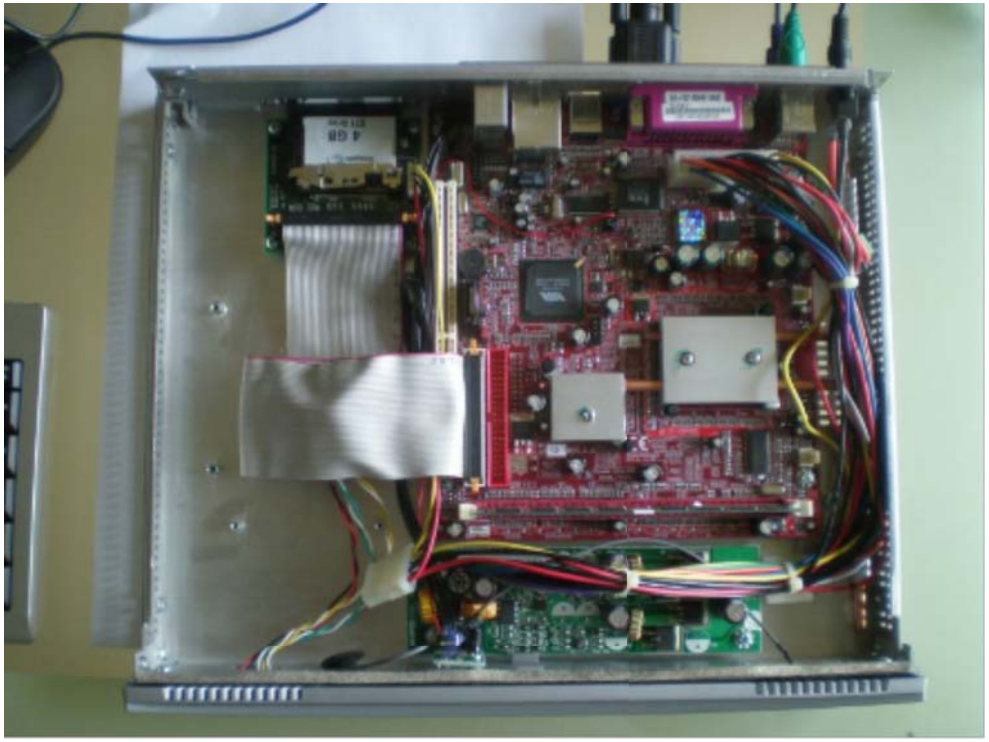
2410 Main Board



2410 Core Module



Mini PC



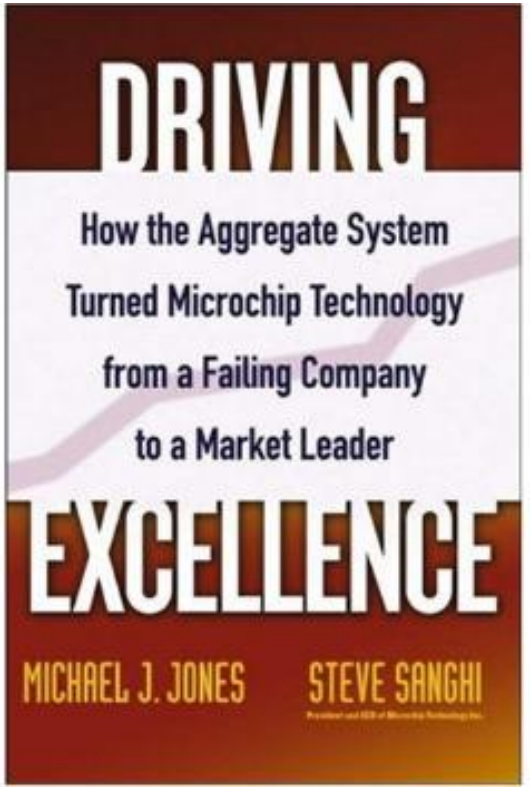
At $100,
the waiting is over?
Even Uli would not build this one!

The 8-bit Story

- 30 years now and no one can get rid of it…
- In the beginning, there were the 4 bits...
- Then they invented the 8 bits…
- Intel, Motorola, TI, NS, Philips, Siemens, NEC, you name it…
- Then came the16, 32 and even 64 bits…
- But one reinvented THE 8 BITS…
  - (They account for 55% of all microprocessors)

The PIC Story

- Microchip Technology (1989 from GI)
  - http://en.wikipedia.org/wiki/Microchip_Technology
  - Steve Sanghi, CEO
  - Michael J Jones, VP Human Resource (retired 2004)
- From failing to #1 in the world (8-bit)
  - Shipped 7,000,000,000 PICs
  - 450 PIC products
  - 2007: revenue $1.039 billion,
  - net income $357 million
  - 2009: revenue $903 million,
  - net income $248 million
- Reason?



PIC MCUs

- RISC-based devices by Microchip Technology Inc.
- Tremendously successful recently
- Hundreds of products and increasing
  - Various memory configurations
  - Low voltage
  - Small footprint
  - Ease of use
- http://www.microchip.com

PIC10F Family

- Smallest
- 6-pin
- 12-bit program word
- 2.0 ~ 5.5 V
- Timer, Watch Dog Timer
- Flash program memory (384/768 bytes)
- $0.5 ~ $1

PIC12 Family

- Smallest
- 8-pin
- 12-bit/14-bit program word
- 2.5V
- Interrupt handling
- A/D
- Flash, OPT or ROM program memory
- EEPROM data memory
- $1~3

PIC16 Family

- Very popular MCUs
- 12-bit wide instructions
- 14-, 18-, 20-, 28-pin
  - SOIC (Small Outline IC), 1.27 mm pitch
  - SSOP (Shrink Small Outline Package), 0.65
- 2V (battery operation)
  - Also, 15 V operation (16HV5XX)

PIC18 Family

- Top of the line
- 16-bit
- Enhanced core
  - ADC, 32 level deep stack
  - Multiple internal and external interrupts
- Programmable low voltage & brown out detection
  - All instruction in 1 cycle, except for branches (2)
  - 77 instructions, up to 10 MIPS

Extreme Low Power Microcontrollers

- http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1484

- Sleep / Power-down current down to 20 nA
- Brown-out Reset down to 45 nA
- Watch-dog Timer down to 400 nA
- Real-time Clock/Calendar down to 500 nA
  - Operation @ 1MHz: 100~200 uA
  - 1 year = 8760 hours
  - 1AH = 10_6 uAH
  - At 1uA, duration 10_6 / 8760 = 114 years

Example: PIC12F675

- CMOS Flash 8-bit MCU
- 8-pin package
- 4-channel 10-bit ADC
- 1-channel comparator
- 128-byte EEPROM data
- Good for small applications when field re-programming is necessary
- $0.73

PIC Applications

- PICs suited for large range of lab applications
- Good for small real-time applications
  - By partitioning tasks to small sub-systems
  - Like encapsulation in OOP
- Real-time tasks easily implemented
  - Crystal oscillator
  - $10^{5 \sim 7}$ stability e.g. accurate 10 s measurements in 1 s possible
  - 1 year = 3.1×10^7 s

Motion Detection

- A small real-time application
- Objective
  - Simple, lightweight and low cost **motion detector**
- Methods
  - Many – video recognition to accelerometers
  - We choose - Light intensity detection

CdS Sensors

- CdS light dependent resistors (LDRs)
  - Small, cheap, available, robust
  - 4 mm, $1
- Signal processing needed to detect motion

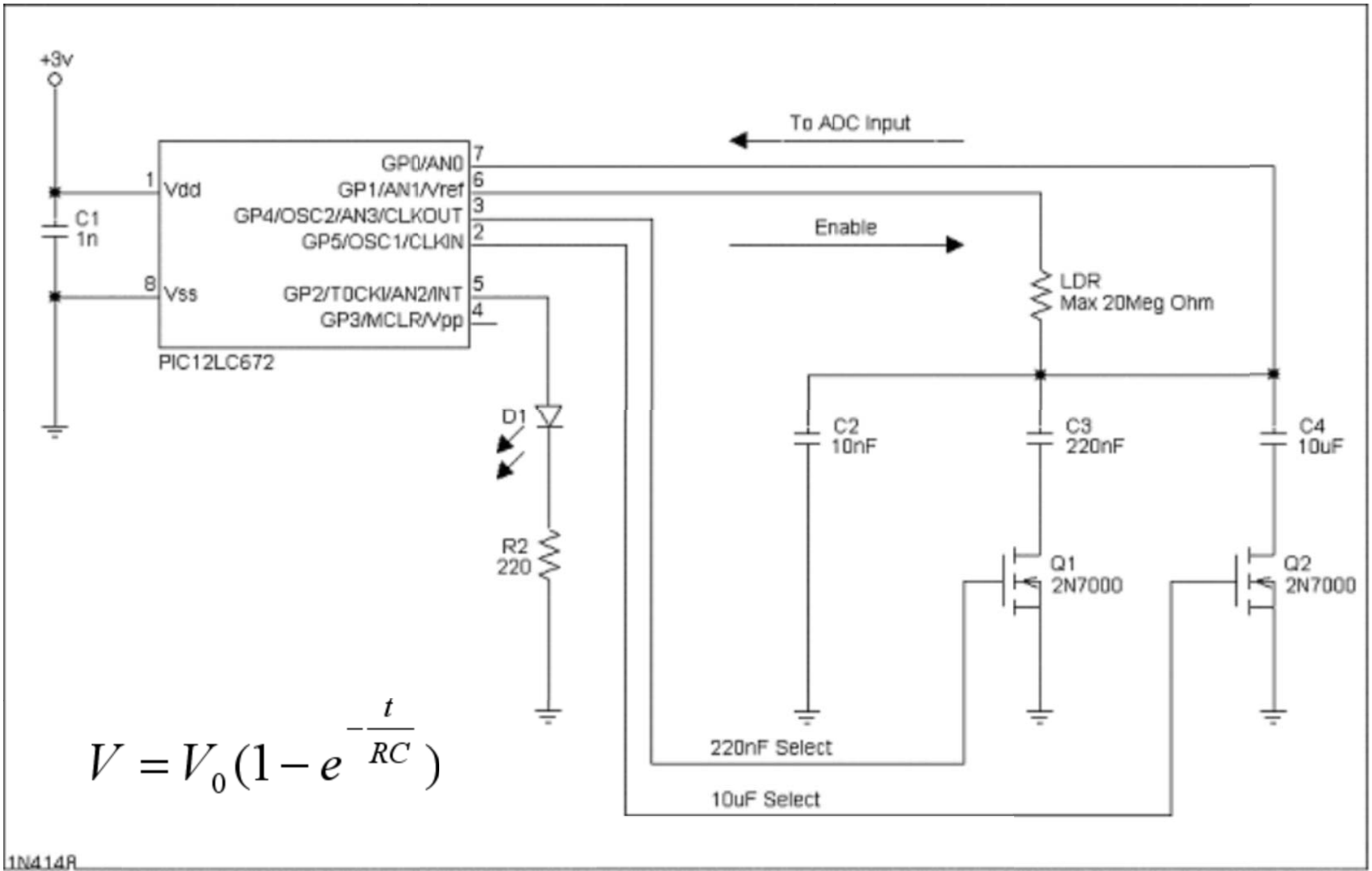
Sensor Characteristics

- 1 k (at 10 lux) – 20 M dark)
- 5 orders of magnitude change
- Practical changes much smaller
- Tunnel or telescopic view helps
- 0.1 to 10 x change possible
- 8-bit ADC is sufficient
- Problems
  - Dynamic range or ambient light intensity
  - Artificial lighting fluctuations

Solutions

- Potential dividers
  - Switch in different resistances
  - Disadvantage – current consumption
  - Fluorescent lighting fluctuation needs integration
- Averaging or integrating over half period of mains needed
  - Accurate sampling and take average
  - Better solution: use RC integrator (over half period)

Motion Detector Circuit



$$V = V_0(1 - e^{-\frac{t}{RC}})$$

The Story of ARM

- http://en.wikipedia.org/wiki/ARM_Holdings
- Most widely used 32-bit processors
  - 1.7 billions chips in 2005
  - 90% embedded 32-bit RISC processors (2009)
  - 98% mobile phones (1 billion in 2007)
- 200+ IP licensees
  - Analog Devices, Atmel, Broadcom, Cirrus Logic, Freescale, Fujitsu, Intel, IBM, Infineon Technologies, Nintendo, NXP Semiconductors (Philips), OKI, Samsung, Sharp, ST Microelectronics, Texas Instruments, VLSI
- Major products
  - Nokia, Sony Ericsson, Samsung
  - Apple iPod, iPhone, Nintendo
  - PDA, GPS, camera, television

The History of ARM

- In the beginning…
  - Acorn Computers (BBC, Archimedes)
  - 1983 Acorn RISC Machine project
  - An advanced MOS Technology 6502
- 1985 – ARM1
- 1986 – ARM2
  - 32 bits (simplest useful 32-bit in the world)
  - 4 MIPS @ 8 MHz
  - No microcode (30,000 transistors, vs 70,000 in 68000)
  - Low power consumption

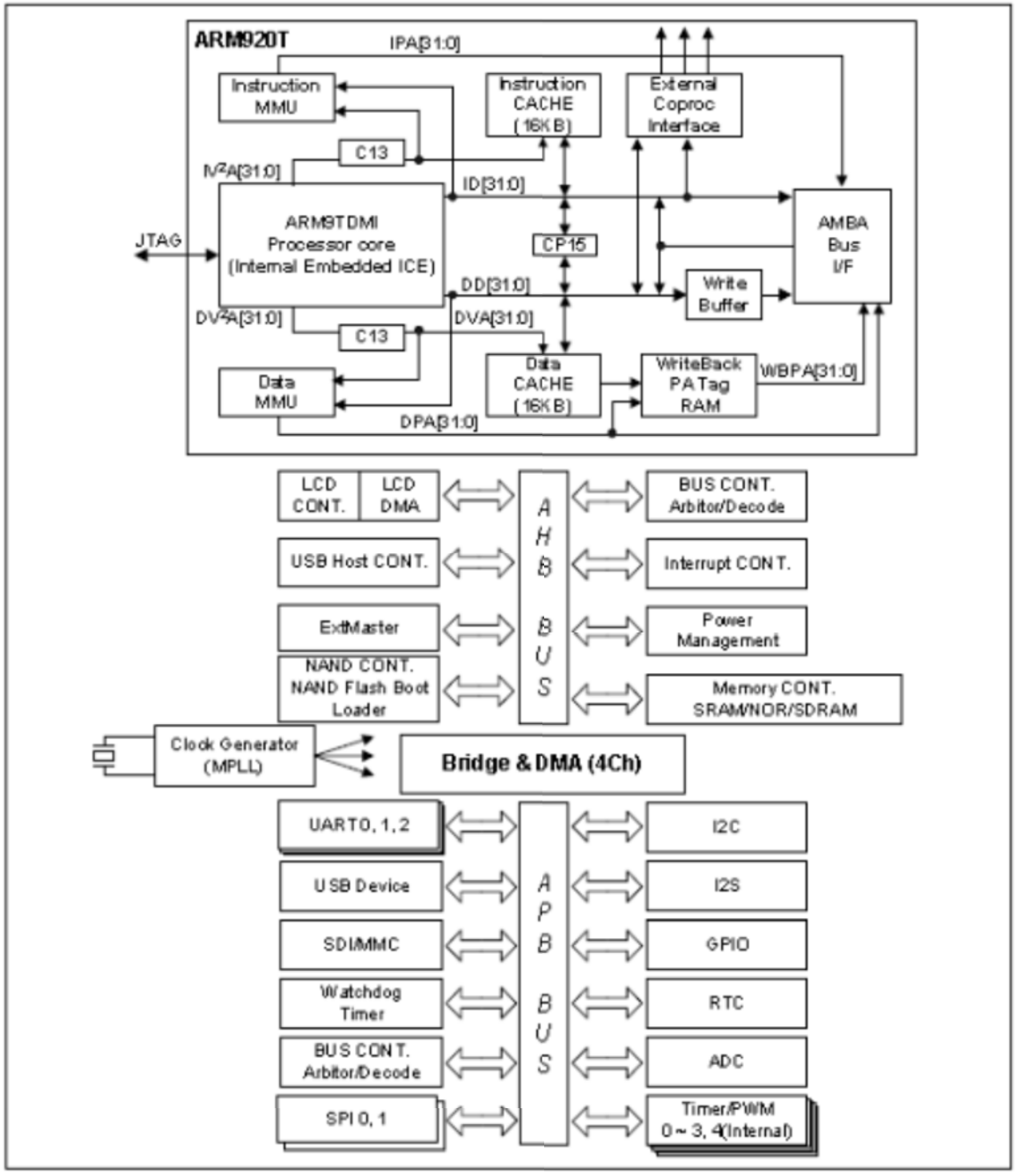
The History of ARM

- 1990 – Advanced RISC Machine Ltd spun off
  - With Apple Computer and VLSI Technology
- 1991 – ARM6
  - Apple Newton PDA
- Successful business model
  - Sell IP cores for others to build microcontrollers. CPU
- 2006 revenues
  - $164 million royalties + $120 million licenses
  - $0.11 per chip

ARM Architecture

- Low power, low cost
- 32-bit RISC
- Hardwired without microcode
- Uniform 16x32-bit register file
- Single cycle execution
- Conditional execution of most instructions
- http://en.wikipedia.org/wiki/ARM_architecture

Samsung S3C2410



Features of S3C2410

- 1.8V int., 3.3V memory, 3.3V external I/O microprocessor with 16KB I-Cache/16KB D-Cache/MMU
- External memory controller (SDRAM Control and Chip Select logic)
- LCD controller (up to 4K color STN and 256K color TFT) with 1-ch LCD-dedicated DMA
- 4-ch DMAs with external request pins
- 3-ch UART (IrDA1.0, 16-Byte Tx FIFO, and 16-Byte Rx FIFO) / 2-ch SPI
- 1-ch multi-master IIC-BUS/1-ch IIS-BUS controller
- SD Host interface version 1.0 & Multi-Media Card Protocol version 2.11 compatible
- 2-port USB Host /1- port USB Device (ver 1.1)
- 4-ch PWM timers & 1-ch internal timer
- Watch Dog Timer
- 117-bit general purpose I/O ports / 24-ch external interrupt source
- Power control: Normal, Slow, Idle and Power-off mode
- 8-ch 10 bit ADC and Touch screen Interface

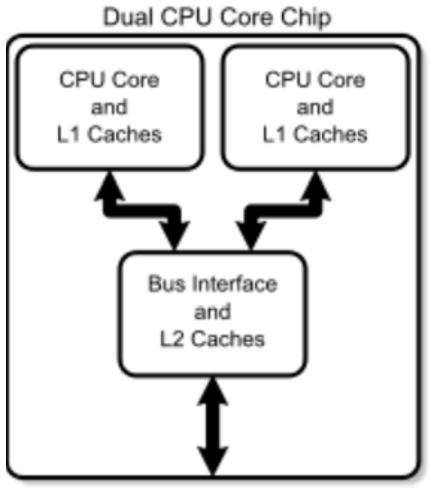
Example 2440 Development Board

- S3C2440A:32bit ARM920T kernel
- System Clock: Internal PLL 400MHz, external bus 100~133MHz
- LCD controller: STN/CSTN/TFT LCD, up to 1024*768 pixels
- LCD interface: 3.5" ~ 10" TFT
- Touch screen controller: 4-wire resistive
- 100MHz Ethernet
- 3 Serial ports
- USB1.1 host
- USB1.1 device
- SD/MMC interface
- Reset button
- RTC with Li-ion battery
- 20-pin JTAG interface
- 4 general purpose LED lamps
- Power indicator LED
- 6 general purpose push-buttons
- Power switch
- SPI I/O
- 64MB Nand Flash

The Story of Intel Atom

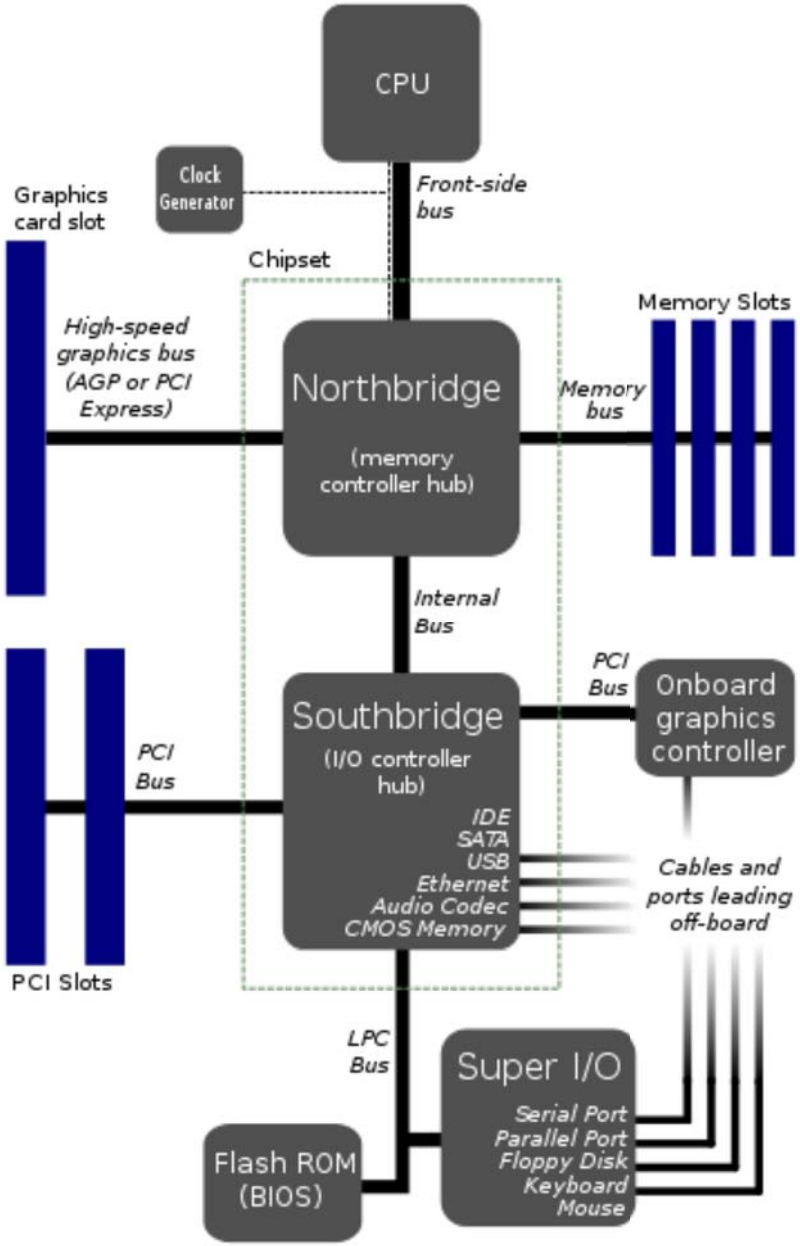
- Intel filing the mobile device gap
- Project in 2004
  - Sold ARM-based XScale line to Marvell in 2006 for USD600 million
- Work with Asustek
  - Eee out in 2007, sold 350,000 units
- Low power and low cost in Netbooks
  - N270 2.5W at 1.6GHz
- Worldwide shipment of netbooks
  - 10 million (2008)
  - 32.7 million (2009)

Intel Atom



- x86 x86-64 CPU *popular*
- 45 nm CMOS *low power*
  - TDP 2.5~8 W
- Single or dual core
- At 1.6 GHz: 3300 MIPS, 2.1 GFLOPS
  - Pentium M740 at 1.73GHz: 7400 MIPS, 3.9 GFLPS, 27 W
- Power
  - CPU: N270 2.5W
  - Chipset: 945GSE 6W
  - I/O Controller: 82801GBM 3.3W
  - Total 11.8W
- http://en.wikipedia.org/wiki/Intel_Atom

Chipset Layout



Rival -VIA Nano

- http://en.wikipedia.org/wiki/Via_nano
  - x86-64 instructions architecture (AMD compatible implementation)
  - 65 nm manufacturing process
  - clock speed of 1 GHz to 1.8 GHz
  - bus speed of 533 MHz or 800 MHz
  - Support for ECC
  - x86 virtualization (Intel compatible implementation)
  - 128 KB L1 cache and 1 MB L2 cache, exclusive
  - Pin compatible with the VIA C7.
  - 5~25 W
  - Performance better than low end single core Atom

Rival – ARMv7 (Cortex)

- http://en.wikipedia.org/wiki/ARM_architecture x86-64
- Cortex family
- ARMv7 architecture
- Similar performance to Atom
- ¼ power consumption
- Single chip

Netbook PCs

- The success story of ASUS Eee in 2007
  - http://en.wikipedia.org/wiki/ASUS_Eee
  - Intel Atom CPU
- Now every PC manufacturer has it
- Looks like it is taking over the low-end notebook market
- Unbranded version: $250~300 at 2009.

Atom-based Netbook PC

- Intel N270 1.6GHz
- RAM: 1GB DDRII
- HDD: 160GB SATA
- 10.2” WXGA 1024*600 LCD
- Wifi 802.11a/b/g
- Standard I/O