Whitepaper

NVIDIA® Tegra™ Multi-processor Architecture

V1.0

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The Mobile Challenge - High Performance and Low Power

Processing capabilities of computers and the internet connection bandwidth available to users have increased by several orders of magnitude over the last two decades. Consequently, there has been explosive growth in the amount and variety of content that is available on the internet. Web pages now include complex Java elements, high definition video content and Flash based games. There are over hundred million websites[1] on the internet and over six billion videos[2] are being viewed on Youtube™ every month. Farmville, a flash based game has alone attracted over 78 million[3] new players on Facebook. Users today want to access and enjoy this rich content not only on their PCs but also on their mobile devices such as tablets and smartphones. Users today expect their mobile device to not only deliver long battery life but also provide the same full high definition web experience that they get from a PC. In addition to web browsing capabilities, users expect their mobile devices to handle a variety of use cases such as gaming, audio playback, navigation and photo/video capture. Current mobile devices are unable to offer both the performance and the battery life required for users to enjoy a high definition web experience

Most mobile device architectures are designed around a general purpose CPU. The CPU, primarily designed to handle general purpose operations, is very inefficient in handling specialized audio-visual tasks such as decoding HD video, 3D gaming and flash video playback. The CPU not only underperforms but also consumes excessive power for today's mobile use cases. Relying on a power hungry CPU either compromises battery life to offer good performance or delivers substandard experiences. This is starkly evident in the number of complaints seen in mobile gadget magazines, websites, and forums regarding current mobile devices providing only a few hours of battery life. In fact, numerous articles have been written to help consumers extend battery life, and these articles basically recommend users to turn off many of the 'smart' features of their smartphones to get longer battery life. We call this the power-performance paradox.

The NVIDIA Tegra processor resolves this paradox with a new purpose-optimized processor architecture that delivers a responsive experience for full-resolution Web pages, full HD 1080p video playback, and days of battery life for typical use.

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[1] http://www.domaintools.com/internet-statistics/
[2] http://techcrunch.com/2009/06/09/youtube-video-streams-top-1-billionday/
[3] http://www.facebook.com/apps/application.php?id=102452128776

Smartphones

Tablets

Portable Media Players

Mobile Internet Devices

NVIDIA Tegra Multi-Processor Architecture

To overcome the power-performance paradox and the limitations associated with single-processor architectures, a revolutionary ground-up approach was taken in the design of the NVIDIA Tegra processor. Extensive architectural simulations and modeling of actual mobile and Web uses cases showed that a heterogeneous multi-processor architecture was required to meet both performance and battery life needs of current and future mobile use cases. A heterogeneous multi-processor by definition consists of several processors that are different in structure and function with each processor optimized for a specific purpose

The NVIDIA Tegra architecture is a heterogeneous multi-processor architecture that consists of eight independent processors for graphics, video encode and decode, image processing, audio processing, power management, and general-purpose functions. These processors are power managed independently with local hardware control and system level control built into each processor. A system-level power monitor allows the Tegra processor to turn on only those processors required for a specific use case, while keeping all other processors turned off.

Tegra's purpose-optimized processors are analogous to a carpenter's tool kit that has various tools such as hammer, saw, screwdriver, and drill. A carpenter does not use a hammer to drive screws or a drill to cut wood. Each tool is optimized for a specific task or function. Likewise, the Tegra processors are all specialized for particular tasks**.**

- **Graphics Processor (GPU)**: Delivers outstanding mobile 3D game playability and is also used for visually engaging, highly-responsive 3D touch user interfaces.

- **Video Decode Processor**: runs video macro-block oriented algorithms including inverse discrete cosine transforms (IDCT), variable length decode (VLD), color space conversion (CSC), and bit stream processing to deliver smooth, full frame rate 1080p HD video playback and streaming HD Flash video playback without compromising battery life.

- **Video Encode Processor**: runs video encode algorithms to deliver full 1080p HD video streams for video recording and conferencing capabilities.

- **Image Signal Processor (ISP)**: handles light balance, edge enhancement, and noise reduction algorithms to deliver real-time photo enhancement capabilities.

- **Audio Processor**: handles analog signal audio processing to deliver over 140 hours of continuous 128kbps mp3 audio playback on a single battery charge.[4]

- **Dual-Core ARM Cortex A9 CPU**: for general-purpose computing delivers faster web browsing and snappier response times on Java enabled websites

- **ARM7 Processor**: handles system management functions and several proprietary battery life extending features on NVIDIA Tegra.

Each processor adds instructions, caches, clocks, and circuits optimized for each specific task, with performance monitors to track system activity. Each processor is designed to provide the performance needed for demanding and heavy workload tasks such as browsing java enabled Web pages, HD video playback, responsive 3D user interfaces, and gaming. The proprietary power management features in the NVIDIA Tegra processor track system workload levels and continuously manage the frequency and voltage of each processor to provide the demanded performance at the lowest possible power. Using a set of dedicated processors, the system can easily handle multi-tasking loads that include a combination of 3D, video, communications, and audio tasks. When loads do not require multi-tasking, only the processor required for the task is used while all other processors in the system are turned off, thus achieving the lowest power consumption possible.

Use Case Examples

[4] Using a standard 2000mAh battery

Following are three example use cases to illustrate how the NVIDIA Tegra power management system optimizes processor use:

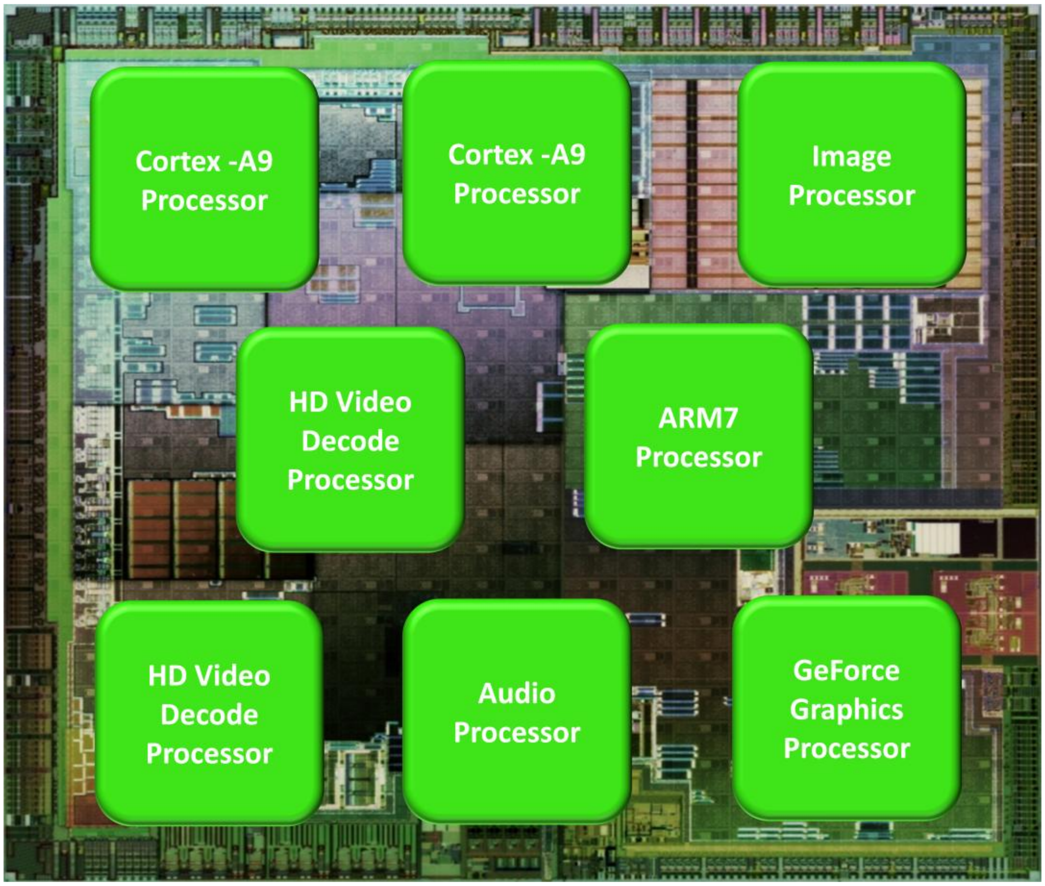
Listening to Music: During audio playback, the dedicated audio processor and the low-power ARM7 processor are turned on and all other processors are turned off. Turning off all the other processors allows the ARM7 processor to fetch a playlist and efficiently decode the audio using only 30 mW of power on average. If the device is in camera mode, the audio processor can be turned off and the ISP is turned on to grab camera sensor data at the click of a button. The ISP can then clean up the image and hand it off to the core processor to save on storage.

Watching Videos: When watching movies, the video decode processor handles all of the H.264 decode of 1080p content and can stream the video to the built-in HDMI port for viewing of HD content on a big screen. In this case, the display processor and actual display screen can be turned off to save significant power. For example, the Tegra-powered Zune HD player from Microsoft can provide eight hours of HD playback with a cell phone-sized battery in this mode.

Playing Games: During game play only the CPUs and the highly optimized NVIDIA GPU are turned on, and the video processors and ISP are turned off. This ensures that the high-performance processors consume power only when demanded and consume zero power when not in use.

Eight Purpose Optimized Processors

The diagram below shows the NVIDIA Tegra purpose-optimized processors. Each of these processors is power managed at a global level through software and locally through hardware mechanisms.



- **Dual-Core ARM Cortex A9 CPU:** NVIDIA Tegra features the world's first dual core CPU for mobile applications in addition to support for Symmetric Multi-Processing (SMP). SMP enables tasks to be parallelized between the two ARM Cortex A9 processors, and delivers faster load times of Web pages, quicker UI responsiveness, and faster rendering of complex Web pages.

  NVIDIA has implemented aggressive dynamic voltage and frequency scaling to minimize the power used by the dual-core Cortex A9 CPU. A typical Web browsing activity consists of a short initial period of Web page load followed by a longer period for reading the content of the page. When a new Web page is opened the CPU springs to life at full speed to quickly load the page and process java elements in the page. The Global Power Management System monitors the workload presented to the CPU and tunes the CPU voltage and frequency to match the needs of the workload. When the CPU is not in use (for example after a Web page has loaded and the user is reading the content of the page), power to the CPU is completely turned off with full power gating. Even when Web pages have Flash visual elements, the CPU can be completely turned off because the Flash visual features are offloaded to the GPU and video processor in the NVIDIA Tegra architecture.

- **ARM7 Processor:** To avoid the use of the higher power Cortex A9 CPU for tasks that have lower performance requirements, an ARM7 processor is included in the Tegra architecture. This processor is primarily used in concert with the audio and video processors to deliver ultra low-power audio and low-power video playback capabilities.

- **Ultra Low-Power Graphics Processor (GPU):** The NVIDIA Tegra processor includes a market-leading NVIDIA GPU with programmable vertex shading and pixel shading processors. The hyper-efficient 2D/ 3D processor renders user interfaces, pictures, fonts, and other graphical elements instantly using only battery-sipping amounts of power. The 3D processor can render Quake 3 at 1024x600 resolution at over 60 frames per second using only a few hundred milliwatts. The GPU in NVIDIA Tegra is also capable of handling the demanding workloads presented by modern game engines. The Unreal® game engine that is used by several hundred PC games runs effortlessly on the NVIDIA Tegra processor. This capability will now enable game developers to easily port PC games to NVIDIA Tegra based mobile platform with minimal effort. The GPU can also render full-screen Flash animations using only 150 mW. This is critical for long battery life when browsing the Web or playing Flash-based games.

  Unlike ARM CPUs, the GPU in the Tegra processor has dedicated hardware to handle video workloads. ARM CPUs are generic processors and the CPU hardware is not optimized for specific tasks. Thus, they struggle to handle Flash content and render Flash video and graphics elements at very low frame rates while consuming relatively large amounts of power. The GPU is specifically optimized to decode Flash video and graphics elements and is able to decode Flash content at full frame rates and render Flash visual elements at much lower power levels.

- **HD Video Decode Processor:** The video decode processor is used to decode video streams from files that are either played from the local disk or streamed off the network. Over 80% of today's top Web sites include video, most of which is Flash-based video content. The dedicated video processor handles all three Flash video formats: H.264, Sorenson and VP6-E. As a result, Flash video runs on NVIDIA Tegra at full frame rates and consumes very low power. Other mobile solutions that use general-purpose CPUs for Flash video deliver stuttering images and drain battery life. The decode processor is based on several generations of NVIDIA hardware decode expertise and is able to deliver flawless 1080p video playback while consuming less than 400 mW of power.

- **HD Video Encode Processor:** The video encode processor can be used to encode 1080p content coming in from an HD video image sensor at 30 fps. The encoded video stream may then be saved locally or transmitted live over a broadband network. The video encode and decode processors can be used together to deliver HD video conferencing.

- **Audio Processor:** The dedicated audio processor is used to deliver ultra low-power audio playback that can last for days. The audio processing pipeline is designed to consume less than 30mW of power while playing back a 128 Kbps MP3 file.

- **Image Signal Processor (ISP):** Many mobile devices include high resolution sensors for taking pictures and lower resolution cameras for Web video. The ISP in the NVIDIA Tegra processor is capable of taking raw camera sensor input at up to 12 megapixel resolution and 30 frames per second. The image processor can then apply real-time image enhancement algorithms like automatic white balance, edge enhancement, and noise reduction, and can even adjust for poor lighting conditions. The output of the ISP is then ideal to save as a picture or as a stream that can be compressed for live video conferencing or sent with HD quality across a broadband network.

The eight independent processors of the NVIDIA Tegra multi-processor architecture deliver unprecedented performance and multimedia capabilities to mobile devices. NVIDIA Tegra implements a Global Power Management System that utilizes hardware feedback and software algorithms to deliver industry-leading battery life for today's mobile devices.

NVIDIA Tegra Global Power Management System

Distributed across the NVIDIA Tegra multi-processor architecture are numerous hardware monitors that collect data on activity levels, frequency, temperature, and incoming request patterns. The Global Power Management System uses the data fed back from these monitors to determine the optimal operating frequency and voltage for the active processors. This type of feedback control ensures that the processors are always running at the lowest possible power level.

Additionally, a feed-forward control mechanism is used to instantaneously boost operating frequency and voltage for specific requests that indicate upcoming high performance requirements. This ensures that users do not experience any lag or performance degradation for activities such as 3D UI navigation and gaming.

Ground-Breaking Performance and Battery Life

The table below illustrates battery life the user can expect from an NVIDIA Tegra-based tablet (with 2000 mAh battery and 400 mW display).

Use Case	Battery Life Estimates
Standby (display and radio off)	**2000 Hours**
128 Kbps MP3 Music Playback	**140 Hours**
HD Video Playback on local LCD	**8 Hours**
HD Video Playback on external display(via HDMI port)	**16 Hours**

Conclusions

The purpose-oriented multi-processor architecture of NVIDIA Tegra is defined by the philosophy of "the right tool for the job". Dedicated, high-performance processors deliver snappy Web browsing, flawless streaming HD Flash video, and an exceptional mobile gaming experience. Additional, processors deliver ultra low-power audio and video capabilities that provide extended audio and video playback times.

The revolutionary multi-processor architecture and power management features of NVIDIA Tegra deliver an exceptional mobile visual computing experience with uncompromised battery life. NVIDIA Tegra processors will be used in a wide range of very capable and enjoyable mobile platforms including smartphones, tablets, e-readers, media players, and mobile Internet devices (MIDs).

With a system-level design built upon more than 10 generations of proven NVIDIA GPU technology, Tegra enables intuitive 3D user interfaces, advanced HD multimedia features, and access to full Web browsing, all while delivering battery performance that leaves the competition far behind.

Document Revision History

- **Initial release**

NVIDIA.