12. Concrete Example: the BeagleBoard

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- Video applications
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- BeagleBoard extensions
- Other kinds of boards
12. Concrete Example: the BeagleBoard

BeagleBoard overview

Presentation

- Single-board computer (SBC): 3” by 3” card
- Produced by Texas Instruments
- Low power: 2.5W, no cooling system
- Low cost: only $149 ($89 for the BeagleBone)
- Open source oriented: open hardware design, interaction with the community
- Intended to promote TI's processors
- Website: http://beagleboard.org

Contributed by Philippe Dumont
BeagleBoard features

Features

- Operating systems: Linux, Android, Windows CE, Symbian
- Accelerated 2D/3D rendering with OpenGL support
- HD video support: up to 720p
BeagleBoard history

<table>
<thead>
<tr>
<th>BeagleBoard Generations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early revision: BeagleBoard A\textsuperscript{x} or B\textsuperscript{4}, B\textsuperscript{5}, B\textsuperscript{6} and B\textsuperscript{7}</td>
</tr>
<tr>
<td>Previous commercial revision: C\textsuperscript{2} and C\textsuperscript{3}</td>
</tr>
<tr>
<td>June 2008 (C\textsuperscript{2}) – May 2009 (C\textsuperscript{3})</td>
</tr>
<tr>
<td>600MHz processor – 256MB RAM</td>
</tr>
<tr>
<td>Commercial revision described in this document: C\textsuperscript{4}</td>
</tr>
<tr>
<td>December 2009</td>
</tr>
<tr>
<td>720MHz processor – 256MB RAM</td>
</tr>
</tbody>
</table>
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Processor

OMAP3530
OMAP family

OMAP: Open Multimedia Application Platform
- System-on-chip dedicated to portable and mobile multimedia applications
- Developed by Texas Instruments
- Used by many embedded devices: Nokia N series, Palm Pre, Archos...

OMAP3530: specification
- Microprocessor unit (MPU): ARM Cortex A8
- Digital signal processor (DSP): TI C64x+
- Graphics processing unit (GPU): PowerVR SGX530
- Image Signal Processor (ISP): *not available with the BeagleBoard*
OMAP3530: block diagram

Figure 1-1. OMAP3530/25 Functional Block Diagram
## OMAP3530: MPU

### MPU: main characteristics
- Revision: ARM Cortex A8 (ARMv7-A - ES3.0)
- Bus size: 32bits
- Frequency: 720MHz
- Cache size: L1: 16KB Instructions + 16KB Data - L2: 256KB
- More than 1200 Dhrystone MIPS

### MPU: additional features
- 13-stage superscalar pipeline
- VFP: Vector Floating Point computation unit
- NEON: SIMD instructions for media/signal processing (64 and 128 bits)
  - Decode MP3 at 10MHz and encode voice at 13MHz
- Jazelle RCT: hardware support for Java bytecodes execution
- Thumb-2: hardware support for a 16bits instruction set
  - Code size reduction with some performance impact
OMAP3530: GPU

GPU: PowerVR SGX530
- OpenGL ES 2.0 / DirectX 10.1 Shader Model 4.1
- Up to 13 Million polygons per sec
- Support dual independent displays

Environment Mapping
Per-Pixel lighting
Reflection and Refraction
Wave Physics
OMAP3530: DSP

DSP: C64x+

- Core: TMS320C64x+
- Fixed point arithmetic
- Frequency: 520MHz
- HD capable: up to 720p @30fps

Advanced Event Triggering (AET)
Instruction Fetch
SPLOP Buffer
16/32-Bit Instruction Dispatch
Instruction Decode
Data Path 1
L1 S1 xT D1 xE
A Register File
Data Path 2
M1 xS M2 xS
B Register File
Interrupt & Exception Controller
Power Control
L1D Cache/SRAM
L1P Cache/SRAM
L2 Cache/SRAM
DMA Slave EF
Master Port (CPU Cache Req.)
External Memory Controller (EMC)
Bandwidth Mgmt.
Memory Protection
Unified Memory Controller (UMC)
Bandwidth Mgmt.
Memory Protection
TMS320C64x™ DSP Core
New Feature
Improved from C64x™
12. **Concrete Example: the BeagleBoard**

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12. Concrete Example: the BeagleBoard – Memory

Memory on top of OMAP
Memory

PoP: Package-on-Package

Two kinds of memory
- 256MB Low Power Double Data Rate (LPDDR) RAM memory
- 256MB NAND flash Memory
12. Concrete Example: the BeagleBoard

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12. Concrete Example: the BeagleBoard – Electricity supply and USB

**Electrical supply**

- Power management
- IC

**Solution 1**
- DC connector

**Solution 2**
- mini USB connector

**Not a solution**
- USB host connector
Electrical supply

Power management
IC

Solution 1
DC connector

Solution 2
mini USB connector
12. Concrete Example: the BeagleBoard – Electricity supply and USB

Electrical supply

Solution 1
DC connector

Solution 2
mini USB connector

Power management IC

Not a solution
USB host connector
Electrical supply

**DC Connector**
- 5V DC from 500mA up to 2A (required by some extension cards)
- Connected to a wall adapter or to a USB power cable

**USB**
- Only on the mini USB connector (*not the USB host connector*)
- Simple or double miniAB cable
  - from 500mA (simple cable) up to 1A (double cable)
  - Double required if any USB device plug in the host port
12. Concrete Example: the BeagleBoard – Electricity supply and USB

Electrical supply

**Power Consumption**

- 2.5W to 5W only
- No need for a cooling system
12. Concrete Example: the BeagleBoard – Electricity supply and USB

USB connectors

**USB host connector**

- USB 2.0 High Speed (HS) port only
- Current available depends on current source

**mini USB connector**

- USB On-The-Go port: can be used as host or client
- Main use as a client port to get power
- To use it as a host port, power must be supplied by the DC connector
Electricity supply and USB devices

Problem

- Need to use many USB devices: keyboard, mouse, . . .
- Need to provide electricity to the board and to the devices

Solution: A USB HUB

- Everything on one HUB
- Provide a RJ45 connector
12. Concrete Example: the BeagleBoard

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Connectors

- Audio in
- Audio out
- S-VIDEO
- DVI-D
- SD/MMC
- Serial
- JTAG
- Expansion
Connectors

SD/MMC
- Main purpose as a storage device with a SD card
- Support of SDHC cards, Wifi cards, camera, GPS modules, . . .

Display
- HDMI connector: provides only DVI-D interface (VGA display impossible)
- S-Video connector: supports PAL and NTSC TV
- Independent displays

Debug
- IDC10 serial connector: provide a RS-232 (COM) port
12. Concrete Example: the BeagleBoard

- Processor
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- Connectors

- Leds and buttons
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Leds and buttons

- Power LED
- 2 users LED
- User button
- Reset button
- Change boot order

Pmu Stat LED

Concrete Example: the BeagleBoard – Leds and buttons
12. Concrete Example: the BeagleBoard

- Processor
- Memory
- Electricity supply and USB
- Connectors
- Leds and buttons

**Typical connection schemas**
- Boot process
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Typical connection schemas

- Simple serial access: $149 (board) + $25 (cables)
Typical connection schemas

- BeagleBoard as a desktop computer: $149 (board) + $70 (cables)
12. Concrete Example: the BeagleBoard

- Processor
- Memory
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- Connectors
- Leds and buttons
- Typical connection schemas

**Boot process**
- Drivers / Hardware Support
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12. Concrete Example: the BeagleBoard – Boot process

**Boot process**

### The 5 boot phases
- ROM loads MLO/X-loader
- MLO/X-loader loads U-boot
- U-boot reads commands
- Commands load kernel
- Kernel reads root file system

### ROM
- Can not be erased, avoids “bricking”
- Looks for MLO/X-loader on
  - Default: NAND → USB → serial (UART) → MMC/SD
  - User button pressed: USB → serial (UART) → MMC/SD → NAND
- Loads MLO/X-loader in SRAM
From ROM to MLO/X-loader

Requirements needed by the ROM to find the MLO/X-loader

- **On NAND**
  - Must be on the first sector *(or on the next one if the first one is corrupted)*

- **On SD/MMC**
  - SD card must have 255 heads and 63 sectors/track
  - First partition is in FAT format and bootable
  - Must have “MLO” as first file and directory entry
  - “MLO” is `x-load.bin.ift` renamed

- **On serial/UART**
  - MLO/X-loader image has to be loaded in SRAM with `pserial` via RS232 connection

- **On USB**
  - More tools needed, no easy procedure

- MLO/X-loader image has to be signed (see `signGP`)
MLO/X-loader

MLO/X-loader presentation

- Website: http://gitorious.org/x-load-omap3
- Derived from the U-boot project
  - Dedicated to OMAP processors
  - Small image which fits in SRAM, able to initiate SDRAM
- Retrieved from booting device and put into SRAM
- Configure SDRAM, NAND and MMC/SD
- Look for U-boot image first on MMC/SD then on NAND

Requirements needed by the MLO/X-loader to find the U-boot image

- On NAND: image must be on the fifth sector
- On SD/MMC: image must be named u-boot.bin and be on first partition
- On serial/UART: image has to be send with kermit via RS232 connection
- On USB: some tools are required, no easy procedure
U-boot

U-boot presentation

- Website: http://www.denx.de/wiki/U-Boot
- Traditional boot loader
- Retrieved from booting device and put into SDRAM
- Allows interaction over the serial and USB ports
  ⇒ You can finally do something
12. Concrete Example: the BeagleBoard – Boot process

**U-boot**

**U-boot presentation**

- Website: [http://www.denx.de/wiki/U-Boot](http://www.denx.de/wiki/U-Boot)
- Traditional boot loader
- Retrieved from booting device and put into SDRAM
- Allows interaction over the serial and USB ports
  - You can finally do something
- Loads a kernel image from an input device and passes its “bootargs”
- U-boot configuration can be saved in NAND
  - Allows to automatically load the same kernel (wherever it is)
  - Allows to save the “bootargs” of this kernel
  - Default behavior is to read `boot.scr` auto-script to find kernel
12. Concrete Example: the BeagleBoard – Boot process

**U-boot interface**

Texas Instruments X-Loader 1.4.2 (Feb 19 2009 - 12:01:24)
Reading boot sector
Loading u-boot.bin from mmc

U-Boot 2009.01-dirty (Feb 19 2009 - 12:23:21)

I2C: ready
OMAP3530-GP rev 2, CPU-OPP2 L3-165MHz
OMAP3 Beagle board + LPDDR/NAND
DRAM: 256 MB
NAND: 256 MiB
Using default environment

MUSB: using high speed
In: serial usbtty
Out: serial usbtty
Err: serial usbtty
Board revision C
Serial #7f6800030000000004013f780601a005
Hit any key to stop autoboot: 0
OMAP3 beagleboard.org #
Conclusion

- Boot process can be quite tortuous

ROM
↓
MLO/X-loader on NAND
↓
U-boot on SD/MMC
↓
kernel on UART/serial
↓
rootfs on network

- Fortunately you can always recover from a failing boot :)
12. Concrete Example: the BeagleBoard – Drivers / Hardware Support

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Drivers / Hardware Support

**MPU**
- Many ARM distributions provide a development tool chain with gcc
- To compile code on x86 for the BeagleBoard
  - a cross-compiler is required
  - some dedicated environment exists: scratchbox, openembedded

**GPU**
- Drivers development is done directly by TI: here
- Linux, Android and Windows CE (at least) are supported

**DSP**
- Drivers and framework development is done directly by TI: here
- Linux, Android and Windows CE (at least) are supported
12. Concrete Example: the BeagleBoard

- Processor
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Linux

Linux and ARM

- Linux kernel supports ARM processors
- Many distributions run natively on ARM: gentoo, slackware, debian, ...

Ångström distribution

- Linux distribution dedicated to embedded devices
- Based on OpenZaurus
- Explicit support of the BeagleBoard
- Ångström distribution provides
  - Demo image dedicated to BeagleBoard with e17 and fullscreen 720p decoding
  - Webpage to build your own image
  - Access to a large collection of packages
  - Documentation to compile your own image

- Watch video tutorial
- Further readings: here
Android

Android and ARM

- Developed by Google for the mobile phone market, based on Linux
- Several revisions: as of early 2011, 2.2 (Froyo) using Linux Kernel 2.6.32
- Different ports exist for the BeagleBoard: Rowboat, 0xdroid

Rowboat distribution

- Port of Google Android on OMAP35x, AM37x and AM35x platforms
- Complete hardware support: ARM plus NEON, DSP, accelerated 2D/3D,…
- Explicit support of the BeagleBoard with a very reactive community
- as of early 2011, revision based on Android 2.1 (Eclair) using Linux Kernel 2.6.29
- Rowboat distribution provides
  - Documentation to compile your own image with 3D support and DSP support
  - Soon prebuilt image should be available
Others

Windows CE and ARM

- Windows® Embedded CE is mainly dedicated to ARM processors: here
- A port exist for the BeagleBoard: here

Symbian platform and ARM

- Operating system and software platform designed for smartphones
- Based on Symbian OS, symbian platform is now open source
- A port for the BeagleBoard exist as part of the wild duck project
12. Concrete Example: the BeagleBoard

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Video players

- Many solutions with partial hardware support: NEON or DSP or OpenGL
- Open source: OmapFbPlayer, XBMC (video)
- Closed source: Ingenient technologies (video) - VisualOn - Ittiam

OmapFbPlayer

- Website: http://git.mansr.com/?p=omapfbplay
- NEON based hardware acceleration - up to 720p
- Available on Linux and on Android
- Allow video walls with network synchronization: here - up to 1080p
HTPC: Home Theater Personal Computer

- Open source: XBMC (video)
- Closed source: N\textsuperscript{th} player (video)

XBMC: XBox Media Center

- Website: http://xbmc.org/
- GSoC 2010: here
- Full hardware support - up to 720p
- SVN repository:
  http://xbmc.svn.sourceforge.net/svnroot/xbmc/branches/gsoc-2010-beagleboard
12. Concrete Example: the BeagleBoard – In an embedded device

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- Other kinds of boards
BeagleBoard as an embedded device

- USB Mass Storage: here
- Autopilot for airplanes: here
- Robot stimulus analysis: here or here
- Real Time Kinematic GPS Receiver: here (accurate up to 1cm)
- Iron Man suit: here

- Repulsor Air – Blow air with CO2 air pump
- Repulsor Missile – Launch paper missiles
- Repulsor Sensor/Light - Hands and eyes light
- Repulsor Sound Effect(s)
- Arc Reactor – Led light on torso
12. Concrete Example: the BeagleBoard

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BeagleJuice

Overview

- Website: [here](#)
- Battery: 4500 mAh - 5V output
- Autonomy: 6.5 hrs
- Price $89
Zippy

Overview

- Website: here
- Two models: Zippy 1 and 2
- Description: provide more ports and a real time clock
- Hardware: 1×Ethernet, 1×SD/MMC, 1×RS-232
- Price: $99
Arduino

Overview

- Website: http://www.arduino.cc/
- Description: *open source* microcontroller
- Usage: read temperatures, control a motor, read accelerometer (*WiiMote*)
- Hardware: Atmel AVR processor and on-board I/O support
- Software: Can be programmed with standard C/C++
- Price: $30
Leopard Board

Overview

- Website: http://leopardboard.org/
- Description: open source webcam
- Two models: Leopard Board 355 and 365
- Hardware details (Leopard Board 365):
  - Processor: TMS320DM365
  - Memory: 256MB NAND and 128MB DDR2 SDRAM
  - VGA, 1.3M, 2M, 3M and 5 Mega-pixel CMOS Sensors supported
  - Ports: 1× Ethernet, 2× USB, 2× AUDIO, 1× SD/MMC
- Video capabilities (Leopard Board 365):
  - Enhanced Video Processing Subsystem with Face Detection module
  - Video Processing Subsystem (VPSS)
  - HD Video Codecs: H.264, MPEG4, MJPEG, WMV9/VC1, MPEG2
  - Audio Codecs: MP3, WMA, AAC, Audio Echo Canceler (AEC)
Leopard Board
12. Concrete Example: the BeagleBoard – BeagleBoard extensions

Display

Overview

- **Touchscreens**
  
<table>
<thead>
<tr>
<th>Type</th>
<th>LCD</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Website</td>
<td>here</td>
<td>here</td>
</tr>
<tr>
<td>Price</td>
<td>$349 (with BeagleBoard)</td>
<td>$258 (without BeagleBoard)</td>
</tr>
</tbody>
</table>

- **DLP® Pico™ Projector**
  - Website: here
  - Price: $349

![LCD](image1.png)  ![OLED](image2.png)  ![Pico](image3.png)
12. Concrete Example: the BeagleBoard

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Other kinds of boards
BeagleBoard competition

Hawk Board

IGEPv2 Board

Overo fire
Hawk Board

Overview

- Website: http://www.hawkboard.org/
- Purpose: similar to BeagleBoard
- Price: around $90
- Processor: Ti OMAP-L138 Low Power Application Processor
  - 300-MHz ARM926EJ-STM RISC CPU
  - 300-MHz C674x VLIW DSP
- Memory:
  - 128 MByte DDRAM running at 150MHz
  - 128 MByte NAND FLASH
  - 1 SD/MMC Slot
- Ports: 1×RS232, 1×Ethernet, 2×USB, 1×SATA, 1×VGA, 2×AUDIO
IGEPv2 Board

Overview

- **Website:** here
- **Purpose:** similar to BeagleBoard
- **Hardware details:**
  - Processor: OMAP 3530@720MHz
  - Memory: 512MB NAND and 512MB DDRAM@200 MHz
  - Ports: 1×HDMI, 1×Ethernet, 2×USB, 2×AUDIO, 1× microSD
  - Wireless: 802.11(g) and Bluetooth®
GUMSTIX Overo™ Fire

Overview

- Website: here
- Purpose: similar to BeagleBoard
- Price: $219.00
- Hardware details (*Leopard Board 365*):
  - Processor: OMAP 3530@720MHz
  - Memory: 256MB NAND and 256MB RAM
  - Ports: 2×USB, 2×AUDIO, 1× microSD
  - Wireless: 802.11(g) and Bluetooth®
Pandora game console
Pandora game console

Overview

- Website: http://www.openpandora.org/
- Purpose: game console *(run Quake I, II, III)*
- Hardware details:
  - OMAP 3530@600MHz - 256MB RAM - 512M BNAND
  - 800x480 4.3” 16.7 million colours touchscreen LCD
  - Wifi 802.11b/g, Bluetooth & High Speed USB 2.0 Host
  - Dual SDHC card slots & SVideo TV output
  - Dual Analogue and Digital gaming controls
  - 43 button QWERTY and numeric keypad
  - Around 10+ Hours battery life