NVIDIA Tegra

Michael Toksvig, Distinguished Engineer, NVIDIA Mobile
Co-authors: Parthasarathy Sriram, John Matheson, Brian Cabral, Brian Smith
Agenda

- What is NVIDIA Tegra?
- The Challenge
- 3D Features
- Interesting Features
- 3D Performance
- Demos
What is NVIDIA Tegra?

Entertainment (Perf/W)

Mobile Computing Devices

Notebook

UMPC

Productivity (Perf/W)
Complete Computer on a Chip

- ARM11 CPU
- GeForce GPU
- Image Processor
- HD Video Processor
- USB OTG
- UART
- SPI SDIO
- Display
- HDMI
- MIPI
- NAND Flash
- Mobile DDR
- Security Engine
- F:S IFC
<table>
<thead>
<tr>
<th></th>
<th>APX 2500</th>
<th>600</th>
<th>650</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. LCD Resolution</td>
<td>854x480</td>
<td>1280x1024</td>
<td>1680x1050</td>
</tr>
<tr>
<td>Video decode</td>
<td>720p 30 fps</td>
<td>720p 30 fps</td>
<td>1080p 24 fps</td>
</tr>
<tr>
<td>Video encode</td>
<td>720p</td>
<td>720p</td>
<td>720p</td>
</tr>
<tr>
<td>CPU speed</td>
<td>600 MHz</td>
<td>700 MHz</td>
<td>800 MHz</td>
</tr>
<tr>
<td>Memory speed</td>
<td>166 MHz</td>
<td>166 MHz</td>
<td>200 MHz</td>
</tr>
<tr>
<td>IDE support</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The Challenge: Power

- A good cell-phone battery holds 1100 mAh
- Lithium-Ion batteries are 3.7 volts
- $1100 \text{ mAh} \times 3.7\text{V} \approx 4\text{ Wh}$
- Improves only 5% per year
The Challenge: MP3 playback

- Just how little is 4 Wh?

Assume your system burns only 250mW
  - Audio processor, CPU, memory controller
  - IOs, RAM, flash storage, DAC...

Further assume 85% PMU efficiency

4000 mWh * 85% / 250 mW = 13.6 hours

Tegra can provide over 100 hours of MP3
The Challenge: Video playback

- Imagine if your system could play HD video
- While burning only 2000 mW
  - Video processor, CPU, memory controller
  - IOs, RAM, display, HDMI output...
- 4000 mWh * 85% / 2000 mW = 102 minutes

- Tegra can provide 10 hours of HD video
  - Whole chip burns well below 200 mW
The Challenge: Doing nothing

- What your phone does before it rings
- Determines how often you must recharge it

**Tegra can provide weeks of nothing**
- Chip burns 10s of μWatts in deep sleep
The Challenge: Gaming

- Tegra can provide over 5 hours of 3D gaming
- Core power is only about 200 mW
- Backlight is a hog
The Challenge: Size

- APX package is 12 x 12 mm
- Size of a fingernail
- And almost impossibly thin

- Imagine the size of the circuit board in your cell phone
- No one asks for a bigger chip
Power was a major challenge
Major rearchitecture required in some areas
But both low power and high performance require maximum efficiency
So cost functions are quite similar to GeForce
Ultra Low Power GeForce

- Fully programmable vertex and pixel shaders
  - High level GLSL programming language
- Floating point top to bottom
- OpenGL ES 2.0
  - OpenGL 2.0 without the fixed function
- Similar to DirectX 9
- Very high quality anisotropic filtering
- Stencil, Multiple Render Targets
- HDR rendering, HDR textures
  ...

5x CSAA  No AA
A Real, Modern GPU
Interesting design decisions

- Early-Z and fragment caching
  - These are big computation and bandwidth savers
- Ultra Efficient 5x Coverage Sampling Anti-Aliasing Scheme
  - Mobile version of CSAA technology from GeForce
- Not a tiling architecture
  - Tiling works reasonably well for DX7-style content
  - For DX9-style content the increased vertex and state traffic was a net loss
- Not a unified architecture
  - Unified hardware is a win for DX10 and compute
  - For DX9-style graphics, however, non-unified is more efficient
Ultra Low Power GeForce Performance

- Tegra APX can achieve:
  - Over 40M triangles/sec
  - Up to 600M pixels/sec
  - Texture 240M pixels/sec
- Run Quake 3 Arena
  - 45+ fps WVGA (800 x 480)
  - 8x Aniso Texture Filtering
  - 5x Coverage Sampling AA
High Definition Audio Video Processor

Video/Image Codec

- **High Definition Decode**
  - 1080P/720P decode
  - Peak bit-rate of 14-20 Mbps
  - H.264, VC1 and MPEG-4

- **High Definition Encode**
  - Up to 720P resolution
  - H.264 and MPEG-4
  - Peak bit-rate of 10 Mbps
  - Flexible Macroblock mode selection

- **Baseline JPEG**
  - Decode and Encode
  - Maximum resolution of 256 MP
  - 4:2:0, 4:2:2, 4:4:4, 4:2:2R support

Audio

- **Formats supported**
  - AAC-LC, AAC+, eAAC+
  - AMR-WB, AMR-NB
  - WMA7, 8, 9
  - WMA10 Pro LBR
  - MP3
  - PCM
  - SBC
  - Real Audio 8, 9, 10
  - MIDI Ringtone
High Definition Audio Video Processor

Broadcast TV
- ISDB-T, DVB-H, DVB-T, T-DMB

Optimized mobile viewing experience
- High-resolution display
- High-quality video playback
- Over 9 hours of continuous live TV
Tegra CPU

- ARM11 Core, optimized for high performance
  - 32K I and 32K D L1 caches
  - 256K L2 cache exclusive with L1
  - Low latency path to DRAM
  - Up to 800 MHz operation
- Importantly also optimized for low power
  - Caches reduce power hungry DRAM accesses
  - A dedicated PLL means the CPU runs just fast enough
  - Extensive clock gating
  - The media processing is done by hardware units, which is much more power efficient than doing it in software
Tegra Memory Controller

Challenge is to share 1.6 GB/s of 200 MHz LP-DDR efficiently
- Optimize DRAM page usage
- Maximize bandwidth for the multi-media clients
- Minimize CPU latency for maximum performance
- High priority for real time display and camera
- Extensive modeling to balance these

While still minimizing power
- DRAM clock stopping and standby modes
- Minimize expensive pre-charge/activates
- Dynamic frequency and voltage scaling
Image Signal Processor (ISP)

- Image processing for 12 Megapixel camera burst mode
- Also needed during video encode, 720p at 30 fps
- Roughly **1.6 GOPS** of image processing required
  - Lens shading
  - De-noising
  - De-mosaicing
  - Color correction
  - Sharpening
  - Contrast enhancement
  - Special effects
ISP Example: Color artifact reduction

- Reduces noise and false chroma ringing in shadows and high frequency regions
ISP Example: Auto White Balance (AWB)

- Make white objects look white under various illuminants

Too yellow

Corrected
ISP Example: Bilateral noise reduction filter

- Small sensors with high resolutions => tiny noisy pixels
## APX 2500 Development Platform Demos

<table>
<thead>
<tr>
<th>AP</th>
<th>NVIDIA APX 2500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory</td>
<td>256MB DDR, 8GB NAND</td>
</tr>
<tr>
<td>Display</td>
<td>Sharp 4” WVGA (800x480x24bit)</td>
</tr>
<tr>
<td>HSDPA</td>
<td>Infineon SGOLD3H</td>
</tr>
<tr>
<td>Audio</td>
<td>Wolfson WM8753L</td>
</tr>
<tr>
<td>WiFi</td>
<td>Atheros 802.11b/g</td>
</tr>
<tr>
<td>BlueTooth</td>
<td>Murata CSR BC5FM</td>
</tr>
<tr>
<td>GPS</td>
<td>SiRF</td>
</tr>
<tr>
<td>Mobile-TV</td>
<td>Siano DVB-H / DVB-T / T-DMB</td>
</tr>
<tr>
<td>Imaging</td>
<td>5MP &amp; VGA Micron Sensors</td>
</tr>
</tbody>
</table>
APX 2500 Demos…

- Also come to the lobby after the talk…
Summary

- Horsepower close to XBOX
- Quality & Features comparable to PLAYSTATION 3
- Tiny and eats power LIKE A BIRD