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ANDROID* DEVELOPMENT FOR INTEL® ARCHITECTURE

Articles

Foreword Android* for Intel Architecture

Michael S. Richmond,
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This issue of the Intel Technical Journal focuses on the Android* operating system and its use on Intel Architecture.

From its inception, architectural independence has been an important goal for Android. The Linux kernel originated on and has always been optimized for Intel architecture, but its use within Android certainly has contributed to improvements in the kernel to better support ARM and other architectures. The kernel project has a long tradition of accommodating optimizations for multiple architectures and contributions from competing companies that move the kernel forward.

For application developers, architectural independence in Android is delivered through the Dalvik virtual machine, where Android applications are executed with no knowledge of the underlying CPU architecture.

At least, that's the theory. In practice, there is wide variance among Android implementations, and plenty of room for competition. And competition is good for Android. For a fascinating example, go along with Ryan Cohen as he installs Beacon Mountain, Intel's development environment for Android. Beacon Mountain allows an application developer to execute Android applications on a PC or Mac (both powered by Intel architecture) using the standard Android SDK. For years, this kind of emulation was painfully slow. Beacon Mountain includes Intel® Hardware Accelerated eXecution Manager (Intel® HAXM), making emulation competitive with execution on a target device. The ironic result: application developers using unique features in Intel Architecture to develop Android applications intended for (mostly ARM-based) phones while learning just how good Android is on Intel Architecture. Ryan Cohen also summarizes the major developments that have made Intel Architecture a first-class platform for Android.

Between the Linux kernel and the Dalvik runtime, there is a wide range of middleware needed to deliver the best Android experiences. Orion Granatir and Clay Montgomery focus on two of the most important visual middleware elements: OpenGL 3D libraries for both Dalvik and native use, and 2D SVG (Scalable Vector Graphics), the resolution-independent graphics specification that is part of the World Wide Web consortium's Open Web Platform initiative. Orion and Clay focus on the use of a spectacular new tool that helps developers to take their onscreen Android experiences from "should be smooth and fluid" to "is smooth and fluid."

Some of the biggest differences between devices and the traditional PC are the sensors embedded in devices to translate a physical experience into the virtual world of applications. Miao Wei introduces the Android Sensor framework and walks us through how motion, position, GPS, and more can be used to deliver signal on a phone or tablet platform without overwhelming the application with environmental noise.

In addition to the interactive experiences enabled by OpenGL, SVG, and sensors, consumers love how devices based on Android allow them to bring their entertainment with them wherever they go. Yuming Li shows how to map techniques proven over two decades on Intel architecture directly to today's Android entertainment and video conferencing experiences when implementing codecs on Intel architecture. Today's CPUs might provide an acceptable frame rate on low-end phones even with sloppy codecs, but the higher resolution phones and tablets of now require state-of-the-art optimization to provide the frame rates consumers expect with great battery life.

Intel has a commitment to Linux and open source that goes back 15 years. Android depends on open source ways of working combining collaboration for the common good along with competition that improves everyone's game. Consumers win, and because of Moore's Law, they win more every year.

AN INTRODUCTION TO ANDROID* ON INTEL PROCESSORS

Contributor

Ryan Cohen

"Since the creation of Android in 2008, it has been considered an ARM-based platform."*

Since the creation of Android* in 2008, it has been considered an ARM-based platform. It was not until mid-2009, when a group of developers created The Android-x86 Project to be able to port Android Open Source Project (AOSP) to the x86 platform, that anyone even considered using x86 processors for Android devices. Intel got directly involved with Android in 2010 with their first mobile platform targeted directly at Android, the Moorestown Platform. In September of 2011, Intel and Google announced a partnership to optimize future versions of Android for x86 processors. Intel went on to announce the Medfield Platform in 2012 followed by Bay Trail and Merrifield in 2013. All three platforms were supported by Android on release.

In this article, we discuss the history of Android on Intel processors from 2009 to today. We also review the first official Android devices to feature Intel processors, as well as other notable devices that have been released. These reviews contain fact-based comparisons of hardware and software specifications as well as benchmarks performed by third-party technical review sites and benchmarking sites.

Intel and Android, a Brief History

The history of Android running on Intel processors goes back to before Intel officially started making chips specifically for Android devices. It started, in 2009, as an unofficial port created by a group of developers who called it The Android-x86 Project. In 2010 Intel announced the Moorestown platform to be used in smartphones and tablets. During 2011, several Android tablets were released with Intel processors. In the fourth quarter of 2011, Intel and Google announced a partnership to optimize future versions of Android for Intel processors. During 2012, the first Android smartphones featuring Intel processors were released, starting with the Lava Xolo X900* in India.

"…Intel and Google announced a partnership to optimize future versions of Android for Intel processors."

Android-x86 Project

Initially called "patch hosting for Android x86," the Android-x86 Project was started by a group of developers in mid-2009. Their goal was to port the Android Open Source Project (AOSP) to the x86 platform. The project can be found at www.android-x86.org. Before the Android SDK and NDK officially supported x86 processors, the Android-x86 project was the go-to source for porting Android to devices with x86 processors.

Moorestown Platform

In 2010, Intel Corporation unveiled its newest Intel® Atom™ processor-based platform, codenamed Moorestown. This platform used significantly less power than previous Intel Atom processor–based platforms and allowed Intel to start targeting smartphones, tablets, and other mobile devices.

"…[Moorestown] used significantly less power than previous Intel Atom processor–based platforms…"

The new platform supported a range of scalable frequencies, up to 1.5 GHz for high-end smartphones and up to 1.9 GHz for tablets and other handheld devices. The chipset also brought support for Wi-Fi*, 3G/HSPA, and WiMAX, as well as a range of operation systems, including Android, MeeGo*, Moblin*, and Windows* 7.

Intel and Google Partnership

On September 13, 2011, Intel Corporation and Google Inc. announced that they would work to enable and optimize future versions of Android for the Intel Atom family of low power processors. This meant that future versions of the Android platform would support Intel technology in addition to other architectures in the software released by Google.

"…future versions of the Android platform would support Intel technology in addition to other architectures in the software released by Google."

"By optimizing the Android platform for Intel architecture, we bring a powerful new capability to market that will accelerate more industry adoption and choice, and bring exciting new products to market that harness the combined potential of Intel technology and the Android platform," said Intel President and CEO at the time, Paul Otellini. "Together we are accelerating Intel architecture and bringing new levels of innovation to a maturing Android platform."

"Combining Android with Intel's low power smartphone roadmap opens up more opportunity for innovation and choice," said Andy Rubin, Senior Vice President of Mobile at Google at the time. "This collaboration will drive the Android ecosystem forward."

The announcement built upon the two companies' recent joint initiatives to enable Intel architecture on Google products, which include Chrome OS and Google TV along with the Android Software Development Kit (SDK) and Native Development Kit (NDK).

International Consumer Electronics Show (CES) 2012

January of 2012, at CES, Intel Corporation announced a number of advancements in its mobile strategy, including a strategic relationship with Motorola Mobility, Inc., a subsidiary of Google Inc., and a handset by Lenovo, the K800*, based on the company's new Intel Atom processor platform. The Intel Atom processor Z2460 platform, formerly codenamed Medfield, was, according to Intel, "specifically designed for smartphones and tablets, and delivers leading performance with competitive energy efficiency." The partnership with Motorola Mobility included smartphones that Motorola would begin to ship in the second half of 2012 using Intel Atom processors and the Android platform. The first product to come of this partnership was the Razr i* smartphone. The collaboration, which also covers tablets, "combines Intel's leadership in silicon technology and computing innovation with Motorola's mobile device design expertise" said Intel.

Intel also announced the Intel® Smartphone Reference Design, with the aim of shrinking device development time and costs for phone OEMs and carriers. This fully functioning smartphone featured a 4.03-inch high-resolution LCD touchscreen, and two cameras, front and back, delivering advanced imaging capabilities, including burst mode that allows individuals to capture 15 pictures in less than a second with 8-megapixel quality.

"…Intel announced their newest low power Intel Atom processor based platform aimed at emerging markets."

International Consumer Electronics Show (CES) 2013

At CES 2013, Intel announced their newest low power Intel Atom processor based platform aimed at emerging markets. The new value offering includes many high-end features including the Intel Atom processor Z2420. Intel also made announcements about their forthcoming Intel Atom Z2580 processor platform targeted at performance and mainstream smartphones. The platform included a dual-core Intel Atom processor with Intel® Hyper-Threading Technology and also featured a dual-core graphics engine. According to Intel "the new platform [would] deliver up to two times the performance benefits over our current-generation solution (Intel Atom processor Z2460 platform), while also offering competitive power and battery life." Finally, Intel announced a new tablet platform, Bay Trail, which would be Intel's first quad-core SoC.

Lenovo* announced the IdeaPhone K900* at CES 2013, which is based on the Intel Atom processor Z2580. The K900 is 6.9-mm thin and also features the world's first 5.5-inch full high-definition 400 + PPI screen. The K900 was the first product to market based on the Intel Atom processor Z2580.

Mobile World Congress (MWC) 2013

"[Intel announced] the company's first global, multimode-multiband LTE solution"

Intel made several announcements at MWC 2013 in Barcelona, Spain. The announcements included more details about a new dual-core Intel Atom SoC platform for smartphones and tablets, and the company's first global, multimode-multiband LTE solution. Intel also discussed Bay Trail momentum, mobile device enabling efforts, and continued smartphone momentum in emerging markets with the Intel Atom Z2420 processor-based platform. Finally, Intel highlighted its forthcoming 22-nm smartphone Intel Atom SoC (codename Merrifield). The product is based on Intel's "leading-edge 22-nm process and an entirely new Intel Atom microarchitecture that will help enable increased smartphone performance, power efficiency, and battery life."

ASUS* announced the FonePad at MWC 2013. The Fonepad combines features of a smartphone with the versatility of a 7-inch tablet. Powered by a new Intel Atom Z2420 processor with Android 4.1, the Fonepad includes 3G mobile data and a vibrant HD display with IPS technology for "wide viewing angles and outstanding clarity." The Fonepad launched in April of 2013.

Intel® Atom™ Platform Z2580

According to Intel, the new Intel Atom processor platform delivers "industry-leading performance with low-power and long battery life that rivals today's most popular Android smartphones."

"…the new Intel Atom processor platform delivers "industryleading performance with low-power and long battery life that rivals today's most popular Android smartphones.""

The platform's 32-nm dual core Intel Atom processors—Z2580, Z2560, and Z2520—are available in speeds up to 2.0 GHz, 1.6 GHz, and 1.2 GHz, respectively.

Intel provided details on key features of the platform including, "support for Intel Hyper-Threading Technology, supporting four simultaneous application threads and further enhancing the overall efficiency of the Intel Atom cores." The integrated platform also includes an "Intel® Graphics Media Accelerator engine with a graphics core supporting up to 533 MHz with boost mode, and delivering up to three times the graphics performance of the Intel Atom Z2460 platform for rich 3-D visuals, lifelike gaming, and smooth, full 1080P hardware-accelerated video encode and decode at 30 FPS." The new Intel Atom platform brings "advanced imaging capabilities, including support for two cameras, with a primary camera sensor up to 16 megapixels." The imaging system also enables panorama capture, "a 15 frame-per-second burst mode for 8 megapixel photos, real-time facial detection and recognition, and mobile HDR image capture with de-ghosting for clearer pictures in flight. With WUXGA display support of 1920   12003, the platform will also enable larger-screen Android tablet designs." The platform also includes support for Android 4.2 (Jelly Bean), Intel Wireless Display Technology, HSPA + at 42 Mbps with the Intel® XMM 6360 slim modem solution, and the new industry-standard UltraViolet* Common File Format.

The platform is also equipped with Intel® Identity Protection Technology (Intel IPT), "helping to enable strong, two-factor authentication for protecting cloud services such as remote banking, e-commerce, online gaming, and social networking from unauthorized access. Since Intel IPT is embedded at chip-level, unlike hardware or phone-based tokens, it can enable more secure yet user-friendly cloud access protection." Intel is working with partners including Feitian, Garanti Bank, MasterCard, McAfee, SecureKey Technologies Inc., Symantec, Vasco Data Security International Inc., and Visa Inc. to "incorporate this technology into their services."

Intel® XMM 7160

According to Intel, the XMM 7160 is "one of the world's smallest and lowest-power multimode-multiband LTE solutions (LTE/DC-HSPA+/EDGE), supporting multiple devices including smartphones, tablets, and Ultrabooks*." The 7160 global modem supports 15 LTE bands simultaneously, "more than any other in-market solution." It also includes a "highly configurable RF architecture running real-time algorithms for envelope tracking and antenna tuning that enables cost-efficient multiband configurations, extended battery life, and global roaming in a single SKU." Intel is currently shipping its single mode and multimode 4G LTE data

"…the XMM 7160 is "one of the world's smallest and lowest-power multimode-multiband LTE solutions (LTE/DC-HSPA+ / EDGE), supporting multiple devices including smartphones, tablets, and Ultrabooks.""*

solutions. Intel is also "optimizing its LTE solutions concurrently with its SoC roadmap to ensure the delivery of leading-edge low-power combined solutions to the marketplace."

Intel® Atom™ Platform Z2420

"The Intel Atom processor Z2420 with Intel Hyper-Threading Technology can achieve speeds of 1.2 GHz…"

The Intel Atom processor Z2420 with Intel Hyper-Threading Technology can achieve speeds of 1.2 GHz, features 1080p hardware-accelerated encode/decode, and support for up to two cameras delivering "advanced imaging capabilities," including burst mode that allows users to capture seven pictures in less than a second in 5-megapixel quality. The platform also includes the Intel XMM 6265 HSPA + modem that offers Dual Sim/Dual Standby capability for cost-conscious consumers. This platform is targeted at emerging markets.

Since the platform was first announced at CES 2013, Acer (Thailand, Malaysia), Lava (India), and Safaricom (Kenya) have all announced new handsets. Etisalat Misr, a leading telecommunications operator based in Egypt and a subsidiary of Etisalat group UAE, in collaboration with Intel announced plans for the Etisalat E-20 Smartphone* with Intel Inside®.

Intel® Atom™ Platform Z2760

The first quad-core Intel Atom SoC (formerly codenamed Bay Trail) "will be the most powerful Intel Atom processor to date, doubling the computing performance of Intel's current generation tablet offering and providing the ecosystem with a strong technology foundation and feature set from which to innovate." The Bay Trail platform is already up and running on Android and will "help enable new experiences in designs as thin as 8 mm that have all-day battery life and weeks of standby."

Intel is currently working with Compal, ECS, Pegatron, Quanta, and Wistron to accelerate Bay Trail tablets to the market. Intel is also "extending its work with leading OEM partners globally, building on the strong foundation of Intel Atom processor Z2760-based tablet designs in market from Acer, ASUS, Dell, Fujitsu, HP, Lenovo, LG Electronics, and Samsung."

Intel Developer Forum 2013 San Francisco (IDF13)

I had the honor of attending IDF, for the first time, in September of 2013 at the Moscone Convention Center in San Francisco, California. IDF is described by Intel as "the leading forum for anyone using Intel Architecture or Intel technologies to change the world." Android had a large presence at IDF13 (see Figure 1), including mentions during keynote speeches and several technical sessions for developers and OEMs/ODMs throughout the event. During the conference, Intel discussed their newest Bay Trail platform, Z3XXX, based on Ivy Bridge architecture. The platform features Intel HD graphics as well as CPU and GPU power sharing. Intel also showed off their Bay Trail Tablet references design for Android, called FFRD8 (8.9"). I found IDF to be a very fun and informative event and would recommend that anyone interested in working with Intel-based Android devices attend next year's IDF if possible.

"…Intel discussed their newest Bay Trail platform, Z3XXX, based on Ivy Bridge architecture."

Figure 1: Me at IDF13
(Source: Taken at IDF13)

Android SDK/NDK x86 Support

Initially, there was no support from Google in the SDK or NDK for x86 processors. Support was gradually added, starting in July of 2011 when revision 12 of the SDK and revision 6 of the NDK were released adding support for x86-based platforms.

Later, in March of 2012, Revision 17 of the SDK was released adding native x86 emulator support. This allowed the Android emulator to run at near-native speeds on development computers that have x86 processors and include virtualization hardware (Intel® Virtualization Technology, or Intel VT), thanks to contributions from Intel.

"…Revision 17 of the SDK added native x86 emulator support."

Intel Software for Android

Intel has released several additional pieces of software to help developers optimize their applications for Intel Atom processors. The most notable are the Intel® Atom™ x86 System Image, Intel® Hardware Accelerated Execution Manager (Intel HAXM), and Intel Graphics Performance Analyzer with Android support.

Intel® Hardware Accelerated Execution Manager (Intel® HAXM)
Released in February of 2012, Intel® HAXM supports Windows, Mac*, and Linux* platforms. Intel HAXM is a "hardware-assisted virtualization engine (hypervisor) that uses Intel Virtualization Technology (Intel VT) to speed up Android application emulation on a host development machine." In combination with Android x86 emulator images provided by Intel and the official Android SDK Manager, Intel HAXM allows for "faster Android emulation on Intel VT enabled development systems."

Intel® Graphics Performance Analyzer (Intel® GPA)
The latest version, with support for Android, was introduced in March of 2012 at the Game Developers Conference (GDC) in San Francisco. Intel® GPA is a "powerful, agile developer tool suite for analyzing and optimizing games, media, and other graphics-intensive applications. It provides real-time charts of CPU metrics, graphics API level metrics, GPU hardware metrics, and power metrics."

Intel® Atom™ X86 System Image for Android*
In May of 2012, Intel released the Intel® Atom™ X86 System Image of Android 4.0 (Ice Cream Sandwich). This emulation platform allows developers without a physical Intel Atom based device to develop and test applications on their PC at "near-native" speeds. As of this writing, the system image for 4.3, the latest Jelly Bean release, is available.

Initial Devices

"The first Android devices powered by Intel Atom processors were tablets…"

The first Android devices powered by Intel Atom processors were tablets, starting with the Avaya Flare* in 2010. During 2011, 30 devices powered by Intel Atom processors were released, all in a tablet form factor. The unique advantage of using the Intel Atom processors in these tablets is that they can run both Android and Windows. In the first half of 2012, smartphones powered by Intel Atom processors came to market, starting with the Lava Xolo X900, Lenovo K800, and Orange San Diego*. All of these phones were released outside of the United States.

Avaya Flare*
Released September 26, 2010, the Flare was the first Android tablet featuring a 1.86-GHz Intel Atom Processor Z540. It ran Android 2.1 (Eclair), and had some good specifications for the time, such as an 11.6-inch screen and a 5-megapixel front camera. However with a battery life of less than three hours and a weight of 3.25 pounds, it had about half the battery life and double the weight of other tablets on the market.

ViewSonic ViewPad 10*
The ViewPad 10* was the first tablet powered by an Intel Atom processor to run both Windows 7 and Android 2.2 (Froyo). It shipped February 3, 2011 featuring a 1.66-GHz processor (N455) and a 10.1-inch screen. With

a 1.3-megapixel front-facing camera, four to six hours of battery life, and a weight of 1.93 pounds, the ViewPad 10 was on par with other tablets of the time.

Lava Xolo X900*

"The X900 was the first Android smartphone powered by an Intel Atom processor."

The X900 was the first Android smartphone powered by an Intel Atom processor. It was released April 2012 in India and is based on Intel's reference design. It has a 4-inch (1024   600) display, 8-megapixel rear camera, 1.3-megapixel front camera, and Near Field Communication (NFC). NFC allows communication with other devices with NFC technology or unpowered NFC chips (tags). This technology has several uses, such as transferring data, making purchases, and changing settings on the phones, to name a few. The X900 runs on a Z2460 1.6-GHz processor with Intel® Hyper-Threading Technology (Intel HT Technology). Intel HT Technology allows one core on the processor to appear like two cores to the operating system. This doubles the execution resources available to the OS, which potentially increases the performance of your overall system. This feature is not available on ARM processors. The device also features a 400-MHz graphics core, 1 GB of RAM, and 16 GB of internal storage, putting it on par with the average high-end smartphone of the time. The X900 came loaded with Android 2.3 (Gingerbread) with no custom UI, like Sense or TouchWiz, but was updated to Android 4.0 (Ice Cream Sandwich) later in 2012. Unlike many Android phones in existence, the Xolo has no removable battery or SD card slot. This is seen as a disadvantage to some in the Android community, but this appears to be the trend for new high-end Android smartphones, including HTC's new One series. The reason for the new trend of nonremovable batteries is that it allows for thinner smartphones. The move away from SD card slots is an effort to increase smartphone performance, since internal storage is faster than SD cards.

Lenovo K800*

"[The K800] is also based on Intel's reference design…"

The K800 was released in China at the end of May 2012. It features many of the same specifications as the Xolo X900, since it is also based on Intel's reference design, including the same 1.6-GHz Intel Atom processor with Intel HT Technology and a 400-MHz graphics processor. Just like the Xolo, the K800 has an 8-megapixel rear camera, a 1.3-megapixel front camera, 1 GB of RAM, and 16 GB of internal storage. It came running Android 2.3 (Gingerbread) with a custom Lenovo UI and was later updated to Android 4.0 (Ice Cream Sandwich). It also has no removable battery. There are few notable differences besides the UI including the larger 4.5-inch screen, larger battery, and an SD card slot.

Orange San Diego*

The third Intel powered smartphone was released in the United Kingdom in June of 2012. Also based on the Intel reference design, this phone is almost identical to the Xolo X900. It has the same 1.6-GHz Intel Atom processor with Intel HT Technology and a 400-MHz graphics processor, the same cameras, 1 GB of RAM, 16 GB of internal storage, and a 4-inch screen. It ran Android 2.3 (Gingerbread) with a custom UI by Orange out of the box, which is different from the custom UI on the K800. The San Diego was later updated to Android 4.0 (Ice Cream Sandwich). Like the two smartphones before it, the battery is not removable and there is no SD card slot.

Smartphones and Tablets with Intel Processors

In this section, I analyze several smartphones and tablets released with Intel processors. These devices are compared with their ARM-based competition based on price, hardware, software, and benchmarks.

"These devices are compared with their ARM-based competition based on price, hardware, software, and benchmarks."

All pricing and release date information is pulled directly from manufacturer announcements made just prior to device releases.

Details about hardware and software for devices was pulled directly from the manufacturers' Web sites whenever possible and supplemented with information from third-party tech sites when not.

The benchmarks used for device comparisons are listed below, along with descriptions of the benchmarking tools provided by the respective sites.

AnTuTu Benchmark* is a benchmarking tool for Android smartphones and tablets. It tests memory performance, CPU integer performance, CPU floating point performance, 2D and 3D graphics performance, SD card reading/writing speed, and database I/O performance testing.

Quadrant* is a benchmarking tool for Android smartphones and tablets made by Aurora Softworks. It measures CPU, Memory, I/O, and graphics performance using twelve CPU tests, one memory test, four I/O tests, one 2D graphics test, and three 3D graphics tests.

GFX Benchmark*, formerly GL Benchmark*, is a cross-platform benchmarking tool. It performs graphics and computation capability tests for OpenGL ES–compliant mobile devices and embedded environments. It can test planar reflection, advanced shading system, animated water with normal maps, triangles with vertex shader texture and lighting, and space portioning and occlusion system with PVS.

Lava Xolo X900*

"[The X900] was the first Android smartphone powered by the Intel Atom processor."

The Lava Xolo X900, shown in Figure 2, was the first Android smartphone powered by the Intel Atom processor. It was released April 19, 2012 in India and based on Intel's reference design. The phone was priced at 22,000 Rupees (INR 22,000), which was approximately 420 U.S. Dollars (USD 420) at the time of release. This is comparable in price to the GSM Samsung Galaxy Nexus*, which was released at the end of 2011 and was USD 400, or about INR 20,900, at the time of the X900's release. The price of the Galaxy Nexus is artificially low since Google subsidizes the price in the hopes of making more content sales in Google Play*. It is however still comparable since this is the price the consumer pays. It is also comparable to the HTC One V*, which was

Figure 2: The Lave Xolo X900
(Source: Intel Corporation, 2012)

released April 2, 2012 in India at a price of INR 19,999 or about USD 382 at the time of the X900's release (see Table 1).

	X900	**Galaxy Nexus**	**One V**
Price in USD	420	400	382
Price in INR	22,000	20,900	19,999

Exchange rate at April 19, 2012

Table 1: Price Comparison for X900, Galaxy Nexus, and One V
(Source: Data from respective manufacturers)

Hardware

The X900 has a 4.03-inch (600 1024) LCD display. The screen is smaller than the Galaxy Nexus' 4.65-inch (720 1280) Super AMOLED display but larger than the One V's 3.7-inch (480 800) LCD display. The X900 features an 8-megapixel rear camera with Intel® Burst Mode Technology, which allows the phone to take up to 10 photos in less than one second. It also records video in full HD 1080p and has superior image quality in low light conditions. Intel Burst Mode Technology is similar to HTC's Image Sense* technology found in most of their One* series phones. The Galaxy Nexus and One V both have 5-megapixel rear cameras. The X900 also features a 1.3-megapixel front camera, and Near Field Communication (NFC), which is the same as the Galaxy Nexus; however, the One V has no front-facing camera and no NFC. The X900 runs on a Z2460 1.6 GHz processor with Intel Hyper-Threading Technology (Intel HT Technology). The Galaxy Nexus runs on a TI OMAP 4460* Dual-core 1.2 GHz Cortex-A9 and the One V runs on a Qualcomm MSM8255 Snapdragon* 1 GHz processor. The X900 device also features a 400 MHz graphics core, 1 GB of RAM and 16 GB of internal storage, putting it on par with the Galaxy Nexus and ahead of the One V, which has 512 MB of RAM and 4 GB of internal storage. The X900 does not feature a removable battery or SD card slot. The X900 has a 1460 mAh battery. The Galaxy Nexus has a 1750 mAh removable battery and no SD card slot while the One V has a 1500 mAh nonremovable battery and an SD card slot. See Table 2 for a product comparison.

"The X900 features an 8-megapixel rear camera with Intel® Burst Mode Technology…"

"The X900 runs on a Z2460 1.6 GHz processor with Intel Hyper-Threading Technology…"

	X900	Galaxy Nexus	One V
Screen	4.03-inch (600 1024) LCD	4.65-inch (720 1280) Super AMOLED	3.7-inch (480 800) LCD display
Rear-Camera	8-megapixel	5-megapixel	5-megapixel
Front-Camera	1.3-megapixel	1.3-megapixel	N/A
NFC	Yes	Yes	No
CPU	Z2460 1.6 GHz with Intel® HT Technology	TI OMAP 4460* dual-core 1.2 GHz Cortex-A9	Qualcomm MSM8255 Snapdragon* single-core 1 GHz
GPU	Imagination Technologies PowerVR SGX 540*	Imagination Technologies PowerVR SGX 540*	Qualcomm Adreno 205*
RAM	1 GB	1 GB	512 MB
Internal Storage	16 GB	16 GB	4 GB
Battery	1460 mAh nonremovable	1750 mAh removable	1500 mAh nonremovable
SD Card	No	No	Yes

Table 2: Hardware Comparison for X900, Galaxy Nexus, and One V
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

"The X900 came loaded with Android 2.3.7 (Gingerbread), with no custom UI…"

Software

The X900 came loaded with Android 2.3.7 (Gingerbread), with no custom UI like HTC Sense* or Samsung TouchWiz*, and was updated to Android 4.0.4 (Ice Cream Sandwich) in October of 2012. Although the X900 has no custom UI, it does still have some extra apps added by Lava such as the XOLO* Care app, built-in DoubleTwist music player and a custom camera app. It also features a custom widget in the notification dropdown that allows the user to quickly toggle Wi-Fi, Bluetooth*, GPS, Auto-Sync, and Auto-Brightness. The phone receives Android software updates from the manufacturer similar to almost all Android smartphones on the market.

The Galaxy Nexus runs a completely stock build of Android with no added apps. At the time of the X900's release, it ran Android 4.0.4 but has since been updated several times. The Galaxy Nexus is currently on Android 4.3. Unlike most Android phones, Nexus phones receive updates straight from Google instead of the manufacturer. For this reason, the Galaxy Nexus is one of the first phones to receive new versions of Android.

The HTC One V runs Android 4.0.3 with HTC's Sense 4.0 UI and Beats Audio* software. The Sense 4.0 UI has many unique apps and features. It has custom camera, music, car, entertainment, and Internet apps, to name a few. Sense 4.0 also has many custom widgets such as bookmarks, calculator, calendar, and the popular weather clock, among others. Beats Audio is sound enhancement software that gives the user authentic sound while watching movies, playing games, and listening to music while wearing headphones. The phone receives updates from HTC and will not receive Android 4.1. (see Table 3).

	X900	Galaxy Nexus	One V
Android OS	4.0.4	4.3	4.0.3
UI	Almost Stock	Pure Stock	Sense 4.0
Updates From	Lava	Google	HTC

As of September 23, 2013

Table 3: Software Comparison for X900, Galaxy Nexus, and One V (Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Benchmarks

The benchmark scores are shown in Table 4. Higher scores mean better performance. The X900 was benchmarked with AnTuTu and Quadrant in an article on ThinkDigit.com written by Vishal Mathur. The Galaxy Nexus running Android 4.1 was benchmarked with AnTuTu and Quadrant by PhoneBuff.com. The One V was benchmarked with AnTuTu and Quadrant in an article on slashgear.com written by Ben Kersey. All GL benchmarks were pulled directly from their Web site and are average scores on August 6, 2012 (http://gfxbench.com/compare.jsp).

"Higher scores mean better performance in the benchmarks."

	X900	Galaxy Nexus	One V
AnTuTu	5,720	5,084	2,544
Quadrant	3,354	2,275	1,980
GL (2.1 Egypt Standard)	3,882 (34.4 FPS)	2,758 (24.2 FPS)	3,605 (31.9 FPS)

Table 4: Benchmark Comparison for X900, Galaxy Nexus, and One V (Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Lenovo K800*

The Lenovo K800*, shown in Figure 3, was released in China on May 30, 2012. It was priced at RMB 3,299, which at the time of release was approximately USD 520. This is comparable in price to the Motorola RAZR V*, which was released July 19, 2012 at a price of RMB 3,298 or about USD 520 at the time of the K800's release and the Sony Xperia S*, which was released March, 2012 at a price of RMB 2,290 or about USD 519 at the time of the K800's release (see Table 5).

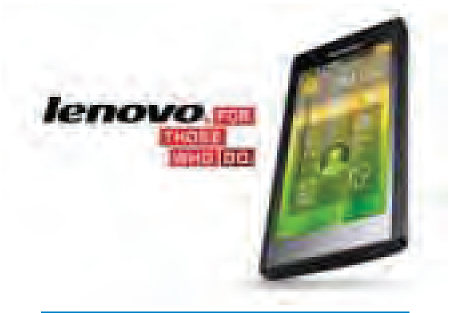

Figure 3: The Lenovo K800 (Source: Intel Corporation, 2012)

	K800	RAZR V	Xperia S
Price in USD	520	520	519
Price in RMB	3,299	3,298	2,290

Exchange rate at May 30, 2012

Table 5: Price Comparison for K800, RAZR V and Xperia S (Source: Data from respective manufacturers)

Hardware

The K800 has a 4.5-inch (720 1280) LCD display. The RAZR V has a 4.3-inch (540x960) LCD display. The Xperia S has a 4.3-inch (720 1280) LCD display. The K800 features an 8-megapixel rear camera with Intel® Burst Mode Technology, which allows the phone to take up to 10 photos in less than one second. It also records video in full HD 1080p and has superior image quality in low light conditions. The RAZR V also has an 8-megapixel rear camera while the Xperia S has a 12-megapixel rear camera. Both phones can also record video in 1080P. The K800 also features a 1.3-megapixel front camera, and Near Field Communication (NFC). The RAZR V and Xperia S also feature 1.3-megapixel front cameras. The RAZR V does not have NFC while the Xperia S does. The X800 runs on a Z2460 1.6 GHz processor with Intel Hyper-Threading Technology. The RAZR V runs on a 1.2 GHz TI OMAP 4430 dual core processor. The Xperia S runs on a 1.5 GHz Qualcomm MSM8260* dual core processor. The K800 also features a 400 MHz graphics core, 1 GB of RAM and 16 GB of internal storage. The RAZR V features an Imagination PowerVR SGX540* GPU, 1 GB of RAM and 4 GB of internal storage. The Xperia S features an Adreno 220* GPU, 1 GB of RAM and 32 GB of internal storage. The K800 has a 1900 mAh nonremovable battery and an SD card slot. The RAZR V and Xperia S both have a 1750 mAh nonremovable battery and an SD card slot. A product comparison is shown in Table 6.

"The X800 runs on a Z2460 1.6 GHz processor with Intel Hyper- Threading Technology"

	K800	**RAZR V**	**Xperia S**
Screen	4.5-inch (720 1280) LCD	4.3-inch (540 960) LCD	4.3-inch (720 1280)
Rear-Camera	8-megapixel	8-megapixel	8-megapixel
Front-Camera	1.3-megapixel	1.3-megapixel	1.3-megapixel
NFC	Yes	No	Yes
CPU	Z2460 1.6 GHz with Intel® HT Technology	1.2 GHz TI OMAP 4430 dual core	1.5 GHz Qualcomm MSM8260* dual core
GPU	Imagination Technologies PowerVR SGX 540*	Imagination PowerVR SGX540*	Adreno 220*
RAM	1 GB	1 GB	1 GB
Internal Storage	16 GB	4 GB	32 GB
Battery	1900 mAh nonremovable	1750 mAh nonremovable	1750 mAh nonremovable
SD Card	Yes	Yes	Yes

Table 6: Hardware Comparison for K800, RAZR V and Xperia S
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Software

The K800 comes with Android 2.3 (Gingerbread) and a custom Lenovo* UI. The custom UI is heavily modified from stock Android. The menus, home screens, and standard apps are all different from stock Android, and it has its own widgets and apps. The K800 is upgradable to Android 4.0 via a manual download. It is unknown if or when the phone will receive Android 4.1 (Jelly Bean). The K800 receives updates from Lenovo.

"The K800 comes with Android 2.3 (Gingerbread) and a custom Lenovo UI."*

The RAZR V comes with Android 4.0 and Motorola's custom UI. The rollout of Android 4.1 started in March of 2013. The Custom UI is much closer to stock Android than Motorola's previous UI, MotoBlur*. It has its own custom icons and widgets and slight changes to the app drawer. The RAZR V receives updates from Motorola.

The Xperia S launched with Android 2.3, but was updated to Android 4.0 in the second quarter of 2012 and later Android 4.1 in 2013, and has Sony's custom UI. The custom UI is close to stock Android but has a few added features such as Overview Mode*, which allows you to pinch out on the screen and see all of the active widgets on one screen. It also displays notifications on the lock-screen such as Facebook* events. There are also many custom Sony widgets not available in other UIs. See Table 7 for a product comparison.

	K800*	**RAZR V**	**Xperia S**
Android OS	4.0.4	4.1.2	4.1.
UI	LeOS*	Motorola UI	Sony UI
Updates From	Lenovo	Motorola	Sony

As of September 23, 2013

Table 7: Software Comparison for K800, RAZR V, and Xperia S
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Benchmarks

The benchmark scores are shown in Table 8. Higher scores mean better performance. The K800 was benchmarked with AnTuTu in an article on netbooknews.com written by Nicole Scott. The Xperia S was benchmarked on AnTuTu by PhoneArena.com in February while it was still running Android 2.3. The K800 was benchmarked with Quadrant in an article on Engaget.com written by Richard Lai. The Xperia S was benchmarked on Quadrant by PhoneArena.com in February while it was still running Android 2.3. All GL benchmarks were pulled directly from their Web site and are average scores on September 2, 2012 (http://gfxbench.com/compare.jsp).

"The third smartphone powered by Intel technology [was], the Orange San Diego"*

	K800	**RAZR V**	**Xperia S**
AnTuTu	5,335	N/A	6,466
Quadrant	3,850	N/A	3,062
GL (2.1 Egypt Standard)	2,913 (25.8 FPS)	N/A	3,365 (29.8 FBS)

Table 8: Benchmark Comparison for K800, RAZR V, and Xperia S
(Source: See Above)

Orange San Diego*

The third smartphone powered by Intel technology, the Orange San Diego*, shown in Figure 4, was released in the United Kingdom on June 6, 2012. Also based on the Intel reference design, this phone is almost identical to the Xolo X900. The price at release was 199 British pounds (GBP 199), which at

Figure 4: The Orange San Diego
(Source: Intel Corporation, 2012)

release was about USD 306. This is comparable in price to the HTC Desire C*, which was released in early June 2012 and priced at GBP 189.99 or about USD 292 at June 6, 2012. It is also comparable in price to the Sony Xperia Go*, released in mid-July 2012 and priced at GBP 229 or about USD 352 using the exchange rate at June 6, 2012 (see Table 9).

	San Diego	Desire C	Xperia Go
Price in USD	306	292	352
Price in GBP	199	189.99	229

Exchange rate at June 6, 2012

Table 9: Price Comparison for San Diego, Desire C, and Xperia Go (Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Hardware

The San Diego has a 4.03-inch (600 1024) LCD display. The Desire C and Xperia Go both have 3.5-inch (320 480) screens. The Xperia Go has a scratch-, dust-, and water-resistant screen. The San Diego features an 8-megapixel rear camera with Intel Burst Mode Technology, which allows the phone to take up to 10 photos in less than one second. It also records video in full HD 1080p and has superior image quality in low light conditions. Intel Burst Mode Technology is similar to HTC's Image Sense technology found in most of their One series phones. The San Diego also features a 1.3-megapixel front camera and Near Field Communication (NFC). The Desire C and Xperia Go both have 5-megapixel rear cameras and no front-facing cameras. They also both have NFC. The San Diego runs on a Z2460 1.6 GHz processor with Intel Hyper-Threading Technology. The Desire C has a 600 MHz Qualcomm MSM7227A Snapdragon* Cortex-A5 processor. The Xperia Go has a 1 GHz NovaThor* U8500 Dual-core Cortex A9 processor. The San Diego also features a 400 MHz graphics core, 1 GB of RAM and 16 GB of internal storage. The Desire C features an Adreno 200* GPU, 512 MB of RAM and 4 GB of internal storage. The Xperia Go features a Mali-400* GPU, 512 MB of RAM and 8 GB of internal storage. The San Diego has a 1460 mAh nonremovable battery and there is no SD card slot. The Desire C has a 1230 mAh removable battery and an SD card slot. The Xperia Go has a 1305 mAh nonremovable battery and an SD card slot. See Table 10 for a product comparison.

"The San Diego runs on a Z2460 1.6 GHz processor with Intel Hyper-Threading Technology"

Software

The San Diego runs Android 2.3 (Gingerbread) with a custom UI by Orange, which is different from the custom UI on the K800. It receives updates from Orange and was updated to Android 4.0.4 (Ice Cream Sandwich) in October of 2012.

"The San Diego runs Android 2.3 (Gingerbread) with a custom UI by Orange…"

The Desire C runs Android 4.0 (Ice Cream Sandwich) with the Sense 4.0 UI and Beats Audio software. The Sense 4.0 UI has many unique apps and features. It has custom camera, music, car, entertainment and Internet apps,

	San Diego	Desire C	Xperia Go
Screen	4.03-inch (600 1024) LCD	3.5-inch (320 480) HVGA	3.5-inch (320 480) TFT LCD
Video Playback	1080p	Not HD	Not HD
Rear-Camera	8-megapixel	5-megapixel	5-megapixel
Front-Camera	1.3-megapixel	N/A	N/A
NFC	Yes	Yes	Yes
CPU	Z2460 1.6 GHz with Intel® HT Technology	Qualcomm MSM7227A Snapdragon* single-core 600 MHz Cortex-A5	1 GHz NovaThor* U8500 dual-core Cortex A9
GPU	Imagination Technologies PowerVR SGX 540*	Qualcomm Adreno 200*	ARM Holdings Mali-400*
RAM	1 GB	512 MB	512 MB
Internal Storage	16 GB	4 GB	8 GB
Battery	1460 mAh nonremovable	1230 mAh removable	1305 mAh nonremovable
SD Card	No	Yes	Yes

Table 10: Hardware Comparison for San Diego, Desire C, and Xperia Go
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

to name a few. Since 4.0, it also has many custom widgets such as bookmarks, calculator, calendar, and the popular weather clock among others. Beats Audio is sound enhancement software that gives the user authentic sound while watching movies, playing games, and listening to music while wearing headphones. It receives updates from HTC.

The Xperia Go ran Android 2.3.7 with a custom UI by Sony at the time of the Orange San Diego's release and has since been updated to Android 4.1.2. The custom UI is close to stock Android but has a few added features such as Overview Mode, which allows you to pinch out on the screen and see all of the actives widgets on one screen. It also displays notifications on the lock-screen such as Facebook events. There are also many custom Sony widgets not available in other UIs. It receives updates from Sony. See Table 11 for a summary of this information.

"The custom UI is close to stock Android…"

	San Diego	Desire C	Xperia Go
Android* OS	4.0.4	4.0.3	4.1.2
UI	Orange UI	Sense 4.0	Sony UI
Updates From	Orange	HTC	Sony

As of September 23, 2013

Table 11: Software Comparison for San Diego, Desire C, and Xperia Go
(Source: Data from respective manufacturers)

Benchmarks

The benchmark scores are shown in Table 12. Higher scores mean better performance. The San Diego was benchmarked with AnTuTu, Quadrant, and GL Benchmark in an article on theverge.com written by Aaron Souppouris. The Desire C was benchmarked with AnTuTu and Quadrant in an article on

	San Diego	Desire C	Xperia Go
AnTuTu	5,602	1,929	5,628
Quadrant	4,127	1,452	2,375
GL (2.1 Egypt Standard)	28 FPS	2,740 (24.2 FPS)	60 FPS

Table 12: Benchmark Comparison for San Diego, Desire C, and Xperia Go (Source: See Above)

gsmdome.com written by Mircea Vasile. Desire C GL benchmark was pulled directly from their Web site and are average scores on August 6, 2012 (http://gfxbench.com/compare.jsp). The Xperia Go was benchmarked with AnTuTu, Quadrant, and GL Benchmark in an article on reviews.cnet.co.uk written by Natasha Lomas.

ZTE Grand X IN*

The ZTE Grand X IN, shown in Figure 5, was released in the U.K. during September of 2012 for a price of GBP 250, or about USD 395 at the time of release. This is comparable to the LG Nexus 4, which was released on November 13, 2012 for a price of GBP 240, or about USD 380 at the time of the Grand X IN's release, for the 8-GB version. The price of the Nexus 4 is artificially low since Google subsidizes the price in the hopes of making more content sales in Google Play. It is however still comparable since this is the price the consumer pays. It is also comparable to the HTC Desire X, which was released in September of 2012 for about GBP 230, or about USD 365 at the time of the Grand X IN's release (see Table 13).

Figure 5: The ZTE Grand X IN (Source: Intel Corporation, 2012)

	Grand X IN	Nexus 4	Desire X
Price in USD	395	380	365
Price in GBP	250	240	230

Exchange rate at September 1, 2012

Table 13: Price Comparison for Grand X IN, Nexus 4, and Desire X (Source: Data from respective manufacturers)

Hardware

The Grand X IN features a 4.3-inch TFT Display. This is smaller than the Nexus 4's 4.7-inch display but larger than the Desire X's 4-inch display. Both the Grand X IN and the Nexus 4 have 8-megapixel rear cameras and feature front-facing cameras, while the Desire X has a 5-megapixel rear camera and no front-facing camera. The Grand X IN and Nexus 4 come with NFC, but the Desire X does not have this feature. These three devices feature vastly different CPUs and GPUs. The Grand X IN includes an Intel® Atom™ Z2460 1.6-GHz processor with Intel Graphics. The Nexus 4 features the Qualcomm Snapdragon S4 Pro* Quad-core 1.5-GHz processor with Adreno 320* GPU. The Desire X comes with the Qualcomm Snapdragon S4 Play MSM8225* 1-GHz Dual-core processor and Adreno 203* GPU. As far as memory is concerned, the Grand X IN has 1 GB of RAM and 16 GB of internal storage. The Nexus 4 has 2 GB

"The Grand X IN includes an Intel® Atom™ Z2460 1.6-GHz processor with Intel Graphics."

of RAM and comes in 8 GB and 16 GB versions for internal storage. The Desire X comes in behind the other two devices with 768 MB of RAM and 4 GB of internal storage. Finally, the Grand X IN and Desire X both have 1650 mAh removable batteries and SD card slots, while the Nexus 4 has a 2100 mAh nonremovable battery and no SD card slot. See Table 14 for a product comparison.

	Grand X IN	**Nexus 4**	**Desire X**
Screen	4.3-inch (540 960) TFT Display	4.7-inch (768 1280) Corning Gorilla Glass 2* Display	4-inch (400 800) Super LCD Display
Rear Camera	8-megapixel	8-megapixel	5-megapixel
Front Camera	VGA	1.3-megapixel	N/A
NFC	Yes	Yes	No
CPU	Intel® Atom™ Z2460 1.6 GHz	Qualcomm Snapdragon S4 Pro* Quad-core 1.5 GHz	Qualcomm Snapdragon S4 Play MSM8225* 1 GHz Dual-core
GPU	Intel Graphics	Adreno 320*	Adreno 203*
RAM	1 GB	2 GB	768 MB
Internal Storage	16 GB	8/16 GB	4 GB
Battery	1650 mAh Removable	2100 mAh Nonremovable	1650 mAh Removable
SD Card	Yes	No	Yes

Table 14: Hardware Comparison for Grand X IN, Nexus 4, and Desire X
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Software

The Grand X IN was released with Android 4.0 (Ice Cream Sandwich). Unlike most Android smartphones, it runs a stock version of Android similar to Nexus devices; however, it receives updates from ZTE. The Grand X IN has been updated to Android 4.1.1 (Jelly Bean).

"The Grand X IN was released with Android 4.0 (Ice Cream Sandwich)."

The Nexus 4 was released with Android 4.2 (Jelly Bean), runs a stock version of Android and receives updates directly from Google. It has since been updated to Android 4.3 (Jelly Bean).

The Desire X was released with Android 4.0 (Ice Cream Sandwich), ran HTC's Sense 4.0 UI, and receives its updates from HTC. It has since been updated to Android 4.1.2 and Sense 4 +. See Table 15 for a summary of this information.

	Grand X IN	**Nexus 4**	**Desire X**
Android* OS	4.1.1	4.3	4.1.2
UI	Stock	Stock	HTC Sense 4 +
Updates From	ZTE	Google	HTC

As of September 23, 2013

Table 15: Software Comparison for Grand X IN, Nexus 4, and Desire X
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Benchmarks

The benchmark scores are shown in Table 16. Higher scores mean better performance. The Grand X IN was benchmarked with Quadrant in an article on engaget.com written by Mat Smith. The Grand X IN was benchmarked with AnTuTu in an article on insidehw.com written by Zeljko Djuric. The Nexus 4 was benchmarked with AnTuTu and Quadrant in an article on gsmarena.com. The Desire X was benchmarked with AnTuTu and Quadrant in an article on Phonearena.com written by Nick T.

The GL benchmark scores for all of these devices come straight from the GFXBench Web site and are average scores on January 7, 2013 (http://gfxbench.com/compare.jsp).

	Grand X IN	Nexus 4	Desire X
AnTuTu	11,281	15,146	4,932
Quadrant	2,710	4,567	2,361
GL (2.1 Egypt Standard)	2202 Frames (19.5 FPS)	N/A	4888 Frames (43.3 FPS)

Table 16: Benchmark Comparison for Grand X IN, Nexus 4, and Desire X
(Source: See Above)

Motorola RAZR i*

The Motorola RAZR i*, shown in Figure 6, was released in the UK, France, Germany, Argentina, Brazil, and Mexico in October of 2012. Its UK release price was GBP 342 or about USD 550. This phone is comparable to the Motorola RAZR M*, which is the U.S. version of the RAZR i. The RAZR M was released on September 13, 2012 on Verizon Wireless* at an unsubsidized price of USD 549.99. The phone is also comparable to the Galaxy S3*. While the S3 was released in the UK at the end of May 2012, it is still seen as one of the top Android smartphones and was priced at around GBP 399 or about USD 642 for the 16-GB version at the time of the RAZR i's release (see Table 17).

Figure 6: The Motorola RAZR i
(Source: Intel Corporation, 2012)

	RAZR i	RAZR M	Galaxy S3
Price in USD	550	550	624
Price in GBP	342	342	399

Exchange rate at October 17, 2012

Table 17: Price Comparison for RAZR i, RAZR M, and Galaxy S3
(Source: Data from respective manufacturers)

Hardware

The RAZR i and M share the same 4.3 inch Super AMOLED display while the Galaxy S3 has a larger 4.8-inch Super AMOLED display. While all three phones have an 8-megapixel rear camera, the S3 has a different front-facing camera from the RAZRs. The RAZR i and M share the same VGA front-facing camera and the S3 has a 1.9-megapixel front-facing camera. The three phones have NFC and an SD card slot. The major difference between these devices is their CPUs and GPUs. The RAZR i has a Z2460 2.0 GHz with Intel HT Technology and an Imagination Technologies PowerVR SGX 540, while the RAZR M has a

"The RAZR i has a Z2460 2.0 GHz with Intel HT Technology…"

Qualcomm MSM8960 Snapdragon Dual-core 1.5 GHz and a Qualcomm Adreno 225. The Galaxy S3 has a Exynos 4412* Quad-core 1.4 GHz and a Mali-400MP. Both RAZRs have 1 GB of RAM, 8 GB of internal storage and a 2000 mAh nonremovable battery. The S3 has 2 GB of RAM, 16 GB of internal storage and a 2100 mAh removable battery. See Table 18 for a product comparison.

	RAZR i	**RAZR M**	**Galaxy S3**
Screen	4.3-inch (540 960) Super AMOLED	4.3-inch (540 960) Super AMOLED	4.8-inch (720 1280) Super AMOLED
Rear Camera	8-megapixel	8-megapixel	8-megapixex
Front Camera	VGA	VGA	1.9-megapixel
NFC	Yes	Yes	Yes
CPU	Z2460 2.0 GHz with Intel® HT Technology	Qualcomm MSM8960 Snapdragon* Dual-core 1.5 GHz	Exynos 4412* Quad-core 1.4 GHz
GPU	Imagination Technologies PowerVR SGX 540*	Qualcomm Adreno 225*	Mali-400MP*
RAM	1 GB	1 GB	2 GB
Internal Storage	8 GB	8 GB	16/32/64 GB
Battery	2000 mAh nonremovable	2000 mAh nonremovable	2100 mAh removable
SD Card	Yes	Yes	Yes

Table 18: Hardware Comparison for RAZR i, RAZR M, and Galaxy S3
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Software

All three devices were released with Android 4.0 (Ice Cream Sandwich), and have since seen updates to Android 4.1 (Jelly Bean). According to Samsung, the Galaxy S3 will skip the Android 4.2 (Jelly Bean) update and go directly to Android 4.3 (Jelly Bean).

"All three devices were released with Android 4.0 (Ice Cream Sandwich), and have since seen updates to Android 4.1 (Jelly Bean)."

Both RAZRs run a custom UI by Motorola that is closer to stock than most custom UIs, while the S3 runs Samsung's TouchWiz UI. The Motorola UI has a few custom features, such as SmartActions*, which allows you to set up rules to save battery life.

The TouchWiz UI has a lot of added features, such as Smart Stay*, which keeps the screen bright as long as you are looking at the screen by tracking your eye movement, and S Voice*, which allows for many custom voice actions not available in stock Android. See Table 19 for a summary of this information.

	RAZR i	**RAZR M**	**Galaxy S3**
Android* OS	4.1.2	4.1.1	4.1.2
UI	Motorola UI	Motorola UI	TouchWiz
Updates From	Motorola	Motorola	Samsung

As of September 23, 2013

Table 19: Software Comparison for RAZR i, RAZR M, and Galaxy S3
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Benchmarks

The benchmark scores are shown in Table 20. Higher scores mean better performance. The RAZR i and M were benchmarked with AnTuTu and Quadrant in an article on engaget.com written by Mat Smith. The Galaxy S3 was benchmarked with AnTuTu and Quadrant in an article on Samsunggeeks.com written by Dom Armstrong. The GL benchmark scores for all of these devices come straight from the GFXBench Web site and are average scores on January 7, 2013 (http://gfxbench.com/compare.jsp).

	RAZR i	**RAZR M**	**Galaxy S3**
AnTuTu	6,175	6,364	12,071
Quadrant	4,125	4,944	5,352
GL (2.1 Egypt Standard)	2616 Frames (23.2 FPS)	1667 Frames (14.8 FPS)	6674 Frames (59.1 FPS)

Table 20: Benchmark Comparison for RAZR i, RAZR M, and Galaxy S3
(Source: See Above)

ASUS Fonepad*

The ASUS Fonepad was announced at Mobile World Congress 2013. It was released in the U.K. on April 26, 2013. The release price was GBP 180 or about USD 235. This is comparable to the Nexus 7*, which was released in mid-2012. The Nexus 7 was made by ASUS for Google. At the time of the Fonepad's release, the 32 GB Nexus 7 was priced at GBP 200 or about USD 260. The Fonepad is also comparable to the Amazon Kindle Fire HD*, which was released at the end of 2012. The 32 GB Fire HD is priced at GBP 180, or about USD 235 (see Table 21).

	Fonepad	**Nexus 7**	**Fire HD**
Price in USD	235	260	235
Price in GBP	180	200	180

Exchange rate at April 26, 2013

Table 21: Price Comparison for Fonepad, Nexus 7, and Fire HD
(Source: Data from respective manufacturers)

Hardware

In terms of hardware, these three devices are very similar, with the exception of their CPUs and a few other features. All three have a 7-inch (1280x800) display. None of them have a rear-facing camera, but they all have a similar front-facing camera. The Nexus 7 has NFC while the Fonepad and Fire HD do not. The major difference in these devices is their CPU and GPU. The Fonepad features an Intel Atom Z2420 clocked at 1.2 GHz with a PowerVR SGX540* GPU. The Nexus 7 comes with an NVIDIA Tegra 3* quad-core clocked at 1.3 GHz with a Tegra 3 GPU. The Fire HD includes a TI OMAP 4460 dual-core clocked at 1.2 GHz with a PowerVR SGX540* GPU. All three devices come with 1 GB of RAM. The Fonepad comes in 8-GB and 16-GB variations, while the Nexus 7 and Fire HD come in 16-GB and 32-GB variations. Each device has a similar size battery, 4,260, 4,325 and 4,400 mAh, respectively. The

"The Fonepad features an Intel Atom Z2420 clocked at 1.2 GHz…"

Fonepad has an SD card slot as well as a SIM card slot. The SIM card slot gives the Fonepad full phone capabilities as well as 3G data. Both the Nexus 7 and Fire HD lack a SD or SIM card slot. See Table 22 for a product comparison.

	Fonepad	**Nexus 7**	**Fire HD**
Screen	7-inch LED Backlit IPS (1280 800)	7-inch LED Backlit IPS display (1280 800)	7-inch IPS Display (1280 800)
Rear Camera	N/A	N/A	N/A
Front Camera	1.2-megapixel	1.2-megapixel	"HD"
NFC	No	Yes	No
CPU	Intel® Atom™ Z2420 1.2 GHz	NVIDIA Tegra 3 quad-core 1.3 GHz	TI OMAP 4460 dual-core 1.2 GHz
GPU	PowerVR SGX540	Tegra 3	PowerVR SGX540
RAM	1 GB	1 GB	1 GB
Internal Storage	8 GB/16 GB	16 GB/32 GB	16 GB/32 GB
Battery	4,260 mAh	4,325 mAh	4,400 mAh
SD Card	Yes	No	No
SIM Card	Yes	No	No

Table 22: Hardware Comparison for Fonepad, Nexus 7, and Fire HD
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Software

The Fonepad launched with Android 4.1.2 (Jelly Bean). The device is close to stock Android. The changes include four constant onscreen buttons instead of the usual three, floating apps such as a calculator and stopwatch among others, such as App Locker and ASUS Story. ASUS has stated that the Fonepad will receive Android 4.2 (Jelly Bean). However at the time of this writing, the update has not been pushed out.

"The Fonepad launched with Android 4.1.2 (Jelly Bean)."

The Nexus 7 launched with Android 4.1 (Jelly Bean) but has since seen several updates. At the time of this writing, it was running 4.3 (Jelly Bean). The Nexus 7 runs a completely stock version of Android with updates directly from Google.

The Fire HD runs a forked version of Android 4.0. This means that the UI is quite different from typical Android devices. There are no Google apps loaded on this device, so Amazon provides their own version of many Google Apps. Apps are downloaded from the Amazon App Store instead of Google Play. For a summary of this information, see Table 23.

	Fonepad	**Nexus 7**	**Fire HD**
OS Version	4.1.2	4.3	4.0
UI	Almost stock	Stock	Kindle Fire
Updates From	ASUS	Google	Amazon

As of September 23, 2013

Table 23: Software Comparison for Fonepad, Nexus 7, and Fire HD
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Benchmarks

The benchmark scores are shown in Table 24. Higher scores mean better performance. AnTuTu and Quadrant scores for the Fonepad come from an article on Pocketnow (http://pocketnow.com/2013/05/02/asus-fonepad-review). AnTuTu and Quadrant scores for the Nexus 7 and Fire HD come from an article on MobileTechReview (http://www.mobiletechreview.com/tablets/Kindle-Fire-HD.htm). The GLbenchmark scores for all of the devices come straight from the GFXBench Web site on September 23, 2013(http://gfxbench.com/compare.jsp).

	Fonepad	**Nexus 7**	**Fire HD**
AnTuTu	6,623	10,456	6,749
Quadrant	2,284	3,638	2,174
GL (2.5 Egypt HD Onscreen)	1330 Frames (11.8 FPS)	1608 Frames (14.2 FPS)	1090 Frames (9.6 FPS)

Table 24: Benchmark Comparison for Fonepad, Nexus 7, and Fire HD (Source: See Above)

Samsung Galaxy Tab 3 10.1*

The Galaxy Tab 3 10.1 was announced by Samsung at Computex 2013. The Tab 3 10.1 launched in the United States in July of 2013 at a price of USD 400. This is comparable in price to the Samsung Nexus 10. The Nexus 10 could be purchased in July, 2013 for USD 400 for the 16 GB option. (see Table 24).

	Tab 3 10.1	**Nexus 10**
Price in USD	400	400

Prices as of July, 2013

Table 24: Hardware Comparison for Tab 3 10.1 and Nexus 10 (Source: Data from respective manufacturers)

Hardware

"The Tab 3 10.1 features an Intel Atom Z2560 dual-core processor clocked at 1.6 GHz…"

The Tab 3 10.1's screen is 10.1 inches and has a resolution of 1280 800. The Nexus 10 has the same size screen but with a considerably higher resolution of 2560 1600. The Tab 3 10.1 features an Intel Atom Z2560 dual-core processor clocked at 1.6 GHz, 1 GB of RAM, and comes with 16 GB of storage. The Nexus 10 also has a dual-core processor; however it is clocked slightly higher at 1.7 GHz, has 2 GB of RAM, and comes with both 16 GB and 32 GB options. The Tab 3 10.1 has a 3.2-megapixel rear camera and a 1.3-megapixel front-facing camera. The Nexus 10 features a 5-megapixel rear camera and a 1.9-megapixel front-facing camera. The Tab 3 10.1 also has an SD card slot, but has no NFC. The Nexus 10 has no SD card slot but does have an NFC. See Table 25 for a product comparison.

"The Tab 3 10.1 launched with Android 4.2.2 (Jelly Bean) and runs Samsung's TouchWiz UI."

Software

The Tab 3 10.1 launched with Android 4.2.2 (Jelly Bean) and runs Samsung's TouchWiz UI. Samsung provides several custom features including Smart Stay,

	Tab 3 10.1	Nexus 10
Screen	10.1-inch TFT LCD display (1280 800)	10.1-inch LCD display (2560 1600)
Rear Camera	3.2-megapixel	5-megapixel
Front Camera	1.3-megapixel	1.9-megapixel
NFC	No	Yes
CPU	Intel® Atom™ Z2560 1.6 GHz	Eynos 5 Dual-core ARM Cortex-A15
GPU	PowerVR SXG544MP2	Mali-T604
RAM	1 GB	2 GB
Internal Storage	16 GB	16 GB/32 GB
SD Card	Yes	No

Table 25: Hardware Comparison for Tab 3 10.1 and Nexus 10
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

which tracks your eyes to see if you are looking at the screen and responds accordingly. Samsung also includes several apps including Samsung Apps, Game Hub, S Planner, and Music Hub.

The Nexus 10 launched with Android 4.2 (Jelly Bean) and runs a completely stock UI. The device has been updated to Android 4.3 (Jelly Bean).

"The Nexus 10 launched with Android 4.2 (Jelly Bean) and runs a completely stock UI. The device has been updated to Android 4.3 (Jelly Bean)."

For a summary of this information, see Table 26.

	Tab 3 10.1	Nexus 10
OS Version	4.2.2	4.3
UI	TouchWiz	Stock
Updates From	Samsung	Google

As of September 23, 2013

Table 26: Software Comparison for Tab 3 10.1 and Nexus 10
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Benchmarks

The benchmark scores are shown in Table 27. Higher scores mean better performance. The AnTuTu and Quadrant Benchmarks for the Tab 3 10.1 and Nexus 10 were pulled from an article written by Taylor Martin on pocketnow.com (http://pocketnow.com/2013/07/25/galaxy-tab-3-10-1-review). The GLbenchmark scores for all of the devices come straight from the GFXBench Web site on September 19, 2013 (http://gfxbench.com/compare.jsp).

	Tab 3 10.1	Nexus 10
AnTuTu	20,063	13,509
Quadrant	6,326	4,193
GL (2.5 Egypt HD Onscreen)	3657 (32.4 FPS)	3492 (30.9 FPS)

Table 27: Benchmark Comparison for Tab 3 10.1 and Nexus 10
(Source: Data from respective manufacturers, supplemented with information from third-party tech sites)

Intel's Future with Android

"Intel's partnerships with Google and many Android device OEMs have helped them go from not participating in the Android market to being a major factor."

Android running on x86 architecture has come a long way since 2009 when a small group of developers starting ported the OS to x86-based devices. Intel's partnerships with Google and many Android device OEMs have helped them go from not participating in the Android market to being a major factor. With the release of the Bay Trail platform and many new Android devices using Intel architecture coming to market, Intel has an excellent opportunity to become a major player in the Android universe. Only time will tell whether or not their strategy will be successful, but I for one believe things are looking very promising for Intel right now.

Author Biography

Ryan Cohen is an Android enthusiast and Portland State graduate. Ryan has been following Android since 2011 when he made the switch from iOS. When he is not writing about Android, he spends his time researching anything and everything new in the world of Android. Ryan can be reached at *ryanaosp@gmail.com*

ANDROID* SECURITY: ISSUES AND FUTURE DIRECTIONS

Contributor

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Any way you look at it, the rise of Android has been a remarkable story within the mobile device world. At the time of this writing, 75 percent of all smartphones now run the Android operating system. With more than 1.0 billion smartphones forecast to ship in 2013, that's a large number of devices.[1] Meanwhile, the number of applications ("apps") available on Google Play* (formerly Android Market) has continued to balloon. A recent announcement from Google puts the number of application downloads at 50 billion and counting.[2]

In an environment of such rapid proliferation, questions surrounding Android security become acute. Is Android's security model robust enough to handle the explosion of new application types and device usages? Can millions of new users understand its permission-based framework for application installation? Are there pitfalls that developers are beginning to show in their handling of intra- or inter-application communication? How might the Android application market better help users to understand the security implications of a given app?

"In this article, we describe Intel's participation in a collaborative university research center for secure computing. We discuss a number of important results and studies that shed light on three different aspects of Android security: user, developer, and marketplace."

One way to explore these and other questions is through university research. In this article, we describe Intel's participation in a collaborative university research center for secure computing. We discuss a number of important results and studies that shed light on three different aspects of Android security: user, developer, and marketplace. Readers will gain a broader perspective on security issues in Android devices and think about potential directions for future frameworks and enhancements.

ISTC for Secure Computing

The *Intel Science and Technology Center for Secure Computing* was founded in 2011 as an industry-academia collaboration for the purpose of "developing security technology that preserves the immense value of digital devices by making them safer."[3] The center is located at the University of California, Berkeley and includes additional researchers from Carnegie Mellon University, Drexel University, Duke University, and University of Illinois at Urbana-Champaign in what is described as a "hub and spokes" model of organization. The center is led jointly by UC Berkeley professor, David Wagner, and Intel senior principal engineer, John Manferdelli.

A key pillar in the ISTC research agenda is "developing secure mobile devices that can be used in all facets of our lives." This includes "dramatically improving the security of smart phones and other mobile devices" and "making third-party applications safe and secure, while supporting a rich market for these applications." In particular, researchers see an opportunity to establish security foundations early on within the evolution of mobile platforms, before legacy architectures constrain the industry's ability to make bold changes that address security shortcomings.[4]

ISTC researchers identify a number of key challenges needed to make mobile platforms more secure: scalable solutions for screening new applications introduced into the marketplace, improved permission frameworks that help users to understand install-time requests and data usage, improved modes of collective feedback by users across the application ecosystem, safe integration of mobile applications and cloud computing, and stronger authentication schemes that better balance tradeoffs between usability and protection against device loss or theft.

This article describes a number of research results that speak to issues and possible future directions in Android security. The discussion is organized into three key areas: users, developers, and marketplace.

Users

Research on security and privacy perceptions[5] demonstrates that mobile platform users are less willing to use their device for tasks that involve money (such as banking and shopping) and sensitive data (such as social security numbers and health records) when compared to laptop computing devices. On the other hand, users are more willing to experiment by installing non-brand-name applications that they discover while browsing or viewing advertisements. In fact, applications play a key role in defining a user's experience of their smartphone device overall.

Understanding user perceptions and behaviors is a key requirement in the very human world of Android device usage, and in designing effective security frameworks and enhancements. This section describes research in two key areas of work: user permissions and user authentication.

"Understanding user perceptions and behaviors is a key requirement in the very human world of Android device usage, and in designing effective security frameworks and enhancements."

User Permissions

Android developers are given considerable freedom to design applications that make broad use of system resources. This includes both hardware resources like the device camera, microphone, storage, SMS, or Internet access, and information resources like user location, calendar, contact data, and phone state and identity. Application access to these resources is governed by an install-time permission exchange with the user. During this exchange, the application lists its requirements and then solicits approval from the user, who can choose whether or not to grant permission and install the application.

ISTC research on user permissions in Android has uncovered some surprising results that suggest the need for a reexamination of this familiar framework.

"…results show only 17 percent of participants paid attention to permissions during an install and 42 percent of lab participants were unaware of the existence of permissions at all."

Researchers in one usability study[6] used both Web surveys and laboratory interviews to study user interaction with permission prompts during the application installation sequence. Their results show that only 17 percent of participants paid attention to permissions during an install and 42 percent of lab participants were unaware of the existence of permissions at all. Only 3 percent of Web survey participants could correctly answer questions about Android permissions, and only 24 percent of lab participants could demonstrate competent comprehension. Finally, while a majority of survey participants claimed to not have installed an application at least once due to permission requests, only 20 percent of lab participants could provide any details to support this claim.

Results would seem to suggest that users do not pay attention or understand permission requests in the manner intended by Android designers. Researchers make several suggestions to mitigate the problems they observe. First, they suggest a review and reorganization of permission categories and a permission renaming effort to improve clarity for the general user. Current categories are often overly broad and are ignored as a result since users quickly learn that almost all applications require dangerous privileges. Second, unnecessary warnings should be eliminated to avoid user "warning fatigue," which occurs when users learn to ignore all warnings due to overly frequent warnings that are often inconsequential. Third, the total number of permissions used by Android (currently 100) should be reduced to improve a user's ability to remember and reason about the presence and absence of permission types within a given install context.

Another research team[7] performed a study of 188,389 Android applications from the Android Market in order to find patterns in permission requests. Using data mining techniques, they observed 30 permission request patterns and then considered whether such patterns could be used as a guide when considering permission risks for a given application install. Results showed that low-reputation applications differ from high-reputation applications in how they request permissions. This result suggests that permission request patterns could be used as an indicator of application quality and user popularity. Perhaps more conservatively, they could be used for comparison when evaluating permission requests for an unfamiliar application.

"Researchers identified two key guiding principles that follow from previous research on closed-form questions (grant or deny) and the contrast between "optimizing" and "satisficing" users: conservation of user attention and avoiding interruptions."

Another study[8] considers how permission systems should best be designed and implemented by the Android UI, especially one where no application review information is available. Researchers identified two key guiding principles that follow from previous research on closed-form questions (grant or deny) and the contrast between "optimizing" and "satisficing" users: *conservation of user attention* and *avoiding interruptions*. To conserve user attention, permission requests should be reserved for only those permissions with severe consequences. Failure to observe this guideline risks user *habituation* in which users pay less and less attention to the meaning of requests and simply approve indiscriminately. Interruptions to a user's primary task likewise promotes indiscriminate click-through behavior (satisficing) with little attempt to understand the consequences. Whenever possible, researchers recommend that a UI avoid interrupting a user with explicit security decisions.

"Whenever possible, researchers recommend avoid interrupting a user with explicit security decisions."

Researchers go on to consider four permission-granting mechanisms in order of preference: automatic grant, trusted UI, confirmation dialog, and install-time warning. For any permission that can easily be undone (revertible) or whose misconfiguration may be merely annoying, *automatic grants* can be used that avoid user involvement entirely. For example, automatic adjustment of global audio settings or phone vibration behavior in response to Web alerts can be handled in an automated manner with the option to undo the permission decision after the fact as needed. To guarantee that users cannot be tricked in various ways, applications may introduce *trusted UI* elements that can be controlled only by the platform itself. Example elements include choosers, review screens, and embedded buttons. Trusted UI elements are useful when the user can initiate a request or when an action can be altered by the user. *Confirmation dialogs* interrupt the user but are necessary when an application will not work without immediate user approval. Too many dialogs are to be avoided because of the potential for satisficing as described above. Finally, *install-time warnings* can be used when no other permission-granting mechanism will suffice.

User Authentication

Even conservative users of mobile devices routinely store and access personal data on their devices[7], for example, photos, email, text messages, GPS traces, and social media feeds. Furthermore, an attacker who has obtained physical possession of the device can easily use one account to gain access to another, for example, using an email account to request a password reset for another service. Add to this the fact that the small, portable form factor of mobile devices makes them easily lost, forgotten, or stolen when users carry them around in the public domain. What better case could there be for widespread use of user authentication mechanisms on nearly all mobile Android devices?

Surprisingly, Fischer et al.[9] note in the literature that 38 percent to 70 percent of smartphone users do not lock their device with passwords or PINs. It would appear that users do not see the need, or else that current password input routines are cumbersome and inconvenient for users who access their device scores of times on an average day of usage. Could there be alternatives that are less cumbersome? Could there be a range of protection mechanisms that offer strong protection in risky environments (such as those encountered when traveling) while offering less protection in routine environments (such as in the home)?

"Fischer et al. note that today's mobile devices offer a variety of sensors that could be leveraged in various ways to provide authentication security in smarter, more flexible ways."

Fischer et al.[9] note that today's mobile devices offer a variety of sensors that could be leveraged in various ways to provide authentication security in smarter, more flexible ways. Some examples of such sensors include GPS location information, accelerometers, gyroscopes, magnetometers, proximity sensors, microphones, cameras, and radio antennas (cellular, Bluetooth*, Wi-Fi*, RFID, NFC). Sensors might, for instance, be used to distinguish a device user by recognizing them biometrically through their gait or face. At the same time, sensors might be used to recognize the location context of use, for example, by enabling user authentication when a user leaves home or when surrounding noise indicates a public context.

ISTC researchers consider several examples of how device context could enable the dynamic scaling of authentication requirements. Current *device unlock* approaches rely on the familiar screenlock, which hides screen information and blocks user input until the correct password or PIN is provided. A context-driven approach might examine whether Wi-Fi radio access points exist, analyze location information, and possibly use image recognition techniques to evaluate the level of risk in the surroundings and whether screenlock mechanisms should be activated. Mobile shopping applications might consider a user's device and location context to identify a frequent shopper in addition to conventional passwords. Patterns in prior shopping behavior and facial recognition may be used to assess risk and increase or decrease authentication tests accordingly. Mobile banking could use context information to categorize an environment as high or low risk. If high risk, two-factor authentication is required and the application restricts operations that can be performed (for example, adding a new user to an existing account). If low risk, then device sensor information is used for additional verification in a transparent manner and operations are not restricted. Context information is collected as part of a transaction for future reference.

"A context-driven approach might examine whether Wi-Fi radio access points exist, analyze location information, and possibly use image recognition techniques to evaluate the level of risk in the surroundings and whether screenlock mechanisms should be activated."

Another research team[10] looked more specifically at whether patterns of touch-screen behavior can be used to authenticate a device user. Researchers propose a set of 30 behavioral features that can be extracted from touch-screen input of commodity mobile devices, including metrics describing direction, stroke length, velocity, acceleration, finger and phone orientation, stroke pressure, and so on. Multiple strokes were also considered to make estimations of user authenticity more robust. A classifier framework is proposed that learns the touch behavior of users during an enrollment phase and then is able to accept or reject the current user by monitoring interaction with the touch screen. Median equal error rates are shown to be below 4 percent for various scenarios comparing touch-screen behavior at different time scales (intra-session, inter-session, one week later).

"While this and other research on biometric authentication may suggest interesting alternatives to widely used password-based schemes, perhaps this overlooks an even bigger opportunity to enhance current schemes in context-intelligent ways."

While this and other research on biometric authentication may suggest interesting alternatives to widely used password-based schemes, perhaps this overlooks an even bigger opportunity to enhance current schemes in context-intelligent ways. Patterns of touch-screen behavior could be used as part of a multimodal biometric authentication system that secures a device from unknown users, even when a screenlock has been bypassed. Even more powerful, touch analytics may provide an approach to continuous authentication that could curb the activities of an intruder or be used as an indicator for further dynamic security mechanisms.

Developers

Another key focus of ISTC research led by UC Berkeley is Android application development. As the number of developers and applications sharply increases, there is a need for research to look at common pitfalls and systemic issues that could be improved in subsequent Android versions. Insights further inform our understanding of software aspects of mobile security more generally.

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Communication Between Apps

Isolation between applications on Android is achieved by requiring each to run under its own UID. This effectively "sandboxes" execution by creating a separate resource environment for each. However, Android facilitates component reuse among applications by supporting a message-passing mechanism called *Intents*. By implementing related APIs, applications can make functionality available to other applications that use the API to invoke services on demand. A key problem identified by researchers in this scheme[11] is that of confusion between intra- and inter-application message passing. Developers may mistakenly expose a component or message unintentionally to a third-party application by implementing the wrong API type.

More specifically, Intents include fields specifying the action to perform, the data to act on, and a category or kind of component that should receive the Intent. Intents can be *explicit* by naming the receiving component or application, or *implicit* by allowing the system to search for a receiving component or application. An application will use an Android API to dispatch the Intent message, an action that implicitly specifies the type of destination component to invoke. Applications implement *Intent Filters* to specify which Intents a component will support. A dispatched Intent will be matched to all Intent Filters using various rules. For example, a Service Intent will be delivered to one receiver at random while a Broadcast Intent will be delivered to all matching receivers.

Researchers identified two types of Intent-based attacks by applications not holding a common signature. The first is *unauthorized Intent receipt*. In this attack, an untrusted application implements matching Intent Filters as a way of eavesdropping on Intent messages intended for other components. This may occur when an application implements Intents intended for intra-communication between components implicitly. It also occurs when an application uses Broadcast Intents. Ordered Broadcast Intents are vulnerable to both denial-of-service attacks and malicious data injection attacks since recipients can fail to propagate the message or change the data before propagating. Activity and Service Intents can be hijacked since a malicious attacker may start an Activity or Service in place of the intended recipient in a manner that is difficult to detect.

A second Intent-based attack is that of *Intent spoofing*. In this attack, a malicious application sends an Intent to an exposed component that implements a matching Intent Filter intended for implicit Intents within the same application. Broadcast recipients are vulnerable to broadcast injection attacks, for example, when a malicious application causes a victim component to change its state in response to a spoofed Intent message. Activities and Services may be invoked in an unauthorized launch or bind attack.

Researchers propose heuristics that could be used to prevent both types of attacks. For unauthorized Intent receipt, they propose that any implicit Intent that does not use a "standard action" (defined in the Android documentation or used by Android applications bundled with the distribution) should automatically be treated as application internal when dispatched. For Intent spoofing, they propose the heuristic that if an Intent Filter is not protected with a signature, it can only be exported if the "exported" flag is explicitly set, if the data field has been set, if it is registered to receive system-only or standard action Intents, or if it is an entry-point Activity (that is, it is an application starting point). Essentially, the heuristic restricts the circumstance under which the Intent Filter can be exported. Researchers augment this scheme with two additional mechanisms: a new "protected" property for Broadcast receivers that ensures only system-only broadcasts match an Intent Filter, and the creation of an "exported" flag for each Intent Filter of a Dynamic receiver.

"In general, researchers propose that software systems require software engineers to make their intentions explicit. Sound system design principles should assume strict isolation unless a developer makes an explicit request to the contrary."

Researchers evaluated the change for 969 popular applications from the Android Market, building upon the ComDroid tool (a static analysis tool identifying message vulnerabilities). Results showed that 99.4 percent of applications were compatible with the first change, and that 93.0 percent were compatible with the second change. Furthermore, the approach solves 31.3 percent of the total security flaws uncovered by their previous work using ComDroid. In general, researchers propose that software systems require software engineers to make their intentions explicit. Sound system design principles should assume strict isolation unless a developer makes an explicit request to the contrary.

Advertising Privileges

"Developer handling of advertising is another much-needed area of study in the Android development ecosystem."

Developer handling of advertising is another much-needed area of study in the Android development ecosystem. Researchers at UC Berkeley[12] looked at 964 real-world applications and found that 49 percent contain at least one advertising networking library. Advertising networks provide libraries to developers to facilitate the insertion of advertisements in application UIs. Libraries handle such operations as fetching, rendering, and tracking of advertisements.

An important security issue with the use of advertisement libraries is that of permission handling. In Android, application permissions are handled in a monolithic manner that doesn't make distinctions between third-party libraries and a developer's own code. As such, advertising libraries inherit all of the permissions requested by their host application. A host application will, furthermore, be required to request permissions that will be used by the advertising network library. Common permissions associated with advertising libraries include INTERNET, ACCESS_NETWORK_STATE (to determine whether the device has Internet access), LOCATION (for location-specific advertisements), and READ_PHONE_STATE (to obtain a customer's IMEI to serve as a unique identifier).

Researchers identified five threats that follow from overprivileging advertising libraries in the above manner. In *legitimate advertising networks*, users are unable to distinguish between application and advertisement network usage of granted permissions and sensitive data. Users, furthermore, are unable to identify whether the application uses advertising network libraries until after the application has been installed and they are exposed to features of the UI. In some cases of *grayware*, a user may trust the reputable advertising network but not the unbranded application. In this situation, the user once again cannot distinguish between application and advertisement network usage of granted permissions and sensitive data. *Benign-but-buggy* applications may leak private information intended for a reputable advertising network, allowing an attacker to track users and violate their privacy in various ways. *Malicious advertising networks* may abuse host application permissions to collect and use user information in an unscrupulous manner and for overtly malicious purposes. Finally, *vulnerable advertising networks* may introduce security vulnerabilities into an application, for example, downloading additional code via HTTP and executing it in an unsafe manner.

To remedy the situation, researchers propose the use of *privilege separation* between components of the same application. Using this scheme, advertising network libraries could run in a different permission domain than the host application, thus avoiding the problem of overprivileging either component as seen in various threat models described above. At installation time, the application could identify each domain and then request privileges separately in a way that led to better user understanding of how user permissions and sensitive data will be used.

"…researchers propose the use of privilege separation between components of the same application. Using this scheme, advertising network libraries could run in a different permission domain than the host application, thus avoiding the problem of overprivileging either component as seen in various threat models described above."

The difficulty here is how to implement the scheme within Android. Researchers note that privilege separation within the same application could be implemented at the class level within the Java virtual machine. The problem here is that use of native libraries could circumvent the fine-grained mechanism entirely as calls are made outside the JVM. Another problem is that the Dalvik virtual machine does not support isolation between sections of Java code within an application. In fact, reflection libraries explicitly violate code encapsulation needed for such a scheme.

Alternatively, privilege separation could be implemented using separate processes. In this scheme, the host application and advertising application would run as separate applications and then use inter-application message passing to communicate. During installation, the host application would install the advertising application automatically, allowing the user to respond to permission requests for each independently. Problems with this scheme include how to keep a user from uninstalling or disabling the advertising process when using the application, how to prevent other applications from interacting with the advertising network application as it is running, how to modify the Android framework and marketplace to support application dependencies and co-installation, and how to prevent rogue or imposter advertisement network libraries that do not, for example, pay the developer properly or handle user data in a reputable manner.

"The option chosen by researchers is to add advertisement support directly to the Android operating system itself. Known as AdDroid, the solution extends the Android API to relay advertising metadata from applications to advertising network servers, to relay advertisements from network servers to applications, and then to assist with user interface events."

The option chosen by researchers is to add advertisement support directly to the Android operating system itself. Known as *AdDroid*, the solution extends the Android API to relay advertising metadata from applications to advertising network servers, to relay advertisements from network servers to applications, and then to assist with user interface events.

Researchers propose the addition of two new permissions to aid the scheme: ADVERTISING, and its location-specific counterpart, LOCATION_ADVERTISING. These permissions would be included in the permission request list presented to the user at application installation time. Granting these permissions would provide advertising network libraries with restricted access to network and location information via the Android API extensions.

The solution addresses the five overprivileging threats described above in various ways: by informing the user when advertising network libraries are being used, by allowing the user to understand which non-advertising permissions are being requested by the host application, by not overprivileging advertisement libraries with host application privileges, by removing advertisement library vulnerabilities from host applications, and by not allowing host applications to abuse information intended only for advertisers. Researchers suggest that the scheme could help to evolve and directly integrate advertisements into the Android market in a way that would not only address security and privacy concerns, but could improve the economic benefits to and incentives for advertisers, developers, and Android itself.

WebView Vulnerabilities

ISTC researchers Chin and Wagner[13], by way of background, explain that WebViews allow Android application developers to display Web content within their application in a seamless and integrated manner. In many ways, WebViews provide application developers with an embedded browser in that not only can content be displayed, but developers can manage the content of what is displayed (for example, address bar, browsing history, search behavior) and the layout (for example, full screen). The framework, furthermore, allows developers to create HTML content and JavaScript code that will be downloaded by the application. This provides an easy and powerful mechanism to update and customize application content, and to extend UI functionality.

More specifically, default WebViews support basic Web document downloads (http://, https://) and file downloads (file://) but do not allow JavaScript execution or the interaction of web content with the application. However, additional capabilities are enabled by API calls like *setWebViewClient()*, *addJavascriptInterface()*, *setJavascriptEnabled()*, *setAllowFileAccess()*, and so on. By associating a WebView with a WebViewClient, a developer may create customized handlers for a range of content and user events. This includes allowing Web content to access Java code (classes and methods) within the host application using JavaScript. In this way, WebViews support co-mingling of Web content and application code in a rich and powerful way.

The problem with all of this, as the researchers point out, is that developers using this framework can dramatically increase the attack surface of their applications. In particular, researchers consider two key vulnerabilities: *excess authorization* and *file-based cross-zone scripting*. The excess authorization vulnerability occurs when registered interfaces enabling application JavaScript also enable third-party JavaScript loaded in the page. Effectively, the application has granted authorization to invoke application Java code beyond what was intended. This can enable a variety of attacks that depend upon the nature of the registered code interfaces—information leakage or injection, malformed input parameters, privilege escalation, inter-application exploitations launched through the application, and so on.

"The problem with all of this, as the researchers point out, is that developers using this framework can dramatically increase the attack surface of their applications. In particular, researchers consider two key vulnerabilities: excess authorization and file-based cross-zone scripting."

File-based cross-zone scripting occurs when untrusted JavaScript gains the ability to read files using "file://" URLs. Essentially, if the application loads untrusted, third-party JavaScript via "http://" or via static content using "file://", the JavaScript can gain access to all files on the device that are accessible to the application using the "file://" mechanism. This includes private, application-internal files and possibly files stored on the SD card. One way this might happen is a man-in-the-middle attack from an untrusted HTTP or HTTPS source that injects the malicious JavaScript.

Researchers propose a tool called *Bifocals* to automatically identify WebView vulnerabilities in Android applications using two types of analysis. First, Bifocals uses static analysis of disassembled Dalvik executable (DEX) files to analyze WebViews state, WebViewsClient state (if it used), and the state of any subclasses. Observations are made about whether JavaScript execution has been enabled, interfaces that have been made accessible to JavaScript, URIs that are to be loaded, and whether a user can navigate to other pages within the WebView. Second, Bifocals will analyze the URIs that are being accessed by the application to determine whether they embed third-party content or whether they navigate to third-party content that might lead to the execution of untrusted JavaScript. For example, frames loading external content or ads that can be supplied by an arbitrary third party are flagged as risks. Any site within the domain of the primary website being visited is considered trustworthy.

"Researchers propose a tool called Bifocals to automatically identify WebView vulnerabilities in Android applications…"

Researchers use the tool to examine 864 popular applications. They find that 608 contain WebViews, 351 of which are displayed by an ad library. One fifth of all applications allow JavaScript code to invoke application code ("authorized WebView"), and one tenth allow ads to invoke application code. Sixty-seven applications (11 percent) are vulnerable to at least one of the attacks described. Sixty-five of these register interfaces that are vulnerable to excess authorization attacks. Only two load files with remote JavaScript, suggesting that the attack is relatively rare.

Recommendations to developers include disabling JavaScript entirely, restricting WebView navigability, limiting the registration of APIs, and using recently added Android mechanisms that more explicitly flag accessible interface methods. Recommendations to Android include the use of policies that narrow the domain origin of content to be loaded in a particular WebView.

Marketplace

A third key focus of ISTC research is the Android application marketplace. Taking a broader view of an exploding software ecosystem, researchers ask whether comparative studies or consumer information might be leveraged to address Android security considerations.

"Taking a broader view of an exploding software ecosystem, researchers ask whether comparative studies or consumer information might be leveraged to address Android security considerations."

Detecting Code Reuse Among Applications

One avenue of ISTC research[14] asks whether automated code comparisons between applications could help to identify security vulnerabilities, malware, and software piracy. Researchers point out that traditional methods for identifying such issues include *review-based approaches* in which marketplace experts manually examine new applications for vulnerabilities or malicious behavior and *reactive approaches* where user reports or ratings identify misbehaving applications which are flagged for manual investigation. Neither approach is scalable as the number of new applications on the market continues to explode.

"Automated code reuse detection could quickly compare hundreds of thousands of applications and identify a small, manageable subset for further investigation during any given time period."

Automated code reuse detection could quickly compare hundreds of thousands of applications and identify a small, manageable subset for further investigation during any given time period. The problem, of course, is how to create such a system in a way that is scalable, resilient to code modification and obfuscation (which are common in Android), and resistant to false positives and false negatives. Researchers answer the challenge with a solution they call *Juxtapplication* for leveraging *k-gram opcode sequences* of compiled applications and *feature hashing*. Their techniques provide a robust and efficient representation of applications that can be used to compute pairwise similarities between applications.

Feature hashing, a popular technique from machine learning, compresses a large data space into a smaller, randomized feature space. In this technique, a hash function is applied to each feature under consideration, and then hash values are used as feature indices into a vector that stores ones and zeros indicating presence or absence of the feature. Within the Android application context, feature hashing may be applied to a representation of DEX files that fully describe the application, including class structure, function information, and so on. For each application, researchers use XML to represent each DEX file, extracting each basic block and labeling it by package. They then process each basic block and retain only opcodes and some constant data.

Feature extraction is accomplished using the djb2 hash function to construct the *k*-gram using a moving window of size *k*. The result is a bit vector representing the features present in the data. The similarity of two applications can be computed using a Jaccard similarity metric and bitwise comparison operations. Two key parameters must be determined. First is *k*-gram length *k*. This governs the granularity of comparisons and needs to be small enough to detect similarities but large enough to make them meaningful. An empirical evaluation of various alternatives leads researchers to choose *k* = 5. The second parameter is bit vector size *m*. The tradeoff here is between computational efficiency and error. If m is too large, then computing pairwise similarity becomes computationally expensive. If *m* is too small, then too many hash collisions compromises the accuracy of the experiment. Researchers argue that *m* should be just large enough to exceed the number of *k*-grams extracted from an application.

Researchers apply their methodology to more than 58,000 applications, including 30,000 from what was then called the Android Market and another 28,159 applications from a third-party application market. In addition, 72 malware applications were used from the Contagio malware dump and other sources to provide samples for code reuse analysis. Results show that code reuse of Google In-Application Billing (IAB) and License Verification Library (LVL) example code is common, both of which include vulnerability caveats in the documentation. Thirty-four instances of malware are detected in applications from the third-party market, 13 of which are repackaged, previously unknown variants. Additionally, pirated applications are identified in third-party markets, illustrating that even significant code variation cannot prevent the tool from identifying code reuse.

Product Labels

As the Android application market continues to rapidly scale, another group of ISTC researchers[15] asks why there isn't better *information symmetry* between application developers and users. That is, application developers know a great deal about the real quality and features of the applications they create. Meanwhile, users know relatively little about the software applications they browse on the market. One consequence for developers is that they find it hard to differentiate their offerings. This removes incentive for developers to invest in developing products of high quality, reliability, and security. Lessons from the world of economics (for example, automobiles) demonstrate that markets thrive when they reduce or eliminate information asymmetry. For example, services like CarFax prevent the used automobile market from becoming a market of lemons by providing accurate vehicle history to consumers. By eliminating information asymmetry between the seller and buyer, the size of a market can expand as both sellers and buyers understand and negotiate product value in a mutually satisfying way.

"As the Android application market continues to rapidly scale, another group of ISTC researchers asks why there isn't better information symmetry between application developers and users."

"By eliminating information asymmetry between the seller and buyer, the size of a market can expand as both sellers and buyers understand and negotiate product value in a mutually satisfying way."

The question, then, is how to improve information asymmetry in the Android application market. For this, researchers propose the notion of *product labels*. A key observation is that today's Android software market is highly centralized, providing an easy opportunity for marketplace modifications. Software labels could easily be inserted within the user's decision-making environment, even personalizing them or filtering them in specialized ways to follow user preferences. But what kind of information might product labels include?

Researchers offer several suggestions on information types and sources that could prove meaningful in product labeling. The first is *certifications*. Researchers point out that certification is widely used across domains in our society (for example, fireproofing or professional pilot training) and something that users can relate to. Certification could be used to verify facts about program operation (for example, device camera is never used) or program communication (for example, limited to recognized domain *X*). Researchers see the market as the final determiner of which certifications are of interest to consumers and which properties are important to developers, including security certification in a variety of spheres.

Another approach is *testing and standards*. Once again, consumers are familiar with the notion in the form of independent test providers who certify product effectiveness with respect to its intended purpose (for example, the American Dental Association and toothpaste), compliance with government safety standards (for example, OSHA), or conformance to widely agreed upon industry practices (for example, Payment Card Industry or PCI). Researchers envision independent testing providers emerging who test Android applications in various ways and report on application behavior and functionality with respect to its stated purpose. Today's environment includes user comments in various forums, but it lacks a more rigorous notion of reviewer reputation and trustworthiness.

"Researchers envision independent testing providers emerging who test Android applications in various ways and report on application behavior and functionality with respect to its stated purpose."

Still another approach is that of *qualitative analysis*. Qualitative metrics could be created that differentiate between low, medium, or high levels of sophistication and thoroughness in the way a particular application addresses an issue. For example, researchers suggest "attack surface" as a security-focused metric that could help differentiate products in the same competitive niche. Another example is the extensiveness of "application permissions," which could be compared across similar applications. Device makers or Android designers could collect relevant data to support such analysis, for example, recording behavior and audit information on communications with Internet domains, GPS requests, number of contact requests over time, and so on.

Finally, researchers propose *quantitative analysis* as another information source for product labels. Quantitative metrics are widely used, for example, by the wine industry, which has critics provide ratings and then communicate them to users with numbers. A simple metric might be "percentage of users who abort installation after reviewing application permission requests" or "rate at which users uninstall an application after auditing its usage." Once again, a central point of application distribution makes possible the use of crowdsourcing data as input to metrics.

In general, researchers call for more user studies to evaluate project label effectiveness and usage.

Summary

In an era of rapid Android proliferation and application development, Intel has invested in collaborative university research to explore the issues surrounding mobile security, including Android. The *Intel Science and Technology Center for Secure Computing*, led by the University of California, Berkeley, has worked to produce research "developing secure mobile devices that can be used in all facets of our lives, dramatically improving the security of smart phones and other mobile devices," and "making third-party applications safe and secure, while supporting a rich market for these applications." In this article, we described a number of research results that speak to issues and possible future directions in Android security. Discussion was organized into three key areas: users, developers, and marketplace. University research provides a broader perspective on security issues in Android devices, including potential directions for future frameworks and enhancements.

"In an era of rapid Android proliferation and application development, Intel has invested in collaborative university research to explore the issues surrounding mobile security, including Android."

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Author Biography

David Ott is a research director for the University Research Office in Intel Labs. His work involves identifying key research challenges and opportunities for innovative technology development in the areas of computer security and communications. Such challenges form the basis for collaborative university research programs with recognized experts in the area under investigation. David Ott joined Intel in 2005 and has worked in a variety of technical roles over the years focusing on enterprise computing, software aspects of upcoming Intel platforms, performance analysis, and computer security. David holds MS and PhD degrees in Computer Science from the University of North Carolina at Chapel Hill.

DEVELOPING SENSOR APPLICATIONS ON INTEL® ATOM™ PROCESSOR-BASED ANDROID* PHONES AND TABLETS

Contributor

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This article provides application developers with an introduction to the Android Sensor framework and discusses how to use some of the generally available sensors on a typical phone or tablet based on the Intel® Atom™ processor. Among the sensors discussed are motion, position, and environment sensors, GPS, and NFC sensors. Optimization techniques and methods, such as filtering and fusing raw sensor data, can be used to improve the user experience of sensor applications. This article also provides a high level introduction on how sensors are used in perceptual computing, such as 3D tracking. This discussion is based on Android 4.2, Jelly Bean.

Sensors on Intel® Atom™ Processor-Based Android Phones and Tablets

"The Android phones and tablets based on Intel Atom processors can support a wide range of hardware sensors."

The Android phones and tablets based on Intel Atom processors can support a wide range of hardware sensors. These sensors are used to detect the motion and position changes, and report the ambient environment parameters. The block diagram in Figure 1 shows a possible sensor configuration on a typical on Intel® Atom™ processor-based Android device.

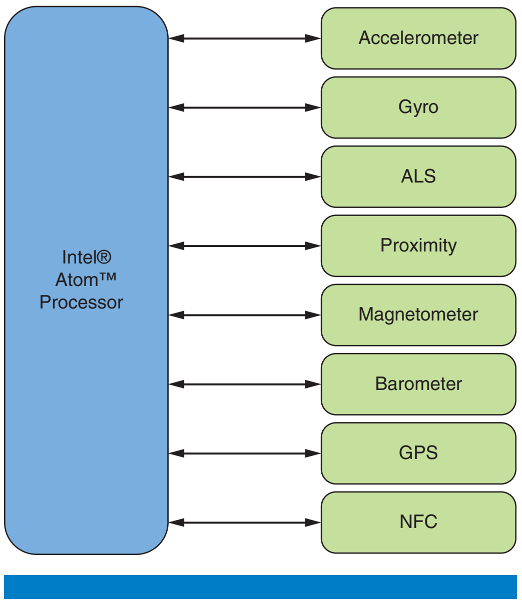

Figure 1: Sensors on a typical Intel® Atom™–based Android system
(Source: Intel Corporation, 2013)

Based on the data they report, we can categorize Android sensors into the classes and types shown in Table 1.

Motion Sensors	Accelerometer (TYPE_ACCELEROMETER)	Measures the device's accelerations in m/s^2	Motion detection
	Gyroscope (TYPE_GYROSCOPE)	Measures a device's rates of rotation	Rotation detection
Position Sensors	Magnetometer (TYPE_MAGNETIC_FIELD)	Measures the Earth geomagnetic field strengths in μT	Compass
	Proximity (TYPE_PROXIMITY)	Measures the proximity of an object in cm	Nearby object detection
	GPS (not a type of android. hardware.Sensor)	Gets the accurate geo- locations of the device	Accurate geo-location detection
	Near Field Communication (NFC, not a type of android. hardware.Sensor)	Shares small payloads of data between an NFC tag and a device, or between two devices	Reading NDEF data from an NFC tag, Beaming NDEF messages to another device
Environment Sensors	ALS (TYPE_LIGHT)	Measures the ambient light level in lx	Automatic screen brightness control
	Barometer	Measures the ambient air pressure in mbar	Altitude detection

Table 1: Sensor Types Supported by the Android Platform
(Source: Intel Corporation, 2013)

Android Sensor Framework

The Android sensor framework provides APIs to access the sensors and sensor data, with the exception of the GPS, which is accessed through the Android location services. We will discuss this later in this article. The sensor framework is part of the android.hardware package. Table 2 lists the main classes and interfaces of the sensor framework.

"The Android sensor framework provides APIs to access the sensors and sensor data…"

SensorManager	Class	Used to create an instance of the sensor service. Provides various methods for accessing sensors, registering and unregistering sensor event listeners, and so on.
Sensor	Class	Used to create an instance of a specific sensor.
SensorEvent	Class	Used by the system to publish sensor data. It includes the raw sensor data values, the sensor type, the data accuracy, and a timestamp.
SensorEventListener	Interface	Provides callback methods to receive notifications from the SensorManager when the sensor data or the sensor accuracy has changed.

Table 2: The Android Platform Sensor Framework
(Source: Intel Corporation, 2013)

Obtaining Sensor Configuration

What sensors are available on the device is solely decided by the device manufacturer. You can use the sensor framework to discover the available sensors at runtime by invoking the *SensorManager getSensorList()* method with

"What sensors are available on the device is solely decided by the device manufacturer."

a parameter "Sensor.TYPE_ALL". Code Example 1 displays a list of available sensors and the vendor, power, and accuracy information of each sensor.

```
package com.intel.deviceinfo;

import java.util.ArrayList;
import java.util.HashMap;
import java.util.List;
import java.util.Map;

import android.app.Fragment;
import android.content.Context;
import android.hardware.Sensor;
import android.hardware.SensorManager;
import android.os.Bundle;
import android.view.LayoutInflater;
import android.view.View;
import android.view.ViewGroup;
import android.widget.AdapterView;
import android.widget.AdapterView
.OnItemClickListener;
import android.widget.ListView;
import android.widget.SimpleAdapter;

public class SensorInfoFragment extends Fragment {

private View mContentView;

privateListViewmSensorInfoList;
SimpleAdaptermSensorInfoListAdapter;

private List<Sensor>mSensorList;

private SensorManagermSensorManager;

@Override
public void onActivityCreated(Bundle
savedInstanceState) {
super.onActivityCreated(savedInstanceState);
}

@Override
public void onPause()
   {
super.onPause();
    }

@Override
public void onResume()
    {
super.onResume();
```

```
    }

    @Override
public View onCreateView(LayoutInflater inflater,
ViewGroup container,
            Bundle savedInstanceState) {
mContentView =
inflater.inflate(R.layout.content_sensorinfo_main,
null);
mContentView.setDrawingCacheEnabled(false);

mSensorManager =
(SensorManager)getActivity().
getSystemService(Context.SENSOR_SERVICE);

mSensorInfoList =
(ListView)mContentView.findViewById
(R.id.listSensorInfo);

mSensorInfoList.setOnItemClickListener( new
OnItemClickListener() {

             @Override
public void onItemClick(AdapterView<?> arg0, View
view, int index, long arg3) {

      // with the index, figure out what sensor was
pressed
      Sensor sensor = mSensorList.get(index);

      // pass the sensor to the dialog.
SensorDialog dialog = new SensorDialog(getActivity (),
sensor);

dialog.setContentView(R.layout.sensor_display);
dialog.setTitle("Sensor Data");
dialog.show();
  }
  });

returnmContentView;
}

void updateContent(int category, int position) {
mSensorInfoListAdapter = new SimpleAdapter(getActivity
(),
         getData() , android.R.layout.simple_list_
         item_2,
         new String[] {
             "NAME",
             "VALUE"
             },
             new int[] { android.R.id.text1,
android.R.id.text2 });

    mSensorInfoList.setAdapter(mSensorInfoListAdap
    ter);
    }


protected void addItem(List<Map<String, String>>
data, String name, String value)   {
   Map<String, String> temp = new HashMap<String,
String>();
temp.put("NAME", name);
       temp.put("VALUE", value);
        data.add(temp);
}


private List<? extends Map<String, ?>> getData() {
        List<Map<String, String>> myData = new
ArrayList<Map<String, String>>();
mSensorList =
mSensorManager.getSensorList(Sensor.TYPE_ALL);

for (Sensor sensor : mSensorList ) {
addItem(myData, sensor.getName(),  "Vendor: " +
sensor.getVendor() + ", min. delay: " +
sensor.getMinDelay() +", power while in use: " +
sensor.getPower() + "mA, maximum range: " +
sensor.getMaximumRange() + ", resolution: " +
sensor.getResolution());
        }

returnmyData;

     }

}
```

Code Example 1: A Fragment that Displays the List of Sensors**
Source: Intel Corporation, 2013

Sensor Coordinate System

"The sensor framework reports sensor data using a standard 3-axis coordinate system…"

The sensor framework reports sensor data using a standard 3-axis coordinate system, in which the X, Y, and Z are represented by *values[0]*, *values[1]*, and *values[2]* in the *SensorEvent* object, respectively.

Some sensors, such as the light sensor, the temperature sensor, the proximity sensor, and the pressure sensor, return only a single value. For these sensors only *values[0]* in the *SensorEvent* object is used.

Other sensors report data in the standard 3-axis sensor coordinate system. The following is a list of such sensors:

- Accelerometer
- Gravity sensor
- Gyroscope
- Geomagnetic field sensor

The 3-axis sensor coordinate system is defined relative to the screen of the device in its natural (default) orientation. For a phone, the default orientation is portrait; for a tablet, the natural orientation is landscape. When a device is held in its natural orientation, the x-axis is horizontal and points to the right, the y-axis is vertical and points up, and the z-axis points outside of the screen (front) face. Figure 2 shows the sensor coordinate system for a phone, while Figure 3 shows the sensor coordinate system for a tablet.

The most important point regarding the sensor coordinate system is that the sensor's coordinate system never changes when the device moves or changes its orientation.

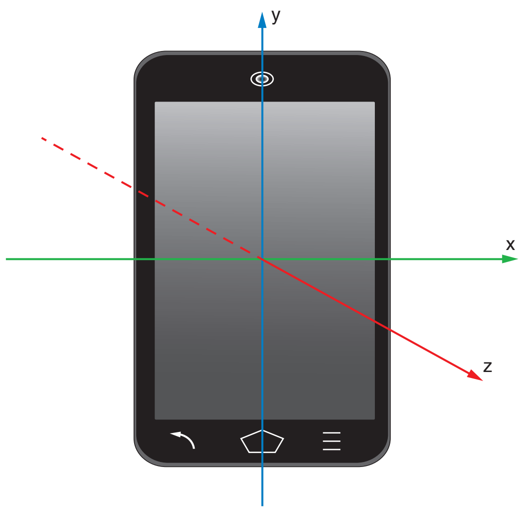

Figure 2: The sensor coordinate system for a phone
(Source: Intel Corporation, 2013)

Monitoring Sensor Events

The sensor framework reports sensor data with the *SensorEvent* objects. A class can monitor a specific sensor's data by implementing the *SensorEventListener* interface and registering with the *SensorManager* for the specific sensor. The sensor framework informs the class about the changes in the sensor states through the following two *SensorEventListener* callback methods implemented by the class:

```
onAccuracyChanged()
```

and

```
onSensorChanged()
```

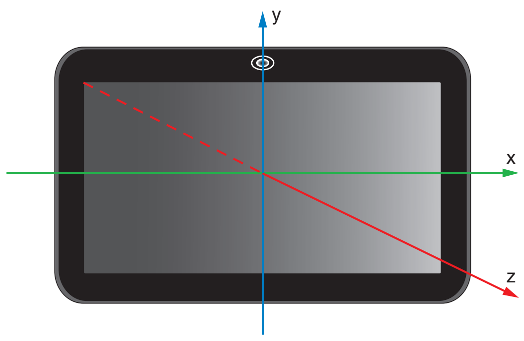

Figure 3: The sensor coordinate system for a tablet
(Source: Intel Corporation, 2013)

Code Example 2 implements the *SensorDialog* used in the *SensorInfoFragment* example we discussed in the section "Obtaining Sensor Configuration."

```
package com.intel.deviceinfo;

import android.app.Dialog;
import android.content.Context;
import android.hardware.Sensor;
import android.hardware.SensorEvent;
import android.hardware.SensorEventListener;
import android.hardware.SensorManager;
import android.os.Bundle;
import android.widget.TextView;

public class SensorDialog extends Dialog implements
SensorEventListener {
Sensor mSensor;
```

"For a phone, the default orientation is portrait; for a tablet, the natural orientation is landscape."

"…The sensor's coordinate system never changes when the device moves or changes its orientation."

"A class can monitor a specific sensor's data by implementing the SensorEventListener interface and registering with the SensorManager for the specific sensor."

```
TextView mDataTxt;
private SensorManager mSensorManager;

public SensorDialog(Context ctx, Sensor sensor) {
this(ctx);

mSensor = sensor;
    }

    @Override
protected void onCreate(Bundle savedInstanceState) {
super.onCreate(savedInstanceState);
mDataTxt = (TextView) findViewById
(R.id.sensorDataTxt);
mDataTxt.setText("...");
setTitle(mSensor.getName());
    }

    @Override
protected void onStart() {
super.onStart();
mSensorManager.registerListener(this, mSensor,
SensorManager.SENSOR_DELAY_FASTEST);
    }

    @Override
protected void onStop() {
super.onStop();
mSensorManager.unregisterListener(this, mSensor);
    }

    @Override
public void onAccuracyChanged(Sensor sensor, int
accuracy)
{

    }


    @Override
public void onSensorChanged(SensorEvent event) {
if (event.sensor.getType() != mSensor.getType()) {
return;
        }
StringBuilder dataStrBuilder = new StringBuilder();
if ((event.sensor.getType() == Sensor.TYPE_
LIGHT)||
           (event.sensor.getType() ==
Sensor.TYPE_TEMPERATURE)||
           (event.sensor.getType() ==
Sensor.TYPE_PRESSURE)) {
```

```
dataStrBuilder.append(String.format("Data: %.3f\n",
event.values[0]));
        }

else{
dataStrBuilder.append(
String.format("Data: %.3f, %.3f, %.3f\n",
event.values[0], event.values[1], event.values[2] ));
        }

mDataTxt.setText(dataStrBuilder.toString());
    }
}
```

Code Example 2: A Dialog that Shows the Sensor Values**
Source: Intel Corporation, 2013

Motion Sensors

Motion sensors are used to monitor device movement, such as shake, rotate, swing, or tilt. The accelerometer and gyroscope are two motion sensors available on many tablet and phone devices.

"Motion sensors are used to monitor device movement, such as shake, rotate, swing, or tilt."

Motion sensors report data using the sensor coordinate system, where the three values in the *SensorEvent* object, *values[0]*, *values[1]*, and *values[2]*, represent values for the x-, y-, and z-axis, respectively.

To understand the motion sensors and apply the data in an application, we need apply some physics formulas related to force, mass, acceleration, Newton's laws of motion, and the relationship between several of these entities in time. To learn more about these formulas and relationships, you may refer to physics textbooks or public domain sources.

Accelerometer

The accelerometer measures the acceleration applied on the device, and its properties are summarized in Table 3.

"The accelerometer measures the acceleration applied on the device…"

The concept for the accelerometer is derived from Newton's second law of motion:

Sensor	Type	SensorEvent Data (m/s^2)	Description
Accelerometer	TYPE_ ACCELEROMETER	values[0] values[1] values[2]	Acceleration along the x-axis Acceleration along the y-axis Acceleration along the z-axis

Table 3: The Accelerometer
(Source: Intel Corporation, 2013)

$a = F/m$

The acceleration of an object is the result of the net external force applied to the object. The external forces include the one that applied to all objects on

Earth, the gravity. It is proportional to the net force F applied to the object and inversely proportional to the object's mass m.

In our code, instead of directly using the above equation, we usually care about the result of the acceleration during a period of time on the device's speed and position. The following equation describes the relationship of an object's velocity v^1, its original velocity v^0, the acceleration a, and the time t:

$v1 = v0 + at$

To calculate the object's position displacement s, we use the following equation:

$s = v^0 t + (1/2)at^2$

In many cases we start with the condition $v0$ is 0 (before the device starts moving), which simplifies the equation as:

$s = at^2/2$

Because of the gravity, the gravitational acceleration, which is represented with the symbol g, is applied to any object on Earth. Regardless of the object's mass, g only depends on the latitude of the object's location with a value in the range of 9.78 to 9.82 (m/s^2). We adopt a conventional standard value for g:

$g = 9.80665$ (m/s^2)

Because the accelerometer returns the values using a multidimensional device coordinate system, in our code we can calculate the distances along the x-, y-, and z-axes using the following equations:

$S_x = A_x T^2/2$

$S_y = A_y T^2/2$

$S_z = A_z T^2/2$

Where S_x, S_y, and S_z are the displacements on the x-axis, y-axis, and z-axis, respectively, and A_x, A_y, and A_z are the accelerations on the x-axis, y-axis, and z-axis, respectively. T is the time of the measurement period.

Code Example 3 shows how to instantiate an accelerometer.

```
public class SensorDialog extends Dialog implements
SensorEventListener {
     ...
private Sensor mSensor;
private SensorManager mSensorManager;

public SensorDialog(Context context) {
super(context);
mSensorManager =
(SensorManager)context.getSystemService(Context.
SENSOR_SERVICE);
mSensor =
mSensorManager.getDefaultSensor(Sensor.TYPE_
ACCELEROMETER);
    ...
}
```

Code Example 3: Instantiation of an Accelerometer **
Source: Intel Corporation, 2013

Sometimes we don't use all three dimension data values. Sometimes we may also need to take the device's orientation into consideration. For example, when we develop a maze application, we only use the x-axis and the y-axis gravitational acceleration to calculate the ball's moving directions and distances based on the orientation of the device. The following code fragment (Code Example 4) outlines the logic.

```
@Override
public void onSensorChanged(SensorEvent event) {
if (event.sensor.getType() != Sensor.TYPE_
ACCELEROMETER) {
return;
    }
floataccelX, accelY;

...
//detect the current rotation currentRotation from
its "natural orientation"
//using the WindowManager
switch (currentRotation) {
case Surface.ROTATION_0:
accelX = event.values[0];
accelY = event.values[1];
break;
case Surface.ROTATION_90:
accelX = -event.values[0];
accelY = event.values[1];
break;
case Surface.ROTATION_180:
accelX = -event.values[0];
accelY = -event.values[1];
break;
case Surface.ROTATION_270:
accelX = event.values[0];
accelY = -event.values[1];
break;
}
    //calculate the ball's moving distances along
x, and y using accelX, accelY and the time delta
```

```
                        . . .
                    }
}
```

Code Example 4: Considering the Device Orientation When Using the Accelerometer Data in a Maze Game**
Source: Intel Corporation, 2013

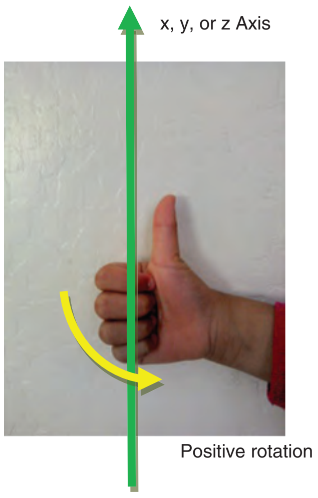

Figure 4: Using the "right-hand rule" to decide the positive rotation direction (Source: Intel Corporation, 2013)

Gyroscope

The gyroscope (or simply gyro) measures the device's rate of rotation around the x-, y-, and z-axis, as shown in Table 4. The gyroscope data values can be positive or negative. By looking at the origin from a position along the positive half of the axis, if the rotation is counterclockwise around the axis, the value is positive; if the rotation around the axis is clockwise, the value is negative. We can also determine the direction of a gyroscope value using the "right-hand rule," illustrated in Figure 4.

Sensor	Type	SensorEvent Data (rad/s)	Description
Gyroscope	TYPE_ GYROSCOPE	values[0]	Rotation rate around the x-axis
		values[1]	Rotation rate around the y-axis
		values[2]	Rotation rate around the z-axis

Table 4: The Gyroscope
(Source: Intel Corporation, 2013)

"The gyroscope measures the device's rate of rotation around the x-, y-, and z-axis…"

Code Example 5 shows how to instantiate a gyroscope.

```
public class SensorDialog extends Dialog implements
SensorEventListener {
    . . .
private Sensor mGyro;
private SensorManager mSensorManager;

public SensorDialog(Context context) {
super(context);
mSensorManager =
(SensorManager)context.getSystemService(Context.
SENSOR_SERVICE);
mGyro =
mSensorManager.getDefaultSensor(Sensor.TYPE_
GYROSCOPE);
    . . .
}
```

Code Example 5: Instantiation of a Gyroscope**
Source: Intel Corporation, 2013

"The magnetometer measures the strengths of the Earth's magnetic field along the x-, y-, and z-axis, while the proximity sensor detects the distance of the device from another object."

Position Sensors

Many Android tablets support two position sensors: the magnetometer and the proximity sensor. The magnetometer measures the strengths of the Earth's magnetic field along the x-, y-, and z-axis, while the proximity sensor detects the distance of the device from another object.

Magnetometer

The most important usage of the magnetometer (described in Table 5) by the Android system is to implement the compass.

Sensor	Type	SensorEvent Data (μT)	Description
Magnetometer	TYPE_ MAGNETIC_ FIELD	values[0]	Earth magnetic field strength along the x-axis
		values[1]	Earth magnetic field strength along the y-axis
		values[2]	Earth magnetic field strength along the z-axis

Table 5: The Magnetometer
(Source: Intel Corporation, 2013)

Code Example 6 shows how to instantiate a magnetometer.

```
public class SensorDialog extends Dialog implements
SensorEventListener {
    ...
private Sensor mMagnetometer;
private SensorManager mSensorManager;

public SensorDialog(Context context) {
super(context);
mSensorManager =
(SensorManager)context.getSystemService(Context.
SENSOR_SERVICE);
mMagnetometer =
mSensorManager.getDefaultSensor(Sensor.TYPE_
MAGNETIC_FIELD);
    ...
}
```

Code Example 6: Instantiation of a Magnetometer**
Source: Intel Corporation, 2013

Proximity

The proximity sensor provides the distance between the device and another object. The device can use it to detect if the device is being held close to the user (see Table 6), thus determining if the user is making or receiving a phone call and turning off the display during the period of the phone call.

Sensor	Type	SensorEvent Data	Description
Proximity	TYPE_ PROXIMITY	values[0]	Distance from an object in cm. Some proximity sensors only report a Boolean value to indicate if the object is close enough.

Table 6: The Proximity Sensor
(Source: Intel Corporation, 2013)

Code Example 7 shows how to instantiate a proximity sensor.

```
public class SensorDialog extends Dialog implements
SensorEventListener {
    ...
private Sensor mProximity;
private SensorManager mSensorManager;

public SensorDialog(Context context) {
super(context);
mSensorManager =
(SensorManager)context.getSystemService(Context.
SENSOR_SERVICE);
mProximity =
mSensorManager.getDefaultSensor(Sensor.TYPE_
PROXIMITY);
    ...
}
```

Code Example 7: Instantiation of a Proximity Sensor**
Source: Intel Corporation, 2013

Environment Sensors

"The environment sensors detect and report the device's ambient environment parameters, such as the light, temperature, pressure, or humidity."

The environment sensors detect and report the device's ambient environment parameters, such as the light, temperature, pressure, or humidity. The availability of a specific sensor is solely determined by the device manufacturer. The ambient light sensor (ALS) and the pressure sensor (barometer) are available on many Android tablets.

Ambient Light Sensor (ALS)

The ambient light sensor, described in Table 7, is used by the system to detect the illumination of the surrounding environment and automatically adjust the screen brightness accordingly.

Sensor	Type	SensorEvent Data (lx)	Description
ALS	TYPE_LIGHT	values[0]	The illumination around the device

Table 7: The Ambient Light Sensor
(Source: Intel Corporation, 2013)

Code Example 8 shows how to instantiate the ALS.

```
    ...
private Sensor mALS;
private SensorManager mSensorManager;
    ...
mSensorManager =
(SensorManager)context.getSystemService(Context.
SENSOR_SERVICE);
mALS = mSensorManager.getDefaultSensor(Sensor.
TYPE_LIGHT);
    ...
```

Code Example 8: Instantiation of an Ambient Light Sensor**
Source: Intel Corporation, 2013

Barometer
The atmosphere pressure sensor (barometer), described in Table 8, can be used by the applications to calculate the altitude of the device's current location.

Sensor	**Type**	**SensorEvent Data (lx)**	**Description**
Barometer	TYPE_PRESSURE	values[0]	The ambient air pressure in mbar

Table 8: The Atmosphere Pressure Sensor
(Source: Intel Corporation, 2013)

Code Example 9 shows how to instantiate the barometer.

```
    ...
private Sensor mBarometer;
private SensorManager mSensorManager;
    ...
mSensorManager =
(SensorManager)context.getSystemService(Context.
SENSOR_SERVICE);
mBarometer =
mSensorManager.getDefaultSensor(Sensor.TYPE_
PRESSURE);
    ...
```

Code Example 9: Instantiation of a barometer**
Source: Intel Corporation, 2013

Sensor Data Optimization

In developing sensor applications, one thing we should know is the raw data returned from the sensors may be quite noisy. Sometimes it may include lots of jitters and interference (Figure 5). To improve the user experience of sensor applications, sometimes we may use techniques to optimize the sensor data.

"…One thing we should know is the raw data returned from the sensors may be quite noisy."

"To improve the user experience of sensor applications, sometimes we may use techniques to optimize the sensor data."

Sensor Data Filtering
One way to remove high frequency noise in sensor data is to use a "rolling average" data value. At a specific data point, the current reading from the sensor only contributes to a portion of the data value; the rolling average value contributes to the rest. This can be represented in the following equation, in which S_{xi}, S_{yi}, and S_{zi} are the data values to be used at the data point on the x-, y-, and z-axes, respectively. X_i, Y_i, and Z_i are the raw sensor readings on the x-, y-, and z-axes, respectively. R_x, R_y, and R_z are the rolling averages up to the previous data point, and α is a selected value; in this case we set it to .15 (15 percent).

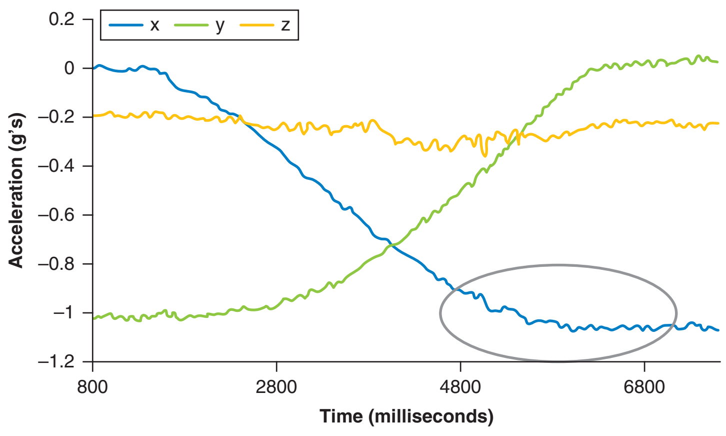

Figure 5: Raw accelerometer readings depicting the tablet's 90° rotation from the landscape position. The ellipse highlights a "jittering" area.
(Source: Intel Corporation, 2013)

$S_{xi} = \alpha^*X_i + (1 - \alpha)^*R_{x(i-1)}$

$S_{yi} = \alpha^*Y_i + (1 - \alpha)^*R_{y(i-1)}$

$S_{zi} = \alpha^*Z_i + (1 - \alpha)^*R_{z(i-1)}$

$\alpha = .15$

Code Example 10 shows how to calculate the filtered sensor data value with the rolling average value and the current raw sensor data input.

```
        ...
private static float FILTERING_FACTOR = .15f;

private float FilterWithRollingValue(float rawVal,
float prevRollingVal)
        {
returnrawVal * FILTERING_FACTOR + prevRollingVal *
(1 - FILTERING_FACTOR);

        }
```

Code Example 10: Filter sensor data with a rolling average value**
Source: Intel Corporation, 2013

"After this rolling average data filtering method is applied, we can see the sensor data becomes smoother than the raw data."

After this rolling average data filtering method is applied, we can see the sensor data becomes smoother than the raw data (Figure 6).

This rolling average method filters out high frequency noise by allowing only 15 percent of the current raw readings affecting the sensor values. The con side of this filtering technique is that a real dramatic change in the sensor state will only appear in the filtered values after several sampling readings. The smaller α value, the longer the lag will be.

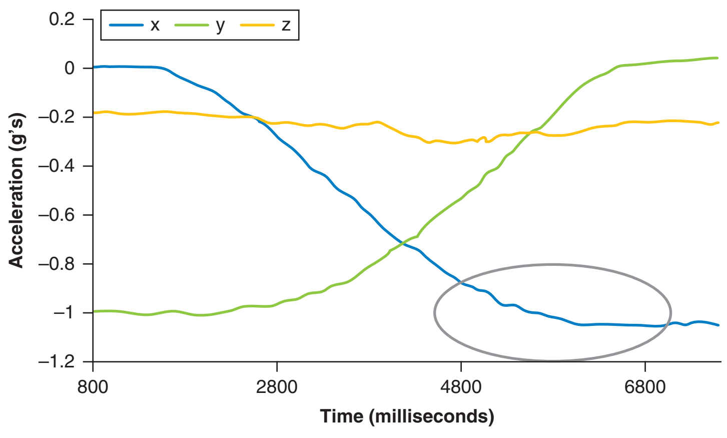

Figure 6: Filtered accelerometer data after the rolling average smoothing method is applied, the ellipse area becomes smoother with high frequency noise filtered out (Source: Intel Corporation, 2013)

Sensor Data Fusion

While sensor data filtering addresses the smoothness and accuracy of a specific sensor, fusing of sensor data is the combining of the data from multiple sensor data sources.

"…Fusing of sensor data is the combining of the data from multiple sensor data sources."

A classic example of fusing sensor data is a compass. To implement a compass we can start with the magnetometer data, which provides the earth magnetic strength values. Then we use the accelerometer, which detects linear acceleration, and the gyroscope, which detects angular velocity; with the two data sources we can produce the device's accurate orientation status. Now with magnetometer, accelerometer, and gyroscope data, we can get the accurate direction of heading. We can also take GPS data, which provides the device's accurate location, to get the true north correction on the direction. The final result is an accurate compass.

Sensor Usage Guidelines

To use sensors in your applications, you should follow the following best practices:

- *Always check the specific sensor's availability before using it* The Android platform does not require the inclusion or exclusion of a specific sensor on the device. The sensor configuration is solely decided by the device manufacturer. Before using a sensor in your application, always first check to see whether it is actually available.
- *Always unregister the sensor listeners* If the activity that implements the sensor listener is becoming invisible, or the dialog is stopping, unregister the sensor listener. It can be done via the activity's *onPause()* method, or in the dialog's *onStop()* method. Otherwise, the sensor will continue acquiring data and as a result drain the battery.

"Before using a sensor in your application, always first check to see whether it is actually available."

- *Don't block the* onSensorChanged() *method* The *onSensorChanged()* method is frequently called by the system to report the sensor data. There should be as little logic inside this method as possible. Complicated calculations with the sensor data should be moved outside of this method.
- *Always test your sensor applications on real devices* All sensors described in this section are hardware sensors. The Android Emulator may not be good enough to simulate the sensor's functions and performance.

"Always test your sensor applications on real devices."

Near Field Communication

"Near Field Communication (NFC) is a set of standards that enables the exchange of small data payloads over a short distance…"

Near Field Communication (NFC) is a set of standards that enables the exchange of small data payloads over a short distance (typically, 4 cm or less), between an NFC tag and a device, or between two devices. The main data format used in NFC is called NDEF, a standard defined by the NFC Forum (http://www.nfc-forum.org/home/).

On Android, NFC is not an *android.hardware.Sensor* type. Instead, the main APIs supporting NFC are in the package *android.nfc*.

NFC provides two basic use cases:

- Reading NDEF data from an NFC tag
- Sending NDEF messages from one device to another using Android Beam*

Using Android Beam to exchange data between two devices is an easier way comparing with other methods, such as Bluetooth*. Because it only requires the two devices to be close enough to each other, or tapping together, no manual device discovery or pairing is needed.

After an NDEF tag is scanned, Android will try to dispatch it to an application that can handle it. This process can be done in two ways:

- Using the Tag Dispatch System
- Using an Android Application Record (AAR, available in Android 4.0 or later)

The Tag Dispatch System

The Tag Dispatch System first parses the NFC tag to get the MIME type or a URI that can identify the data type of the payload. Then it constructs an intent based on the MIME type or URI. Finally, it starts an activity based on the intent.

In order to access the device's NFC hardware and handle NFC intents, your app must request NFC access in the AndroidManifest.xml file:

```
<uses-permission android:name="android.permission.
NFC" />
<uses-sdk android:minSdkVersion="10"/>
<uses-feature android:name="android.hardware.nfc"
android:required="true" />
```

Your app can filter for the NFC intents it want to handle; for example, the *ACTION_NDEF_DISCOVERED* intent. The following example filters for

ACTION_NDEF_DISCOVERED intents with a MIME type of image/jpeg:

```
<intent-filter>
<action android:name=”android.nfc.action.NDEF
_DISCOVERED”/>
<category android:name=”android.intent.category.
DEFAULT”/>
<data android:mimeType=”image/jpeg”/> </intent-
filter>
```

An app started because of an NFC intent can obtain information coded in the intent extras.

Android Application Records

On Android 4.0 (API level 14) or later releases, an Android Application Record (AAR) can be included in any NDEF record of an NDEF message to specify the application's package name, which will be used to handle the NFC intent. If Android finds the application, it will launch; otherwise, it will launch Google Play to download the application.

Advanced NFC Usages

We have discussed the basic concepts and use cases of NFC. NFC has many other advanced usages that are not covered in details in this article, such as:

- Supporting various tag technologies
- Supporting the *ACTION_TECH_DISCOVERED* and *ACTION_TAG_DISCOVERED* intents
- Reading and writing to tags

GPS and Location

GPS (Global Positioning System) is a satellite-based system that provides accurate geo-location information around the world. GPS is available on many Android phones and tablets. From many perspectives GPS behaves like a position sensor. It can provide accurate location data available for the applications running on the device. On the Android platform, GPS is not directly managed by the sensor framework. Instead, the Android location service accesses and transfers GPS data to an application through the location listener callbacks.

"GPS is available on many Android phones and tablets."

This section only discusses the GPS and location services from a hardware sensor point of view.

Android Location Services

Using GPS is not the only way to obtain location information on an Android device. The system may also use Wi-Fi*, cellular networks, or other wireless networks to get the device's current location. GPS and wireless networks (including Wi-Fi and cellular networks) act as "location providers" for Android location services. Table 9 lists the main classes and interfaces used to access Android location services:

"GPS and wireless networks (including Wi-Fi and cellular networks) act as location providers for Android location services."

Name	Type	Description
LocationManager	Class	Used to access location services. Provides various methods for requesting periodic location updates for an application, or sending proximity alerts
LocationProvider	Abstract class	The abstract super class for location providers
Location	Class	Used by the location providers to encapsulate geographical data
LocationListener	Interface	Used to receive location notifications from the location manager

Table 9: The Android Platform Location Service
(Source: Intel Corporation, 2013)

Obtaining GPS Location Updates

Similar to the mechanism of using the sensor framework to access sensor data, the application implements several callback methods defined in the *LocationListener* interface to receive GPS location updates. The location manager sends GPS update notifications to the application through these callbacks (the "Don't call us, we will call you" rule).

To access GPS location data in the application, you need to request the fine location access permission in your Android manifest file (Code Example 10).

```
<manifest ...>

...
<uses-permission android:name= "android.permission.
ACCESS_FINE_LOCATION" />

...
</manifest>
```

Code Example 11: Requesting the Fine Location Access Permission in the Manifest File**
Source: Intel Corporation, 2013

Code Example 12 shows how to get GPS updates and display the latitude and longitude coordinates on a dialog text view.

```
package com.intel.deviceinfo;

importandroid.app.Dialog;
importandroid.content.Context;
importandroid.location.Location;
importandroid.location.LocationListener;
importandroid.location.LocationManager;
importandroid.os.Bundle;
importandroid.widget.TextView;

publicclass GpsDialog extends Dialog implements
LocationListener {
TextView mDataTxt;
```

```
private LocationManager mLocationManager;

publicGpsDialog(Context context) {
super(context);
mLocationManager=
(LocationManager)context.getSystemService(Context.
LOCATION_SERVICE);
    }

    @Override
protected void onCreate(Bundle savedInstanceState) {
super.onCreate(savedInstanceState);
     mDataTxt=(TextView)
findViewById(R.id.sensorDataTxt);
mDataTxt.setText("...");

setTitle("Gps Data");
    }

    @Override
protected void onStart() {
super.onStart();
mLocationManager.requestLocationUpdates(
LocationManager.GPS_PROVIDER, 0, 0, this);
    }

    @Override
protected void onStop() {
super.onStop();
mLocationManager.removeUpdates(this);
    }

    @Override
public void onStatusChanged(String provider, int
status,
        Bundle extras) {
    }

    @Override
public void onProviderEnabled(String provider) {
    }

    @Override
public void onProviderDisabled(String provider) {
    }

    @Override
public void onLocationChanged(Location location) {
StringBuilderdataStrBuilder = new StringBuilder();
dataStrBuilder.append(String.format("Latitude: %.3f,
Logitude%.3f\n", location.getLatitude(), location
.getLongitude()));
mDataTxt.setText(dataStrBuilder.toString());

     }

}
```

Code Example 12: A Dialog that Displays the GPS Location Data**
Source: Intel Corporation, 2013

GPS and Location Usage Guidelines

GPS provides the most accurate location information on the device. On the other hand, as a hardware feature, it consumes extra energy. It also takes time for the GPS to get the first location fix. Here are some guidelines you should follow when developing GPS and location aware applications:

- *Consider all available location providers* Besides the *GPS_PROVIDER*, there is also *NETWORK_PROVIDER*. If your applications only need the coarse location data, you may consider using the *NETWORK_PROVIDER*.
- *Use the cached locations* It takes time for the GPS to get the first location fix. When your application is waiting for the GPS to get an accurate location update, you can first use the locations provided by the location manager's *getlastKnownLocation()* method to perform part of the work.
- *Minimize the frequency and duration of location update requests* You should request the location update only when needed and promptly de-register from the location manager once you no longer need location updates.

Sensors in Perceptual Computing

"The objective of perceptual computing is to enable the devices to understand our intentions in a more natural way."

The objective of perceptual computing is to enable the devices to understand our intentions in a more natural way. Here are some use cases of perceptual technologies:

- Hand and finger tracking and gesture recognition
- Facial analysis
- Augmented reality
- Speech recognition

Depth sensors are based on inferred or other sensing technologies. They play an important role in perceptual computing. The common uses of depth sensors include:

- Finger and hand tracking
- Full body tracking
- Face detection

"…Perceptual computing will be advancing in the next several years. It will provide a foundation to redefine the human/device interfaces and user experiences."

While it is still in its early stages, we believe perceptual computing will be advancing in the next several years. It will provide a foundation to redefine the human/device interfaces and user experiences.

Summary

The Android platform provides APIs for developers to access the device's built-in sensors. These sensors are capable of providing raw data about the device's current motion, position, and ambient environment conditions. When using the sensor data, filtering and fusing methods can be used to improve user experience. In developing sensor applications, you should follow the best practices to improve the performance and power efficiency.

Acknowledgment

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Author Biography

Miao Wei *is a software engineer in Intel Corporation's Software and Services Group. He currently works on the Intel Atom Scale Enabling projects, including tablets and handsets based on Intel architecture running Android and Windows 8. He also provides help and supports for software developers around the world to develop applications on platforms based on Intel Architecture.*

Optimization Notice

INSTALLING THE ANDROID* SDK FOR INTEL® ARCHITECTURE

Contributor

Ryan Cohen

"With over one million applications available in the Google Play store, and only a small percentage of them optimized for Intel architecture, it is important to provide developers with the proper tools and instructions to optimize their applications."*

With the recent increase in Android devices featuring Intel processors, it is important for developers to be able to write applications for Intel Architecture. With over one million applications available in the Google Play* store, and only a small percentage of them optimized for Intel architecture, it is important to provide developers with the proper tools and instructions to optimize their applications.

This article starts with my experience installing the Android development tools. Then I develop and test my first Android application for Intel-based Android devices. The device that was used for testing the application was the Samsung Galaxy Tab 3 10.1*, which was released in the United States in July of 2013 and is the first major tablet released in the United States to feature an Intel processor. Next I cover the development tools provided by Intel to help developers optimize their applications for Intel Architecture. Finally I talk about the different options for posting your Android application to Google Play.

Introduction

For this article I start with how to set up the development environment from scratch. I will be focusing on Intel's new development application called Beacon Mountain. Beacon Mountain is a program that installs all of the applications necessary to start developing for both x86 and ARM* architectures. However, since this program is still in beta, I have included instructions for installing everything you need without using Beacon Mountain. These instructions can be found at the end of this article and start with the section "Downloading the SDK Bundle from Google and Updating the SDK." Before we install Beacon Mountain, we need to install the Oracle* Java Development Kit (JDK).

"Beacon Mountain is a program that installs all of the applications necessary to start developing for both x86 and ARM architectures."*

Installing the Java Development Kit (JDK)

The JDK can be found at the link below.

http://www.oracle.com/technetwork/java/javase/downloads/index.html

Click the download link for the JDK. Accept the license and select the operating system you are using on your development machine. In my case, I selected the download for Microsoft Windows* x64 since I am running a 64-bit version of Windows 8.1 on my development machine. Once the download is complete, run the program and follow the installation prompts. Now that we have installed the JDK we can move on to Beacon Mountain.

Beacon Mountain

When I attended the Intel Developers Forum 2013 in San Francisco, Beacon Mountain was a major focus at all of the technical sessions on Android development. At the time of this writing, Beacon Mountain is in beta and on version 0.6. All statements made about the program going forward are based on this version and are likely to change as it moves closer to a 1.0 release. Beacon Mountain supports both Apple* OS X (10.8.3) and Microsoft Windows 7 and 8 (64-bit) operating systems.

"…Beacon Mountain was a major focus [at the Intel Developers Forum]."

At this point, Beacon Mountain includes some Intel tools that only support Android 4.1 (Jelly Bean) and up. Because of this, I will be focusing on development on Android 4.1 and up so that you can take advantage of these tools. If you wish to develop for a lower version of Android, all of the third-party tools included in Beacon Mountain will work with Android 2.3 (Gingerbread) and up. So Beacon Mountain is still the best way to get everything you need installed if you wish to develop for any Android version 2.3 and up.

When deciding what version of Android to develop for, there are a few factors you should consider. First, do you want to use Intel's provided tools that require Android 4.1? If you do, then you don't have much of a choice but to develop for that version, or above, of Android. Second, what Android features do you need for your application? If you are not doing anything that requires a later version of Android, and you don't want to use Intel's tools, there is probably no reason to set the minimum SDK level to higher than 2.3.3. Finally, you should consider the distribution of Android versions on devices. Google provides a distribution chart at the developer Website (http://developer.android.com/about/dashboards/index.html). At the time of this writing, about 97 percent of devices are running Android 2.3.3 or higher and about 66 percent of devices are running Android 4.0.3 or higher. Ultimately this is a decision you will need to make after doing your own research, considering what you want to do with your application and determining the audience you wish to target.

What Does Beacon Mountain Install?

Beacon Mountain installs several Intel and third-party tools that will allow you to start developing your Android applications. I have listed these tools below.

"Beacon Mountain installs several Intel and third-party tools that will allow you to start developing your Android applications."

Intel x86 Tools

- Intel® Hardware Accelerated Execution Manager (Intel HAXM)
- Intel® Graphics Performance Analyzers System Analyzer (Intel GPA)
- Intel® Integrated Performance Primitives Preview for Android (Intel IPP)
- Intel® Threading Building Blocks
- Intel Software Manager

Third-Party x86 and ARM Tools

- Google Android SDK with ADT Bundle
- Android NDK
- Eclipse
- Android Design
- Cygwin*

Downloading and Installing Beacon Mountain

The product page can be found at (www.intel.com/software/BeaconMountain). The first thing you will need to do is visit the Web site listed above and select the download for the operating system of your development machine. Since I am using a Windows machine, I selected Download for Windows. You will be prompted to enter your email address and will have the option to agree to help shape the product by being contacted by Intel.

The download is about 300 MB in size and took me about three minutes to download. Obviously if you have a slower Internet connection it will take longer. Once the program is finished downloading, run it. Just follow the onscreen prompts to install Beacon Mountain. I chose to "participate and improve Intel Software," but you are not required to. With a strong Internet connection, the installation should take approximately 45 minutes. However, if you do not have a strong connection, the installation can take a *very* long time—be patient. Once the installation is complete just hit "Finish". (Note that at the time of this writing, the ADT bundle is not compatible with Windows 8.1. I can only hope that it will be compatible soon. Because of this you will need to install Beacon Mountain in "Compatibility Troubleshooter" mode if you are using Windows 8.1 and this problem has not been fixed.)

"After going through the steps described above, you will have the necessary tools available to start developing Android applications for Intel architecture (as well as ARM)."

After going through the steps described above, you will have the necessary tools available to start developing Android applications for Intel architecture (as well as ARM). You now have everything you need to write your first app, but it would probably be best to also set up an x86 Android Virtual Device (AVD) at this time, so that you can test your app as soon as it is ready. The next section takes you through the reasons for using the Intel Architecture (x86) Emulator and how to set up your x86 AVD.

Android Virtual Device Emulation

Android runs on devices in a variety of form factors with different screen sizes, hardware capabilities, and features. A typical device has a multitude of software (Android API) and hardware capabilities like sensors, GPS, camera, SD card, and multitouch screen with specific dimensions.

"The emulator is quite flexible and configurable with different software and hardware configuration options."

The emulator is quite flexible and configurable with different software and hardware configuration options. Developers can customize the emulator using the emulator configuration called Android Virtual Device (AVD). AVD can be thought of as a set of configuration files that specify different Android software and device hardware capabilities. The Android Emulator uses these AVD configurations to configure and start the appropriate Android virtual image on the emulator.

As documented on the Android Website (http://developer.android.com/guide/developing/devices/index.html), a typical AVD configuration has:

- A hardware profile that specifies all the device capabilities (examples: camera, sensors).
- A System image, which will be used by the emulator for this AVD (API level to target, such as Ice Cream Sandwich or Jelly Bean).
- A Data image that acts as the dedicated storage space for user's data, settings, and SD card.
- Other options including emulator skin, the screen dimensions, and SD card size.

Developers are encouraged to target different API levels, screen sizes, and hardware capabilities (such as camera, sensors, and multitouch). The AVD configuration can be used to customize the emulator as needed. Developers can create as many AVDs as desired, each one targeting a different Intel architecture–based Android device: for example, a developer can create an Intel architecture–based Ice Cream Sandwich AVD with a built-in skin like WVGA800, or a custom one manually specifying the screen resolution to be used.

"Developers are encouraged to target different API levels, screen sizes, and hardware capabilities (such as camera, sensors, and multitouch)."

The Android SDK has supported Intel architecture–based Android Emulation since Revision 12. The SDK integrates this support into all developer tools including the Eclipse ADT plugin.

For detailed instructions on how to use the emulator, please refer to the following Android documentation: http://developer.android.com/guide/developing/devices/emulator.html.

What Emulator Should You Use?

At the time of this writing, there are five emulator images available for Intel architecture (x86): one each for Android 2.3.7 (Gingerbread), 4.0.4 (Ice Cream Sandwich), 4.1.2 (Jelly Bean), 4.2.2 (Jelly Bean), and 4.3 (Jelly Bean).

While there are many advantages to developing for the latest Android operating system release, many developers prefer to target Android 2.x. When I started this paper, I was informed that some of Intel's tools in Beacon Mountain would only support Android 4.2 and up, so I chose to target Android 4.2. I later found out that this is not the case, so you can develop for Android 4.1 and still take advantage of Intel's tools.

Why Use the Emulator?

First of all, it's *free*. The Android SDK and its third-party add-ons cost absolutely nothing and allow developers to emulate devices that they do not own and may not have access to. This is important because not all phones

"…[The emulator] allow[s] developers to emulate devices that they do not own and may not have access to."

acquire the latest Android OS versions via Over The Air (OTA) updates, and it may not be feasible for developers to purchase every device that is expected to support their software package(s).

"Developers can use the SDK to create several Android Virtual Device (AVD) configurations for development and testing purposes."

Development and Testing

Developers can use the SDK to create several Android Virtual Device (AVD) configurations for development and testing purposes. Each AVD can have varying screen dimensions, SD card sizes, or even versions of the Android SDK (which is useful for testing backward compatibility with prior Android builds).

Playing with a New Build

The emulator allows developers to just have fun with a new build of Android and learn more about it.

Setting Up Your x86 Virtual Device (AVD)

"…the emulator performance will see drastic improvements if you use Intel® Hardware Acceleration Execution Manager (Intel® HAXM) in conjunction with this system image…"

Please note that the emulator performance will see drastic improvements if you use Intel® Hardware Acceleration Execution Manager (Intel® HAXM) in conjunction with this system image—without it, performance may vary. (Intel HAXM requires an Intel processor with Intel VT-x support. For more information about Intel HAXM, visit http://int-software.intel.com/en-us/android.) If you do not have Intel VT turned on when installing Intel HAXM, Beacon Mountain will remind you to do so.

It is now time to create the x86 Android Virtual Device running Android 4.2 (Jelly Bean). My physical testing device is the Samsung Galaxy Tab 3 10.1 running Android 4.2.2. However, many of you will not have this physical device. Therefore the virtual device I decided to create features similar specifications to the Galaxy Tab 3, and runs Android 4.2.2. You can create a different AVD for each type of device you want to test your application on.

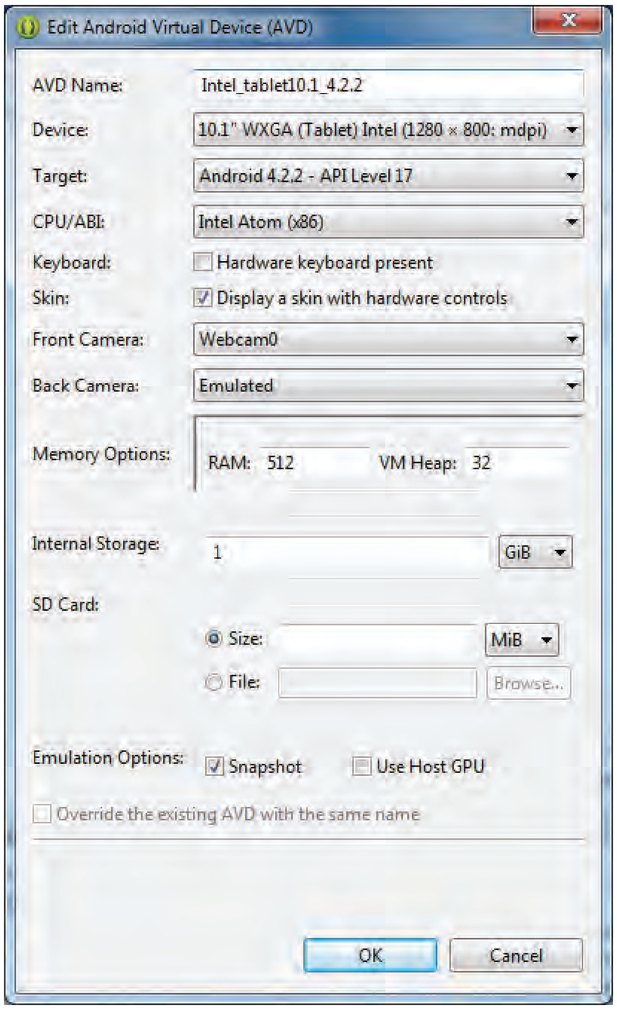
In Eclipse,

1. Select the Window menu and choose Android Virtual Device Manager.
2. Select New in the upper right of the AVD.
3. Under AVD Name: type the name for your virtual device. I chose "Intel_Tablet10.1_4.2.2". However, you can give it any name you want that will help your remember which virtual device this is.
4. Under Device: select the device that is closest to the device you wish to emulate. I chose 10.1" WXGA Tablet since that is closest to my target device. You may need to edit a few things about the device such as whether it has hardware buttons or not. To do this,
   a. Select the Device Definitions tab.
   b. Select the device that is closest to the device you wish to emulate.
   c. Click the clone button on the right side of the screen.
   d. Rename the device so that you can identify it later.
   e. Now you can change around the options so that the device most closely reflects the device you wish to emulate.

I edited the device I chose to have hardware buttons and changed the name to 10.1" WXGA (Tablet) Intel.

5. The Target: tab lets you select your target Android OS version. I chose 4.2.2 as I explained above.
6. In the CPU/ABI: tab select "Intel Atom (x86)".
7. The next two options ask if your device has a hardware keyboard and/or hardware buttons. Check or uncheck the options as they apply to the device you wish to emulate. Note: you must do this in addition to editing the device under device definitions. I unchecked "Hardware keyboard present" and checked "Display a skin with hardware controls". I did this because my target device does not have a hardware keyboard, but it does have hardware buttons for home, menu and back keys.
8. For the front and rear camera options, you need to select if your target device has them, and if so, whether you wish to emulate them or use your development machines camera. Since my development machine has a front facing camera, I chose "Webcam0" for the front camera and "emulated" for the back camera.
9. Next set how much RAM, in megabytes, your virtual device will have. If you go over 768, you will get a warning that reads "On Windows, emulating RAM greater than 768M may fail depending on the system load. Try progressively smaller values of RAM if the emulator fails to launch." This may or may not be completely visible on your screen, which is why I included it here. I set mine to 512 MB since the device failed to launch with 1024 MB. I left VM Heap at the default 32.
10. Under Internal Storage: set the amount of storage you wish for you virtual device to have. I recommend using a low number unless you need a lot of storage for your application. The larger the amount of storage the longer it takes to load the AVD. I chose 1 GB since I won't need much space for my applications and the load time is pretty quick.
11. For SD Card: Set the size of the SD your virtual device will have. Please note that you must have free disk space greater than the size of the SD card you wish to emulate. I chose not to have an SD card in my virtual device because I won't need it for my application and it adds significant time to creating the virtual device.
12. For the Emulation Options: you can select to use Snapshot or Host GPU. If you experience long load times on an AVD I would recommend Snapshot. This allows you to take a snapshot of the AVD and load that instead of loading the entire device again. The two options cannot be used together. I chose to use Snapshot for my device.
13. Figure 1 shows my completed AVD form.
14. Now that you are finished selecting options for your virtual device, select OK. This could take a long time to complete if you chose to create an SD card. It may also say the window is not responding, just leave it until it completes.

"…set the amount of storage you wish for you virtual device to have. I recommend using a low number unless you need a lot of storage for your application."



AVD Name:	Intel_tablet10.1_4.2.2
Device:	10.1" WXGA (Tablet) Intel (1280 × 800: mdpi)
Target:	Android 4.2.2 - API Level 17
CPU/ABI:	Intel Atom (x86)
Keyboard:	☐ Hardware keyboard present
Skin:	✓ Display a skin with hardware controls
Front Camera:	Webcam0
Back Camera:	Emulated
Memory Options:	RAM: 512 VM Heap: 32
Internal Storage:	1 GiB
SD Card:	● Size: MiB ○ File:
Emulation Options:	✓ Snapshot ☐ Use Host GPU
☐ Override the existing AVD with the same name	

Figure 1: Completed AVD Form
(Source: Screen Shot by Ryan Cohen)

15. Test the x86 Jelly Bean AVD by selecting the AVD and clicking Start. If you want to make sure the Intel HAXM is running before you start emulation, run the command prompt and type
```
sc query intelhaxm
```
The state: should be "4 RUNNING". If the AVD takes too long to load, consider lowering the amount of internal storage and size of the SD card.

"Google provides a simple walkthrough for creating your first Android application on their Android developers Website…"

Creating Your First Android App with Eclipse

Google provides a simple walkthrough for creating your first Android application on their Android developers Website, http://developer.android.com/training/index.html. By following the steps to set up an Android project, I created my first application. Below I list my commentary to supplement the instructions provided by Google.

- *Minimum Required SDK* I choose to set my minimum required SDK to 4.2.2 since I decided earlier that I would be targeting Android 4.2.2 and newer.
- *Target SDK* I set my target SDK to 4.3 since this is the latest version of Android that Intel has created a system image for at the time of this writing.
- *Compile With* I chose to set this as Android 4.3 since is it the latest Android version at the time of this writing.

After following the steps provided by Google, along with my commentary, we have created our first Android application. Now we can test it on our AVDs and/or hardware devices.

"After following the steps provided by Google, along with my commentary, we have created our first Android application."

Testing Your Android Application

Let's start with testing our application on the AVD we set up earlier.

Testing on an AVD

The first thing we need to do is run the AVD. Open the AVD Manager and select the AVD you wish to use. Click Start to run the AVD. Once it has finished booting up, you can test your application on the device by selecting Run from the toolbar. If a Run As prompt comes up, select Android Application. Your application should now be running on your AVD. Figure 2 shows the application running on my AVD.

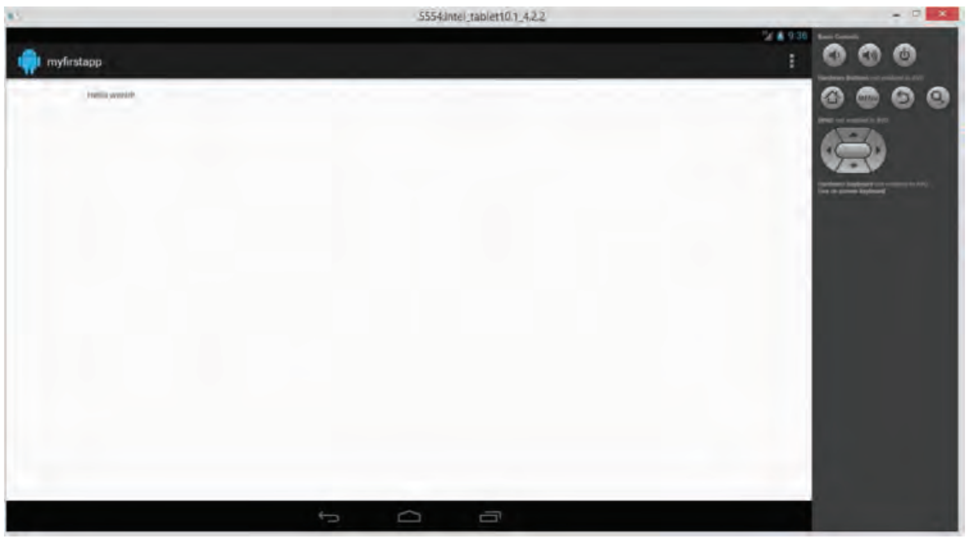


Figure 2: My First App Running on an AVD
(Source: Screen Shot by Ryan Cohen)

Testing on a Hardware Device

Testing the application on a hardware device requires a few more steps than testing on an AVD. The first thing you need to do is connect the hardware device to your development machine using the USB cable that came with your device. If you are using a Windows* machine, it will likely attempt to install the necessary drivers. This may or may not be successful. In my case it was not, so I

"Testing the application on a hardware device requires a few more steps than testing on an AVD."

"Google provides a very useful guide for installing drivers for different devices and different versions of Windows."

had to hunt down the drivers manually. Google provides a very useful guide for installing drivers for different devices and different versions of Windows. The guide can be found at http://developer.android.com/tools/extras/oem-usb.html. The next paragraph will take you through the steps I took to get my Samsung Galaxy Tab 3 10.1 connected to my PC. If you are using a different hardware device for testing, follow the steps in the guide linked to above and find the support page for the device you are using in order to get the drivers.

At the bottom of the guide, you will find a list of support pages for the different Android device manufacturers. For Samsung devices, the support page asks you to select the device you need support for. When you start typing, a dropdown list of devices is displayed for you to choose from. Select the page for the Galaxy Tab 3 10.1 (brown or white). The page (http://www.samsung.com/us/support/owners/product/GT-P5210ZWYXAR) provides a download link for a program called Kies*. This program does several things for different Samsung devices. The only thing we need it for in this case is installing the drivers. Download the program and install it. Once you run it, it should install the drivers and detect your device. If it does not, then you will have to do some troubleshooting. Samsung provides a great troubleshooting guide at http://www.samsung.com/us/support/faq/FAQ00029015/29183.

Now that your hardware device is connected to your development machine we need to turn on USB debugging. The steps to do this are slightly different depending on what version of Android your device is running. Since your x86 device should be running Android 4.0.3 or later, you will find the setting under Settings in the Developer Options. If you are running Android 4.2 or newer, this tab is hidden from the settings by default. In order to access it, you will need to go to About Phone/Device on the Settings menu and tap "Build number" seven times. As you are tapping, it should start to say something like "You are *x* number of taps away from being a developer." Once you are done the developer options should appear in your settings. In the Developer Options under Debugging there should be a check box for "USB debugging". Make sure it is checked.

Now all you have to do is run the application by selecting Run from the toolbar and selecting Android Application in the Run As window. This should install the application on the hardware device and run it. You should now be able to find the application in your apps drawer and run it anytime you wish just like any other application on your device. Figure 3 shows the application running on my hardware device.

Testing a Native Android Application Compiled for x86

"Google provides a sample CPU-intensive native app, RSballs…"

Google provides a sample CPU-intensive native app, RSballs, which can be found in the SDK Manager under Android 4.0.3 (API 15) > Samples for SDK. Simply check the box next to "Samples for SDK" and then click "Install Package…". This application can clearly show the benefits of compiling a native app for x86 versus ARM. Once you have seen the difference, you will surely want to compile your native app for x86.

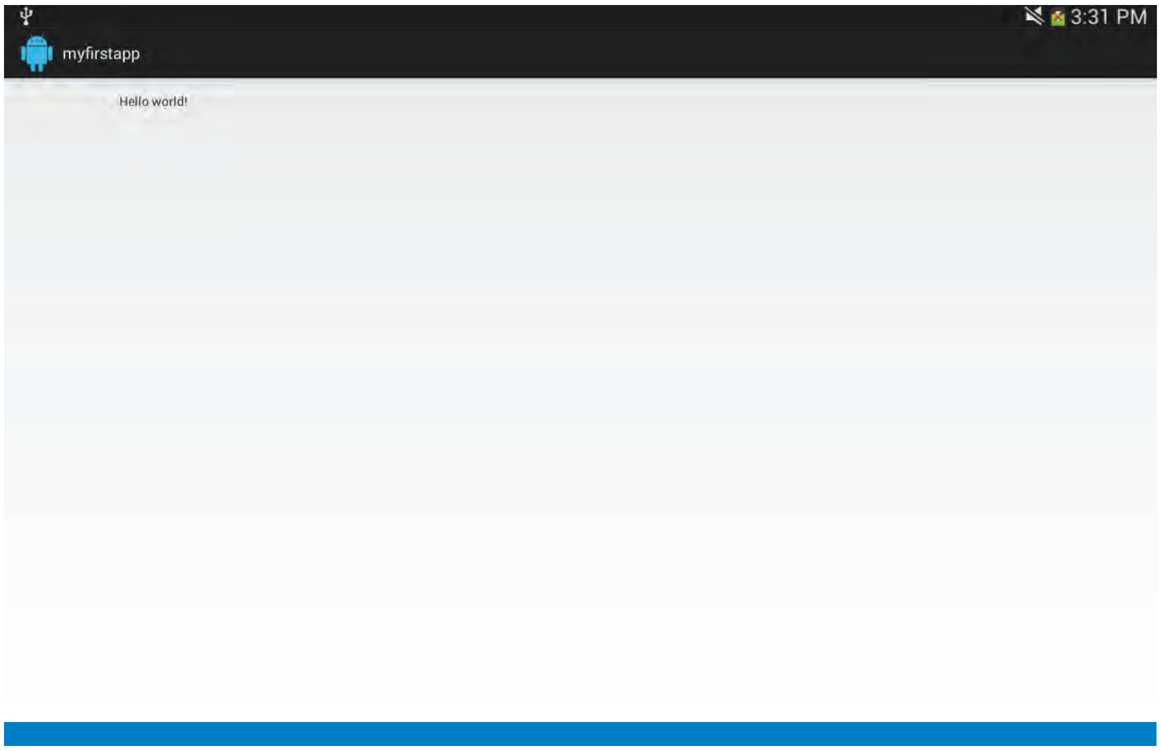


Figure 3: My First App Running on a Hardware Device
(Source: Screen Shot by Ryan Cohen)

Building and Testing the ARM Application

Once you have downloaded the Samples from the SDK as described above, you will need to use the "New Project Wizard" in Eclipse and select "Import from existing source."

In Eclipse, select "File", "New", "Project…".

Double-click "Android" and select "Android Project from Existing Code". Hit "Next >".

Input C:\Intel\BeaconMountain\ADT\sdk\samples\android-15 in the "Root Directory".

Check the box for "RenderScript\Balls".

Click "Finish."

Now you should be able to test this application using the same steps we used above to test our MyFirstApp application.

Building and Testing the x86 Application

All you will need to do is recompile the application in the NDK for x86. An Intel employee, Jun Tian, has provided instructions on how to build the application for x86:

"All you will need to do is recompile the application in the NDK for x86."

```
Get into the Android source tree. Before
configuration, you must set the
```

```
“WITH_DEXPREOPT” option to false in
build/target/board/generic_x86/BoardConfig.mk
for x86:
WITH_DEXPREOPT:= false
Configure to build the apps for x86 (if
with native libs):
$ lunch sdk_x86-eng
Get into the aosp/framworks/rs/java/tests
and run the mm command to build the sample
apps.
$ cd aosp/framworks/rs/java/tests
$ mm”
```

For further information on how to do this, please reference the article “Creating and Porting NDK-based Android* Applications for Intel® Architecture” in this issue of the *Intel Technical Journal*.

Once you do this, you should be able to test the application and see a noticeable difference from the ARM version.

Intel’s Development Tools

Now that we have all of our development tools set up and know how to test our applications on both hardware devices and AVDs, we can discuss the tools that Intel provides us.

Intel® Hardware Accelerated Execution Manager (Intel® HAXM)
Since we have already discussed Intel HAXM above, I will keep this brief. Intel describes it as “a hardware-assisted virtualization engine (hypervisor) that uses Intel Virtualization Technology (Intel® VT) to speed up Android app emulation on a host machine. In combination with Android x86 emulator images provided by Intel and the official Android SDK Manager, HAXM allows for faster Android emulation on Intel VT enabled systems.”

“In combination with Android x86 emulator images provided by Intel and the official Android SDK Manager, HAXM allows for faster Android emulation on Intel VT enabled systems.”

The following platforms are supported by Intel HAXM: Windows 8 (32/64-bit), Windows 7 (32/64-bit), Windows Vista (32/64-bit), and Windows XP (32-bit). If you use only one of Intel’s development tools, this is the one to use. Trying to run an x86 virtual device without Intel HAXM is nothing short of a nightmare.

Intel® Graphics Performance Analyzers (Intel® GPA)
Intel describes Intel GPA as a “set of powerful graphics and gaming analysis tools that are designed to work the way game developers do, saving valuable optimization time by quickly providing actionable data to help developers find performance opportunities from the system level down to the individual draw call.” A key feature of Intel GPA is the ability to profile both performance and power. This is very useful because an application that runs super-fast but has horrible battery performance is not very useful. For further information on the GPA, please refer to the article “Introduction to Graphics and Media Resources in Android*” in this issue of the *Intel Technical Journal*.

“A key feature of Intel GPA is the ability to profile both performance and power.”

Intel® Integrated Performance Preview for Android (Intel® IPP)

Intel® IPP is described as "an extensive library of software functions for multimedia processing, data processing, and communications applications for Windows*, Linux*, Android*, and OS X* environments." Intel IPP is hand-tuned for specific Intel processors, though it will run on any x86 device. Included in Beacon Mountain are the libraries that support Android running on an Intel® architecture processor. Intel IPP includes support for the key domains used in tablets and smartphones, such as image/frame processing and signal processing. The goals behind Intel IPP for Android are not just raw performance but also power efficiency. For further information on how to use Intel IPP for Android, see the article "Introduction to Intel® Integrated Performance Primitives for Android* with a Case Study" in this issue of the *Intel Technical Journal.*

"Intel IPP is handtuned for specific Intel processors, though it will run on any x86 device."

Intel® Threading Building Blocks (Intel® TBB)

Intel® TBB is described by Intel as "a widely used, award-winning C and C++ library for creating high performance, scalable parallel applications." Intel TBB allows developers to specify the task they wish to perform instead of dealing with the minutiae of manipulating threads. Intel TBB maps your logical tasks into threads that can be hosted on multiple cores. For more information on Intel TBB, visit the Intel Developer Zone section on Intel TBB (http://software.intel.com/en-us/intel-tbb/).

Posting Your x86 Application to Google Play

Google provides information on how to post your application on their developer Website (http://developer.android.com/distribute/googleplay/about/distribution.html). If you look under the "Multiple APK Support" section, you will see that you basically have two options for posting your application. You can have one APK for both x86 and ARM, which will require a large APK file. The other option is to have two different APKs, one for x86 and one for ARM. You will need to make your own decision about which option will be best for your application.

"You can have one APK for both x86 and ARM, which will require a large APK file."

Conclusion

You should now have all the tools you need to either develop or port an application for x86 devices. For further reading, please refer to the other sections of this *ITJ*. Also, you can find a lot of useful information at the Intel Developer Zone (http://software.intel.com/en-us/android). I hope that you have found the information provided in this article useful and I look forward to seeing some excellent applications optimized for x86 devices.

"You should now have all the tools you need to either develop or port an application for x86 devices."

Downloading the SDK Bundle from Google and Updating the SDK

The SDK Bundle can be found at http://developer.android.com/sdk/index.html. Click the link to download the SDK ADT Bundle for Windows. Once the download is complete, unzip the file to your C: drive. Next create a shortcut on your desktop for the Eclipse.exe, which can be found within the Eclipse folder. Then run Eclipse and select your workspace location. Open the Android SDK Manager, which can be found under the Window tab. In the Android SDK manager, select the packages you wish to install by checking the boxes, and then click Install Packages. I chose to install all of the packages, except for the deprecated ones, so that I would have anything I needed. Since we will be developing for an Intel-based device running Android 4.0, there is no need to download the packages for API 3 through 13. Finally, you can install the Intel® Hardware Accelerated Execution Manager (Intel® HAXM) if your development machine supports Intel® Virtualization Technology (Intel® VT-x). It is located under the extras section of the SDK Manager. Once installed from the SDK, navigate to the .exe install file, which can be found in the extracted zip file we downloaded from Google earlier. Within the folder we extracted, the install file will be under: SDK>extras>Intel>Hardware_Accelerated_Execution_Manager. Install the IntelHaxm.exe.

Please note: you may see an error message displayed if you attempt to download from behind a firewall. If this occurs, please try again from outside the firewall.

If you still see an error message, close the SDK Manager, then right-click it in the Start menu and select *Run as administrator*. These two steps will resolve most error messages you may see when attempting to download.

Manually Installing Intel's Development Tools

"All of Intel's development tools that are included in Beacon Mountain can be found as standalone downloads on their developer zone website for Android…"

All of Intel's development tools that are included in Beacon Mountain can be found as standalone downloads on their developer zone website for Android (http://software.intel.com/en-us/android). Simply select the tool you wish to install and find the download instructions included in the product page.

Author Biography

Ryan Cohen is an Android enthusiast and Portland State graduate. Ryan has been following Android since 2011 when he made the switch from Apple iOS*. When he is not writing about Android, he spends his time researching anything and everything new in the world of Android. Ryan can be reached at *ryanaosp@gmail.com*

CREATING AND PORTING NDK-BASED ANDROID* APPLICATIONS FOR INTEL® ARCHITECTURE

Contributors

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Intel Corporation

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Intel Corporation

Android applications can incorporate native code using the Native Development Kit (NDK) toolset. It allows developers to reuse legacy code, code to low-level hardware, improve the performance by managing hardware resources directly, or differentiate their applications by taking advantage of features otherwise not optimal or possible.

This article is a basic introduction to creating native applications for Intel architecture from start to finish, and it also provides examples of simple use cases for porting existing native applications to devices based on Intel architecture. The authors walk through a simple step-by-step app development scenario to demonstrate the process. A separate section outlines optimization of native applications for Android using SIMD extensions, IPO, PGO, and Intel® Cilk™ Plus.

"Programming native code allows developers to reuse legacy code, code to low-level hardware, improve the performance by managing hardware resources directly, or differentiate their applications by taking advantage of features otherwise not optimal or possible."

Introduction to the Native Development Kit

Building a native application should be considered when the performance is an issue or when platform features are not otherwise accessible. The problem with developing a native application is that it requires a lot of effort to support the application on multiple architectures and on different generations of the same architecture.

This article assumes some familiarity with creating simple Java applications and assumes that the environment for Java application development is already in place. Before proceeding further NDK should be installed from http://developer.android.com.

Building a "Hello, world!" Application with the NDK

The purpose of this section is to build the first sample application from the NDK for x86 target with both the GNU* compiler and Intel® C++ Compiler. A few tweaks of the build system to change configuration for the application are presented.

Prepare and Validate the Environment

To start experimenting with samples from the NDK distribution, one needs to become familiar with the *ndk-build* utility and with the syntax of two makefiles: *Application.mk and Android.mk.*

The *ndk-build* utility abstracts out the details of build system; *Application.mk and Android.mk* contain variable definitions to configure the build system. The *Android.mk* file provides details about modules to the build system: the list of sources to be used in the build of a module, dependencies on other modules, and so on. *Application.mk* describes the native application, the modules it uses, and other configuration parameters for the whole application, such as which optimization level to use, debug or release; target architecture; path to the project; and so on.

For convenience it is better to add paths to the *ndk-build* and *android* utilities from NDK and SDK correspondingly to the PATH environment variable:

```
PATH=<NDK>:<SDK>/tools:$PATH
```

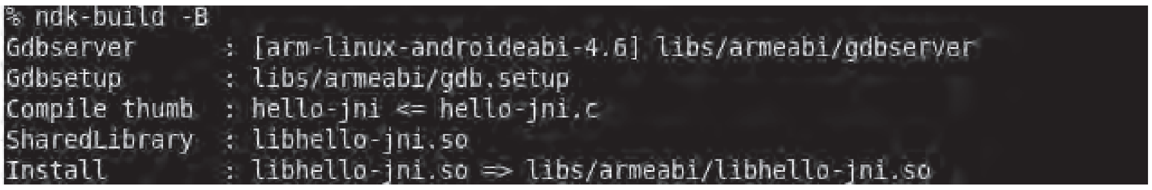
or

```
PATH=<NDK>:<ADT>/sdk/tools:$PATH
```

if SDK is installed as a part of the "Android Development Tools" (ADT) bundle.

The easiest way to validate the environment is to rebuild the *hello-jni* sample from the NDK. Copy *hello-jni* somewhere and run *ndk-build –B* in the new directory. The *–B* option forces the rebuild of the native application. It is advised to use the *–B* option after each modification of the *Android.mk* or *Application.mk* files. Successful compilation will look like Figure 1.

"The easiest way to validate the environment is to rebuild the hello-jni sample from the NDK."



```
% ndk-build -B
Gdbserver      : [arm-linux-androideabi-4.6] libs/armeabi/gdbserver
Gdbsetup       : libs/armeabi/gdb.setup
Compile thumb  : hello-jni <= hello-jni.c
SharedLibrary  : libhello-jni.so
Install        : libhello-jni.so => libs/armeabi/libhello-jni.so
```

Figure 1: Successful compilation of the *hello-jni* application.
(Source: Intel Corporation, 2013)

Only the library *libs/armeabi/libhello-jni.so* for the default target ARM hardware is generated.

Building for x86 Hardware

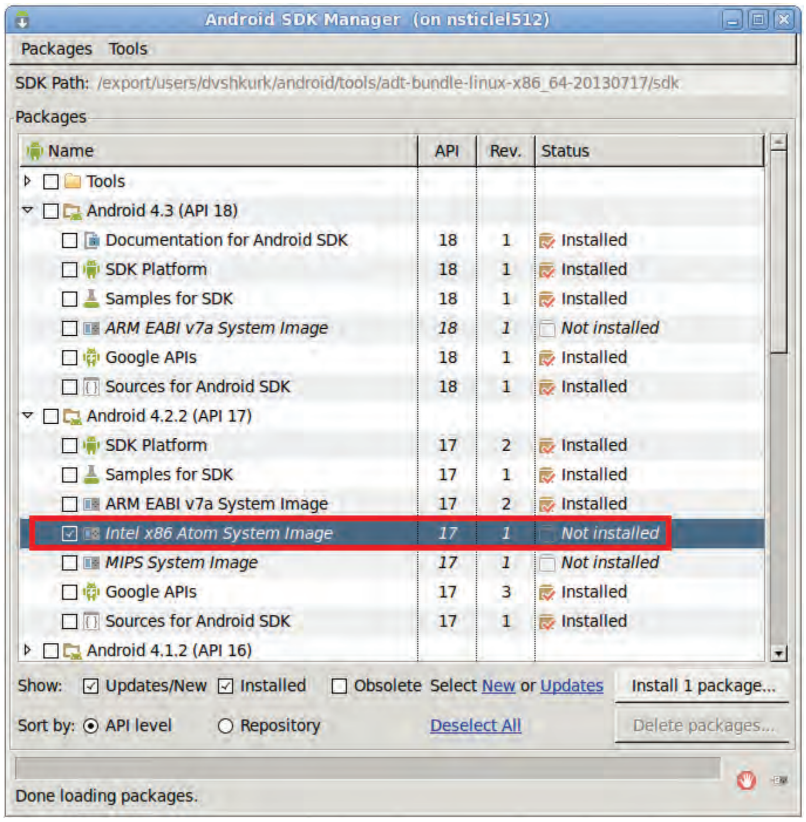
In the previous section the environment was validated and *libhello-jni.so* was built in *libs/armeabi*. The new library can be run on ARM* only, because the ARM target is the default target for native applications. As the primary interest is developing for x86, the application should be configured properly.

Create the file *hello-jni/jni/Application.mk* and add the following definition into this file:

```
APP_ABI:=x86
```

The library is ready to be built for x86; the cross-compiler and other binary tools are retargeted to x86. This time verbose *ndk-build* output will be enabled with the *V*=1 option to see commands and their parameters as they are invoked by make. Run *ndk-build –B V*=1 to rebuild from scratch.

Before creating the application for the x86 target, check that SDK support for x86 architecture is installed. If there is no x86 system, either phone or tablet, then an emulator should be installed using the *android sdk* command. An example of configuring the x86 system image with the Android SDK Manager is shown in Figure 2.


Android SDK Manager (on nsticlel512)

Packages Tools

SDK Path: /export/users/dvshkurk/android/tools/adt-bundle-linux-x86_64-20130717/sdk

Packages

Name	API	Rev.	Status
☐ Tools			
☐ Android 4.3 (API 18)			
☐ Documentation for Android SDK	18	1	Installed
☐ SDK Platform	18	1	Installed
☐ Samples for SDK	18	1	Installed
☐ *ARM EABI v7a System Image*	*18*	*1*	*Not installed*
☐ Google APIs	18	1	Installed
☐ Sources for Android SDK	18	1	Installed
☐ Android 4.2.2 (API 17)			
☐ SDK Platform	17	2	Installed
☐ Samples for SDK	17	1	Installed
☐ ARM EABI v7a System Image	17	2	Installed
☑ *Intel x86 Atom System Image*	*17*	*1*	*Not installed*
☐ *MIPS System Image*	*17*	*1*	*Not installed*
☐ Google APIs	17	3	Installed
☐ Sources for Android SDK	17	1	Installed
☐ Android 4.1.2 (API 16)			

Show: ☑ Updates/New ☑ Installed ☐ Obsolete Select New or Updates Install 1 package...

Sort by: ◉ API level ○ Repository Deselect All Delete packages...

Done loading packages.

Figure 2: The GUI frontend of the Android SDK. An OS image for the x86 target should be installed to experiment with applications.
(Source: Intel Corporation, 2013)

"The built APK contains the library libs/x86/libhello-jni.so, compiled Java code in Android-specific DEX format, and other auxiliary data for the Android OS package manager."*

When the library is ready, the Android Package (APK) should be created and installed. The APK contains the library *libs/x86/libhello-jni.so,* compiled Java* code in Android-specific DEX format, and other auxiliary data for the Android OS package manager.

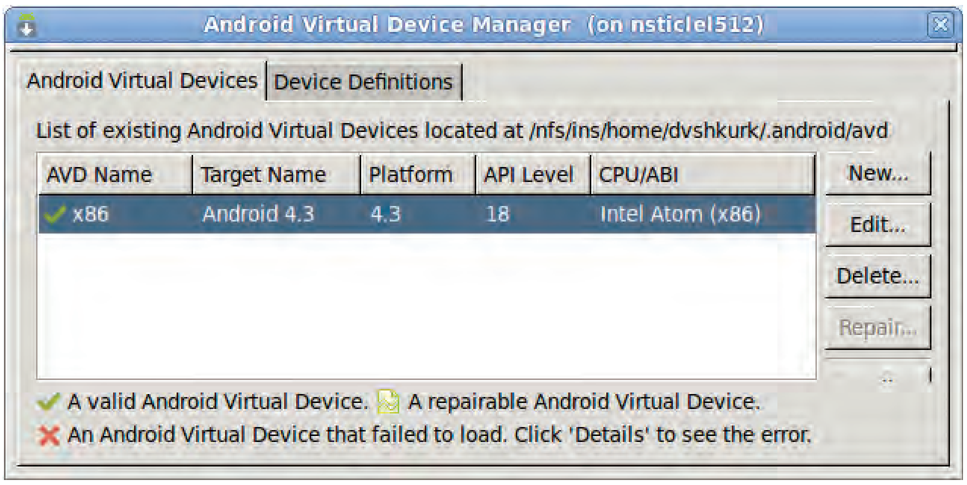
Finalize the creation of the test APK. Run the following commands from the top-level project directory:

- *android update project \*
  —target android-18 \
  —name HelloJni \
  —path $PWD \
  —subprojects
- *ant debug*

(Note: We did not use the ant release command, because it requires properly configured package signing.)

The name of the x86 target in the Android NDK release 9 is *android-18*. One can always check the list of available targets by using the command *android list targets.*

At this point there should be an Android device connected to the development machine, or an emulator should be started. The emulator can be configured and started from the Android SDK application. The configuration dialog box is accessible through the main menu, *Tools/Manage AVDs* . . . . AVD is an acronym for Android virtual device. See Figure 3.



List of existing Android Virtual Devices located at /nfs/ins/home/dvshkurk/.android/avd

AVD Name	Target Name	Platform	API Level	CPU/ABI
✓ x86	Android 4.3	4.3	18	Intel Atom (x86)

✓ A valid Android Virtual Device. A repairable Android Virtual Device.
✗ An Android Virtual Device that failed to load. Click 'Details' to see the error.

Figure 3: Android Virtual Device (AVD) configuration dialog box of the Android SDK. (Source: Intel Corporation, 2013)

After the emulator is launched and the *ant install* command is run, *HelloJni* appears in the list of the installed applications on the emulator, as shown in Figure 4.

There are several important variables from *Application.mk* that are relevant to performance optimization.

The first one is *APP_OPTIM.* It should be set to the value *release* to obtain optimized binary. By default the application is built for debugging. To check which optimization options are enabled by default, update *APP_OPTIM* and run *ndk-build –B V=1.*

"…APP_OPTIM. It should be set to the value release to obtain optimized binary. By default the application is built for debugging."

If default optimization options are not suitable, there are special variables to add additional options during compilation. They are *APP_CFLAGS* and *APP_CPPFLAGS*. Options specified in the *APP_CFLAGS* variable are added during compilation of both C and C++ files and the *APP_CPPFLAGS* variable applies only to C++ files.

To increase optimization level to –O3, add *APP_CFLAGS:=–O3* to *Application.mk.*

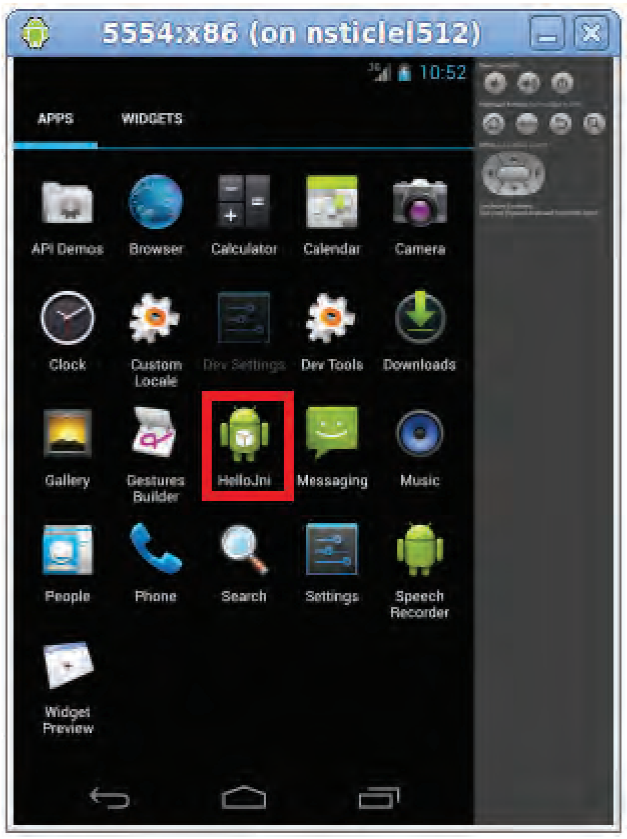


Figure 4: HelloJni appears in the list of the installed applications on the emulator.
(Source: Intel Corporation, 2013)

"It is possible to avoid editing the Application.mk file altogether and specify all options on the command line"

It is possible to avoid editing the *Application.mk* file altogether and specify all options on the command line:

```
ndk-build -B APP_OPTIM=release APP_ABI=x86 V=1\
APP_CFLAGS=–O3
```

So far the application was compiled by the default GNU* compiler version 4.6. There are a few other compilers provided with the Android NDK revision 9. For example, to compile the application using Clang* compiler version 3.3, one may use the following command:

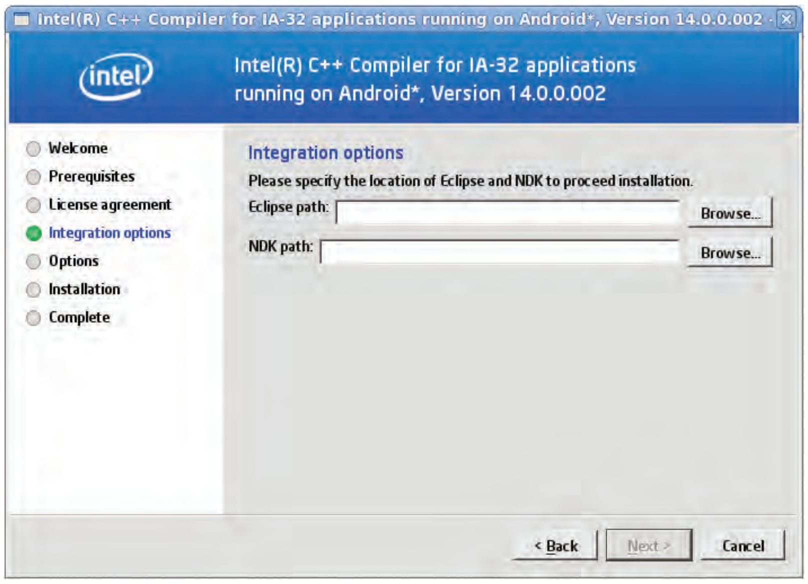
```
ndk-build -B NDK_TOOLCHAIN_VERSION=clang3.3
```

All the provided compilers are compatible with some version of the GNU* compiler. For backward compatibility, older compilers are preserved while newer are added. Newer compilers are likely to be faster optimizing for newer target microarchitecture; they may provide experimental features and so on. One can add a new compiler from the NDK if it supports Android OS target.

More information can be found at http://software.intel.com/en-us/articles/creating-and-porting-ndk-based-android-apps-for-ia/.

Building with the Intel® C++ Compiler

The Intel C/C++ compiler is not provided as part of the Android NDK and needs to be installed separately. The Compiler package installer integrates the Intel compiler into the NDK (see Figure 5).


Intel(R) C++ Compiler for IA-32 applications running on Android*, Version 14.0.0.002

Integration options

Please specify the location of Eclipse and NDK to proceed installation.

Eclipse path:

NDK path:

Figure 5: Intel® C/C++ compiler package installer.
(Source: Intel Corporation, 2013)

The Intel compiler provides several libraries containing optimized standard system functions for:

- string processing
- random number generators
- optimized math functions

By default these libraries are linked statically, but if an application is rather big and consists of many libraries, then linking with dynamic compiler libraries can reduce the size of the application's package. In this case the *–shared-intel* option should be added to the *APP_LDFLAGS* variable in the *Application.mk* file. Thanks to special handling of the *–shared-intel* option in the Intel compiler's configuration file, the libraries are packaged automatically with the application.

"By default compiler's libraries are linked statically, but if an application is big and consists of many libraries, then linking with dynamic compiler libraries can reduce the size of the application's package."

Using shared libraries has one inconvenience: the Intel compiler's library should be loaded from the code. For example, for the *hello-jni* application, three additional libraries should be loaded before the *libhello-jni.so* library:

```
static {
System.loadLibrary("intlc");
System.loadLibrary("irng");
System.loadLibrary("svml");
System.loadLibrary("hello-jni");
}
```

Lack of dependency checking during library loading from Java Virtual Machine (JVM) was found inconvenient by developers and reported as a feature request to Google. The request was implemented in the Android Open Source Project in December, 2012. The most recent and future versions of Android OS do not require manual loading of libraries that are required by *libhello-jni.so*.

Intel® C++ Compiler Options

The Intel compiler supports most of the GNU compiler options, but not all. When the Intel compiler encounters an unknown or unsupported option, it issues a warning**.** It is advised to review warnings.

Building fat APK

Packages, which were built in the previous examples, supported single target architecture: ARM* or Intel IA32*. Although it is possible to provide multiple packages for the same application in Google Play*, it is not recommended. The better solution is to pack all the needed native libraries in a single package known as fat APK.

The following simple example demonstrates building such APK for ARM* and Intel IA32* architectures. The first command prepares library for ARM* using GNU* C/C++ compiler version 4.8 and the second command creates library for Intel IA32* using Intel C/C++ compiler.

```
ndk-build -B APP_ABI=armeabi NDK_TOOLCHAIN_VERSION=4.8

ndk-build APP_ABI=x86 NDK_TOOLCHAIN_VERSION=icc \
NDK_APP.local.cleaned_binaries=true
```

There is a notable difference between two commands: the second command omits *–B* option and adds the *NDK_APP. local. cleaned_binaries=true* parameter. It is needed to avoid cleanup of the ARM* library built by the first command.

Details can be found at http://software.intel.com/en-us/android/articles/creating-an-x86-and-arm-apk-using-the-intelr-compiler-and-gnu-gcc.

Compatibility Options

"In general, the Intel compiler produces more warnings than the GNU compiler."

There are a number of incompatibilities related to warnings. It is a matter of much debate just which constructs are dangerous and which are not. In general, the Intel compiler produces more warnings than the GNU compiler. It was noticed that the GNU compiler also changed its warning setup between releases 4.4.3 and 4.6. The Intel compiler tries to support the GNU options format for warnings, but the support may be incomplete as the GNU compiler evolves.

The GNU compiler uses various mnemonic names with *–W<diag name >* and *–Werror*=<diag name>. The first option enables an additional warning and the second option makes the GNU compiler treat it as an error. In that case, the compiler does not generate an output file and produces only diagnostic data. There is a complementary option **–***Wno-<diag name>* that suppresses a corresponding warning. The GNU compiler option *-fdiagnostics-show-option* helps to disable options: for each warning emitted there is a hint added, which explains how to control the warning.

The Intel compiler does not recognize some of these options and they can be ignored or, even better, fixed. Sometimes all warnings are turned into errors with the *–Werror* option. In this case the build with the Intel compiler may break. This consideration attracted more attention to warning compatibility in the Intel C++ compiler team. There are two ways to avoid the problem: either to fix a warning in the source code, or to disable it with *–diag-disable <id>***,** where *<id>* is the unique number assigned to the warning. This unique *<id>* is a part of warning's text. Fixing the source code is the preferred way if the reported language construct is dangerous.

The Android OS build system was modified to use the Intel compiler instead of GNU* compiler in Android Open Source Project (AOSP). The approach to implement integration of the Intel compiler is discussed in a later section (we can provide all the materials for AOSP Android version 4.3 and Intel C/C++ compiler version 14.0. Please contact the authors directly). Several options were found that are not supported and are not related to warnings. Most of them can be ignored as explained in Table 1. Equivalent Intel compiler options were used for the remaining.

Additional details about Intel and GNU compiler compatibility can be found in the white paper at http://software.intel.com/en-us/articles/intel-c-compiler-for-linux-compatibility-with-the-gnu-compilers/.

Optimization Options

Work on the performance always incurs a tradeoff. The x86 processors differ by the microarchitecture; and for optimal performance, microarchitecture-specific optimizations are required. It should be decided whether the application is going to be generic and run on any x86 processors or the application is targeted only for smartphones or tablets. If the application is generic, then the performance will be suboptimal on specific hardware. Most of the optimizations in the Intel compiler are tuned for Intel processors.

"If the application is generic, then the performance will be suboptimal on specific hardware."

Most x86 Android devices are based on the following microarchitectures:

- Fourth generation Intel® Core™ microarchitecture on the 22 nm process, released in 2013. *-xCORE-AVX2* enables all the optimizations for the processors based on this microarchitecture.
- Third generation Intel Core microarchitecture on the 22 nm process. Corresponding option is *-xCORE-AVX-I.*

GNU compiler option	Equivalent option of Intel compiler
-mbionic, makes compiler aware that the target C library implementation is Bionic	Not needed, it is the default mode of Intel compiler for Android
-mandroid, enables code generation according to Android ABI	Not needed, it is the default mode of Intel compiler for Android
-fno-inline-functions-called-once, inline heuristics override	Not needed.
-mpreferred-stack-boundary=2, align stack pointer on 4 byte	*-falign-stack=assume-4-byte*
-mstackrealign, align stack to 16 byte in each prologue. Needed for compatibility between old code assuming 4-byte alignment and new code with 16-byte stack alignment	*-falign-stack=maintain-16-byte*
-mfpmath=sse, use SSE instruction for scalar FP arithmetic	Not needed. When the target instruction set is to at least SSE2, Intel compiler generates SSE instructions for FP arithmetic.**
-funwind-tables, turns on the generation of the stack unwinding tables	Not needed. Intel compiler generates these tables by default.
-funswitch-loops, overrides GNU compiler heuristics and turns on loop unswitching optimization at *–O2* and *–O1.*	Not needed. Allow Intel compiler to use its own heuristics.
-fconserve-stack, disables optimizations that increase stack size	Not needed.
-fno-align-jumps, disables optimization that aligns branch targets.	Not needed.
-fprefetch-loop-arrays, enables generation of prefetch instructions. Prefetching may lead to performance degradation. Use with care.	Not needed, but if you want to experiment use *-opt-prefetch*
-fwrapv. According to C standard the result of integer arithmetic is undefined if overflow occurs. This option makes compiler to assume wrapping on overflow and disables some optimizations.	-fno-strict-overflow
-msoft-float, implements the floating point arithmetic in software. This option is used during kernel build.	Not implemented. During kernel build the generation of processor instructions for the floating point operations is disabled. Intel compiler will generate an error if the code contains operations on floating point data. We did not encounter such errors.
-mno-mmx, -mno-3dnow, disable generation of MMX* and 3DNow* instructions	Not needed. Intel compiler does not generate them.
-maccumulate-outgoing-args, enables optimization that allocates space for calls' output arguments on the stack in advance.	Not needed.

** Scalar SSE instructions do not perform arithmetic in extended precision. If your application depends on extended precision for intermediate calculations, use –mp option.

Table 1: Compiler Option Comparison
(Source: Intel Corporation, 2013)

- First generation of Intel® Atom™ microarchitecture. The first single- and dual-core smartphones are based on this microarchitecture. The processor-specific option is *-xATOM_SSSE3.*
- Next generation of Intel Atom microarchitecture. The corresponding option is *-xATOM_SSE4.2.*

It is assumed that the target is the Intel Atom processor, because this is the most widespread Intel processor for mobile devices. In this case, for the best performance one needs to add *–xATOM_SSSE3* options during compilation. The application will run on any Intel processor that supports Intel Atom instructions. The code compiled with this option will run on any processor mentioned above, although the performance may be inferior, especially for processors based on Intel Core microarchitectures. To enable *–xATOM_SSSE3* for all files in "Hello, world!" application, add the following line to *Application.mk:*

```
APP_CFLAGS := -xATOM_SSSE3
```

After the target processor is chosen, the optimization level can be adjusted. By default, the build system disables optimizations with *–O0* completely in debug mode and sets default *–O2* optimization level in release mode. One may try aggressive optimizations with *–O3*, but it may result in increased code size. On the other hand, if the code size is an important parameter, then it is suggested to try *–Os*.

Optimization level for the whole application can be changed by adding *–O0 -- –O3* to *APP_CFLAGS*:

```
APP_CFLAGS := -xATOM_SSSE3  -O3
```

The remaining optimization options are covered in the sections "Vectorization" and "Interprocedural Optimization." Parallelization with Intel Cilk technology will be covered in the section "Intel® Cilk™ Plus Technology."

Vectorization

Most modern microprocessors provide special instructions allowing them to process several data elements at a time. For example, four pairs of 32-bit integers can be added using one instruction on Intel Atom processors. Operations working on several elements are called vector instructions.

Vector instructions usually improve application performance, because microprocessors allow for parallel processing of data by vector instructions. Often the data should be prepared for vector operations and developers can either prepare the data themselves or rely on the compiler. In the first case, the developer should take care of the additional burden, like choosing optimal instruction sequences, learning processor instructions, and so on. This approach is not forward-scalable and incurs high development costs. The work should be redone when the new microprocessor with advanced instruction support is released. For example, early Intel Atom microprocessors did not benefit from vectorization of loops processing double-precision floating point while single-precision was processed by SIMD instructions effectively. The compiler can simplify these tasks and generate vector instructions automatically. Such automatic generation by a compiler is called auto-vectorization.

"Manual vectorization is not forward-scalable and incurs high development costs"

The Intel C/C++ Compiler supports advanced code generation including auto-vectorization. The Intel compiler always supports the latest generations of Intel microprocessors.

The *-vec* option turns on vectorization at the default optimization level for microprocessors supporting the IA32 architecture: both Intel and non-Intel. To improve the quality of vectorization, the target microprocessor should be specified. The *–xATOM_SSSE3, –xATOM_SSSE4. 2 and -xCORE-AVX2* options discussed in the previous section have major impact on the vectorization quality: modern processors provide more opportunities for the compiler to vectorize code.

Vectorization is enabled with the Intel C++ Compiler at optimization levels of *–O2* and higher.

Many loops are vectorized automatically and most of the time the compiler generates optimal code, but sometimes it may require guidance from the programmer. The biggest problem with efficient vectorization is to make the compiler estimate data dependencies as precisely as possible. To take full advantage of Intel compiler vectorization, the following techniques are useful:

- Generate and understand a vectorization report
- Improve analysis performed by compiler using pointer disambiguation; more loops are candidates for vectorization with improved analysis
- Improve performance using interprocedural optimization
- Compiler pragmas

Vectorization Report

One of the simplest candidates for vectorization is memory copying, but it is recognized by the Intel compiler and a call to optimized function is generated. As a result, copying is a bad candidate for a tutorial. A slightly more complicated loop will be used in the following example.

The following loop has the structure commonly used in Android sources:

```
// It is assumed that the memory pointed to by dst
// does not intersect with the memory pointed
// to by src1 and src2
void triad_int(int *dst, int *src1, int *src2, int num)

{
    int left = num;
    if (left<=0) return;
    do {
        left--;
        *dst++ = *src1++ + *src2++;
     } while (left > 0);
}
```

The easiest approach to experiment with the compiler is to create new project from *hello-jni*. In this case there is no need to configure paths to system header files and libraries. Code for experiments should be put into an example.cc file and hello-jni.c should be removed. Simple changes in LOCAL_SRC_FILES and LOCAL_MODULE in *Android.mk* are also needed.

```
LOCAL_MODULE    := example
LOCAL_SRC_FILES := example.cc
```

To enable a detailed vectorization report, add the *–vec-report3* option to the *APP_CFLAGS* variable in *Application.mk*:

“Add the –vec-report3 option to the APP_CFLAGS variable in Application.mk to enable a detailed vectorization report”

```
APP_CFLAGS := -O3 -xATOM_SSSE3 -vec-report3
```

Several remarks will be generated while the library is rebuilt:

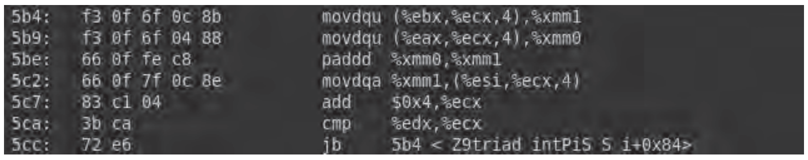
```
jni/example.cc(4): (col. 5) remark: LOOP WAS
VECTORIZED

jni/example.cc(4): (col. 5) remark: loop skipped:
multiversioned
```

Unfortunately auto-vectorization failed for all generated loops, because too little information was available to the compiler. If the vectorization were successful, then the assignment

```
*dst++ = *src1++;
would be replaced with
*dst = *src1 + *src2;
*(dst+1) = *(src1+1) + *(src2+1);
*(dst+2) = *(src1+2) + *(src2+2);
*(dst+3) = *(src1+3) + *(src2+3);
dst += 4; src1 += 4; src2 += 4;
```

and the first four assignments would be performed in parallel by SIMD instructions. The code for a vectorized loop would look like the one shown in Figure 6.



```
5b4:   f3 0f 6f 0c 8b          movdqu (%ebx,%ecx,4),%xmm1
5b9:   f3 0f 6f 04 88          movdqu (%eax,%ecx,4),%xmm0
5be:   66 0f fe c8             paddd  %xmm0,%xmm1
5c2:   66 0f 7f 0c 8e          movdqa %xmm1,(%esi,%ecx,4)
5c7:   83 c1 04                add    $0x4,%ecx
5ca:   3b ca                   cmp    %edx,%ecx
5cc:   72 e6                   jb     5b4 < Z9triad intPiS S i+0x84>
```

Figure 6: Vectorized loop from example.cc
(Source: Intel Corporation, 2013)

The *movdqu* instructions load data from locations pointed by the *src1* and the *src2* variables, *paddd* adds four pairs at a time, and *movdqa* saves data to locations pointed to *dst* variable.

Unfortunately parallel execution of assignments is invalid if the memory accessed on the left sides is also accessed on the right sides of assignment. Consider, for example, the case when *dst* + *1* is equal to *src1* + *2;* in this case the final value at *dst* + *2* address would be incorrect.

"Intel C/C++ compiler generates two versions of the loop. One loop is vectorized by the compiler and the other loop is not. Vectorized loop is executed only when it is safe to execute several iterations of the original loop simultaneously."

To overcome the problem with location ambiguity, the compiler generates two versions of the loop. One loop is vectorized by the compiler and this loop is executed only if it is safe to unroll the loop and to execute iterations simultaneously. The other loop is not vectorized and it is executed if it is not proved that a vectorized loop produces the same result.

The compiler generates two messages for these two loops: one about successful vectorization and the other about a failure to vectorize.

The function comment tells us that the author required memory pointed to by *dst* and *src1* not to overlap. To communicate information to the compiler it is sufficient to add *restrict* qualifiers to *dst src1, src2* arguments.

The *restrict* qualifier was added to the C standard published in 1999. The *restrict* qualifier tells the compiler that the memory locations accessed using, for example, *dst,* are different from locations accessed using any other pointer. This assumption applies only to the region where the *dst* pointer is visible, that is to the body of the *triad_int* function.

To enable support of C99 one needs to add *–std=c99* to options. Alternatively, the *–restrict* option enables recognition of the qualifier for C++ and other C dialects. In the code above the *__restrict__* keyword was inserted; this keyword is always recognized as a synonym for the *restrict* keyword.

```
void triad_int(int * __restrict__ dst,
int *__restrict__ src1,
int *__restrict__ src2,
int num)
```

If the library is rebuilt again, the diagnostic will change:

```
jni/example.cc(4): (col. 5) remark: LOOP WAS
VECTORIZED
```

There is single loop generated and it is vectorized.

In the original example, vectorization failed due to compiler conservative analysis. There are other cases when the loop is not vectorized:

- The instruction set does not allow for efficient vectorization
- Compiler heuristics prevent vectorization; vectorization is possible but may actually lead to slow down
- The vectorizer's shortcomings

The amount of information produced by the vectorizer is controlled by *–vec-reportN*. Additional details are provided in the compiler documentation.

Pragmas

The *restrict* pointer qualifier can be used to avoid conservative assumptions about data dependencies. But sometimes it might be tricky to insert *restrict* keywords. If many arrays are accessed in the loop, it might also be too laborious to annotate all pointers. To simplify vectorization in these cases, there is an Intel-specific pragma *simd*. Pragma *simd* forces the compiler to vectorize the loop if it can, ignoring internal heuristics and information from data analysis. It is used to vectorize inner loops assuming there are no dependencies between iterations.

"Pragma simd forces the compiler to vectorize the loop if it can, ignoring internal heuristics and information from data analysis."

Pragma *simd* applies only to *for* loops operating on native integer and floating-point types, although there are other minor limitations (please check references; the compiler will warn if syntax was violated or if the vectorization with simd pragma failed):

- The *for* loop should be countable with the number of iterations known before loop starts
- The loop should be innermost
- All memory references in the loop should not fault (it is important for masked indirect references)

To vectorize our loop with a pragma, the loop is rewritten into a *for* loop:

```
void triad_int(int *dst, int *src1, int *src2, int num)
{
#pragma simd
    for (int i = 0; i < num; i++) {
        *dst++ = *src1++ + *src2++;
    }
}
```

The compiler produces a special option during recompilation that the loop with the pragma is vectorized:

```
jni/example.cc(4): (col. 5) remark: SIMD LOOP WAS
VECTORIZED
```

Pragma simd was added to OpenMP standard version 4.0 with some modifications in syntax (see http://www.openmp.org/mp-documents/OpenMP4.0.0.pdf).

Limitations of Auto-Vectorization

Vectorization cannot be used to speed up the Linux kernel code, because SIMD instructions are disabled in kernel mode with the *–mno-sse* option. It was made intentionally by kernel developers to avoid saving additional process' context related to processor's vector unit during system calls.

Improving Data Dependence Analysis

The approaches to improve performance, described in the previous sections, required good understanding of the code. If there is no expert knowledge about the code available, then only conservative assumptions are safe. These assumptions depend on the amount of information available to compiler and can be relaxed by extending the scope of the compiler analysis. In the example with summing, the compiler should have taken conservative assumptions because it knew nothing about the *triad_int* routine's parameters. If call sites were available for analysis then the compiler could try to prove that the parameters were safe for vectorization.

"To extend the scope of the analysis and enable more aggressive optimizations, one needs to enable interprocedural optimizations."

To extend the scope of the analysis, one needs to enable interprocedural optimizations. Few of these optimizations are already enabled by default during single file compilation. Interprocedural optimizations are described in the next section.

Interprocedural Optimizations

The compiler can perform additional optimizations if it is able to optimize across function boundaries. For example, if the compiler knows that some function call argument is constant then it may create special version of the function specifically tailored for this constant argument. This special version later can be optimized with knowledge about the parameter value.

Interprocedural optimization within a single file is performed at the default optimization level –O2 and above. To make optimizations more aggressive, the *–ip* option can be added. When optimization does not extend beyond a single file, the compiler generates an object file. The disadvantage of generating an object file is almost complete information loss; the compiler does not even attempt to extract information from the object files.

Single file scope may be insufficient for the analysis in some cases. To expand the scope beyond a single file, one needs to add the *–ipo* option. When this option is given, the compiler compiles files into intermediate representation that is later processed by special Intel tools: *xiar, xild, icc,* or *icpc.*

The *xiar* tool should be used for creating static libraries instead of the GNU archiver *ar*, and *xild* should be used instead of the GNU linker *ld*. It is only required when linker and archiver are called directly. A better approach is to use compiler drivers *icc* or *icpc* for final linking (The NDK tool chain for the Intel C/C++ Compiler redefines TARGET_AR to point to *xiar* and TARGET_LD to point to *xild*). The downside of the extended scope is that the advantage of separate compilation is lost: each modification of the source requires relinking and relinking causes complete recompilation.

There is an extensive list of advanced optimization techniques that benefit from global analysis. Some of them are listed in reference documentation. Note that some optimizations are Intel-specific and are enabled with –x* options discussed before (See the optimization note at the end).

"Symbol id() that is defined and referenced in libtwo.so shared library can be resolved at run time in libone.so."

Symbol Preemption

Unfortunately things are slightly more complicated with respect to shared libraries on systems with the ELF object file format. Analysis scope cannot be expanded simply by adding the *–ipo* option. By default, all global symbols are preemptible. Preemptability is easy to explain by example. Consider two libraries linked into the same executable

```
libone.so:

  int id(void) {
    return 1;
  }

libtwo.so:
  int id(void) {
    return 2;
  }
  int foo(void) {
    return id();
  }
```

If the system dynamic linker loads the library *libone.so* before the library *libtwo.so*, then the call to the function *id()* from the function *foo()* is resolved in the *libone.so* library.

"If the system dynamic linker loads the library libone.so before the library libtwo.so, then the call to the function id() from the function foo() is resolved in the libone.so library."

When the compiler optimizes the function *foo()*, it cannot use its knowledge about *id()* from the *libtwo.so* library. For example, it cannot inline the *id()* function. If the compiler inlined the *id()* function, it would break the scenario involving *libone.so* and *libtwo.so*.

There is, however, a difference on Android though. GNU* and Intel C/C++ compilers for Android add the *–Bsymbolic* linker option by default, and the *id*() function in the *libtwo.so* is resolved in the *libtwo.so* library itself. The *–Bsymbolic* option speeds up processing libraries at runtime, but it does not signal the compiler that certain optimizations are correct. As a consequence, optimization opportunities may be lost. To get all the possible optimizations from the compiler, one should carefully specify which functions can be preempted.

The hello-*jni* application will be used to demonstrate the impact of symbol preemptability on compiler optimizations and the approaches to handle preemptability. Assume string literal "Hello from JNI !" is moved out of the *Java_com_example_hellojni_HelloJni_stringFromJNI* function:

```
const char * message() {
   return "Hello from JNI!";
}
jstring
Java_com_example_hellojni_HelloJni_stringFromJNI
(JNIEnv* env,jobject thiz)

{
   return (*env)->NewStringUTF(env, message());
}
```

The *libhello-jni.so* library should be recompiled with the latest GNU* compiler version 4.8 as of NDK r9:

```
ndk-build -B APP_ABI=x86 -B APP_OPTIM=release\
NDK_TOOLCHAIN_VERSION=4.8
```

The *libhello-jni.so* library's disassembly can be inspected for calls to message function:

```
objdump --disassemble libs/x86/libhello-jni.so|\
grep call.*message
```

There are calls to the *message()* function generated. The compiler cannot inline the *message* function due to reasons outlined above. But in this case it is known that *message()* is a function internal to the library. (The possibility to make the *message()* function local to a file is not considered here for exposition only. In real life the functions used in the single file should be made local to that file using the static function specifier.) On the other hand, the JNI method should be exported, but it is not expected to be preempted.

"The safe and portable way to pass the information about preemptability to the compiler is to specify symbol visibility by function or variable attribute."

The safe and portable way to pass the information about preemptability to the compiler is to specify symbol visibility by function or variable attribute.

- "default" visibility makes a global symbol visible outside the shared library and to be preemptible. (A global symbol is a symbol that is visible from other compilation units. Global functions and variables can be accessed from any object files that comprise a given shared library. Visibility attributes specify relations between function and variables in different shared libraries.)
- "protected" visibility make a symbol visible outside the shared library, but the symbol cannot be preempted by some external symbol
- "hidden" visibility makes a global symbol visible only within the shared library and forbids preemption

The *libhello-jni.so* library will have hidden visibility by default and the JNI method will have default visibility. To set default visibility to hidden, the *-fvisibility=hidden* option should be added to compiler flags. Then to override hidden visibility of *Java_com_example_hellojni_HelloJni_stringFromJNI*, the attribute to the function definition should be added:

```
Jstring __attribute__((visibility("default")))
   Java_com_example_hellojni_HelloJni_stringFromJNI
(JNIEnv* env, jobject thiz)
```

Disassembly inspection after rebuild:

```
ndk-build -B APP_ABI=x86 -B APP_OPTIM=release\
NDK_TOOLCHAIN_VERSION=4.8 \
APP_CFLAGS=-fvisibility=hidden
```

shows that there are no calls to the *message()* function in the *libhello-jni.so* library. There is the helper *JNIEXPORT* macro definition in *jni.h*. This macro can be used instead of *__attribute__((visibility("default")))* in JNI function declarations.

JNI functions can use protected visibility if they are not subject for preemption.

Parallelization Using Intel® Cilk™ Plus

Modern mobile platforms use multi-core CPUs where each core in its turn supports vector instructions. Serialized code works well on these CPUs but to effectively utilize the power of mobile x86 platforms a program may be parallelized. Intel® Cilk™ Plus technology enables fine-grained parallelism in a native code. This technology employs both SIMD instructions and multiple cores of modern CPUs—it provides language extensions to control task and data parallelism in C and C++ programs.

"Intel® Cilk™ Plus technology enables fine-grained parallelism in a native code."

Task parallelism in Intel Cilk Plus is represented by a set of *keywords* (*_Cilk_spawn*,*_Cilk_sync* and *_Cilk_for*)and *reducers* that eliminate contention for shared data between the tasks running in parallel. Data parallelism is represented by *array notations* that provide parallel work on sub-arrays or on arrays as whole, *elemental functions* that can operate on multiple data at once, and the *simd pragma* already discussed above. For detailed description of the Intel Cilk Plus technology refer to compiler documentation or look for the information on https://www.cilkplus.org/.

Consider the example loop we managed to vectorize when we learned the simd pragma:

```
void triad_int(int *dst, int *src1, int *src2, int num)
{
#pragma simd
   for (int i = 0; i < num; i++) {
        *dst++ = *src1++ + *src2++;
    }
}
```

This loop does simple arithmetic operations. For such operations vectorization works effectively by employing simd instructions. But what if our code does something more sophisticated than numeric calculations? For example, consider that we have a function doing some work on every array element:

```
void arr_work(int *arr, int num)
{

      for (int i = 0; i < num; i++) {
        do_some_work(&arr[num]);
    }
}
```

This work can be effectively parallelized by using _Cilk_for loops:

```
void arr_work(int* arr, int num) {
     int i;
    _Cilk_for (i = 0; i < num; i++) {
        do_some_work(&arr[num]);
    }
}
```

In *_Cilk_for* loops the compiler converts the loop body to a function that is called recursively using a divide-and-conquer strategy. Thus the work done on loop iterations may be distributed on several available threads and finally on several available cores. This approach gives significantly better performance on multi-core platforms.

"Programming using Intel Cilk Plus on Android is in large part similar to programming on Linux or Windows,…"*

Programming using Intel Cilk Plus on Android is in large part similar to programming on Linux or Windows*, though some peculiarities still exist. The Intel Cilk Plus runtime library requires a Standard C++ Library implementation to work on a target platform. Android has several implementations available to a user and only some of them may work with Intel Cilk Plus: *gnustl_shared*, *gnustl_static* and *stlport_shared*. Other implementations do not provide required functionality and are not supported with Intel Cilk Plus; static linking is not recommended by Google and we do not specifically support the *stlport_static* standard library implementation. If the remaining code of your application does not require standard C++ library, we recommend using *gnustl_static* library. In this case no additional dependency on a shared library is introduced.

There is no static implementation of the Intel Cilk Plus library. If you're curious why this is so, the reasons are explained in detail here: https://www.cilkplus.org/faq/there-version-intel-cilk-plus-provides-statically-linked-libraries. For Android development with JNI that means the application must load the Intel Cilk Plus library:

```
System.loadLibrary("cilkrts");
```

Since the default *system* STL implementation in the Android NDK is not compatible with Intel Cilk Plus, you have to redefine the default STL library when using Intel Cilk Plus and use it consistently across the program. The STL implementation that should be used in the program can be specified by the *APP_STL* parameter in the *Application.mk* file:

```
APP_STL:=gnustl_static
```

"Intel Cilk Plus libraries are linked automatically if a compatible C++ library implementation is specified for the application."

Starting from the Intel Compiler for Android version 14.0, Intel Cilk Plus libraries are linked automatically if a compatible C++ library implementation is specified for the application.

The NDK build system does not link C++ libraries for modules written in C; as a result, the compiler cannot choose the correct Intel Cilk Plus library during linking and there could be linking errors. Add an empty C++ file to the project to force standard C++ library linking and rebuild the application.

```
ndk-build -B APP_OPTIM=release \
NDK_TOOLCHAIN_VERSION=icc V=1 \
APP_ABI=x86  APP_STL:=gnustl_static
```

As the last step, you have to make sure the Intel Cilk Plus library is included into the resulting application package. Intel C/C++ Compiler integration with the NDK makes sure that the correct Intel Cilk Plus library is packaged with an application.

Building Android OS Images with the Intel® C++ Compiler for Android

Google provides access to source code of the Android OS, allowing anyone to build images for several hardware configurations as well as for a software emulator. The Android OS build system and NDK build system share the same core files. Modules in Android OS are configured using the *Android.mk* files; parameters in these files are the same as in *Android.mk* files from the NDK.

Global settings for x86 target are specified *build/core/combo/TARGET_linux-x86.mk.* The paths to the compilers and compiler options applicable to all modules are set in this file. It is easy, for example, to switch to the GNU* compiler for Android of some other version. If the default compiler is changed, then options should be updated to match the behavior of the original compiler.

Unfortunately changing the compiler globally is not convenient while enabling a new compiler. It is safer to enable the compiler gradually, switching more and more modules to the new compiler.

The compiler can be overridden for a given module by specifying the path to the compiler in the *LOCAL_CC* variable of the module's *Android.mk*, but the new compiler should support all the options that set globally in the file *build/core/combo/TARGET_linux-x86.mk.*

Google faced these problems when they started enabling the Clang compiler. In the past, all C and C++ files were compiled by the GNU* compiler, but today a few modules are configured to be built by Clang*.

To avoid the problem with global options while enabling the Clang* compiler, a new option *LOCAL_CLANG* was introduced. If *LOCAL_CLANG* is set to *true* then Clang*-specific global options from the *build/core/llvm_config.mk* file are used instead of default options. The implementation of Clang* compiler support is spread across three files: *build/core/llvm_config.mk, build/core/clear_vars.mk,* and *build/core/binary.mk.* The *binary.mk* file is a place where the compiler is reset and options are modified for the Clang* compiler.

Intel C/C++ integration to the Android OS build was also implemented by hooks in *build/core/binary.mk* using functions and parameters from *build/core/icc_config.mk.* (We can provide all the materials for AOSP Android version 4.3 and Intel C/C++ Compiler version 14.0. Please contact the authors directly.)

"Intel C/C++ integration to the Android OS build was implemented by hooks in build/core/binary.mk using functions…"

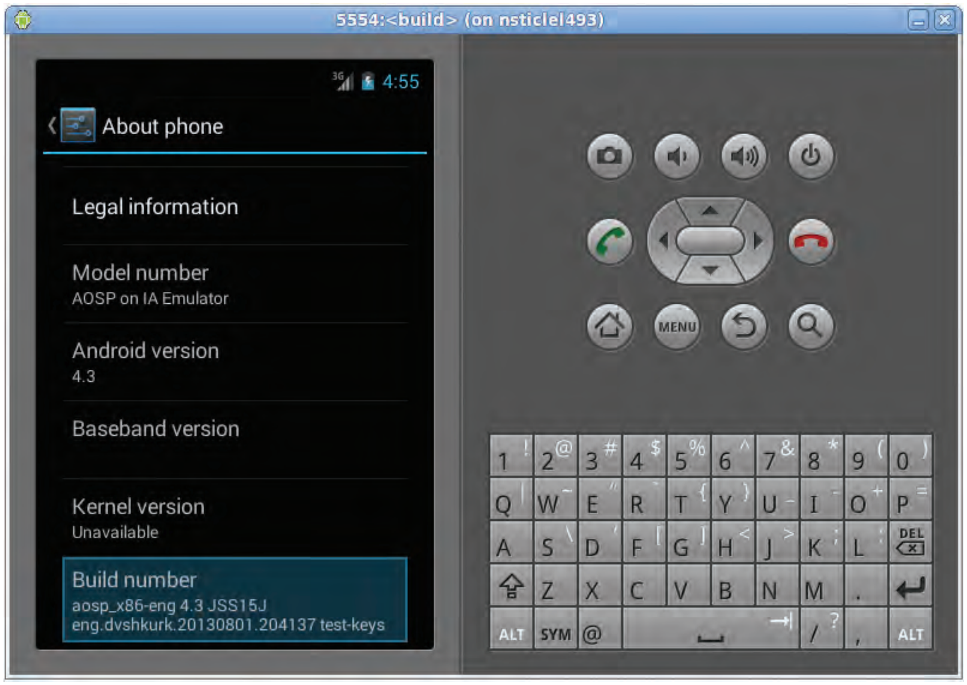
The Intel C++ Compiler provides several performance and supplemental libraries. Unless the code is compiled with the *–ffrestanding* option, the resulting object files may have references to the functions from these libraries.

The Android OS build system requires that all dependencies are specified explicitly. To facilitate these dependencies *LOCAL_SHARED_LIBRARIES* and *LOCAL_STATIC_LIBRARIES* are adjusted from *build/core/binary.mk.*

To save space, supplemental libraries are linked dynamically during system image build.

The way modules are compiled can be configured: the default compiler can be the GNU* compiler or the Intel C Compiler, and there are configuration parameters to specify exceptions. Exceptions can be specified in the *build/core/icc_config.mk* file instead of modifying the corresponding *Android.mk.* It was more convenient for our experiments.

Figure 7 shows the emulator running an image compiled by the Intel C++ Compiler.



Legal information

Model number
AOSP on IA Emulator

Android version
4.3

Baseband version

Kernel version
Unavailable

Build number
aosp_x86-eng 4.3 JSS15J
eng.dvshkurk.20130801.204137 test-keys

Figure 7: Emulator running the image built completely by the Intel® C/C++ Compiler. (Source: Intel Corporation, 2013)

Using PGO to Improve Application Performance

Sometimes performance of the application can be improved if the compiler is made aware of runtime behavior of the application.

"Profile-guided optimization (PGO) uses runtime information to change code and data layout."

Cache problems, branch mispredictions, and code size may be reduced by reorganizing code instructions. Profile-guided optimization (PGO) uses runtime information to change code and data layout. It provides information about areas of an application that are most frequently executed. By knowing these areas, the compiler is able to be more selective and specific in optimizing the application.

PGO consists of three phases or steps.

1. *Instrumentation.* In this phase, the compiler creates and links an instrumented program from your source code and special code from the compiler.
2. *Running instrumented executable.* Each time you execute the instrumented code, the instrumented program generates a dynamic information file, which is used in the final compilation.
3. *Final compilation.* During second compilation, the dynamic information files are merged into a summary file. Using the summary of the profile information in this file, the compiler attempts to optimize the execution of the most heavily traveled paths in the program.

For experiments the same *hello-jni* application will be used.

Instrumentation and Running Phases

First of all, the application should be granted permission to write files with dynamic information to external storage. The following line should the added to the *AndroidManifest.xml* file:

```
<uses-permission
android:name="android.permission.WRITE_EXTERNAL_
STORAGE" />
```

Then the application should be prepared to store files during execution. By default the files are written when the application calls the system *exit*() function. The function *exit()* can be called from any native method, or directly from Java code using *System.exit(0)*, but this approach is not convenient for profiling Android applications.

Another approach is to dump information explicitly. In the following example dynamic information will be reset when activity is brought to the front and written to disk when the activity is paused:

"It is convenient to use PGO API to handle profile information from the application's callbacks onPause/onStart."

```
@Override
public void onStart() {
     super.onStart();
     resetProfile();
}

@Override
public void onPause() {
     super.onPause();
     dumpProfile();
}
public native String resetProfile();
public native String dumpProfile();
```

The new *resetProfile()* method resets dynamic information. Similarly the *dumpProfile()* method dumps information to disk. These functions are called from the corresponding Activity callbacks.

The *resetProfile()* and *dumpProfile()* methods are simple wrappers of functions from the PGO application programming interface:

```
#include <pgouser.h>
jstring
Java_com_example_hellojni_HelloJni_resetProfile
(JNIEnv* env,jobject thiz ) {
    _PGOPTI_Prof_Reset_All();
}

jstring
Java_com_example_hellojni_HelloJni_dumpProfile
(JNIEnv* env, jobject thiz) {
    _PGOPTI_Prof_Dump_All();
}
```

Finally *libhello-jni.so* should be recompiled with options *-prof-gen -prof-dir /sdcard:*

```
ndk-build -B APP_OPTIM=debug \
NDK_TOOLCHAIN_VERSION=icc \
APP_ABI=x86 \
APP_CFLAGS='-prof-gen -prof-dir /sdcard'
```

The *–prof-gen* option directs the compiler to instrument a shared library and the second option tells the name of the directory where dynamic information is stored.

The Java package should be rebuilt and reinstalled. After the application is run two times there will be generated two files with the *.dyn* extension in the */sdcard* directory:

```
% adb shell ls /sdcard/

..

523a96f9_10912.dyn
523a9b67_11053.dyn
```

"Information should be collected during carefully chosen scenarios, otherwise irrelevant information will be collected and the frequently executed code will not be optimized with proper diligence."

The file names will be different at each application invocation. Information should be collected during carefully chosen scenarios, otherwise irrelevant information will be collected and the frequently executed code will not be optimized with proper diligence.

Final Compilation

The files with dynamic information should be pulled from the device or emulator:

```
adb pull /sdcard/523a96f9_10912.dyn jni
adb pull /sdcard/523a9b67_11053.dyn jni
```

and the application should be rebuilt

```
ndk-build -B APP_OPTIM=release \
NDK_TOOLCHAIN_VERSION=icc V=1 \
APP_ABI=x86 \
APP_CFLAGS='-prof-use -prof-dir jni -ipo'
```

The *–prof-use* option causes the compiler to use files with dynamic information from the *jni* directory specified by the *-prof-dir jni* option.

Note that *.dyn* files in the *jni* directory are merged to the new file *jni/pgopti.dpi.*

All phases of performance-guided optimization should be performed after each modification to source code to obtain the correct results.

Optimization Notice

Intel's compilers may or may not optimize to the same degree for non-Intel microprocessors for optimizations that are not unique to Intel microprocessors. These optimizations include SSE2, SSE3, and SSSE3 instruction sets and other optimizations. Intel does not guarantee the availability, functionality, or effectiveness of any optimization on microprocessors not manufactured by Intel. Microprocessor-dependent optimizations in this product are intended for use with Intel microprocessors. Certain optimizations not specific to Intel microarchitecture are reserved for Intel microprocessors. Please refer to the applicable product User and Reference Guides for more information regarding the specific instruction sets covered by this notice.

Notice revision #20110804

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Dmitry Shkurko received BS and MSc degrees from Novosibirsk State University in 2004. He started at Intel in 2005 as an application engineer in the Math Kernel Library team and worked on optimization of numerical weather simulation and climate cluster applications. Since 2010 he has worked in the Intel Compiler Group in the embedded compiler team. Before joining Intel, he worked on testing a binary translator for the Elbrus family of CPUs at Novosibirsk IT centre UniPro. His e-mail is dmitry.v.shkurko@intel.com.

DEBUGGING AND INTEL® HARDWARE ACCELERATED EXECUTION MANAGER

Contributor

Omar A. Rodriguez
Software and Services Group,
Intel Corporation

The challenges of identifying runtime issues and possible problem code in an Android* application or in the Android system software stack is going to be remarkably similar, regardless of whether the underlying platform architecture is based on Intel® or ARM* architecture. This article provides an overview of the available debug methodologies and tools for Android applications on Intel architecture. The author also touches on the setup and configuration of application and system software debug environments targeting Android and Intel architecture. In the process of doing so, the author also points out the differences of the experience when developing for ARM architecture.

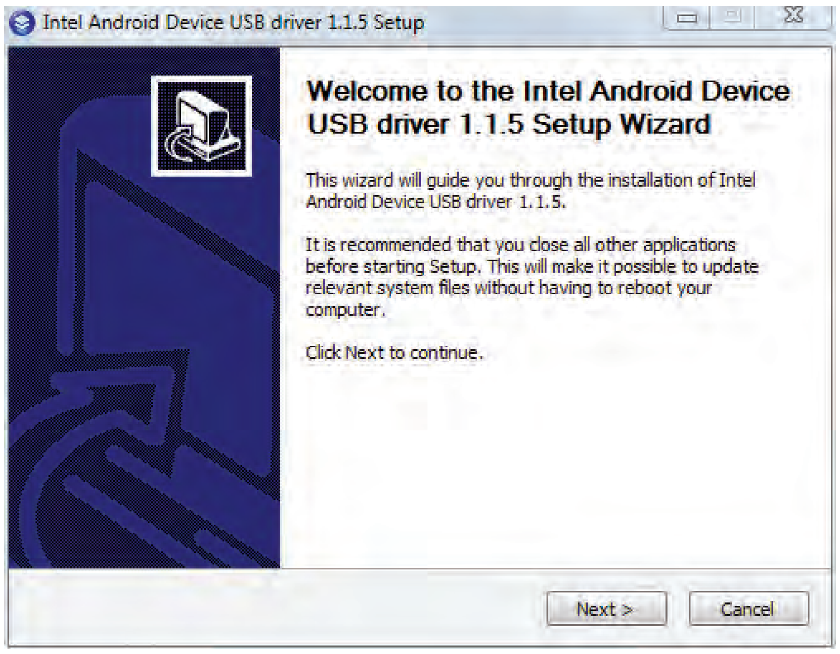
Prerequisites

Before getting into the details of debugging on Android, we'll cover the prerequisite USB drivers and Android images needed for the rest of the article. These will enable remote application debugging on a device based on the Intel® Atom™ processor running Android OS. If no physical device is available, having a virtual device based on the Intel Atom processor emulated inside the Android SDK's device emulation layer is the next best option.

Intel® USB Driver for Android Devices

The Intel® USB Driver is needed if your development machine is running the Windows* operating system. Let us first look at the Intel® Android USB Driver package, which enables the connection of your host development machine to your Android device that contains an Intel Atom processor inside.

1. Download the installer package from http://www.intel.com/software/android.
2. Run the installer and accept the Windows User Account Control (UAC) prompt, if applicable.
3. You will see the screen shown in Figure 1. Click Next to continue. (If the installer detects an older version of the driver, accept to uninstall it.)
4. Read and agree to the Intel Android USB Driver End-User License Agreement (EULA).
5. You will be prompted to select components. Click Next to proceed.
6. Choose the path for the installation and click Install.
7. The installer installs Android USB drivers. This may take a few minutes to complete (Figure 2).
8. After the driver installation is completed, click OK on the pop-up note and then click Finish to close the installation program.



Intel Android Device USB driver 1.1.5 Setup

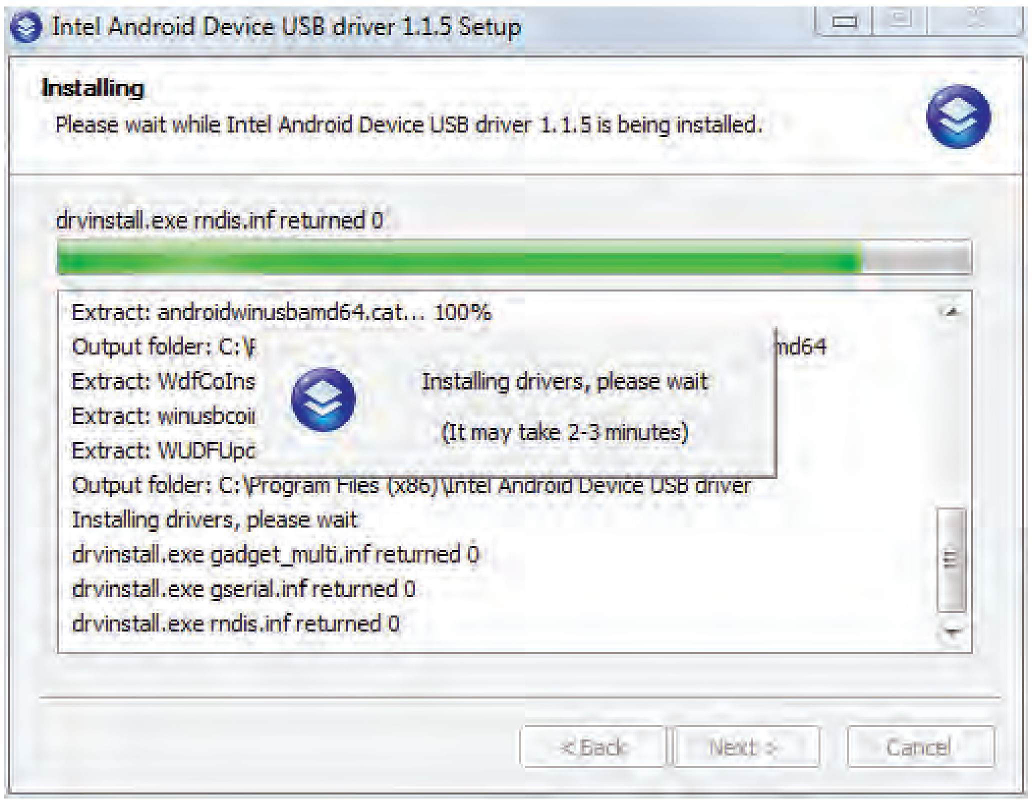
Welcome to the Intel Android Device USB driver 1.1.5 Setup Wizard

This wizard will guide you through the installation of Intel Android Device USB driver 1.1.5.

It is recommended that you close all other applications before starting Setup. This will make it possible to update relevant system files without having to reboot your computer.

Click Next to continue.

Figure 1: USB device driver installation start screen
(Source: Intel Corporation, 2013)



Intel Android Device USB driver 1.1.5 Setup

Installing

Please wait while Intel Android Device USB driver 1.1.5 is being installed.

```
drvinstall.exe rndis.inf returned 0

Extract: androidwinusbamd64.cat... 100%
Output folder: C:\F                                   nd64
Extract: WdfCoIns
Extract: winusbcoii
Extract: WUDFUpc
Output folder: C:\Program Files (x86)\Intel Android Device USB driver
Installing drivers, please wait
drvinstall.exe gadget_multi.inf returned 0
drvinstall.exe gserial.inf returned 0
drvinstall.exe rndis.inf returned 0
```

Installing drivers, please wait

(It may take 2-3 minutes)

Figure 2: USB device driver installation progress screen
(Source: Intel Corporation, 2013)

Installing the Intel® Atom™ x86 System Image for Android Emulator

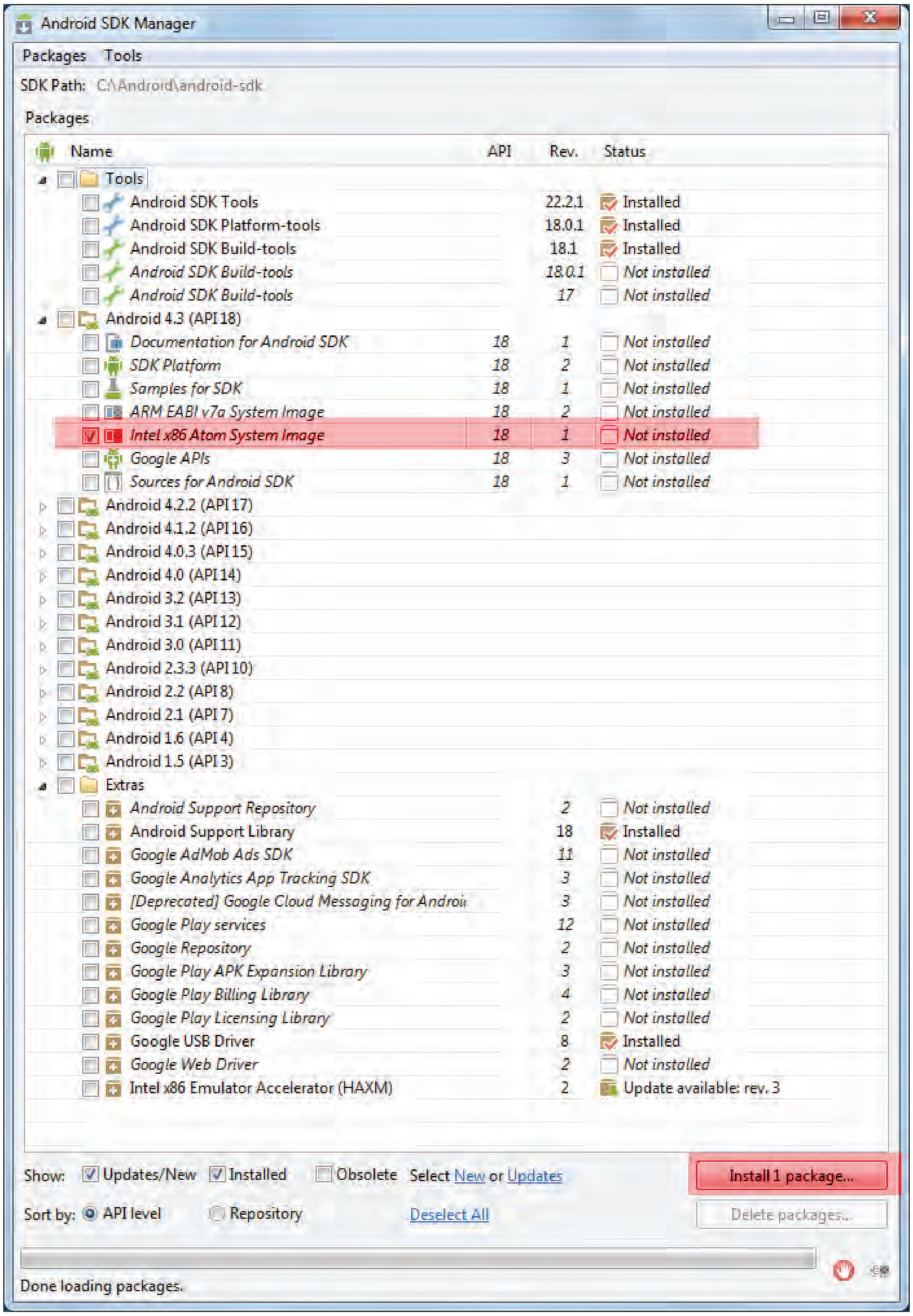
Ideally you will debug your Android application on a physical device. As we mentioned before, the next best option is to set up a virtual device. This section walks you through the steps of installing the Intel Android x86 System Image.

The Intel Android x86 System Image requires the Android SDK to be installed. Please refer to the Android developer Web site (http://developer.android.com/sdk/installing.html) for Android SDK installation instructions. The Android SDK Manager allows you to download and install the Intel Atom x86 System Image. Follow the steps below:

1. Start the Android SDK Manager.
2. Under the Android 4.*x.x* (API 1*x*) section of Packages, check the box to select *Intel Atom x86 System Image by Intel Corporation*.
3. Once selected, click Install Package, as shown in Figure 3. (Note: You may have more than one package to install, based on other packages that you or the Android SDK Manager program preselect.)
4. Review the Intel Corporation license agreement. If you accept the terms, select the Accept option and click Install, as shown in Figure 4.
5. At this point, the Android SDK Manager downloads and installs the image to your Android SDK system-images folder (<sdk>/system-images/). The download and install will take several minutes, depending on your connection speed.
6. Select Manage AVDs from the Tools menu (Figure 5).
7. The Android Virtual Device Manager window should appear. Click New (Figure 6).
8. Enter a name for your virtual device in the Name field. Note: spaces are not allowed in the name.
9. Select *Intel Atomx86 System Image (Intel Corporation) — API Level XX* from the dropdown list of the Target field (Figure 7).
10. Once you select your configuration settings, click Create AVD.
11. The new virtual device should appear on the Android Virtual Device Manager. Select the new device and click Start, as shown in Figure 8.
12. The Launch Options window should appear. Select the screen size and dpi for your system. Otherwise, the emulator might exceed the dimensions of your viewing screen. Click Launch (Figure 9).
13. After a few moments, the emulator will launch and show you the screen in Figure 10.

Application Debug using the Android Debug Bridge

Once you have your development machine set up with the prerequisites outlined above, you will be able to communicate with your device using the Android Debug Bridge (ADB). The Android Debug Bridge (ADB) is a command-line



Android SDK Manager

Packages Tools

SDK Path: C:\Android\android-sdk

Packages

	Name	API	Rev.	Status
	Tools			
	Android SDK Tools		22.2.1	Installed
	Android SDK Platform-tools		18.0.1	Installed
	Android SDK Build-tools		18.1	Installed
	Android SDK Build-tools		18.0.1	Not installed
	Android SDK Build-tools		17	Not installed
	Android 4.3 (API 18)			
	Documentation for Android SDK	18	1	Not installed
	SDK Platform	18	2	Not installed
	Samples for SDK	18	1	Not installed
	ARM EABI v7a System Image	18	2	Not installed
✓	Intel x86 Atom System Image	18	1	Not installed
	Google APIs	18	3	Not installed
	Sources for Android SDK	18	1	Not installed
	Android 4.2.2 (API 17)			
	Android 4.1.2 (API 16)			
	Android 4.0.3 (API 15)			
	Android 4.0 (API 14)			
	Android 3.2 (API 13)			
	Android 3.1 (API 12)			
	Android 3.0 (API 11)			
	Android 2.3.3 (API 10)			
	Android 2.2 (API 8)			
	Android 2.1 (API 7)			
	Android 1.6 (API 4)			
	Android 1.5 (API 3)			
	Extras			
	Android Support Repository		2	Not installed
	Android Support Library		18	Installed
	Google AdMob Ads SDK		11	Not installed
	Google Analytics App Tracking SDK		3	Not installed
	[Deprecated] Google Cloud Messaging for Androi		3	Not installed
	Google Play services		12	Not installed
	Google Repository		2	Not installed
	Google Play APK Expansion Library		3	Not installed
	Google Play Billing Library		4	Not installed
	Google Play Licensing Library		2	Not installed
	Google USB Driver		8	Installed
	Google Web Driver		2	Not installed
	Intel x86 Emulator Accelerator (HAXM)		2	Update available: rev. 3

Show: [✓] Updates/New [✓] Installed [ ] Obsolete Select New or Updates

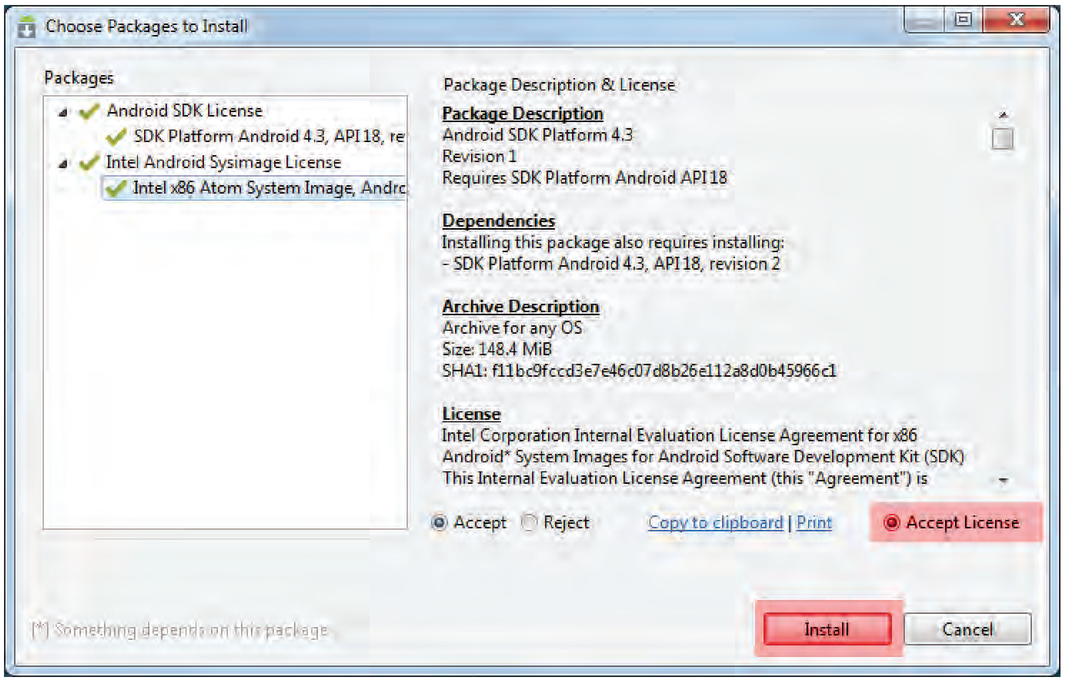
Install 1 package...

Sort by: (●) API level ( ) Repository Deselect All

Delete packages...

Done loading packages.

Figure 3: Android SDK Manager selection for x86 System Image (Source: Intel Corporation, 2013)


Choose Packages to Install

Packages
- Android SDK License
  - SDK Platform Android 4.3, API 18, re
- Intel Android Sysimage License
  - Intel x86 Atom System Image, Andro

Package Description & License

Package Description
Android SDK Platform 4.3
Revision 1
Requires SDK Platform Android API 18

Dependencies
Installing this package also requires installing:
- SDK Platform Android 4.3, API 18, revision 2

Archive Description
Archive for any OS
Size: 148.4 MiB
SHA1: f11bc9fccd3e7e46c07d8b26e112a8d0b45966c1

License
Intel Corporation Internal Evaluation License Agreement for x86
Android* System Images for Android Software Development Kit (SDK)
This Internal Evaluation License Agreement (this "Agreement") is

[✓ Accept] Reject Copy to clipboard | Print [✓ Accept License]

[*] Something depends on this package

Install Cancel

Figure 4: Android SDK Manager — Accepting licensing terms
(Source: Intel Corporation, 2013)

tool that handles debug communication between a debugger on the host and an Android image running on the target. The target image could be running on device emulation or running on a physical device, which you communicate with via a USB-OTG (On-The-Go) or USB-to-Ethernet connection. In short, ADB is the glue that makes application debug on Android possible.

Setting Up ADB

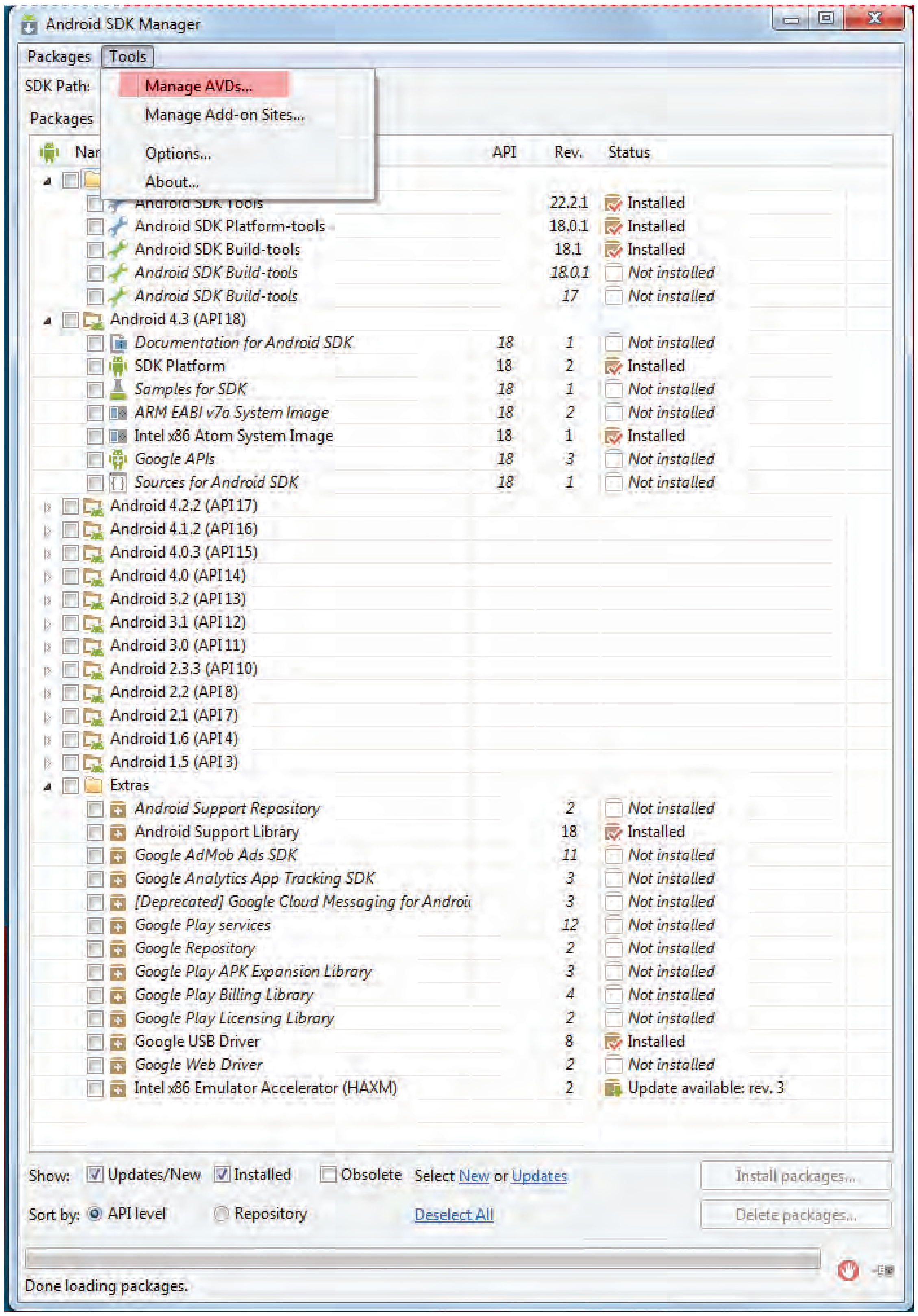
First you will need the Android SDK including ADB installed on the development host. Instructions for this can be found at http://developer.android.com/sdk/installing.html.

"The standard method for remote application debug is to use the existing USB-OTG interface of most Android devices."

The standard method for remote application debug is to use the existing USB-OTG interface of most Android devices. The setup is described in quite some detail at the Android developer Web site: http://developer.android.com/guide/developing/device.html.

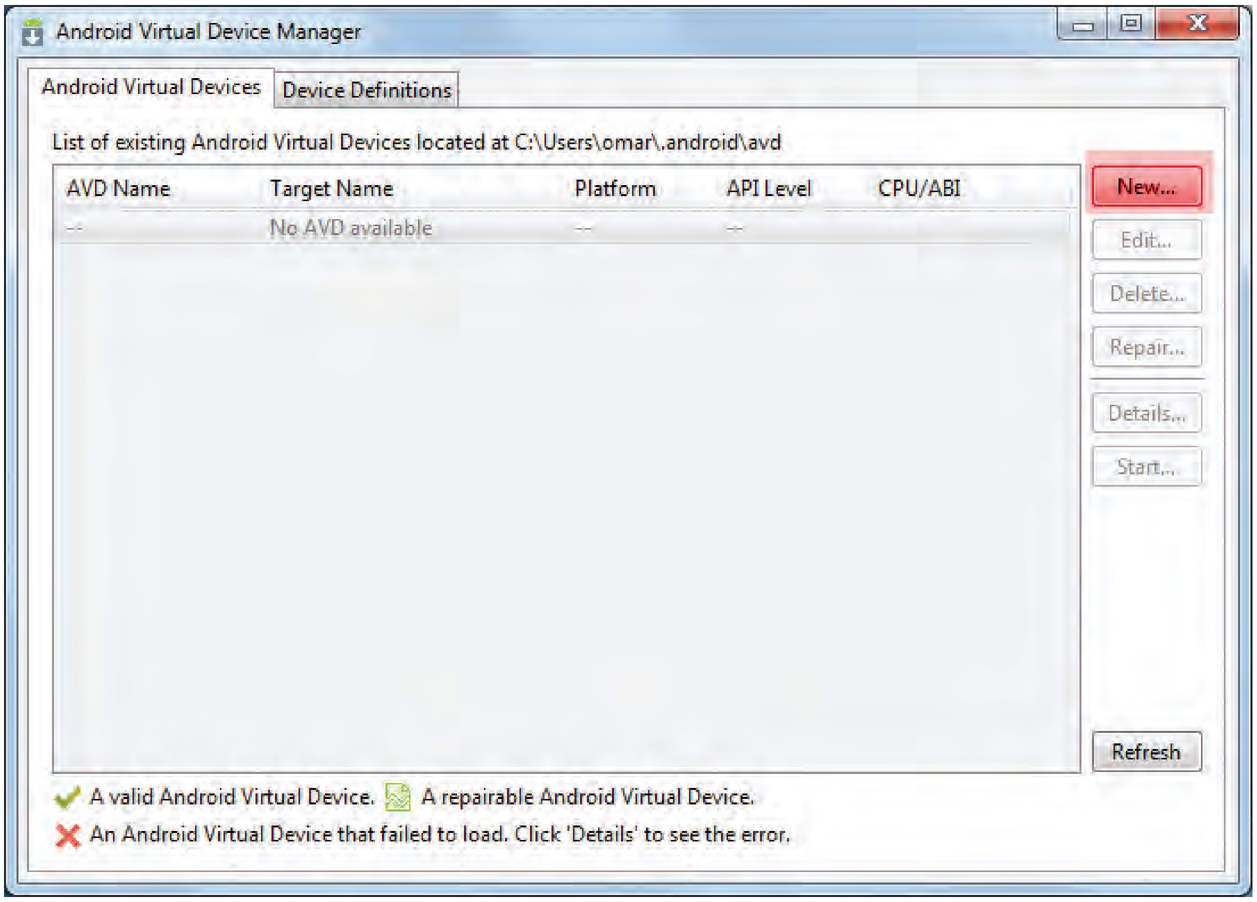
The key steps as outlined there are

1. Declare your application as "debuggable" in your Android Manifest.
2. Turn on "USB Debugging" on your device.
3. On the device, go to Settings > Applications > Development and enable USB debugging (on an Android 4.*x.x* device, the setting is located in Settings > Developer options).
4. Set up your system to detect your device.



Nar	API	Rev.	Status
Android SDK Tools		22.2.1	Installed
Android SDK Platform-tools		18.0.1	Installed
Android SDK Build-tools		18.1	Installed
Android SDK Build-tools		*18.0.1*	*Not installed*
Android SDK Build-tools		*17*	*Not installed*
Android 4.3 (API 18)			
Documentation for Android SDK	*18*	*1*	*Not installed*
SDK Platform	18	2	Installed
Samples for SDK	*18*	*1*	*Not installed*
ARM EABI v7a System Image	*18*	*2*	*Not installed*
Intel x86 Atom System Image	18	1	Installed
Google APIs	*18*	*3*	*Not installed*
Sources for Android SDK	*18*	*1*	*Not installed*
Android 4.2.2 (API 17)			
Android 4.1.2 (API 16)			
Android 4.0.3 (API 15)			
Android 4.0 (API 14)			
Android 3.2 (API 13)			
Android 3.1 (API 12)			
Android 3.0 (API 11)			
Android 2.3.3 (API 10)			
Android 2.2 (API 8)			
Android 2.1 (API 7)			
Android 1.6 (API 4)			
Android 1.5 (API 3)			
Extras			
Android Support Repository		*2*	*Not installed*
Android Support Library		18	Installed
Google AdMob Ads SDK		*11*	*Not installed*
Google Analytics App Tracking SDK		*3*	*Not installed*
[Deprecated] Google Cloud Messaging for Androi		*3*	*Not installed*
Google Play services		*12*	*Not installed*
Google Repository		*2*	*Not installed*
Google Play APK Expansion Library		*3*	*Not installed*
Google Play Billing Library		*4*	*Not installed*
Google Play Licensing Library		*2*	*Not installed*
Google USB Driver		8	Installed
Google Web Driver		*2*	*Not installed*
Intel x86 Emulator Accelerator (HAXM)		2	Update available: rev. 3

Figure 5: Android SDK Manager — Manage Android Virtual Devices
(Source: Intel Corporation, 2013)


Android Virtual Device Manager

List of existing Android Virtual Devices located at C:\Users\omar\.android\avd

AVD Name	Target Name	Platform	API Level	CPU/ABI
--	No AVD available	--	--	

✓ A valid Android Virtual Device. ▨ A repairable Android Virtual Device.
✗ An Android Virtual Device that failed to load. Click 'Details' to see the error.

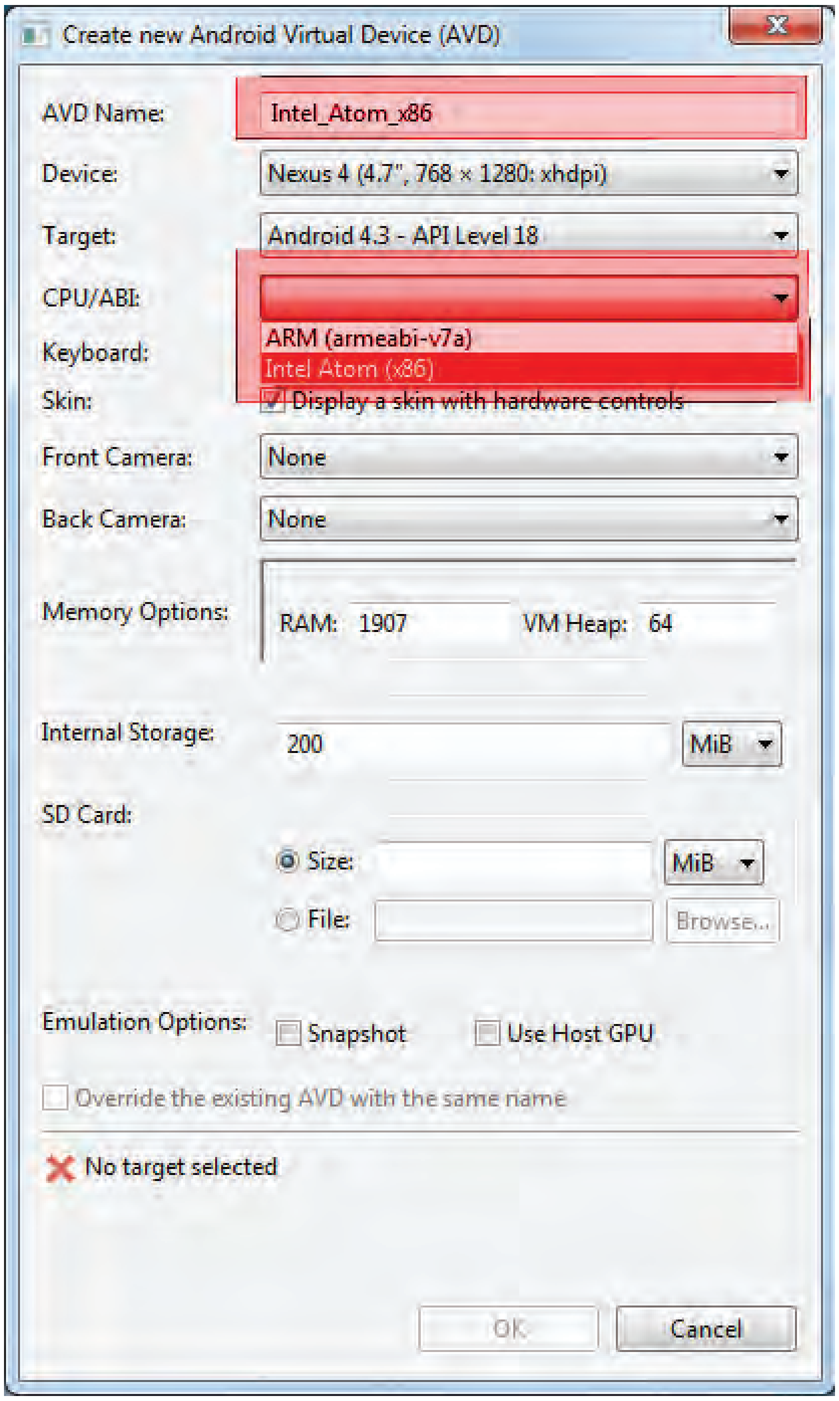
Figure 6: Adding new Android* Virtual Device
(Source: Intel Corporation, 2013)

- If you're developing on Windows, you need to install a USB driver for ADB—see prerequisites.
- If you're developing on Ubuntu* Linux, you need to add a *udev* rules file that contains a USB configuration for each type of device you want to use for development. In the rules file, each device manufacturer is identified by a unique vendor ID, as specified by the *ATTR{idVendor}* property. For a list of vendor IDs, see http://developer.android.com/tools/device.html#VendorIds.
- To set up device detection on Ubuntu Linux, log in as root and create this file:

  ```
  /etc/udev/rules.d/51-android.rules
  ```
- Use this format to add each vendor to the file:

  ```
  SUBSYSTEM=="usb", ATTR{idVendor}=="????",
  MODE="0666", GROUP="plugdev"
  ```

  The MODE assignment specifies read/write permissions, and GROUP defines which Unix group owns the device node.



Create new Android Virtual Device (AVD)

AVD Name: Intel_Atom_x86

Device: Nexus 4 (4.7", 768 × 1280: xhdpi)

Target: Android 4.3 - API Level 18

CPU/ABI:

ARM (armeabi-v7a)

Intel Atom (x86)

Keyboard:

Skin: Display a skin with hardware controls

Front Camera: None

Back Camera: None

Memory Options: RAM: 1907 VM Heap: 64

Internal Storage: 200 MiB

SD Card: Size: MiB

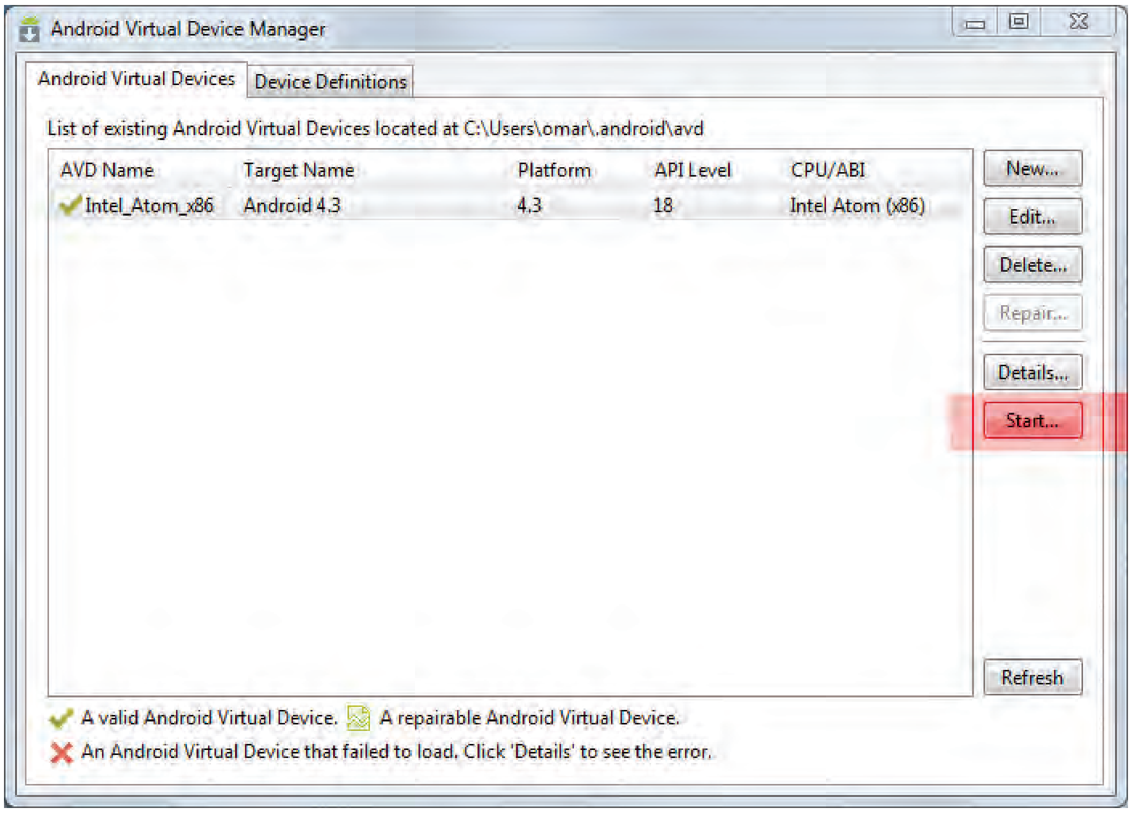
File: Browse...

Emulation Options: Snapshot Use Host GPU

Override the existing AVD with the same name

No target selected

Figure 7: The Intel Atom x86 System Image as a Virtual Device Target (Source: Intel Corporation, 2013)


Android Virtual Device Manager

Android Virtual Devices | Device Definitions

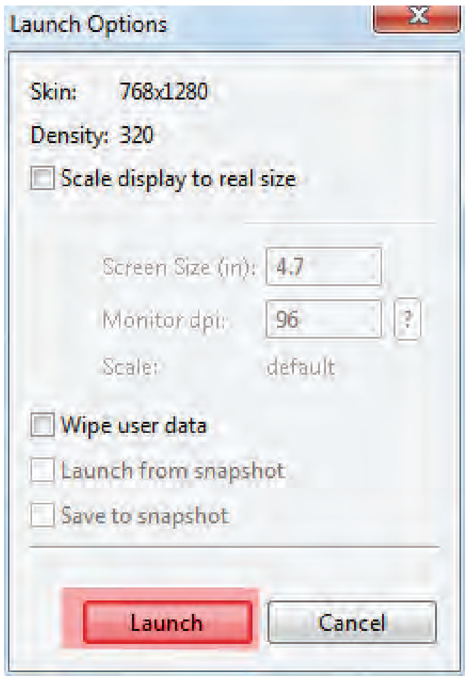
List of existing Android Virtual Devices located at C:\Users\omar\.android\avd

AVD Name	Target Name	Platform	API Level	CPU/ABI
✓ Intel_Atom_x86	Android 4.3	4.3	18	Intel Atom (x86)

✓ A valid Android Virtual Device. A repairable Android Virtual Device.

An Android Virtual Device that failed to load. Click 'Details' to see the error.

Figure 8: Starting Android* Virtual Device
(Source: Intel Corporation, 2013)


Launch Options

Skin: 768x1280

Density: 320

☐ Scale display to real size

Screen Size (in): 4.7

Monitor dpi: 96

Scale: default

☐ Wipe user data

☐ Launch from snapshot

☐ Save to snapshot

Figure 9: Virtual Device Launch Options
(Source: Intel Corporation, 2013)

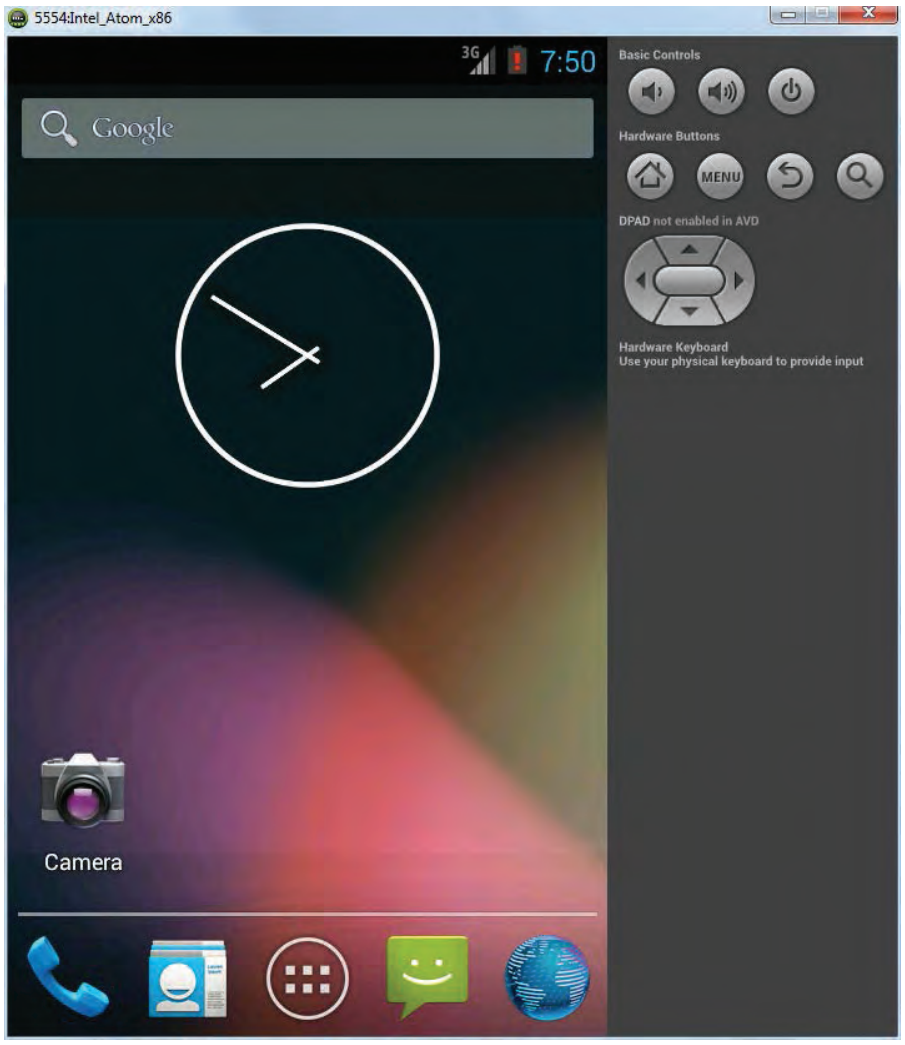


Figure 10: AVD* Emulation of Intel® Architecture based Android* Device (Source: Intel Corporation, 2013)

- Execute:

```
chmod a+r /etc/udev/rules.d/51-android.rules
```

- When plugged in over USB, you can verify that your device is connected by executing the command "adb devices" from your SDK platform-tools/ directory. If connected, you'll see the device name listed as a "device."

If everything is working you should be able to run the following command to see the attached device:

```
$ adb devices
* daemon not running. starting it now *
* daemon started successfully *
List of devices attached
0123456789ABCDEF  device
```

Note: To see which device name is assigned to this connection on the Linux development host you can look at *dmesg* to find the address of the "usb-storage: device found at <num>" and then do an "ls -l /dev/bus/usb/*" listing to find that number.

Add ADB to the PATH

An extra step that will make your development life easier is to add the Android SDK tools path to the system environment PATH. You will most likely end up executing the Android build tools from your project directory. For Windows, add these to the PATH in the environment variables. On Linux and Mac* OS X, append the path to Android tools in your shell configuration/profile script.

"An extra step that will make your development life easier is to add the Android SDK tools path to the system environment PATH."

ADB Host-Client Communication

Thus far we focused on installing ADB on the development host. In reality it is a client-server program that includes three components:

- A client, which runs on your development machine. You can invoke a client from a shell by issuing an ADB command. Other Android tools such as the ADT plugin and DDMS also create ADB clients.
- A server, which runs as a background process on your development machine. The server manages communication between the client and the ADB daemon running on an emulator or device.
- A daemon, which runs as a background process on each emulator or device instance.

When you start an ADB client, the client first checks whether there is an ADB server process already running. If there isn't, it starts the server process. When the server starts, it binds to local TCP port 5037 and listens for commands sent from ADB clients—all ADB clients use port 5037 to communicate with the ADB server.

The server then sets up connections to all running emulator/device instances. It locates emulator/device instances by scanning odd-numbered ports in the range 5555 to 5585, the range used by emulators/devices. Where the server finds an ADB daemon, it sets up a connection to that port. Note that each emulator/device instance acquires a pair of sequential ports—an even-numbered port for console connections and an odd-numbered port for ADB connections. For example:

```
Emulator 1, console: 5554
Emulator 1, adb: 5555
Emulator 2, console: 5556
Emulator 2, adb: 5557 ...
```

As shown, the emulator instance connected to ADB on port 5555 is the same as the instance whose console listens on port 5554.

Once the server has set up connections to all emulator instances, you can use ADB commands to control and access those instances. Because the server manages connections to emulator/device instances and handles commands from multiple ADB clients, you can control any emulator/device instance from any client (or from a script).

Key ADB Device Commands

The commands listed below help to transfer the debug application onto the target device or emulation from the command line. This can be very helpful, especially if no ssh terminal connection is available. In the rest of this article, we will be making use of the following ADB commands:

- *adb install* — push APK to device/emulator and install it
- *adb devices* — list all connected devices
- *adb pull* — copy file/directory from device
- *adb push* — copy file/directory to device
- *adb logcat* — view device log
- *adb forward* — forward socket connections
- *adb shell* — run remote shell interactively

More details on ADB setup and usage can be found at http://developer.android.com/guide/developing/tools/adb.html.

Intel® Hardware Accelerated Execution Manager

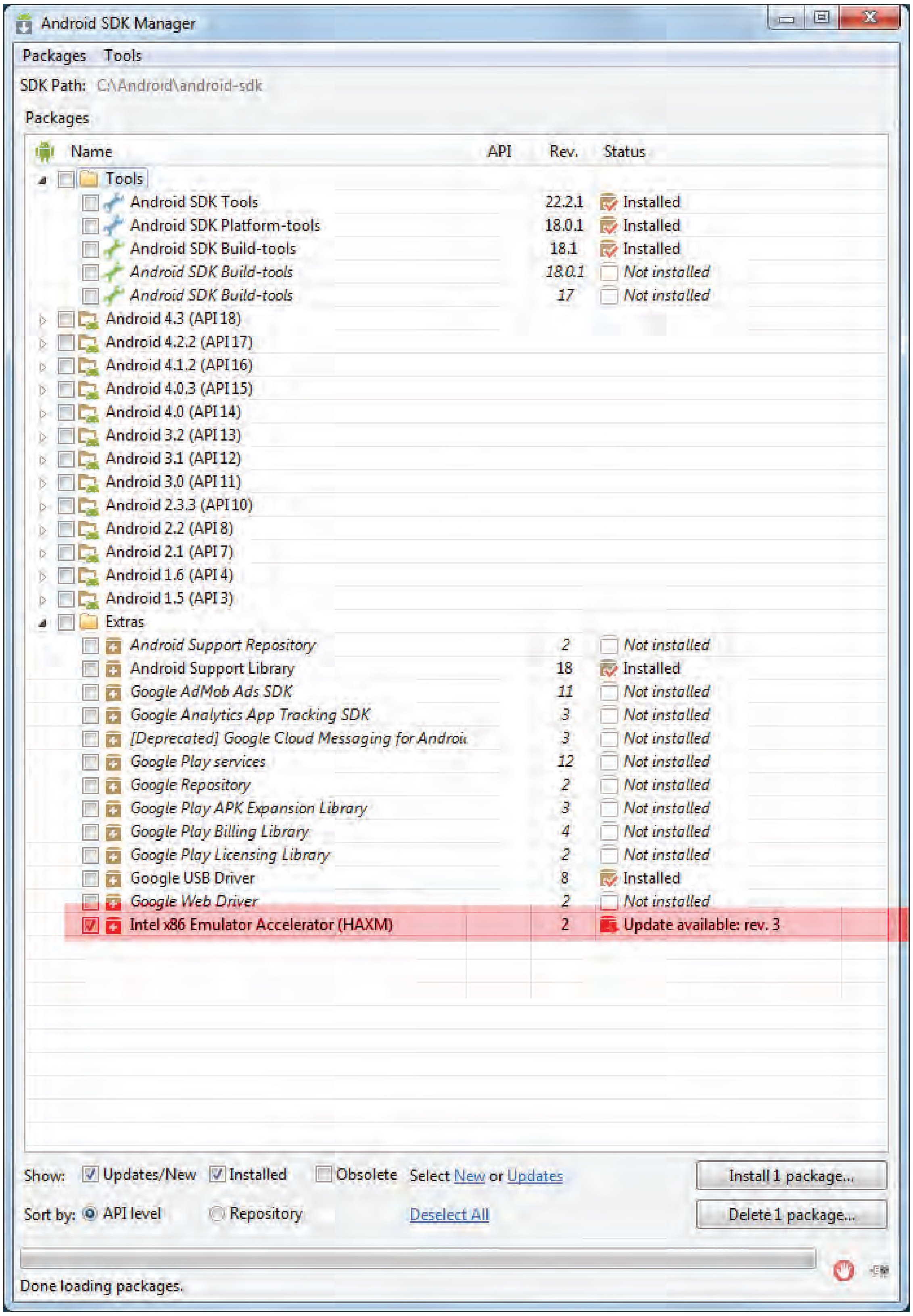
The Intel Hardware Accelerated Execution Manager (Intel® HAXM) is a hardware-assisted virtualization engine (hypervisor) that uses Intel Virtualization Technology (Intel® VT) to speed up Android app emulation on a host machine. In combination with Android x86 emulator images provided by Intel and the official Android SDK Manager, Intel HAXM allows for faster Android emulation on Intel VT–enabled systems.

"In combination with Android x86 emulator images provided by Intel and the official Android SDK Manager, Intel HAXM allows for faster Android emulation on Intel VT–enabled systems."

The x86 Android* emulator system image, since version 4.0.4 (Ice Cream Sandwich), enables you to run an emulation of Android on your development machine. In combination with the Android SDK, you can test out your Android applications on a virtual Android device based on Intel architecture taking full advantage of the underlying Intel architecture and Intel Virtualization Technology.

In order to install the emulator system image, you can use the Android SDK Manager. Intel HAXM can be installed through the Android SDK Manager (Figure 11). Intel HAXM requires the Android SDK to be installed (version 17 or higher). For more information, refer to the Android developer Web site (http://developer.android.com/sdk/).

Intel HAXM is available for Linux, Windows, and Mac OS X. Below are quick steps on how to install, enable KVM on Ubuntu host platform, and start the Intel Android x86 emulator with Intel hardware-assisted virtualization (hypervisor). Android Virtual Devices (AVD) taking advantage of Intel HAXM runs significantly faster and smoother than without the hypervisor.



SDK Path: C:\Android\android-sdk

Packages

Name	API	Rev.	Status
Tools			
Android SDK Tools		22.2.1	Installed
Android SDK Platform-tools		18.0.1	Installed
Android SDK Build-tools		18.1	Installed
Android SDK Build-tools		*18.0.1*	*Not installed*
Android SDK Build-tools		*17*	*Not installed*
Android 4.3 (API 18)			
Android 4.2.2 (API 17)			
Android 4.1.2 (API 16)			
Android 4.0.3 (API 15)			
Android 4.0 (API 14)			
Android 3.2 (API 13)			
Android 3.1 (API 12)			
Android 3.0 (API 11)			
Android 2.3.3 (API 10)			
Android 2.2 (API 8)			
Android 2.1 (API 7)			
Android 1.6 (API 4)			
Android 1.5 (API 3)			
Extras			
Android Support Repository		*2*	*Not installed*
Android Support Library		18	Installed
Google AdMob Ads SDK		*11*	*Not installed*
Google Analytics App Tracking SDK		*3*	*Not installed*
[Deprecated] Google Cloud Messaging for Androi		*3*	*Not installed*
Google Play services		*12*	*Not installed*
Google Repository		*2*	*Not installed*
Google Play APK Expansion Library		*3*	*Not installed*
Google Play Billing Library		*4*	*Not installed*
Google Play Licensing Library		*2*	*Not installed*
Google USB Driver		8	Installed
Google Web Driver		*2*	*Not installed*
✓ Intel x86 Emulator Accelerator (HAXM)		2	Update available: rev. 3

Show: [✓] Updates/New [✓] Installed [ ] Obsolete Select New or Updates

Sort by: (●) API level ( ) Repository Deselect All

Done loading packages.

Figure 11: Intel® Hardware Accelerated Execution Manager Download (Source: Intel Corporation, 2013)

KVM Installation

To see if your processor supports hardware virtualization,

1. You can review the output from this command:

   ```
   $ egrep -c '(vmx|svm)' /proc/cpuinfo
   ```

   If this command returns 0, your CPU doesn't support hardware virtualization.
2. Next install the CPU checker:

   ```
   $ sudo apt-get install cpu-checker
   ```
3. Now you can check to see whether your CPU supports KVM:

   ```
   $kvm-ok
   ```

If you see:

```
"INFO: Your CPU supports KVM extensions
INFO: /dev/kvm exists
KVM acceleration can be used"
```

you can run your virtual machine faster with the KVM extensions.
If you see:

```
"INFO: KVM is disabled by your BIOS
HINT: Enter your BIOS setup and enable
Virtualization Technology (VT),
and then hard poweroff/poweron your system
KVM acceleration can NOT be used"
```

you need to go to BIOS setup and enable Intel VT.

Using a 64-Bit Kernel

Running a 64-bit kernel on the host operating system is recommended but not required. To serve more than 2 GB of RAM for your VMs, you must use a 64-bit kernel. On a 32-bit kernel install, you'll be limited to 2 GB RAM at maximum for a given VM. Also, a 64-bit system can host both 32-bit and 64-bit guests. A 32-bit system can only host 32-bit guests.

1. To see if your processor is 64-bit, you can run this command:

   ```
   $ egrep -c ' lm ' /proc/cpuinfo
   ```

   If 0 is printed, it means that your CPU is not 64-bit. If 1 or higher, it is. Note: *lm* stands for Long Mode, which equates to a 64-bit CPU.
2. To see whether your running kernel is 64-bit, just issue the following command:

   ```
   $ uname -m
   ```

   The return value x86_64 indicates a running 64-bit kernel. If you see i386, i486, i586, or i686, you're running a 32-bit kernel.

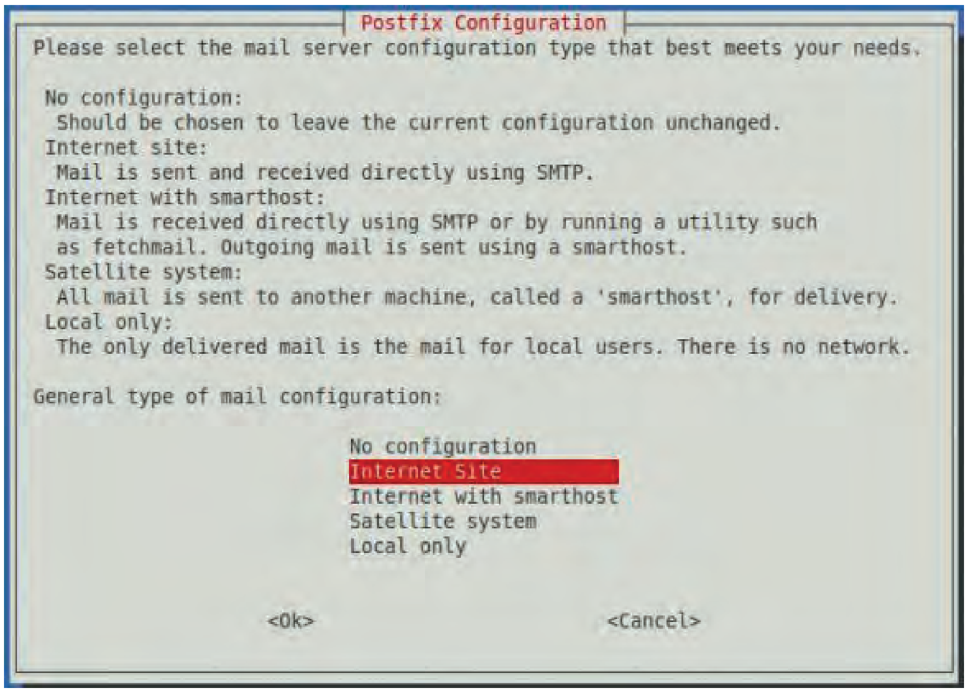
Install KVM

To install KVM, follow these steps.

1. For Ubuntu 10.04 or later:

   ```
   $ sudo apt-get install qemu-kvm libvirt-bin
   ubuntu-vm-builder bridge-utils
   ```

   You may ignore the Postfix Configuration request shown in Figure 12 by selecting *No configuration*.



```
                    Postfix Configuration
Please select the mail server configuration type that best meets your needs.

 No configuration:
  Should be chosen to leave the current configuration unchanged.
 Internet site:
  Mail is sent and received directly using SMTP.
 Internet with smarthost:
  Mail is received directly using SMTP or by running a utility such
  as fetchmail. Outgoing mail is sent using a smarthost.
 Satellite system:
  All mail is sent to another machine, called a 'smarthost', for delivery.
 Local only:
  The only delivered mail is the mail for local users. There is no network.

General type of mail configuration:

                           No configuration
                           Internet Site
                           Internet with smarthost
                           Satellite system
                           Local only

              <Ok>                           <Cancel>
```

Figure 12: KVM install Postfix configuration settings
(Source: Intel Corporation, 2012)

2. Next, add your <username> account to the group *kvm* and *libvirtd*:

   ```
   $ sudo adduser your_user_name kvm
   $ sudo adduser your_user_name libvirtd
   ```

   After the installation, you need to log in again so that your user account becomes an active member of the *kvm* and *libvirtd* user groups. The members of this group can run virtual machines.

3. To verify installation, you can test whether your install has been successful with the following command:

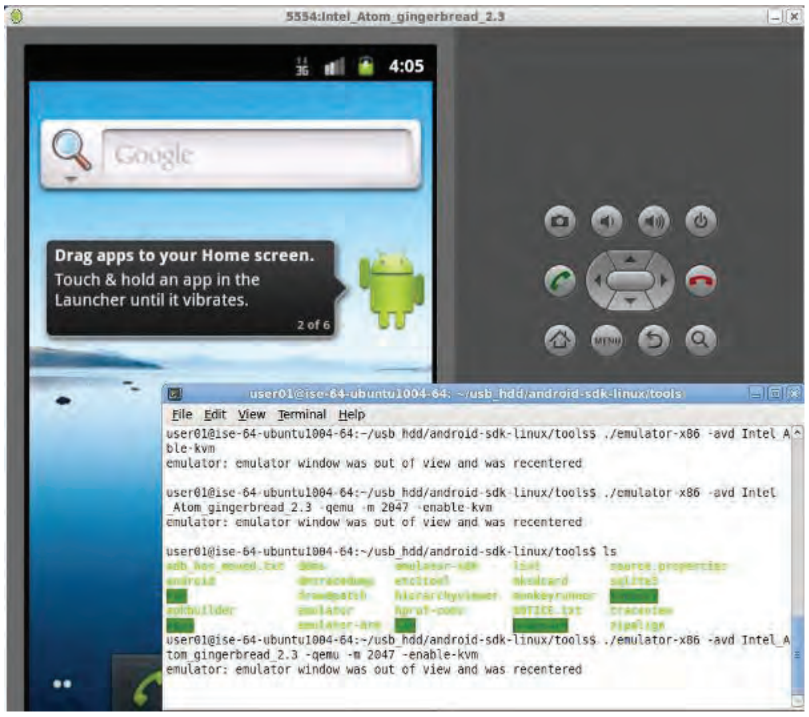
   ```
   $ sudo virsh -c qemu:///system list
   ```

Starting the Android Virtual Device

The Android for x86 Intel Emulator (Figure 13) can be started using the following command:

```
$ <SDK directory>/tools/emulator-x86 -avd Your_AVD_
Name -qemu -m 2047 -enable-kvm
```

with *Your_AVD_Name* being a name of your choice; *-qemu* provides the options to *qemu*, and *-m* specifies the amount of memory for the emulated Android (that is, guest). If you use too small a value for your memory, it is possible that performance will suffer because of frequent swapping activities.


5554:Intel_Atom_gingerbread_2.3
4:05
Google
Drag apps to your Home screen.
Touch & hold an app in the
Launcher until it vibrates.
2 of 6
MENU
user01@ise-64-ubuntu1004-64: ~/usb_hdd/android-sdk-linux/tools
File Edit View Terminal Help

```
user01@ise-64-ubuntu1004-64:~/usb_hdd/android-sdk-linux/tools$ ./emulator-x86 -avd Intel_A
ble-kvm
emulator: emulator window was out of view and was recentered

user01@ise-64-ubuntu1004-64:~/usb_hdd/android-sdk-linux/tools$ ./emulator-x86 -avd Intel
_Atom_gingerbread_2.3 -qemu -m 2047 -enable-kvm
emulator: emulator window was out of view and was recentered

user01@ise-64-ubuntu1004-64:~/usb_hdd/android-sdk-linux/tools$ ls
adb_has_moved.txt  ddms          emulator-x86     lint          source.properties
android            dmtracedump   etc1tool         mksdcard      sqlite3
ant                draw9patch    hierarchyviewer  monkeyrunner  [illegible]
apkbuilder         emulator      hprof-conv       NOTICE.txt    traceview
[illegible]        emulator-arm  [illegible]      proguard      zipalign
user01@ise-64-ubuntu1004-64:~/usb_hdd/android-sdk-linux/tools$ ./emulator-x86 -avd Intel_A
tom_gingerbread_2.3 -qemu -m 2047 -enable-kvm
emulator: emulator window was out of view and was recentered
```

Figure 13: AVD running Android in Intel® Architecture Emulation layers (Source: Intel Corporation, 2012)

Using AVD Manager in Eclipse to Launch a Virtual Device

The following steps are recommended by Google to start debugging an application using AVD from within the Eclipse IDE:

1. In Eclipse, click your Android project folder and then select Run > Run Configurations.
2. In the left panel of the Run Configurations dialog, select your Android project run configuration or create a new configuration.
3. Click the Target tab.
4. Select the Intel architecture–based AVD you created previously.
5. In the Additional Emulator Command Line Options field, enter:

   ```
   -qemu -m 2047 -enable-kvm
   ```
6. Run your Android project using this run configuration.

Debugging with GDB, the GNU Project Debugger

The Android NDK includes the GNU debugger (GDB), which allows you to start, pause, examine, and alter a program. On Android devices and more generally on embedded devices, GDB is configured in client/server mode. The program runs on a device as a server and a remote client. The developer's workstation connects to it and sends debugging commands similar to a local application. GDB itself is a command-line utility. Let us first look at its basic usage model before looking at the Eclipse CDT integration as well.

When debugging with GDB, gdbserver running on the device is used to handle debug communication, but you may still be using a an underlying USB-to-Ethernet dongle driver with ADB to handle to communication transport layer on which gdbserver communicates via TCP/IP with GDB running on the development host.

There is a gdbclient application that sets up the debug communication environment and launches gdbserver on the debuggee device.

```
usage: gdbclient EXECUTABLE :PORT [PROG_PATH]

EXECUTABLE  executable name (default app_process)
PORT        connection port (default :1234)
PROG_PATH   executable full path on target (ex /
            system/bin/mediaserver)
```

If PROG_PATH is set, gdclient tries to launch gdbserver and attach it to the running PROG_PATH.

To launch gdbserver explicitly, the following command can be used:

```
# gdbserver :1234 --attach 269
Attached; pid = 269
Listening on port 1234
```

The step-by-step debug session launch instructions below illustrate how ADB is still underlying the debug communication even if GDB and not ADT or DDMS are used for debug. Let us assume that port 1234 is being used.

Launch process:
`gdbserver :1234 /system/bin/executable`
or attach to an existing process:
`gdbserver :1234 --attach pid`
On your workstation, forward port 1234 to the device with adb:
`adb forward tcp:1234 tcp:1234`

Start a special version of gdb that lives in the "prebuilt" area of the source tree:

```
prebuilt/Linux/toolchain-eabi-4.x.x/bin/i686-
android-linux-gdb (for Linux)
prebuilt/darwin-x86/toolchain-eabi-4.x.x/bin/i686-
android-linux-gdb (for Darwin)
```

If you can't find either special version of GDB, run *find prebuilt –name i686-android-linux-gdbin* on your source tree to find and run the latest version. Make sure to use the copy of the executable in the symbols directory, not the primary Android directory, because the one in the primary directory has been stripped of its symbol information.

In GDB, tell GDB where to find the shared libraries that will get loaded:

```
set solib-absolute-prefix /absolute-source-path/
out/target/product/product-name/symbols
set solib-search-path /absolute-source-path/out/
target/product/product-name/symbols/system/lib
```

The path to your source tree is absolute-source-path. Make sure you specify the correct directories—GDB may not tell you if you make a mistake. Connect to the device by issuing the GDB command:

```
(gdb) target remote :1234
```

The *:1234* tells GDB to connect to the localhost port 1234, which is bridged to the device by ADB.

Now you can start debugging native C/C++ code running on Android with GDB the same way you are used to. If you also have Eclipse installed, which you probably do if you are using the Android SDK for Dalvik*/Java*-based application development, Eclipse and the GDB integration of Eclipse can be used directly to add breakpoints and inspect a program.

Indeed, Eclipse can insert breakpoints easily in Java as well as C/C++ source files by clicking in the left margin of the text editor. Java breakpoints work out of the box thanks to the ADT plug-in, which manages debugging through the Android Debug Bridge. This is not true for CDT, which is, of course, not Android-aware. Thus, inserting a breakpoint will do nothing unless we configure CDT to use the NDK's GDB, which itself needs to be bound to the native Android application in order to debug it. First, enable debugging mode in our application by following these steps:

1. An important thing to do, but something that is really easy to forget, is to activate the debugging flag in your Android project. This is done in the application manifest AndroidManifest.xml. Do not forget to use the appropriate SDK version for native code:

   ```
   <?xml version="1.0" encoding="utf-8"?> <manifest
   ...> <uses-sdk android:minSdkVersion="10"/>
   <application ... android:debuggable="true"> ...
   ```

"An important thing to do, but something that is really easy to forget, is to activate the debugging flag in your Android project."

2. Enabling the debug flag in the manifest automatically activates debug mode in native code. However, the APP_OPTIM flag also controls debug mode. If it has been manually set in Android.mk, then check that its value is set to debug (and not release) or simply remove it:

   ```
   APP_OPTIM := debug
   ```

3. Now let's configure the GDB client that will connect to the device. Recompile the project and plug your device in or launch the emulator. Run and leave your application. Ensure the application is loaded and its PID available. You can check it by listing processes using the following command (use Cygwin in Windows):

   ```
   $ adb shell ps |grep gl2jni
   ```

   One line should be returned:

   ```
   app_75 13178 1378 201108 68672 ffffffff 80118883
   S com.android.gl2jni
   ```

4. Open a terminal window and go to your project directory. Run the *ndk-gdb* command (located in the Android NDK folder, for example android-ndk-r8\):

   ```
   $ ndk-gdb
   ```

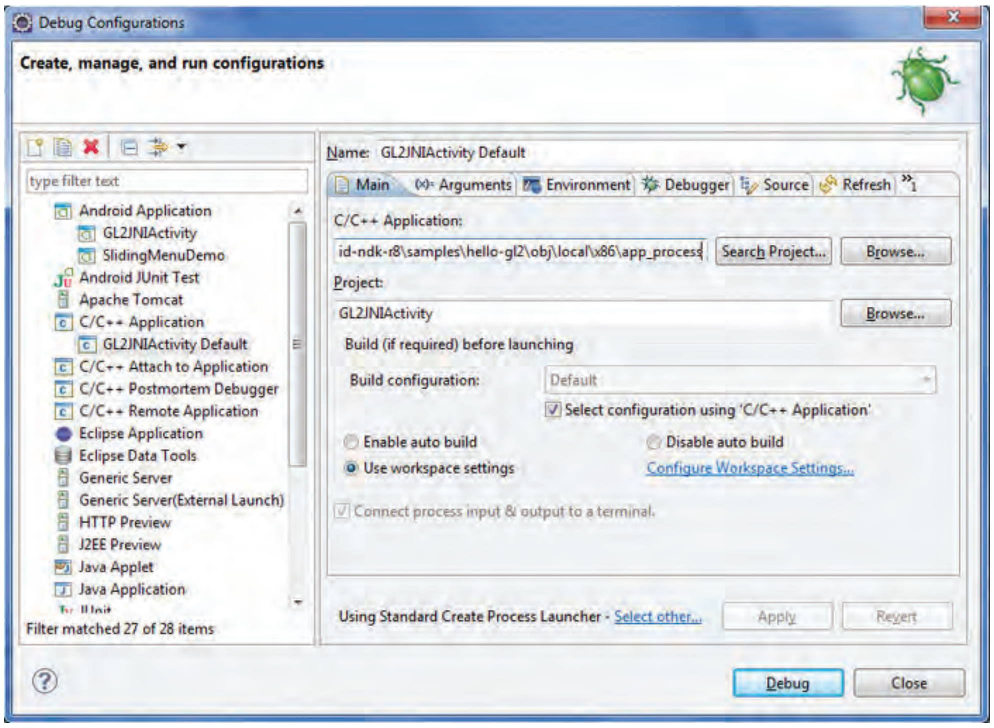
   This command should not return a message, but will create three files in the obj\local\x86 directory:

   - *gdb.setup*: This is a configuration file generated for GDB client.
   - *app_process*: This file is retrieved directly from your device. It is a system executable file, launched when the system starts up and forked to start a new application. GBD needs this reference file to find its marks. In some ways, it is the binary entry point of your app.
   - *libc.so*: This is also retrieved from your device. It is the Android standard C library (commonly referred to as bionic) used by GDB to keep track of all the native threads created during runtime.

5. In your project directory, copy *obj\local\x86\gdb.setup* and name it *gdb2.setup*. Open it and remove the following line that requests the GDB client to connect to the GDB server running on the device (to be performed by Eclipse itself):

   ```
   gdb) target remote :1234
   ```

6. In the Eclipse main menu, go to *Run* > *Debug Configurations...* and create a new Debug configuration in the C/C++ application item called *GL2JNIActivityDefault*. This configuration will start the GDB client on your computer and connect to the GDB Server running on the device.
7. In the Main tab (Figure 14), set the project to your own project directory and the C/C++application to point to *obj\local\ x86\app_process* using the Browse button (you can use either an absolute or a relative path).
8. Switch the launcher type to *Standard Create Process Launcher* (Figure 15) using the link *Select other...* at the bottom of the window.
9. Go to the debugger file and set the debugger type to *gdbserver*, set the GDB debugger to *android-ndk-r8\toolchains\x86-4.4.3\prebuilt\windows\bin\i686-android-linux-gdb.exe*. The GDB command file (Figure 16) needs to point to the *gdb2.setup* file located in *\obj\local\x86* (you can use either an absolute or a relative path).



Debug Configurations

Create, manage, and run configurations

type filter text

- Android Application
  - GL2JNIActivity
  - SlidingMenuDemo
- Android JUnit Test
- Apache Tomcat
- C/C++ Application
  - GL2JNIActivity Default
- C/C++ Attach to Application
- C/C++ Postmortem Debugger
- C/C++ Remote Application
- Eclipse Application
- Eclipse Data Tools
- Generic Server
- Generic Server(External Launch)
- HTTP Preview
- J2EE Preview
- Java Applet
- Java Application
- JUnit

Filter matched 27 of 28 items

Name: GL2JNIActivity Default

Main | Arguments | Environment | Debugger | Source | Refresh

C/C++ Application:
id-ndk-r8\samples\hello-gl2\obj\local\x86\app_process

Project:
GL2JNIActivity

Build (if required) before launching

Build configuration: Default

[✓] Select configuration using 'C/C++ Application'

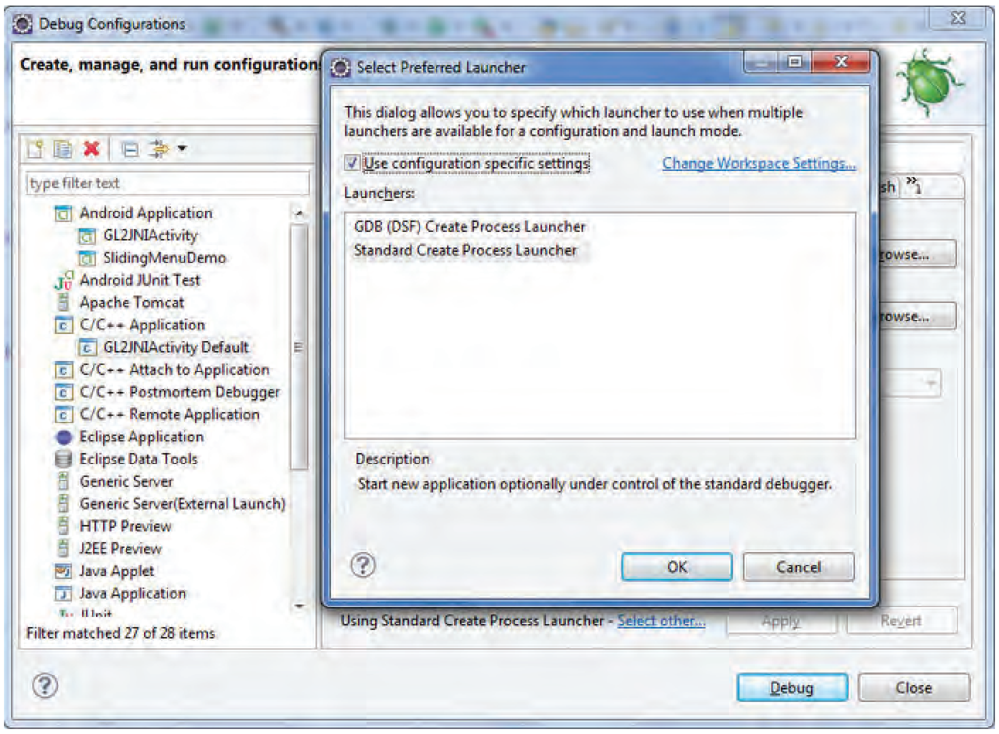
( ) Enable auto build   ( ) Disable auto build

(●) Use workspace settings   Configure Workspace Settings...

[✓] Connect process input & output to a terminal.

Using Standard Create Process Launcher - Select other...

Figure 14: Debug configurations for C/C++ application
(Source: Intel Corporation, 2012)



Select Preferred Launcher

This dialog allows you to specify which launcher to use when multiple launchers are available for a configuration and launch mode.

[✓] Use configuration specific settings   Change Workspace Settings...

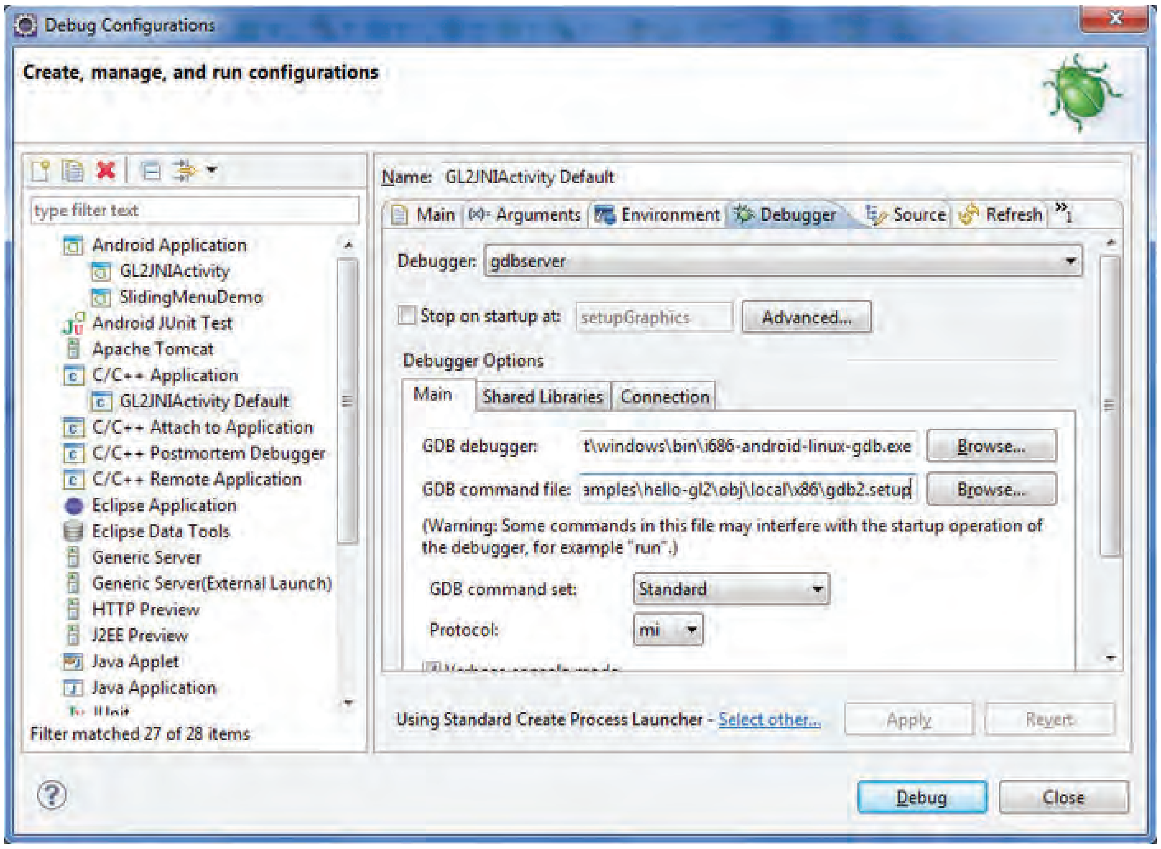
Launchers:

GDB (DSF) Create Process Launcher
Standard Create Process Launcher

Description
Start new application optionally under control of the standard debugger.

Using Standard Create Process Launcher - Select other...

Figure 15: Select Preferred Launcher
(Source: Intel Corporation, 2012)



Filter matched 27 of 28 items

Name: GL2JNIActivity Default

Debugger: gdbserver

Stop on startup at: setupGraphics

GDB debugger: t\windows\bin\i686-android-linux-gdb.exe

GDB command file: amples\hello-gl2\obj\local\x86\gdb2.setup

(Warning: Some commands in this file may interfere with the startup operation of the debugger, for example "run".)

GDB command set: Standard

Protocol: mi

Using Standard Create Process Launcher - Select other...

Figure 16: Debugger Options Panel
(Source: Intel Corporation, 2012)

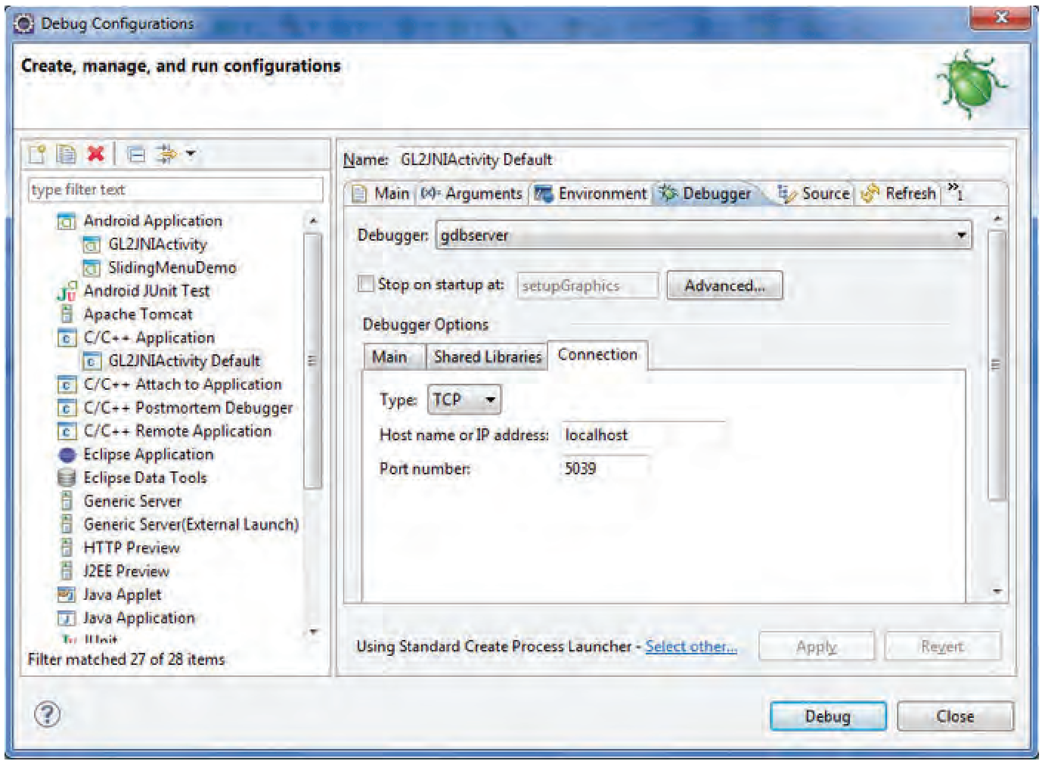
10. Go to the Connection tab (Figure 17) and set Type to *TCP*. Keep the default values for Host name or IP address and Port number (*localhost, 5039*).
11. Now, let's configure Eclipse to run the GDB server on the device. Make a copy of *android-ndk-r8\ndk-gdb* and open it with a text editor. Find the following line:

    ```
    $GDBCLIENT -x 'native_path $GDBSETUP'
    ```

    Comment it out because the GDB client is going to be run by Eclipse itself:

    ```
    #$GDBCLIENT -x 'native_path $GDBSETUP'
    ```

12. In the Eclipse main menu, go to *Run* > *External Tools* > *External Tools* > *Configurations* . . . (Figure 18), and create a new configuration *GL2JNIActivity_GDB*. This configuration will launch GDB server on the device.
13. On the Main tab, set the Location pointing to our modified ndk-gdb in android-ndk-r8. Set the working directory to your application directory location. Optionally, set the Arguments textbox:
    - verbose: To see in detail what happens in the Eclipse console.
    - force: To automatically kill any previous session.



Name: GL2JNIActivity Default

Debugger: gdbserver

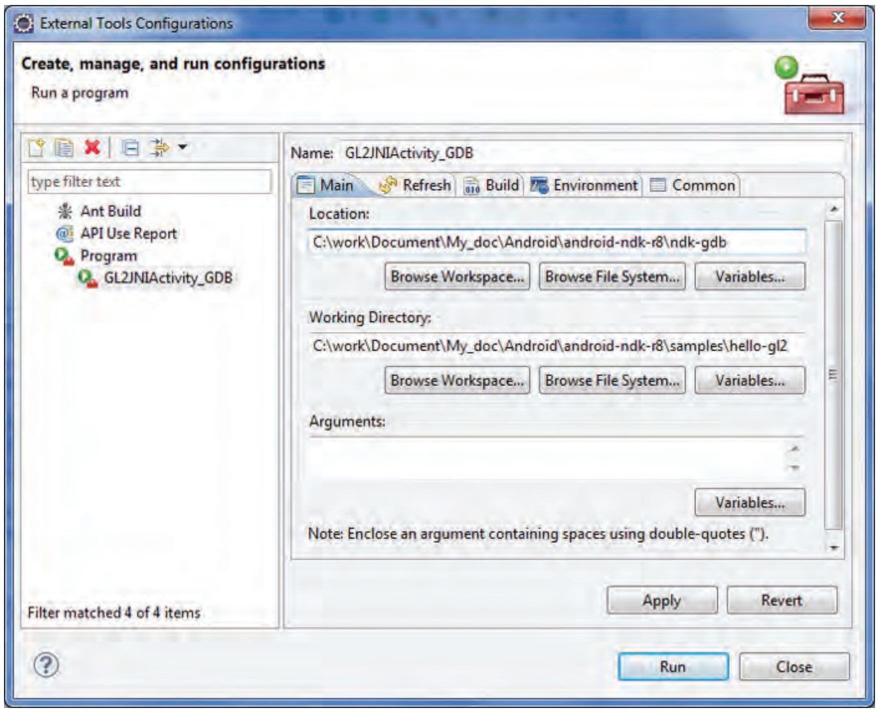
Stop on startup at: setupGraphics

Type: TCP

Host name or IP address: localhost

Port number: 5039

Figure 17: Connection setting on Debugger setting panel
(Source: Intel Corporation, 2012)



Name: GL2JNIActivity_GDB

Location:
C:\work\Document\My_doc\Android\android-ndk-r8\ndk-gdb

Working Directory:
C:\work\Document\My_doc\Android\android-ndk-r8\samples\hello-gl2

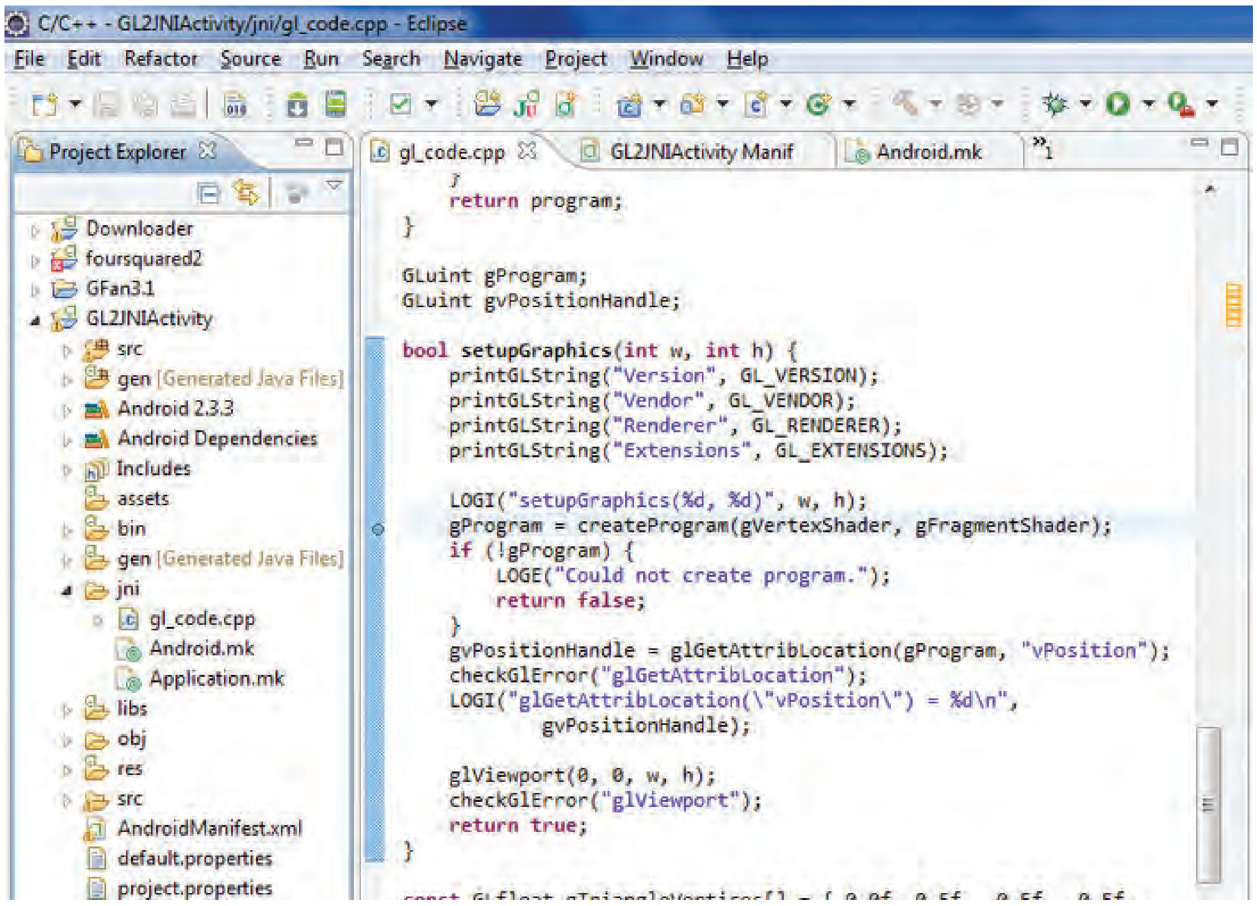
Arguments:

Note: Enclose an argument containing spaces using double-quotes (").

Figure 18: External Tools Configurations
(Source: Intel Corporation, 2012)

- start: To let the GDB server start the application instead of getting attached to the application after it has been started. This option is interesting if you debug native code only and not Java.

14. Now, launch your application as usual.
15. Once the application starts, you could launch ndk-gdb by console directly or launch the external tool configuration *GL2JNIActivity_GDB*, which is going to start the GDB server on the device. The GDB server receives debug commands sent by the remote GDB client and debugs your application locally.
16. Open *jni\gl_code.cpp* and set a breakpoint (Figure 19) in *setupGraphics* by double-clicking the left margin of the text editor (or right-clicking and selecting Toggle breakpoint).



```
    }
    return program;
}

GLuint gProgram;
GLuint gvPositionHandle;

bool setupGraphics(int w, int h) {
    printGLString("Version", GL_VERSION);
    printGLString("Vendor", GL_VENDOR);
    printGLString("Renderer", GL_RENDERER);
    printGLString("Extensions", GL_EXTENSIONS);

    LOGI("setupGraphics(%d, %d)", w, h);
    gProgram = createProgram(gVertexShader, gFragmentShader);
    if (!gProgram) {
        LOGE("Could not create program.");
        return false;
    }
    gvPositionHandle = glGetAttribLocation(gProgram, "vPosition");
    checkGlError("glGetAttribLocation");
    LOGI("glGetAttribLocation(\"vPosition\") = %d\n",
            gvPositionHandle);

    glViewport(0, 0, w, h);
    checkGlError("glViewport");
    return true;
}

const GLfloat gTriangleVertices[] = { 0.0f, 0.5f, -0.5f, -0.5f,
```

Figure 19: Setting breakpoints
(Source: Intel Corporation, 2012)

17. Finally, launch GL2JNIActivity Default C/C++ application configuration to start the GDB client. It relays debug commands from Eclipse CDT to the GDB server over a socket connection. From the developer's point of view, this is almost like debugging a local application.

The Intel® Graphics Performance Analyzer (Intel® GPA)

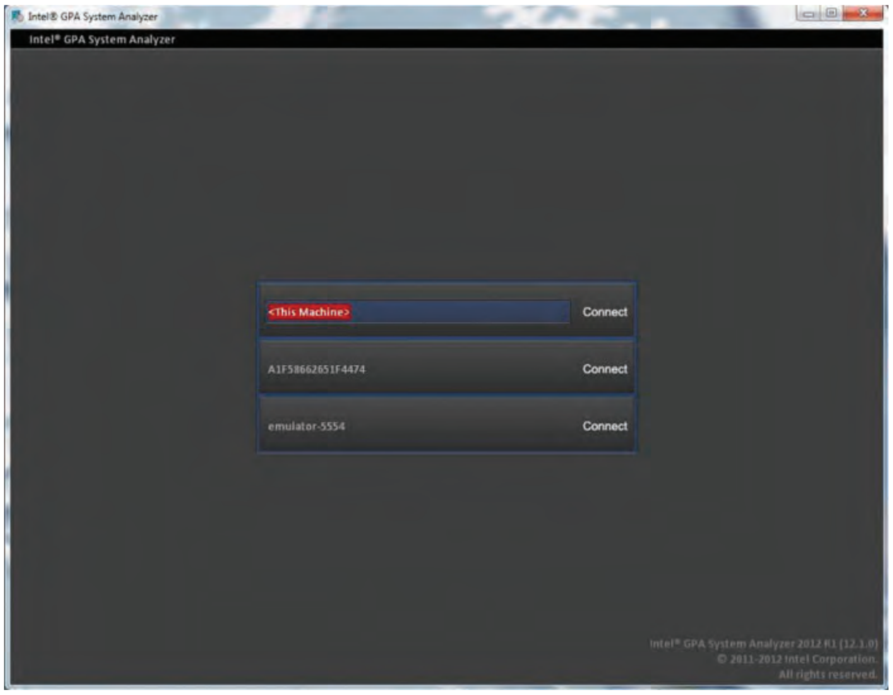
There are also some specific tools for debugging graphics performance. The Intel® GPA System Analyzer is one of the Intel® Graphics Performance Analyzers (Intel® GPA) with new support for Intel-based Android devices and is intended for application and driver engineers to optimize their OpenGL* ES workloads.

This section provides instructions on how to configure and use Intel GPA with your Android device over a USB connection. When connected to an Android device, the Intel GPA System Analyzer provides OpenGL ES API, CPU, and GPU performance metrics, and also provides multiple graphics pipeline state overrides to aid with your analysis of OpenGL ES application performance.

To use the Intel GPA System Analyzer on Android x86-based devices, you need to check the target machine and firmware/version from the document.

To start collecting metrics you need to install the Intel GPA System Analyzer on the client system and connect it to the target device:

1. Install Intel GPA 2012 on the Windows/Linux client machine.
2. Launch the Intel GPA System Analyzer.
3. Make sure that the Android device(s) is connected to the client system using a USB cable.
4. Wait up to 10 seconds while your client system is detecting the target device(s). Found devices appear in the dialog window. The list of the target devices refreshes every 5 to 6 seconds.
5. Find the device you want to connect to and click Connect (Figure 20). The Intel GPA System Analyzer copies required components to the target device and generates the list of installed applications. You can interrupt the connection process by clicking Stop.
6. Select the desired application from the list of available ones. The Application List (Figure 21) screen displays all user and system applications installed on the Android device.
7. The application is launched and you will see its data in the Intel GPA System Analyzer window.
8. To switch to a different application, click Back. Note that the running application will be forced to close.
9. To switch to a different target device, click Back. PowerVR graphics architecture consists of the following core modules that convert the submitted 3D application data into a rendered image: Tile Accelerator (TA), Image Synthesis Processor (ISP), and the Texture and Shading Processor (TSP). Intel GPA metrics in the "GPU" group correspond to one of these core modules, and the order of metrics in the Metrics List depends on the order of the core modules in the graphics pipeline (Figure 22).


Intel® GPA System Analyzer
Intel® GPA System Analyzer
<This Machine>
Connect
A1F58662651F4474
Connect
emulator-5554
Connect
Intel® GPA System Analyzer 2012 R1 (12.1.0)
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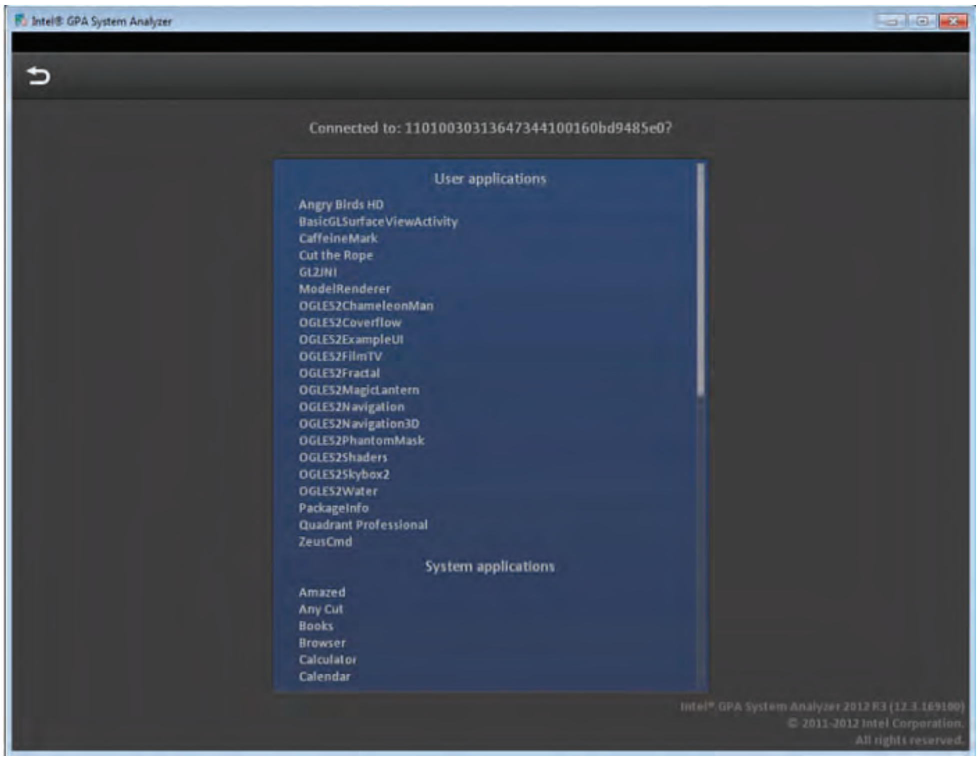
All rights reserved.

Figure 20: Select connected device
(Source: Intel Corporation, 2012)


Intel® GPA System Analyzer

Connected to: 1101003031364734410016 0bd9485e0?

User applications

Angry Birds HD
BasicGLSurfaceViewActivity
CaffeineMark
Cut the Rope
GL2JNI
ModelRenderer
OGLES2ChameleonMan
OGLES2Coverflow
OGLES2ExampleUI
OGLES2FilmTV
OGLES2Fractal
OGLES2MagicLantern
OGLES2Navigation
OGLES2Navigation3D
OGLES2PhantomMask
OGLES2Shaders
OGLES2Skybox2
OGLES2Water
PackageInfo
Quadrant Professional
ZeusCmd

System applications

Amazed
Any Cut
Books
Browser
Calculator
Calendar

Intel® GPA System Analyzer 2012 R3 (12.3.169100)
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Figure 21: Applications list
(Source: Intel Corporation, 2012)

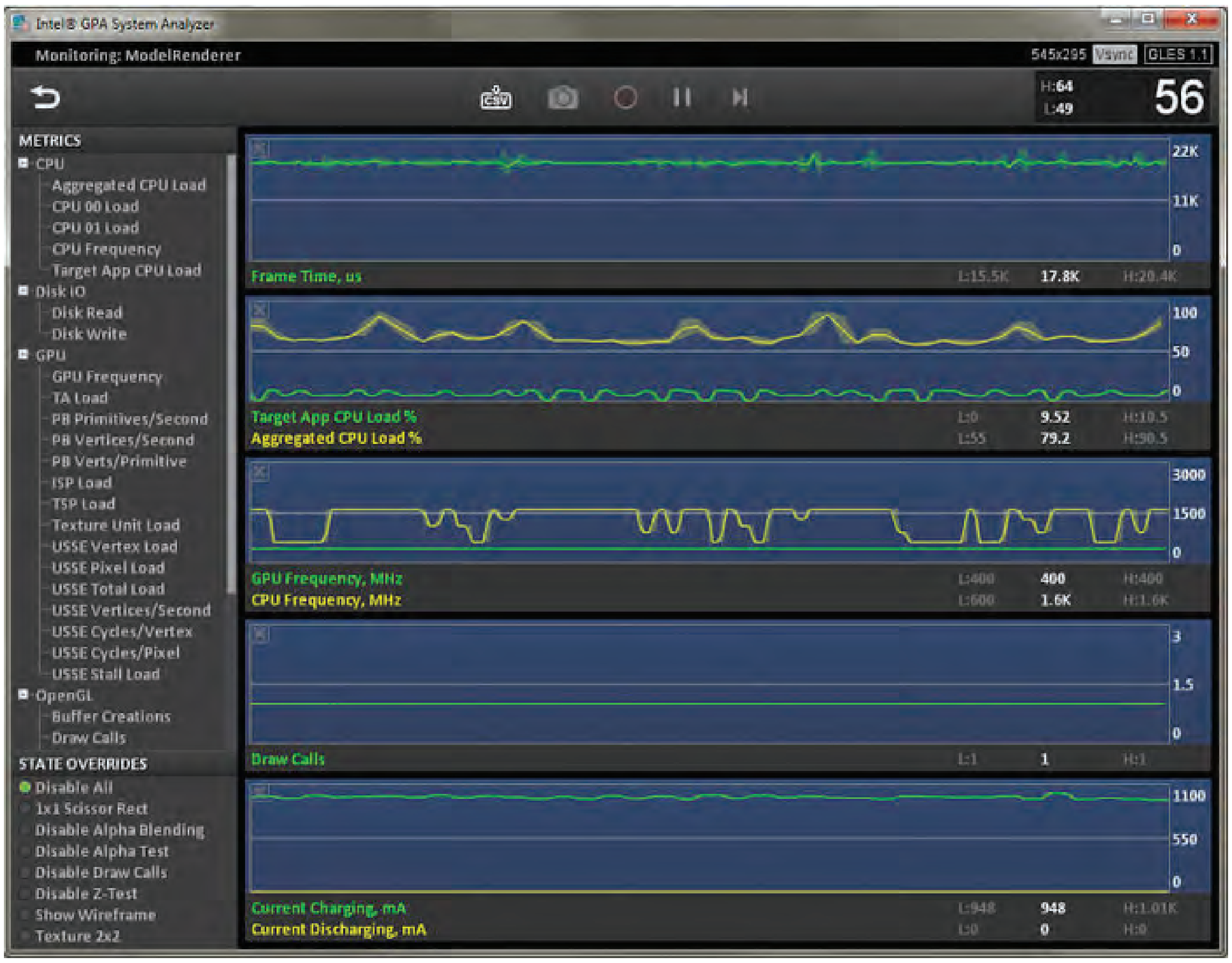


Figure 22: Intel® GPA System Analyzer window
(Source: Intel Corporation, 2012)

System Debug of Android OS Running on an Intel® Atom™ Processor

Until now we focused on developing and debugging applications, whether they use Android's Java runtime alone or run natively as x86 Intel architecture binaries and shared objects.

For the system integrator and device manufacturer it may however very well be necessary to work on the device driver and system software stack layer as well. This is especially true if additional platform-specific peripheral device support needs to be implemented or if the first operating system port to a new device based on the Intel® Atom™ processor is undertaken.

In the following sections we look at IEEE 1149.1 (JTAG) standard–based debug solutions for this purpose as well as architectural differences between ARM architecture and Intel architecture that may impact system-level debugging.

JTAG Debugging

For true firmware, OS level system and device driver debug, using a JTAG interface is the most commonly used method in the embedded intelligent systems world. The Joint Test Action Group (JTAG) IEEE 1149.1 standard defines a "Standard Test Access Port and Boundary-Scan Architecture for test access ports used for testing printed circuit boards." This standard is commonly simply referred to as the JTAG debug interface. From its beginnings as a standard for circuit board testing it has developed into the de facto interface standard for OS independent and OS system level platform debug.

More background information on JTAG and its usage in modern system software stack debugging is available in an article by Randy Johnson and Stewart Christie.[6]

From the OEM's perspective and that of their partner application and driver developers, understanding the interaction between the driver and software stack components running on the different parts of the system-on-chip (SoC) integrated intelligent system or smartphone form factor device is critical for determining platform stability. From a silicon validator's perspective, the low level software stack provides the test environment that exposes the kind of stress factors the platform will be exposed to in real-world use cases. In short, modern SoCs require understanding the complete package and its complex real-world interactions, not just positive unit test results for individual hardware components. This is the level of insight a JTAG-based system software debug approach can provide. This can be achieved by merging the in-depth hardware awareness JTAG inherently provides with the ability to export state information of the Android OS running on the target.

"…for device driver debug, it is important to understand both the exact state of the peripheral device on the chipset and the interaction of the device driver with the OS layer and the rest of the software stack."

Especially for device driver debug, it is important to understand both the exact state of the peripheral device on the chipset and the interaction of the device driver with the OS layer and the rest of the software stack.

If you are looking at Android from the perspective of system debugging, looking at device drivers and the OS kernel, it is really just a specialized branch of Linux. Thus it can be treated like any 2.6.3x or higher Linux.

The Intel® Atom™ Processor Z2460 supports IEEE-1149.1 and IEEE-1149.7 (JTAG) Boundary Scan and MPI Parallel Trace Interface (PTI) as well as Branch Trace Storage (BTS) based instruction tracing through Intel's JTAG-compliant eXtended Debug Port (XDP).

Various JTAG vendors offer system debug solutions with Android support including:

- Wind River (http://www.windriver.com/products/JTAG-debugging/)
- Lauterbach (http://www.lauterbach.com)
- Intel (http://software.intel.com/en-us/articles/embedded-development-tools/)

Android OS Debugging

What complicates debugging an Android-based platform is that Android usually very aggressively takes advantage of low power idle states and sleep states to optimize for power consumption. Thus the real challenge becomes debugging through low power states and

- either maintaining JTAG functionality through some of the low power states
- or, where this is not possible, reattaching JTAG as soon as the chipset power domain for JTAG is re-enabled.

"…the real challenge becomes debugging through low power states…"

Many OS level issues on these types of platforms tend to center around power mode changes and sleep/wakeup sequences.

A system debugger, whether based on a debug agent or a JTAG device interface, is a very useful tool to help satisfy several of the key objectives of OS development.

The debugger can be used to validate the boot process and to analyze and correct stability issues like runtime errors, segmentation faults, or services not being started correctly during boot.

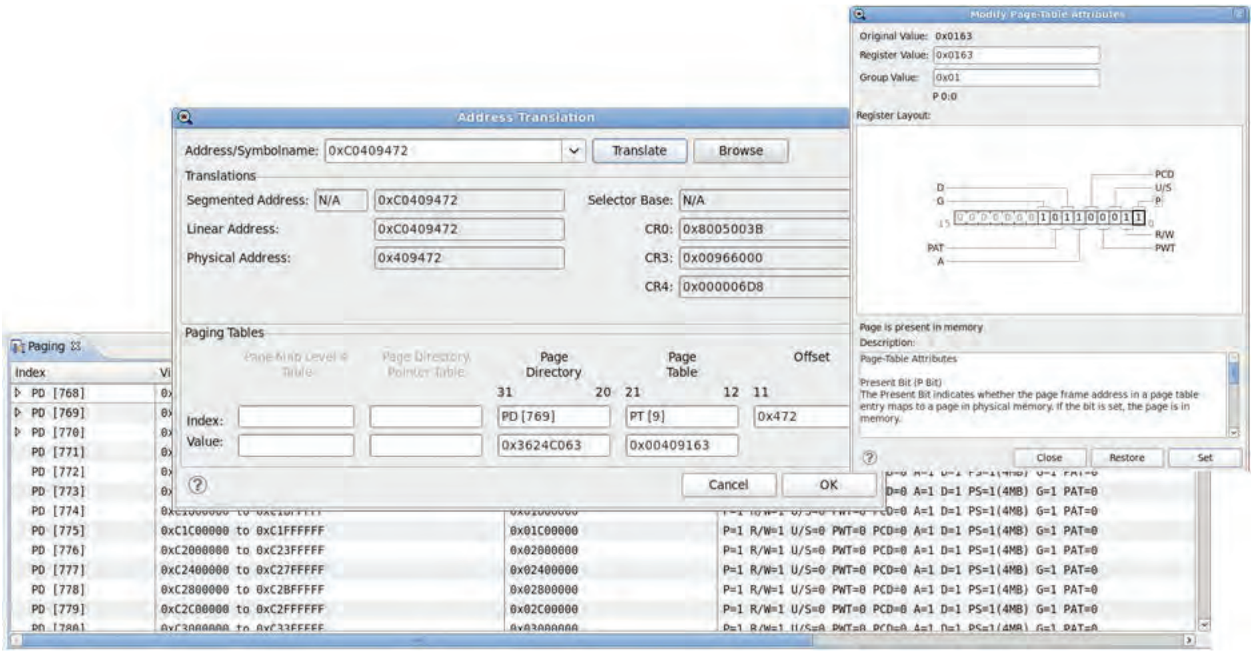
It can also be used to identify and correct OS configuration issues by providing detailed access and representations of page tables, descriptor tables, and also instruction trace. The combination of instruction trace and memory table access can be a very powerful tool to identify the root causes for stack overflow, memory leak, or even data abort scenarios.

"The combination of instruction trace and memory table access can be a very powerful tool to identify the root causes for stack overflow, memory leak, or even data abort scenarios."

Figure 23 shows the detailed access to page translation attributes and descriptor tables as provided by the Intel® JTAG Debugger. With the high level of flexibility that is available on x86 in defining the depth of translation tables and granularity of the addressed memory blocks, this level of easy access and visibility of the memory layout becomes even more important for system development on the OS level.

This highlights two key differences between developing and configuring the Android OS software stack on Intel architecture and many other architectures. The selector base and offset addressing model, combined with the local descriptor table (LDT) and global descriptor table (GDT) allow for deep, multilayered address translation from physical to virtual memory with variable address chunk granularity as well. This is a powerful capability for custom memory configuration in a compartmentalized environment with protected isolated memory spaces. If used incorrectly it can, however, also increase memory access times. Thus the good visibility of memory page translation is desirable.

One other difference between Intel architecture and others is the handling of system interrupts. On ARM, for instance, you have a predefined set of hardware interrupts in the reserved address space from 0×0 through



Address/Symbolname: 0xC0409472

Segmented Address: N/A 0xC0409472
Linear Address: 0xC0409472
Physical Address: 0x409472

Selector Base: N/A
CR0: 0x8005003B
CR3: 0x00966000
CR4: 0x000006D8

Index: PD [769] PT [9] 0x472
Value: 0x3624C063 0x00409163

Original Value: 0x0163
Register Value: 0x0163
Group Value: 0x01
P 0:0

0 0 0 0 0 0 0 1 0 1 1 0 0 0 1 1

Page is present in memory
Description:
Page-Table Attributes

Present Bit (P Bit)
The Present Bit indicates whether the page frame address in a page table entry maps to a page in physical memory. If the bit is set, the page is in memory.

```
Index      Vi
PD [768]   0x
PD [769]   0x
PD [770]   0x
PD [771]   0x
PD [772]   0x
PD [773]   0x                                                    D=0 A=1 D=1 PS=1(4MB) G=1 PAT=0
PD [774]                                                         D=0 A=1 D=1 PS=1(4MB) G=1 PAT=0
PD [775]   0xC1C00000 to 0xC1FFFFFF   0x01C00000   P=1 R/W=1 U/S=0 PWT=0 PCD=0 A=1 D=1 PS=1(4MB) G=1 PAT=0
PD [776]   0xC2000000 to 0xC23FFFFF   0x02000000   P=1 R/W=1 U/S=0 PWT=0 PCD=0 A=1 D=1 PS=1(4MB) G=1 PAT=0
PD [777]   0xC2400000 to 0xC27FFFFF   0x02400000   P=1 R/W=1 U/S=0 PWT=0 PCD=0 A=1 D=1 PS=1(4MB) G=1 PAT=0
PD [778]   0xC2800000 to 0xC2BFFFFF   0x02800000   P=1 R/W=1 U/S=0 PWT=0 PCD=0 A=1 D=1 PS=1(4MB) G=1 PAT=0
PD [779]   0xC2C00000 to 0xC2FFFFFF   0x02C00000   P=1 R/W=1 U/S=0 PWT=0 PCD=0 A=1 D=1 PS=1(4MB) G=1 PAT=0
PD [780]   0xC3000000 to 0xC33FFFFF   0x03000000   P=1 R/W=1 U/S=0 PWT=0 PCD=0 A=1 D=1 PS=1(4MB) G=1 PAT=0
```

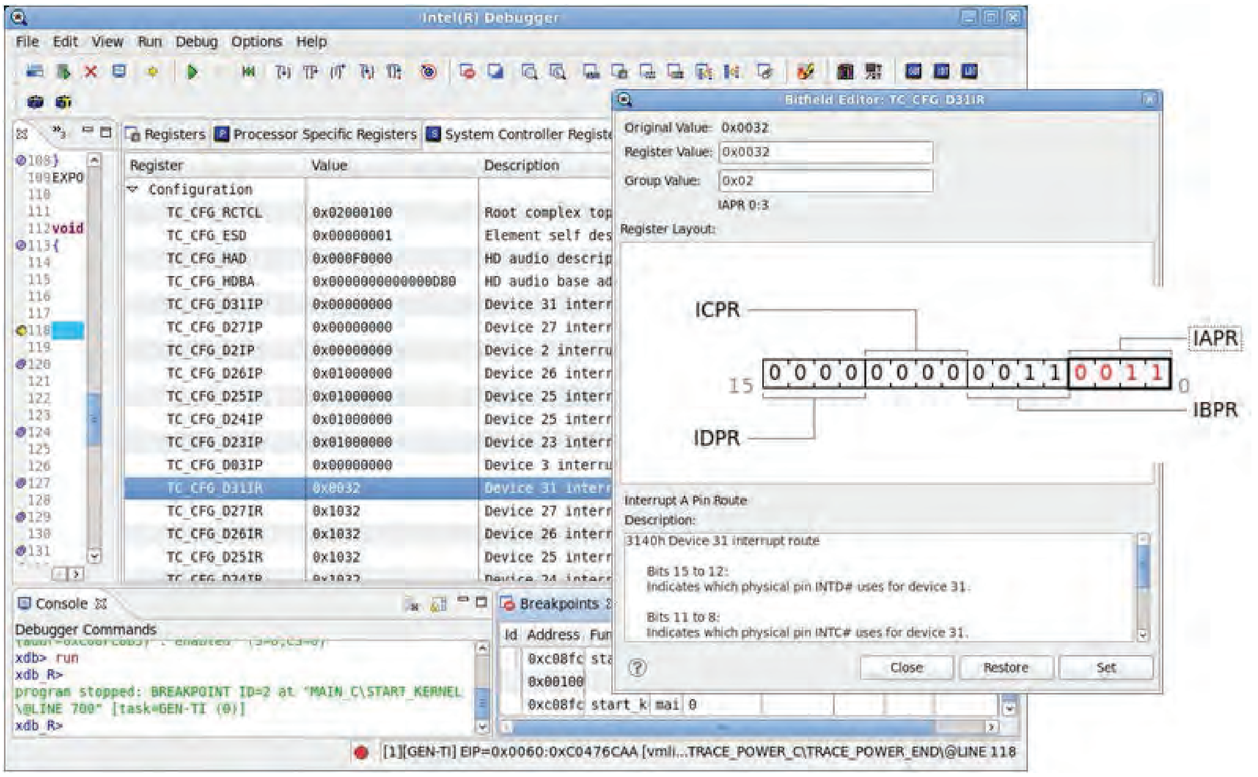
Figure 23: Example of debugger views for memory configuration
(Source: Intel Corporation, 2012)

0×20. These locations then contain jump instructions to the interrupt handler. On Intel architecture a dedicated hardware interrupt controller is employed. The hardware interrupts are not accessed directly through memory space, but by accessing the Intel® 8529 interrupt controller. The advantage of this approach is that the interrupt handler already allows for direct handling for I/O interrupts for attached devices. In architectures that don't use a dedicated interrupt controller, usually the IRQ interrupt has be overloaded with a more complex interrupt handler routine to accomplish this.

Device Driver Debugging

A good JTAG debugger solution for OS level debug should furthermore provide visibility of kernel threads and active kernel modules along with other information exported by the kernel. To allow for debugging dynamically loaded services and device drivers, a kernel patch or a kernel module that exports the memory location of a driver's initialization method and destruction method may be used.

Especially for system configuration and device driver debugging, it is also important to be able to directly access and check the contents of device configuration registers. The concept of bitfield editors as shown in Figure 24 can be very useful for this. A bitfield editor is a bitwise visualization of SoC device registers that allows monitoring changes to a device state in real time while the associated device driver is interacting with it.


Intel(R) Debugger
File Edit View Run Debug Options Help
Registers
Processor Specific Registers
System Controller Registe
Bitfield Editor: TC_CFG_D31IR
ICPR
IAPR
IDPR
IBPR
15
0
Close
Restore
Set
Console
Breakpoints

Register	Value	Description
Configuration		
TC_CFG_RCTCL	0x02000100	Root complex top
TC_CFG_ESD	0x00000001	Element self des
TC_CFG_HAD	0x000F0000	HD audio descrip
TC_CFG_HDBA	0x0000000000000D80	HD audio base ad
TC_CFG_D31IP	0x00000000	Device 31 interr
TC_CFG_D27IP	0x00000000	Device 27 interr
TC_CFG_D2IP	0x00000000	Device 2 interru
TC_CFG_D26IP	0x01000000	Device 26 interr
TC_CFG_D25IP	0x01000000	Device 25 interr
TC_CFG_D24IP	0x01000000	Device 25 interr
TC_CFG_D23IP	0x01000000	Device 23 interr
TC_CFG_D03IP	0x00000000	Device 3 interru
TC_CFG_D31IR	0x0032	Device 31 interr
TC_CFG_D27IR	0x1032	Device 27 interr
TC_CFG_D26IR	0x1032	Device 26 interr
TC_CFG_D25IR	0x1032	Device 25 interr

Original Value: 0x0032
Register Value: 0x0032
Group Value: 0x02
IAPR 0:3
Register Layout:

```
0 0 0 0 | 0 0 0 0 | 0 0 1 1 | 0 0 1 1
```

Interrupt A Pin Route
Description:
3140h Device 31 interrupt route

Bits 15 to 12:
Indicates which physical pin INTD# uses for device 31.

Bits 11 to 8:
Indicates which physical pin INTC# uses for device 31.

Debugger Commands

```
xdb> run
xdb_R>
program stopped: BREAKPOINT ID=2 at "MAIN_C\START_KERNEL
\@LINE 700" [task=GEN-TI (0)]
xdb_R>
```

Id	Address	Fun		
	0xc08fc	sta		
	0x00100			
	0xc08fc	start_k	mai	0

[1][GEN-TI] EIP=0x0060:0xC0476CAA [vmli...TRACE_POWER_C\TRACE_POWER_END\@LINE 118

Figure 24: Device Register Bitfield Editor View
(Source: Intel Corporation, 2012)

Analyzing the code after the Android compressed zImage kernel image has been unpacked into memory is possible by simply releasing run control in the debugger until *start_kernel* is reached. This implies of course that the *vmlinux* file that contains the kernel symbol information has been loaded. At this point the use of software breakpoints is possible. Prior to this point in the boot process, only breakpoint-register–based hardware breakpoints should be used, to avoid the debugger attempting to write breakpoint instructions into uninitialized memory. The operating system is then successfully booted once the idle loop *mwait_idle* has been reached.

Additionally, if your debug solution provides access to Branch Trace Store (BTS) based instruction trace, this capability can, in conjunction with all the regular run control features of a JTAG Debugger, be used to force execution stop at an exception and analyze the execution flow in reverse identifying the root cause for runtime issues.

Hardware Breakpoints

Just as on ARM architecture, processors based on Intel architecture support breakpoint instructions for software breakpoints as well as hardware breakpoints for data as well as code. On ARM architecture you usually have a set of dedicated registers for breakpoints and data breakpoints (*watchpoints*).

The common implementation tends to provide two of each. When these registers contain a value, the processor checks against accesses to the set memory address by the program counter register or a memory read/write. As soon as the access happens, execution is halted. This is different from software breakpoints in that their execution is halted as soon as a breakpoint instruction is encountered. Since the breakpoint instruction replaces the assembly instruction that would normally be at a given memory address, the execution effectively halts before the instruction that normally would be at the breakpoint location is executed.

"The implementation of hardware breakpoints on Intel architecture is very similar to that on ARM, although it is a bit more flexible."

The implementation of hardware breakpoints on Intel architecture is very similar to that on ARM, although it is a bit more flexible.

On all Intel Atom processor cores, there are four DR registers that store addresses, which are compared to the fetched address on the memory bus before (sometimes after) a memory fetch.

You can use all four of these registers to provide addresses that trigger any of the following debug run control events:

- 00—break on instruction execution
- 01—break on data write only
- 10—Undefined OR (if architecture allows it) break on I/O reads or writes
- 11—break on data reads or writes but not instruction fetch

Thus, all four hardware breakpoints can be used to be either breakpoints or watchpoints. Watchpoints can be either Write-Only or Read-Write (or I/O) watchpoints.

Cross-Debug: Intel® Atom™ Processor and ARM Architecture

Many developers targeting the Intel Atom processor may have experience developing primarily for RISC architectures with fixed instruction length. MIPS and ARM are prime examples of ISAs with a fixed length. In general, the cross-debug usage model between an Intel Atom processor and ARM architecture processor is very similar. Many of the conceptual debug methods and issues are the same.

"In general, the cross-debug usage model between an Intel Atom processor and ARM architecture processor is very similar."

Developing on a development host based on Intel architecture for an Intel Atom processor target does, however, offer two big advantages, especially when the embedded operating system of choice is a derivative of one of the common standard operating systems like Linux or Windows. The first advantage is the rich ecosystem of performance, power analysis, and debug tools available for the broader software development market on Intel architecture. The second advantage is that debugging functional correctness and multithreading behavior of the application may be accomplished locally. This advantage is discussed later in the article.

There are a few differences between Intel Atom processors and ARM processors that developers should know. These differences are summarized in the next two subsections.

Variable Length Instructions

The IA-32 and Intel 64 instruction sets have variable instruction length. The impact on the debugger is that it cannot just inspect the code in fixed 32-bit intervals, but must interpret and disassemble the machine instructions of the application based on the context of these instructions; the location of the next instruction depends on the location, size, and correct decoding of the previous. In contrast, on ARM architecture all the debugger needs to monitor is the code sequence that switches from ARM mode to Thumb mode or enhanced Thumb mode and back. Once in a specific mode, all instructions and memory addresses are either 32-bit or 16-bit in size. Firmware developers and device driver developers who need to precisely align calls to specific device registers and may want to rely on understanding the debugger's memory window printout should understand the potential impact of variable length instructions.

Hardware Interrupts

One other architectural difference that may be relevant when debugging system code is how hardware interrupts are handled. On ARM architecture the exception vectors

- 0 Reset
- 1 Abort
- 2 Data Abort
- 3 Prefetch Abort
- 4 Undefined Instruction
- 5 Interrupt (IRQ)
- 6 Fast Interrupt (FIRQ)

are mapped from address 0×0 to address 0×20. This memory area is protected and cannot normally be remapped. Commonly, all of the vector locations at 0×0 through 0×20 contain jumps to the memory address where the real exception handler code resides. For the reset vector that implies that at 0×0 will be a jump to the location of the firmware or platform boot code. This approach makes the implementation of hardware interrupts and OS signal handlers less flexible on ARM architecture, but also more standardized. It is easy to trap an interrupt in the debugger by simply setting a hardware breakpoint at the location of the vector in the 0×0 through 0×20 address range.

On Intel architecture a dedicated hardware interrupt controller is employed. The interrupts

- 0 System timer
- 1 Keyboard
- 2 Cascaded second interrupt controller

- 3 COM2—serial interface
- 4 COM1—serial interface
- 5 LPT—parallel interface
- 6 Floppy disk controller
- 7 Available
- 8 CMOS real-time clock
- 9 Sound card
- 10 Network adapter
- 11 Available
- 12 Available
- 13 Numeric processor
- 14 IDE—Hard disk interface
- 15 IDE—Hard disk interface

cannot be accessed directly through the processor memory address space, but are handled by accessing the Intel 8259 Interrupt Controller. As can be seen from the list of interrupts, the controller already allows for direct handling of hardware I/O interrupts of attached devices, which are handled through the IRQ interrupt or fast interrupt on an ARM platform. This feature makes the implementation of proper interrupt handling at the operating system level easier on Intel architecture, especially for device I/O. The mapping of software exceptions like data aborts or segmentation faults is more flexible on Intel architecture as well and corresponds to an interrupt controller port that is addressed via the Interrupt Descriptor Table (IDT). The mapping of the IDT to the hardware interrupts definable by the software stack. In addition, trapping these exceptions cannot as easily be done from a software stack agnostic debug implementation. In order to trap software events that trigger hardware interrupts on Intel architecture, some knowledge of the OS layer is required. It is necessary to know how the OS signals for these exceptions map to the underlying interrupt controller. Most commonly, even in a system-level debugger a memory-mapped signal table from the operating system will trap exceptions instead of attempting to trap exceptions directly on the hardware level.

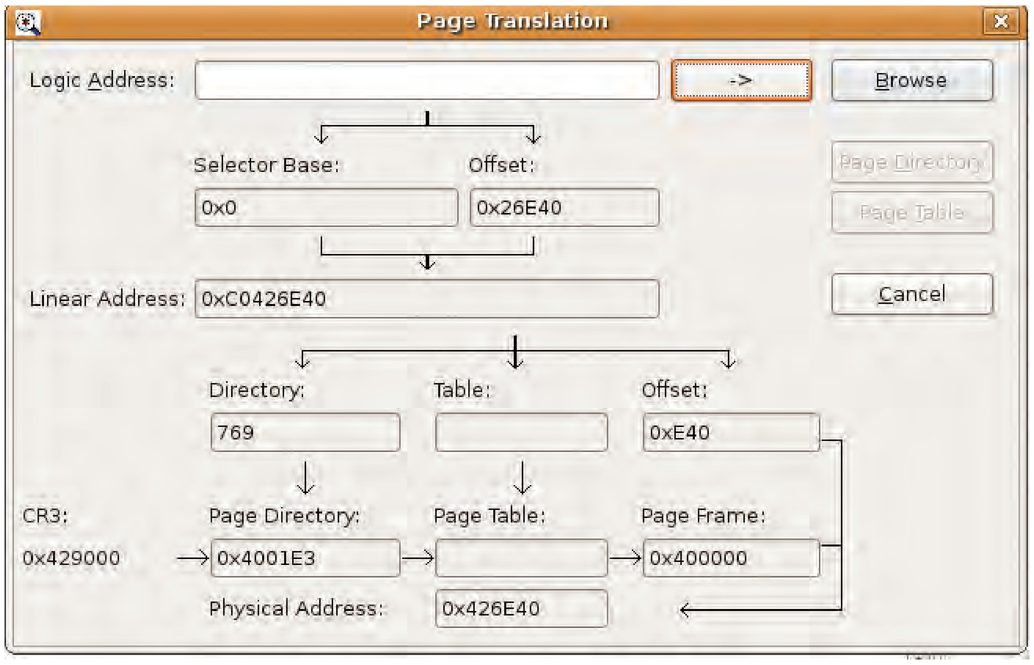
"The mapping of software exceptions like data aborts or segmentation faults is more flexible on Intel architecture…"

Single Step

ARM architecture does not have an explicit single-step instruction. On Intel architecture, an assembly level single step is commonly implemented in the debugger directly via such an instruction. On ARM, a single instruction step is implemented as a "run until break" command. The debugger is required to do some code inspection to ensure that all possible code paths (especially if stepping away from a branch instruction or such) are covered. From a debugger implementation standpoint this does generate a slight overhead but is not excessive, since this "run until break" implementation will be frequently needed for high level language stepping anyway. Software developers in general should be aware of this difference since this can lead to slightly different stepping behavior.

Virtual Memory Mapping

The descriptor table and page translation implementation for virtual memory mapping is surprisingly similar, at least conceptually. On Intel architecture, the Global Descriptor Table (GDT) and Local Descriptor Table (LDT) enable nested coarseness adjustments to memory pages are mapped into the virtual address space. Figure 25 uses the page translation feature of the debugger to graphically represent the linear to physical address translation on Intel architecture.



Logic Address:

Selector Base: 0x0

Offset: 0x26E40

Linear Address: 0xC0426E40

Directory: 769

Table:

Offset: 0xE40

CR3: 0x429000

Page Directory: 0x4001E3

Page Table:

Page Frame: 0x400000

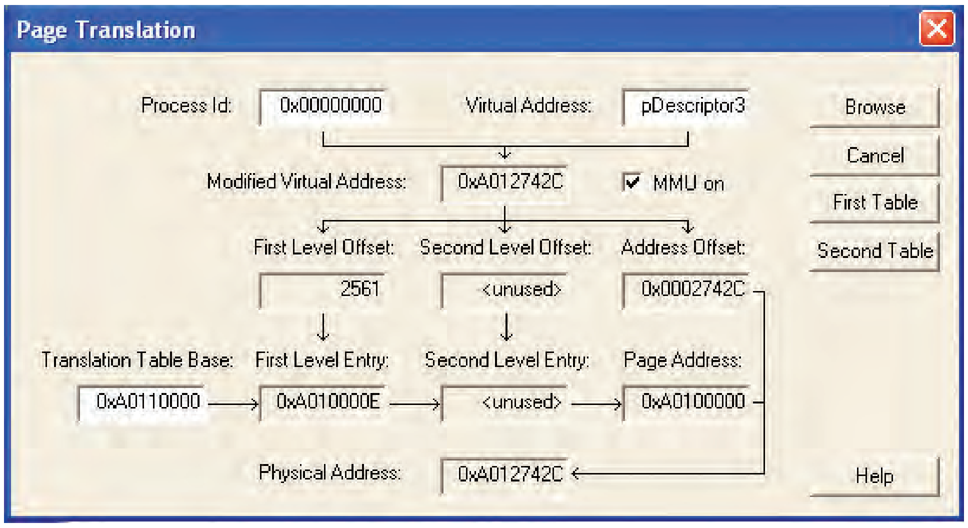
Physical Address: 0x426E40

Figure 25: Page Translation on Intel® Architecture
(Source: Intel Corporation, 2012)

On ARM, the first level and second level page tables define a more direct and at maximum, a one- or two-level–deep page search for virtual memory. Figure 26 shows a sample linear address to physical address translation.

Intel architecture offers multiple levels of coarseness for the descriptor tables, page tables, 32-bit address space access in real mode, and 64-bit addressing in protected mode that's dependent on the selector base:offset model. ARM does not employ base:offset in its various modes. On Intel architecture, the page table search can implicitly be deeper. On ARM, the defined set is two page tables. On Intel architecture, the descriptor tables can actually mask nested tables and thus the true depth of a page table run can easily reach twice or three times the depth on ARM.

The page translation mechanism on Intel architecture provides for greater flexibility in the system memory layout and mechanisms used by the OS layer to allocate specific memory chunks as protected blocks for application execution. However, it does add challenges for the developer to have a full



Page Translation

Process Id: 0x00000000

Virtual Address: pDescriptor3

Modified Virtual Address: 0xA012742C

[✓ MMU on]

First Level Offset: 2561

Second Level Offset: <unused>

Address Offset: 0x0002742C

Translation Table Base: 0xA0110000

First Level Entry: 0xA010000E

Second Level Entry: <unused>

Page Address: 0xA0100000

Physical Address: 0xA012742C

Figure 26: Page Translation on ARM
(Source: Intel Corporation, 2012)

overview of the memory virtualization and thus avoid memory leaks and memory access violations (segmentation faults). On a full-featured OS with plenty of memory, this issue is less of a concern. Real-time operating systems with more visibility into memory handling may be more exposed to this issue.

Considerations for Intel® Hyper-Threading Technology

From a debugging perspective there is really no practical difference between a physical processor core and a logical core that has been enabled via Intel Hyper-Threading Technology. Enabling hyper-threading occurs as part of the platform initialization process in your BIOS. Therefore, there is no noticeable difference from the application standpoint between a true physical processor core and an additional logical processor core. Since this technology enables concurrent execution of multiple threads, the debugging challenges are similar to true multicore debug.

SoC and Interaction of Heterogeneous Multi-Core

"Interactions between the different software components are often timing sensitive."

Dozens of software components and hardware components interacting on SoCs increase the amount of time it takes to determine the root cause of issues during debug. Interactions between the different software components are often timing sensitive. When trying to debug a code base with many interactions between components single-stepping through one specific component is usually not a viable option. Traditional *printf* debugging is also not effective in this context because the debugging changes can adversely affect timing behavior and cause even worse problems (also known as "Heisenbugs").

SVEN (System Visible Event Nexus)

SVEN is a software technology (and API) that collects real-time, full-system visible software "event traces." SVEN is currently built into all media/display drivers and is the primary debug tool for the Intel® Media processor CE3100 and Intel Atom processor CE4100 platforms providing debug, performance measurement, and regression testing capabilities.

Ultimately, SVEN is simply a list of software events with high-resolution timestamps. The SVEN API provides developers a method of transmitting events from any operating system context and firmware. The SVEN Debug infrastructure consists of a small and fast "event transmit" (SVEN-TX) library and a verbose capture and analysis (SVEN-RX) capability.

"…SVEN is simply a list of software events with high-resolution timestamps."

This so called System Visible Event Nexus in the form of the SVEN-TX library provides an instrumentation API with low and deterministic overhead. It does not cause any additional timing-dependent effects. There are no changes in the behavior of the system because of the instrumentation observation. In other words, there is no software Heisenberg effect. The events to monitor can be issued by any software component on the entire platform. These can be interrupt service routines (ISRs), drivers, application, even firmware.

"There are no changes in the behavior of the system because of the instrumentation observation. In other words, there is no software Heisenberg effect."

A real-time monitor interface named SVEN-RX provides real-time and offline analysis of the data exported by the SVEN-TX API. SVEN-RX is an interface that can monitor an executing system and analyze failures on the executing application. In addition, it provides detailed information for fine-grained performance tuning.

Lastly, the SVEN Debug console is a command-line utility that attaches to the Nexus and observes all events being generated by the SVEN-TX instrumented code (drivers, user apps, libraries). A scriptable filter dynamically accepts or rejects any describable event category (for example, "only record events from MPEG decoder"). Scriptable "triggers" stop recording of events to halt local capture of events leading up to a failure. A "Reverse Engineer" feature transfers all register reads/writes from physical address to the unit and External Architecture Specification (EAS) registers.

The SVEN debug console can save all the recorded events collected from the entire SoC to a disk file for offline debugging.

Signal Encode/Decode Debug

The SVEN Debug console has a built-in Streaming Media Decoder (SMD) buffer flow monitor that checks on SMD ports/queues for data flow between drivers. It also samples the SMD circular buffer utilization over time. Its health monitor is capable of triggering an execution stop and data capture if, for example, it fails to detect video flip or an audio decode within a specified period of time.

SVEN Benefits

SVEN enables an accelerated platform debug process providing the developers with all of the required evidence for problem triage. The included automation tools can diagnose most of the common system failures automatically. In short, it speeds up the development cycle on complex Intel Atom processor–based SoC designs by reducing the time it takes the developer to understand issues that occur in the data exchanges and handshake between all of the system components.

Summary

In this article we went over the configuration and installation details of the necessary drivers and debug tools. In addition we highlighted some of the underlying architectural differences that may impact debug, but usually only for those developers who are interested in development very close to the system layer.

As we have seen in our overview of available debug solutions and debug configurations for Android running on systems based on Intel architecture, there is a full set of debug environments available covering the needs of the Java application developer, the native C/C++ code developer, and the system software stack developer.

"…Intel as well as other ecosystem players provide debug solutions that expand on these available debug tools and provide solutions for system software stack debug as well as graphics performance debug."

Debugging on Intel architecture is supported with the standard Android SDK and Android NDK tool sets provided by Google. In addition Intel as well as other ecosystem players provide debug solutions that expand on these available debug tools and provide solutions for system software stack debug as well as graphics performance debug.

If you are familiar debugging and developing for Android running on ARM architecture the same debug methods apply for Intel architecture as well. The available debug tools and development tools infrastructure is based on the Android SDK and extended by solutions from Intel as well as ecosystem partners that are often also familiar from ARM. Thus there should be few surprises debugging software on Android devices based on an Intel Atom processor versus devices based on ARM.

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Author Biography

Omar A. Rodriguez is a software engineer in the Intel Software and Services Group, where he supports mobile games/graphics in the Personal Form Factors team. He holds a BS in Computer Science from Arizona State University. Omar is not the lead guitarist for the Mars Volta.

OPTIMIZING INTEL® ARCHITECTURE MULTIMEDIA APPLICATIONS BY SOFTWARE TUNING AND HARDWARE ACCELERATION

Contributor

Yuming Li
Software and Services Group,
Intel Corporation

"The complexity and large calculating quantity of multimedia applications need giving priority to optimization."

"Software optimization (SIMD and TBB) and hardware acceleration (OpenGL and MediaCodec) can reduce power dissipation evidently."

Multimedia applications are becoming increasingly common in personal computers. For the reason of data level parallelism for multimedia data, SIMD (Single Instruction, Multiple Data) has commonly been adapted for multimedia optimization in general-purpose processors. Because SIMD (MMX and SSE) is supported by all of the Intel CPUs for mobile and desktop devices, many past PC code optimizations and technology can be used for Intel architecture–based Android applications. On the other hand, hardware acceleration is used to improve performance too. Offloading the compute-intensive multimedia work from software running on the CPU to dedicated video acceleration hardware will save a large amount of CPU resources and power.

In this article, an open-source full format player is given as an example to explain the software and hardware optimization technology. The author gives a general introduction of SIMD and Intel® Threaded Building Blocks (Intel® TBB) for Intel architecture. For the hardware acceleration, an unofficial hardware encoder solution that directly calls Openmax-IL and two official solutions, Openmax-Al and MediaCodec, which Google provides, are discussed. MediaCodec should be a very important API after Jelly Bean. In this article, improvements for MediaCodec are given. With the freeing up of additional CPU power, some amazing ideas can be realized by using software optimization and hardware acceleration.

Introduction

Current and next-generation consumer electronics such as mobile and home entertainment devices must deliver very high-quality audio, video, image, and graphics performance in order to be competitive. Several different technologies assist in this: SIMD (Single Instruction Multiple Data) is a technology for modern CPU designs that improves performance by allowing efficient parallel processing of vector operations. This is an important software optimization technology for multimedia applications. Hardware acceleration is the use of computer hardware to perform some function faster than is possible in software running on the general-purpose CPU. Normally, processors are sequential, and instructions are executed one by one. The main difference between hardware and software is concurrency, allowing hardware to be much faster than software. Hardware accelerators are designed for computationally intensive software code.

In this article, the author uses an open-source all-format player as an example to explain several of these software optimization technologies. Examples are also given to explain how to offload the compute-intensive multimedia work from software running on the CPU to dedicated video acceleration hardware.

SIMD Software Optimizations

Off-the-shelf SIMD software optimizations are available in the open source. Take Tewilove faplayer (a full-format video player) as an example. Integrating these with Tewilove does require a few tricks:

1. Obtaining the source
2. Building ffmpeg
3. Compiling the optimized SIMD assembly codes with yasm
4. Modifying tweilove to use ffmpeg and the optimized assembly code

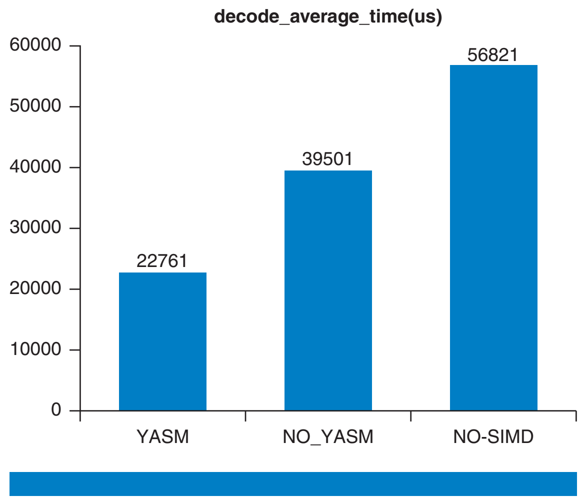
Instructions on the above may be found in Appendix A.

Note: the Google NDK build script does not support .asm. I have done an improvement of the Google NDK build script. You can see http://software.intel.com/en-us/articles/using-yasm-compiler-on-android-ndkbuild for more detail. If you need to compile .asm on Android source, which will use "mm", you can modify the ndk folder on the Android source. The "mm" will use ndk-build scripts in the ndk folder.

"FFMpeg (a famous cross-platform software codes open source) is widely used on android multimedia applications. Take it as an example for the research of software optimization."

The Result of Using SIMD Optimizations

For 1080p mp4 software decoding, I compare three configurations in Figure 1.



YASM: -enable yasm -enable asm

NO-YASM: -disable yasm -enable asm

NO-SIMD: -disable yasm -disable asm

Figure 1: Average Decoding Time for 1080p mp4 Software Decoding (Source: Intel China Ltd., 2013)

Enabling yasm can achievement an improvement in performance of 149.6 percent (149.6 percent: 56821/22761 = 2.496), and not only for FFmpeg.

"Android native build script (ndk-build) does not support .asm file, use YASM can get significant performance gains."

Actually, nearly all open source needs Yasm to achieve the best performance, including, for example, Vp8 and x264. With the help of yasm, a small change on makefile can get a significant improvement. Yasm is useful when porting from traditional PC code to Android Intel architecture code.

Use SSE (SIMD Technology) to Optimize Color Space Transformation

We usually must do color space transformation, because video is generally YUV format, but an LCD screen is RGB format, and camera output is generally nv21 format. All these must do color space transformation. FFmpeg provides the *swscale* function to do this transformation. But for large size pictures, color space transformation will consume many more CPU resources, as you can see in Table 1: SSE optimization can get 6 to 16x performance improvement! It's amazing!

"SSE optimization can get 6x to 16x performance improvement on color space transformation"

3040*1824 NV21-RGB888	SWS_BILINEAR	SWS_FAST_BILINEAR
Not using yasm	425 ms	158 ms
Using yasm	179 ms	155 ms
Using fast SSE NV21-RGB888	27 ms	27 ms

Table 1: SSE Optimization for NV21 to RGB Transformation
(Source: Intel China Ltd., 2013)

SSE (SIMD technology) is the most important optimization technology on x86 Android (ARM has NEON—it is also an SIMD technology), especially for multimedia apps.

What Is SIMD?

"Single Instruction stream, Multiple Data streams (SIMD) computing first entered the personal computing world in the form of Intel's neglected addition to the x86 instruction set. "

Single instruction, multiple data (SIMD)[3] describes a class of computers with multiple processing elements that perform the same operation on multiple data points simultaneously. Most modern CPU designs include SIMD instructions in order to improve the performance of multimedia use. Intel® Atom™ processor code name Medfield supports MMX™, MMX2, Intel® SSE, SSE2, SSE3, SSSE3, but SSE4 and Intel® AVX are not supported. You can also dynamically check SIMD supporting runtime, reference cpuid on FFmpeg 1.0 (function *ff_get_cpu_flags_x86* on *cpu.c*).

There are three ways to implement SIMD code:

1. C/C++ language-level (intrinsic functions), defined with *emmintrin.h*. Few open-source libraries use it as yet, except WEBP. If SIMD code is implemented in this way, it's easy adapting to all hardware platforms. (That is to say, you can change it to NEON code if on the ARM platform.)
2. Inline assembler (the most widely used). It doesn't require separate assembly and link steps and is more convenient than a separate assembler.

3. Separate assembler. It has many styles (NASM, TASM, MASM…), and the file extension: .s , .asm. (Assembler with the file extension .asm cannot be compiled by the Android NDK; you must use the patch that I provided in the section "How to Use Yasm").

How the SIMD Works

The core idea of SIMD is to improve the short data parallelism. For example, if you want to add two 8-bit integer arrays, generic C code looks like this:

"The core idea of SIMD is to improve the short data parallelism."

```
Int s[16];
for(int i=0;i<16;i++){
     S[i]=data1[i]+data2[i];  //ensure s[i] is 0~255
}
```

But if you use SSE, you just need

```
movups data1,xmm1
movups data2,xmm2
paddusb xmm1,xmm2
movntq xmm2,S
```

With the one instruction *paddusb*, it can do 16 add operations at the same time. It sounds good, but actually it has limitations. All data must be well organized, and the algorithm can be vectorized. But even though it has limitations, it indeed improves the performance, especially for multimedia applications.

"The limitation is SIMD short data must be well organized, and the algorithm can be vectorized, that is especially suitable for multimedia applications."

SIMD has five types of instructions:

1. Data Movement: such as *movd*, *movq*, and *movups*
2. Boolean Logic: *psllw*, *psrlw*
3. Math: *paddb*, *pmulhw*
4. Comparisons: *pcmpeqb*
5. Data Packing: *packssdw*, *punpcklbw*, and *pshufb*

Data packing is the most difficult part for SIMD. The data packing instructions are illustrated in Figure 2, Figure 3, and Figure 4.

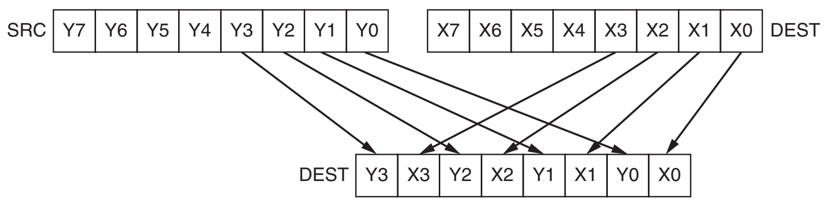


Figure 2: Punpcklbw
(Source: Intel China Ltd., 2013)

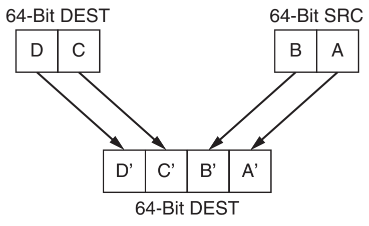
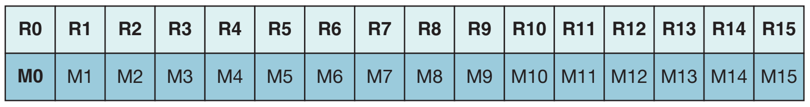


Figure 3: Packssdw
(Source: Intel China Ltd., 2013)



R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
M0	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15

Figure 4: Powerful and flexible SSSE3 instruction - Pshufb
(Source: Intel China Ltd., 2013)

```
R0  := (mask0 & 0x80) ? 0 : SELECT(a, mask0 & 0x07)
R1  := (mask1 & 0x80) ? 0 : SELECT(a, mask1 & 0x07)
...
R15  := (mask15 & 0x80) ? 0 : SELECT(a, mask15 & 0x0f)
```

The *pshufb* instruction can put any 8 bits of data into any place according to a 128-bit mask.

Implementing YUV2RGB SSE Code

FFmpeg yuv2rgb is MMX2 code, so you must first modify it to SSE code; please reference Appendix B for more detail.

You can find more efficient YUV2RGB color space transformation open source form the link https://code.google.com/p/libyuv/.

LibYuv is an open source project that includes YUV conversion and scaling functionality. LibYuv has implemented SSE and AVX code for x86.

Multi-core Application Optimization with Intel® Threaded Building Blocks

"Intel® Threading Building Blocks (Intel® TBB) can take full advantage of multicore performance. Using together with SIMD, data and CPU core parallelism can be released sufficiently and get best performance."

Android 4.1 has made a big improvement in multi-core optimization. When running apps that have multi-threading, the operating system can schedule each thread to each CPU core. But on X86-based Android devices, you have another choice to implement multi-core optimization, Intel® Threaded Building Blocks (Intel® TBB).

Intel TBB can be downloaded from http://threadingbuildingblocks.org/download. You must choose the Linux version. You can get *libtbb.so* and *libtbbmalloc.so* under *lib/android*.

Using Intel® TBB Together with SSE

As we know, SSE can get amazing performance improvement for Intel architecture devices. But it only works for single core. Using Intel TBB together with SSE will get the best performance on multi-core devices. Here I use the *yuv2rgb* function as an example.

Yuv2rgb is a color space transform function. You can find this function in many open-source libraries, such as FFmpeg and OpenCV. Generally it has SSE (or

MMX2) functions for the x86 platform. SSE optimization can produce nearly 6x performance improvement, as shown in Table 2.

3040*1824 YUV2RGB888	SWS_BILINEAR	SWS_FAST_BILINEAR
Using C code	179 ms	155 ms
Using SSE code	27 ms	27 ms

Table 2: Running Time for 3040*1824 YUV2RGB888
(Source: Intel China Ltd., 2013)

On Intel® Atom™ processor code name Clover Trail+, which has two cores, Intel TBB can achieve a 2.2X performance improvement, as shown in Table 3. The score should be better in more CPU cores.

"On Intel® Atom™ processor code name Clover Trail+, which has two cores, TBB can achieve a 2.2X performance improvement."

Use SSE code + Intel® TBB	12 ms	12 ms

Table 3: Running Time with TBB for 3040*1824 YUV2RGB888
(Source: Intel China Ltd., 2013)

Optimization Details

For image processing, we apply SSE optimization on the image width. That is to say, we get approximately 8 to 16 pixels and package them into the XMM register, and then they are operated on by SSE instruction for the whole width. Generally, for each width the operation is nearly the same, so parallelism is possible for the height. A code example for parallelism image processing looks like this:

```
#include "tbb/task_scheduler_init.h"
#include "tbb/blocked_range.h"
#include "tbb/parallel_for.h"

using namespace tbb;

class multi_two
{
public:
  void operator()(const tbb::blocked_range<size_t>&
range) const

  {

          Log ("range.begin(),range.end()");
          for(int j=range.begin();j<range.
          end();j++) {
               for(i=0; i<ImgWidth; i+=8) {
                    __asm__ volatile(
                    // do sse
               );
```

```
                        YUVBuffer+=8;
                   }
              }
              //.. the same as UV
      }
        multi_two(BYTE * _RGBBuffer, BYTE * _YUVBuffer)
        {
        RGBBuffer = _ RGBBuffer;
             YUVBuffer = _ YUVBuffer;
        }
private:
      BYTE * RGBBuffer;
BYTE * YUVBuffer;
};

void YUV2RGB(BYTE * YUVBuffer, BYTE * RGBBuffer)
{

     tbb::parallel_for(tbb::blocked_range<size_t>(0,
height/2), multi_two(YUVBuffer , RGBBuffer ));

     //if using MMX, remember to add emms after all
parallel computing finish
     //__asm__ volatile("emms");
}
```

"TBB lets you easily write parallel C++ programs that take full advantage of multicore performance"

The *parallel_for* function has the simplest usage for Intel TBB. You must create a class that has the function name "operator", and then pass this class as a parameter. The blocked range is important to Intel TBB. Intel TBB will split the whole operation into several task ranges from *range.begin()* to *range.end()*. So if you set the range as [0,4], you can get four logs, which may be [2,3], [0,1], [3,4], and [1,2]. Generally, we set the task range from 0 to *height*/2 (for UV, *height* is *Y height*/2). Note: the task is not threaded. Intel TBB will create a thread pool according to the CPU core number and will distribute these tasks into running threads (from the thread pool). So Intel TBB will try splitting tasks evenly into each thread (each thread binding into each CPU core), and get the best performance compared to multi-thread.

Intel® TBB vs. Multi-Thread

"Use TBB or just thread, that is a question."

I have done a demo for comparing Intel TBB and multi-thread. I split a single thread like this:

```
    pthread_create(&m_StreamingThread1, NULL,
streamingThreadProc1, NULL);
    pthread_create(&m_StreamingThread2, NULL,
streamingThreadProc2, NULL);
    pthread_create(&m_StreamingThread3, NULL,
streamingThreadProc3, NULL);
```

```
    pthread_create(&m_StreamingThread4, NULL,
streamingThreadProc4, NULL);

    void* status;

    pthread_join(m_StreamingThread1,&status);  //
wait thread1 finish

    pthread_join(m_StreamingThread2,&status);  //
wait thread2 finish

    pthread_join(m_StreamingThread3,&status);  //
wait thread3 finish

    pthread_join(m_StreamingThread4,&status);  //
wait thread4 finish
```

When no other thread is running, the time for Intel TBB and multi-thread is nearly the same. But when I add some dummy threads that just wait 200 ms, things change. Multi-thread will be slower even than a single thread, but Intel TBB is still good. The reason is you assume all threads will be finished at the same time. But actually some other threads will block the four threads running, so that the total finish time will be the slowest.

"Multi-thread may be slower even than a single thread in some case while TBB not. TBB is a good choice for multi-core optimization"

The test result is shown in Table 4 (each step adds two dummy threads; the dummy thread is just waiting 10 ms).

STEP	Multi-Thread	Intel® TBB
1	296 ms	272 ms
2	316 ms	280 ms
3	341 ms	292 ms
4	363 ms	298 ms
5	457 ms	310 ms

Table 4: Comparison for Multi-Thread and Intel® TBB
(Source: Intel China Ltd., 2013)

With the improvement of the x86 SOC, I believe embedded CPUs will more and more approach the traditional PC CPU. If Intel® Streaming SIMD Extensions 4 (Intel® SSE4) and Intel® Advanced Vector Extensions (Intel® AVX) can be included on the SOC, you will be able to achieve a greater performance improvement when developing multimedia apps.

Using the Integration Layer (IL) to Do Hardware Encoding

OpenMax[4] is a multimedia application standard which is launched by NVIDIA and Khronos* in 2006. It is a free, cross-platform software abstract layer for multimedia acceleration. It has three layers: the application layer (AL), the integration layer (IL), and the development layer (DL). The IL has become the de facto standard multimedia framework and also has been accepted as an Android multimedia framework.

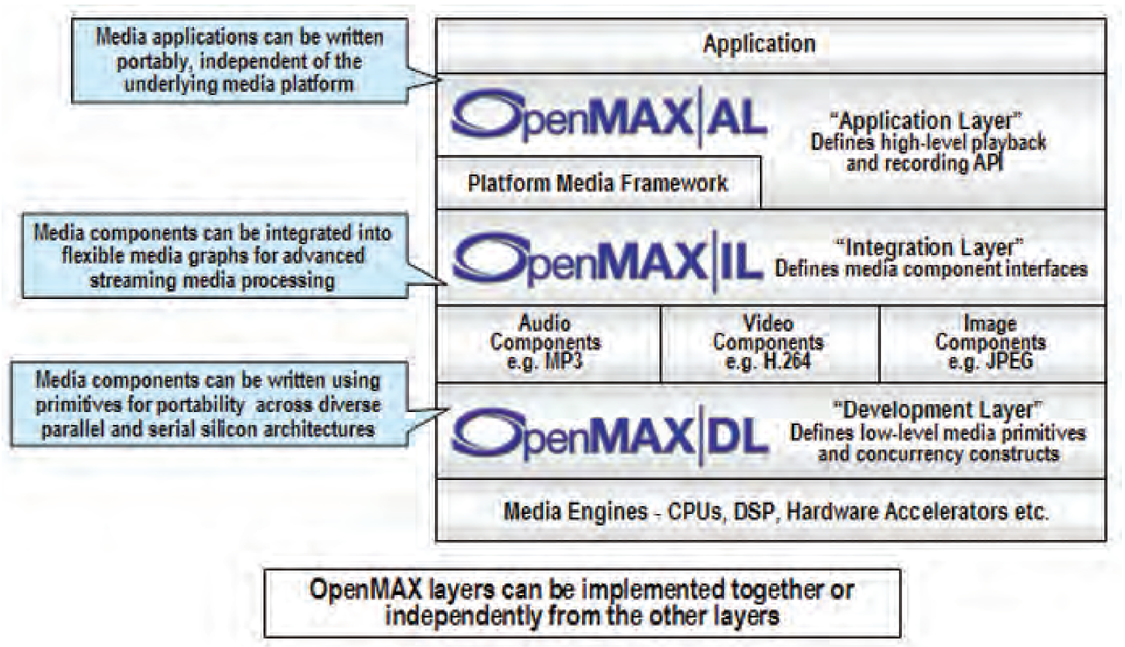

Media applications can be written portably, independent of the underlying media platform
Media components can be integrated into flexible media graphs for advanced streaming media processing
Media components can be written using primitives for portability across diverse parallel and serial silicon architectures
Application
OpenMAX|AL
"Application Layer" Defines high-level playback and recording API
Platform Media Framework
OpenMAX|IL
"Integration Layer" Defines media component interfaces
Audio Components e.g. MP3
Video Components e.g. H.264
Image Components e.g. JPEG
OpenMAX|DL
"Development Layer" Defines low-level media primitives and concurrency constructs
Media Engines - CPUs, DSP, Hardware Accelerators etc.
OpenMAX layers can be implemented together or independently from the other layers

Figure 5: OpenMax Structure Block[4]
(Source: Khronos* (http://www.khronos.org/openmax), 2006)

"Developers can use the OpenMax Integration Layer (IL) to get the hardware codec interface without compatibility guarantee."

Before Android 4.1, Google had not exposed any hardware codec interface to developers, so a large number of multimedia apps have had to use FFmpeg, x264, and vp8 as software video codecs. Especially for video encoding, software encoding uses most of the CPU resources (640*480 h264 encoding will occupy nearly 90 percent of the CPU's resources for an ARM v9 1.2G dual-core). In fact, developers can use the OpenMax Integration Layer (IL) to get the hardware encoder interface. Here I must clarify that both ARM and Intel architecture can use this method to do hardware encoding, but it will meet with compatibility issues. The OpenMax IL is implemented by various vendors and Google does not guarantee its compatibility, so it's hard to ensure working well on all Android systems. For Android on Intel architecture, with only one vendor, it would have no compatibility issue.

How to Get the OMX-IL Interface on Android on Intel Architecture

Libwrs_omxil_core_pvwrapped.so is the OMX-IL interface layer on the Intel Atom processor code name clover trail. Developers can load this as follows to get some of the OMX-IL interface.

```
pf_init = dlsym( dll_handle, "OMX_Init" );
pf_deinit = dlsym( dll_handle, "OMX_Deinit" );
pf_get_handle = dlsym( dll_handle, "OMX_GetHandle" );
pf_free_handle = dlsym( dll_handle, "OMX_
FreeHandle" );
pf_component_enum = dlsym( dll_handle,
"OMX_ComponentNameEnum" );
pf_get_roles_of_component = dlsym( dll_handle,
"OMX_GetRolesOfComponent" );
```

After getting these handles, you can call *pf_component_enum* and *pf_get_roles_of_component* to get the right hardware encoding interface. All of the video codec interface is listed as follows:

```
component OMX.Intel.VideoDecoder.AVC
  – role: video_decoder.avc
component OMX.Intel.VideoDecoder.H263
  – role: video_decoder.h263
component OMX.Intel.VideoDecoder.WMV
  – role: video_decoder.wmv
component OMX.Intel.VideoDecoder.MPEG4
  – role: video_decoder.mpeg4
component OMX.Intel.VideoDecoder.PAVC
  – role: video_decoder.pavc
component OMX.Intel.VideoDecoder.AVC.secure
  – role: video_decoder.avc
component OMX.Intel.VideoEncoder.AVC
  – role: video_encoder.avc
component OMX.Intel.VideoEncoder.H263
  – role: video_encoder.h263
component OMX.Intel.VideoEncoder.MPEG4
  – role: video_encoder.mpeg4
```

You can choose the right component according to your usage. For example, if you want to do MP4 encoding, you can choose "OMX.Intel.VideoEncoder.MPEG4", and call *pf_get_handle* to get the hardware MP4 encoding handle.

How the OMX-IL Works

As shown in Figure 6, in order to create or configure and connect the OpenMax components, the application is written as an Integration Layer (IL) client. This IL client is used to invoke OpenMax APIs for different components. In this application, components allocate the video buffers in response to OMX APIs on the IL client. The IL client is responsible for taking the buffers from one component and passing them to other components. Functions *OMX_GetParameter* and *OMX_SetParameter* are used as parameter/configuration set and get. *OMX_SendCommand* is used for port enable and the state following changing. *OMX_EmptyThisBuffer* and *OMX_FillThisBuffer* are used to pass the buffers to components. *OmxEventHandler*, *OmxEmptyBufferDone*, and *OmxFillBufferDone (OMX_CALLBACKTYPE)* must be registered when calling *pf_get_handle*.

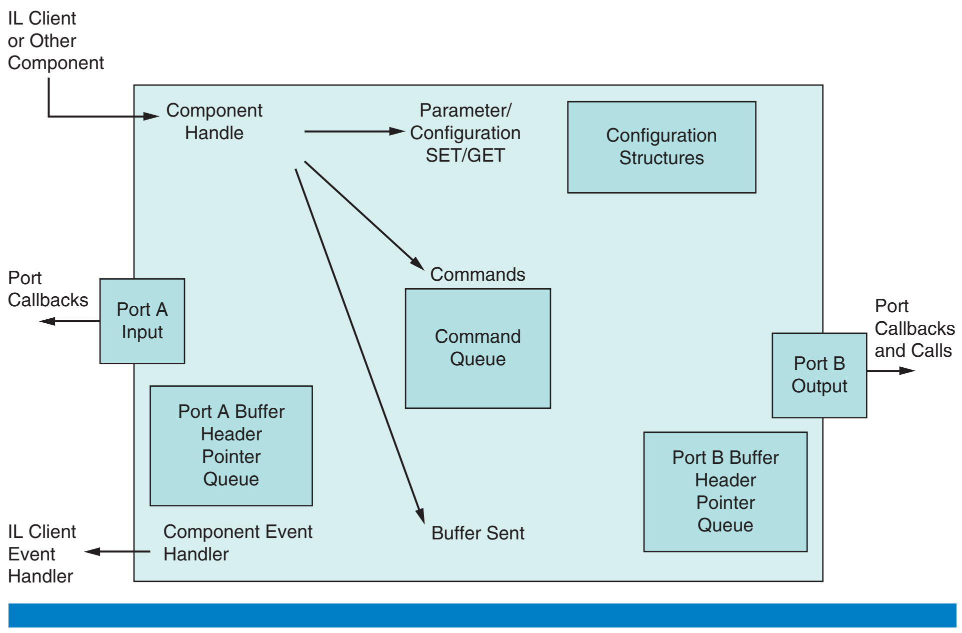


Figure 6: OpenMax IL API Component Architecture[5]
(Source: OpenMAX IL 1.1.2 Specification, 2008)

After allocating the OMX buffer and calling *OMX_SendCommand* to set the *OMX_StateExecuting* state, you can use *FillThisBuffer*, *EmptyThisBuffer*, and their callback functions to do hardware encoding. Figure 6 is the call sequence.

Call *FillThisBuffer* to fill one raw picture into the OMX local buffer and call *EmptyThisBuffer* to make the OMX component do the hardware encoding; when finished encoding or when the local output buffer is full, the OMX component will call *OnEmptyThisBufferDone* to tell the client to do *EmptyThisBuffer* again. So one *FillThisBuffer* may make several *OnEmptyThisBufferDone* to be called. If the OMX component finds the input buffer is empty, it will call *OnFillThisBufferDone* to tell the client to fill more buffers.

"Hardware encoder can get best performance according to software encoder. Screen projection (4.2 has Miracst) and self-defined video recorder can be done by hardware encoder"

Using Hardware Encoder to Improve a Video Recorder

Now, let us try using a hardware video encoder to implement a special effects video recorder. The design is to get data from the camera and add a mark to the camera preview image. When doing recoding, the mark should be recorded into the video file. It sounds like a simple design, but before Android 4.1, without compatibility issues, you could only choose a software encoder (FFmpeg or x264), which would waste lots of CPU resources. (Starting with Android 4.1, a new class MediaCodec has been introduced; it's the same as OMX-IL, but implemented by Google, and Google guarantees its compatibility).

I have tried developing this demo and doing a test. The recorder file format is MP4 (encoder: MPEG-4).

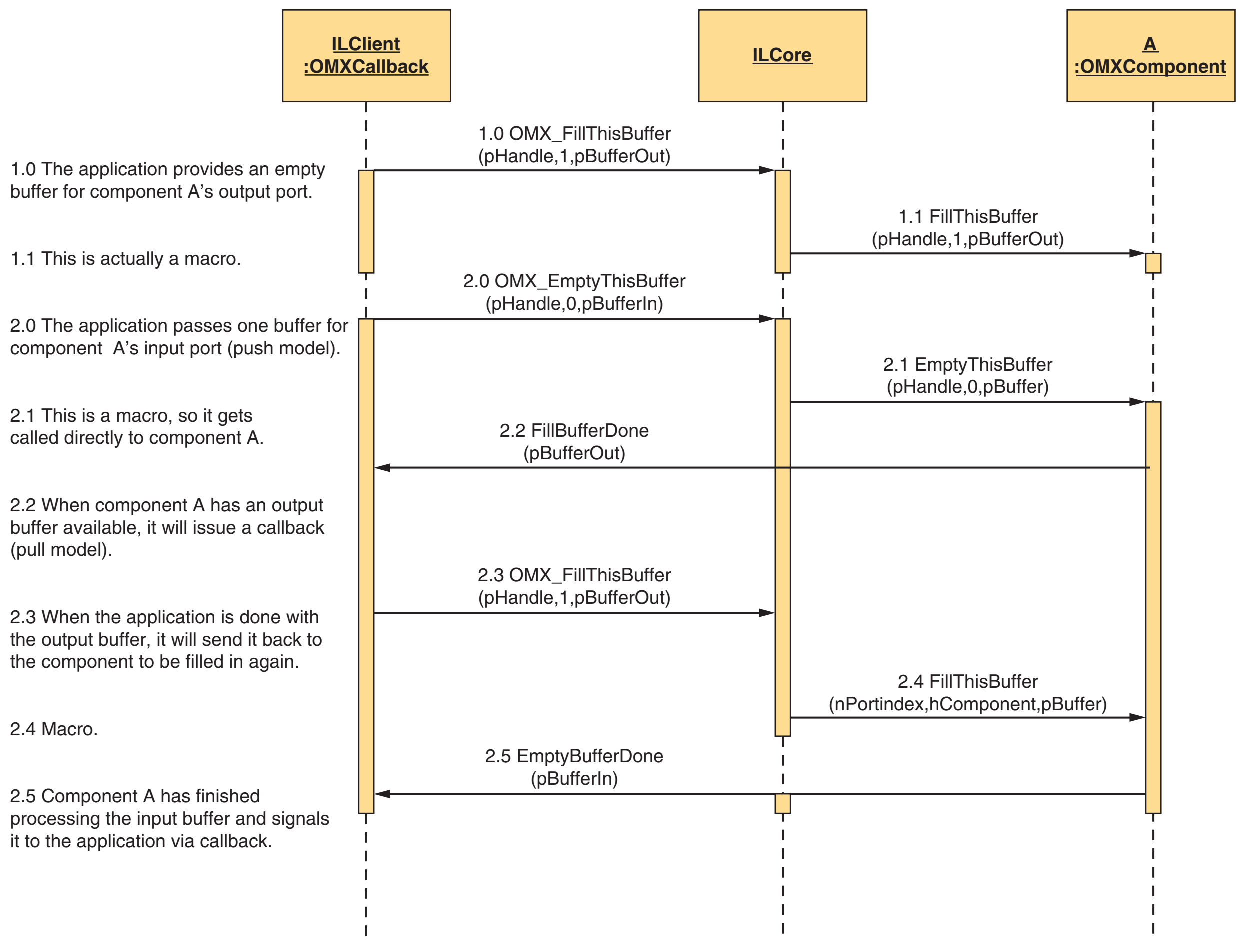

ILClient :OMXCallback
ILCore
A :OMXComponent
1.0 OMX_FillThisBuffer (pHandle,1,pBufferOut)
1.1 FillThisBuffer (pHandle,1,pBufferOut)
2.0 OMX_EmptyThisBuffer (pHandle,0,pBufferIn)
2.1 EmptyThisBuffer (pHandle,0,pBuffer)
2.2 FillBufferDone (pBufferOut)
2.3 OMX_FillThisBuffer (pHandle,1,pBufferOut)
2.4 FillThisBuffer (nPortindex,hComponent,pBuffer)
2.5 EmptyBufferDone (pBufferIn)
1.0 The application provides an empty buffer for component A's output port.
1.1 This is actually a macro.
2.0 The application passes one buffer for component A's input port (push model).
2.1 This is a macro, so it gets called directly to component A.
2.2 When component A has an output buffer available, it will issue a callback (pull model).
2.3 When the application is done with the output buffer, it will send it back to the component to be filled in again.
2.4 Macro.
2.5 Component A has finished processing the input buffer and signals it to the application via callback.

Figure 7: OpenMax Data Flow[5]
(Source: OpenMAX IL 1.1.2 Specification, 2008)

If using a hardware encoder, total CPU resources just need 3.7 percent (hardware encoding – preview), while a software encoder will need 46.9 percent (the size is just 1024×576). If you want 1080P video recording, the software solution is impossible! The results of the test are shown in Table 5.

1024 × 576 Video recorder	Frequency	CPU usage	Total Resource
1024 576 preview	600 MHz	35%	35% 600/1600 = 13.125%
Hardware encoder without sound	600 MHz	45%	45% 600/1600 = 16.875%
Software encoder without sound	1600 MHz	50%	50% 1600/1600 = 50%

Table 5: Comparison for Software and Hardware Video Recodring
(Source: Intel China Ltd., 2013)

Using a Powerful Media API: MediaCodec on Jelly Bean

Android has a great media library allowing all sorts of things. Until recently though, there was no way to encode and decode audio/video, which gives developers the ability to do almost anything. Fortunately, the Jelly Bean release introduced the android.media.MediaCodec API. The API is designed following the same principles and architecture of OpenMAX (a well-known standard in the media industry), transitioning from a pure high level media player to the encoder/decoder level.

"MediaCodec (Android 4.1 new API) provides a simple way to access build-in codecs. MediaCodec support pipeline on Android 4.3, Adaptive playback (enabling seamless change in resolution during playback) and image post processing on Android 4.4."

Sample Code: Video Decoder

This sample code shows how to implement a decoder. It uses two classes, MediaCodec and MediaExtractor. MediaExtractor facilitates extraction of demuxed, typically encoded, media data from a data source. MediaCodec, of course, is used as a low level codec.

First, you should use *MediaExtractor* to get the media format

```
MediaExtractor extractor = new MediaExtractor();
extractor.setDataSource(sampleFD
.getFileDescriptor (),sampleFD.getStartOffset(),
sampleFD.getLength());
MediaFormat format = extractor.getTrackFormat(0);
```

Second, you can create MediaCodec and configure it.

```
MediaCodec codec;
ByteBuffer[] codecInputBuffers;
ByteBuffer[] codecOutputBuffers;

MediaCodec codec = MediaCodec
.createByCodecName(name);
codec.configure(format, null,null,0);  //if no
display, set surface to null, otherwise, it better
to set the surface to get best performance.
codec.start();
```

Finally, do decoding. Like OMX-IL, it has two ports. You should call *dequeueInputBuffer* to send decoding buffer to MediaCodec and call *dequeueOutputBuffer* to receive the outside buffer.

```
int inputBufIndex = codec
.dequeueInputBuffer(TIMEOUT_US);
if (inputBufIndex >= 0) {
    ByteBuffer dstBuf = codecInputBuffers
[inputBufIndex];
    int sampleSize = extractor
.readSampleData(dstBuf, 0);
    long presentationTimeUs = 0;
    if (sampleSize < 0) {
            sawInputEOS = true;  sampleSize = 0;
    } else {
            presentationTimeUs =
extractor.getSampleTime();
    }
    codec.queueInputBuffer(inputBufIndex, 0,
sampleSize,
                    presentationTimeUs,
                    sawInputEOS ?
MediaCodec.BUFFER_FLAG_END_OF_STREAM : 0);
    if(!sawInputEOS){
            extractor.advance();
    }
}

final int res = codec.dequeueOutputBuffer(info,
TIMEOUT_US);
if(res >= 0){
        int outputBufIndex = res;
        ByteBuffer buf =
codecOutputBuffers[outputBufIndex];
        codec.releaseOutputBuffer(outputBufIndex,
false);
//set true ,if need rendering
        if((info.flags &&
MediaCodec.BUFFER_FLAG_END_OF_STREAM) != 0){
                sawOutputEOS = true;
        }
} else if(res == MediaCodec.INFO_OUTPUT_BUFFERS_
CHANGED){
        codecOutputBuffers = codec.
getOutputBuffers();

} else if(res == MediaCodec.INFO_OUTPUT_FORMAT_
CHANGED){
        final MediaFormat offormat =
codec.getOutputFormat();
}
```

"MediaCodec is low-level codec, according to Mediaplayer, synchronization of video and audio is done by you."

Using MediaCodec in NDK

MediaCodec is a Java layer class, while we must do decoding (or encoding) in C code, which is in the NDK layer. So it is important to call the Java class in NDK. This can be done by using the JNI function *FindClass*.

"You can call MediaCodec from native layer. This can be done by using the JNI function FindClass"

Sample code for *FindClass* is shown below:

```
jclass audio_record_class =
jni_env->FindClass("android/media/AudioRecord");
int size = jni_env->CallStaticIntMethod(audio_
record_class
     ,jni_env->GetStaticMethodID(audio_record_
class,"getMinBufferSize", "(III)I")
                                              ,prefered_rate
```

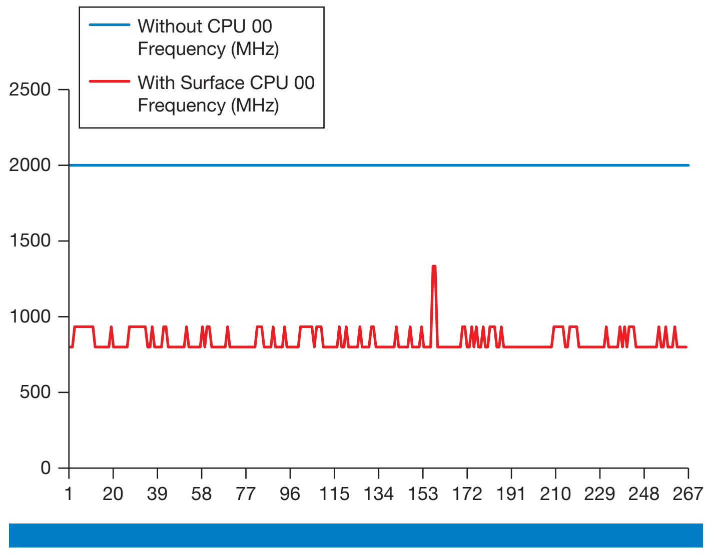


Figure 8: CPU Frequency Comparison for two kinds of MediaCodec configuration
(Source: Intel China Ltd., 2013)

```
     ,2/*CHANNEL_CONFIGURATION_MONO*/
,2/*ENCODING_PCM_16BIT */);
```

"If surface is not configured in MediaCodec, performance may be poor in some platform. That is caused by memory copy from GPU to CPU side. "

Configuring MediaCodec with a surface will get best performance. And it would be very poor if configuring without a surface. I have done a test for the two configurations. The test is decoding an MP4 file with full speed (full speed means decoding as quickly as possible without sound). Configuring a surface will perform two or three times faster than without a surface. The CPU frequency is also quite different. If configuring without a surface, the CPU will always run at the highest frequency, as shown in Figure 8.

The reason for the poor performance is that the hardware decoder must first output its raw buffer (a very large buffer; for HD film, the size is larger than 1920 1080 1.5) into a kernel buffer and then call function MapRawNV12 to change the buffer format from the private to nv12 (the buffer is configured without memory cache. On the new firmware version, it can be fixed); whereas if configuring with a surface, the hardware decoder will output its raw buffer directly into the GFX buffer and no format transform is needed. It is called "zero copy," and it will get the best performance.

"OpenGL is recommended for image post-processing on MediaCodec, SurfaceTexture can be used in this case. "

Unfortunately, now many developers use the slower solution. Most developers would transfer form FFmpeg software decoding into MediaCodec hardware decoding. With the inertial thinking, the developer would like to get the buffer and then swap the buffer into OpenGL (or use *surface_lock* in NDK). And some developers indeed have the requirement for getting the buffer in order to do some color enhancement or computer vision and image analysis.

There are two solutions to solve these problems. The first solution is to modify the MediaCodec interface to allow the developer to get the buffer even if they configure with a surface. That can be done by adding *GraphicBuffer* in *ACodec::PortDescription*. *ACodec* uses class *PortDescription* to pass the buffer to MediaCodec. The original design will hide *GraphicBuffer* so that the *MediaCodec* can't get buffer information of *NativeWindow* (*NativeWindow* is the internal call for surface).

"Surface image reader is added on Android 4.4. It is useful for video processing with CPU. The author has implemented a NativeMediaCodec which has the same function as Surface image reader on Android 4.2."

The two functions added in NativeMediaCodec are:

```
status_t LocalMediaCodec::GetOutputInfo(

        size_t index,
        uint8_t** pbuf,
        uint32_t *width,
        uint32_t *height,
        uint32_t *stride,
        int32_t *format,
        bool *needunlock) {

    BufferInfo *info = &mPortBuffers[kPortIndexOutput].editItemAt(index);
    if(info->mGraphicBuffer!=NULL){
       *width = info->mGraphicBuffer->getWidth();
       *height = info->mGraphicBuffer->getHeight();
       *stride = info->mGraphicBuffer->getStride();
       *format = info->mGraphicBuffer->getPixelFormat();

    info->mGraphicBuffer->lock(GraphicBuffer::USAGE_SW_READ_
OFTEN|GraphicBuffer::USAGE_SW_WRITE_OFTEN,(void**)pbuf);
        *needunlock = true;
    }
    else
    {
      *pbuf = mPortBuffers[kPortIndexOutput].itemAt(index).mData->base();
                  mOutputFormat->findInt32("color-format", format);
                  mOutputFormat->findInt32("width", (int32_t*)width);
                  mOutputFormat->findInt32("height", (int32_t*)height);
         *stride = *width;
         *needunlock = false;
    }

      return OK;
}

status_t LocalMediaCodec::UnLockBuffer(size_t index)
{
    BufferInfo *info = &mPortBuffers[kPortIndexOutput].editItemAt(index);
    if(info->mGraphicBuffer!=NULL){
      info->mGraphicBuffer->unlock();
    }
      return OK;
}
```

"The chart shows the performance of using NativeMediaCodec for video image real-time post-processing. NativeMediaCodec can't guarantee compatibility on all android platform, so Surface image reader is a good choice on Android 4.4"

A demo has been done by the author to verify the performance for this solution. It will use the function lock of class *GraphicBuffer* to get the buffer from the GFX driver and the function *getPixelFormat* to get the buffer color format.

It is important to note here: do not directly use the buffer. The GFX buffer is uncached and the access time is very slow by the CPU. So it is important to first do a *memcopy* operation to copy the memory from the GFX to general user space memory.

The CPU usage for 1080p WMV decoding is shown in Figure 9.

As the graphs show, if the *GraphicBuffer* and *memcopy* lock the GFX buffer to general user space memory, the performance will become a little poor. When

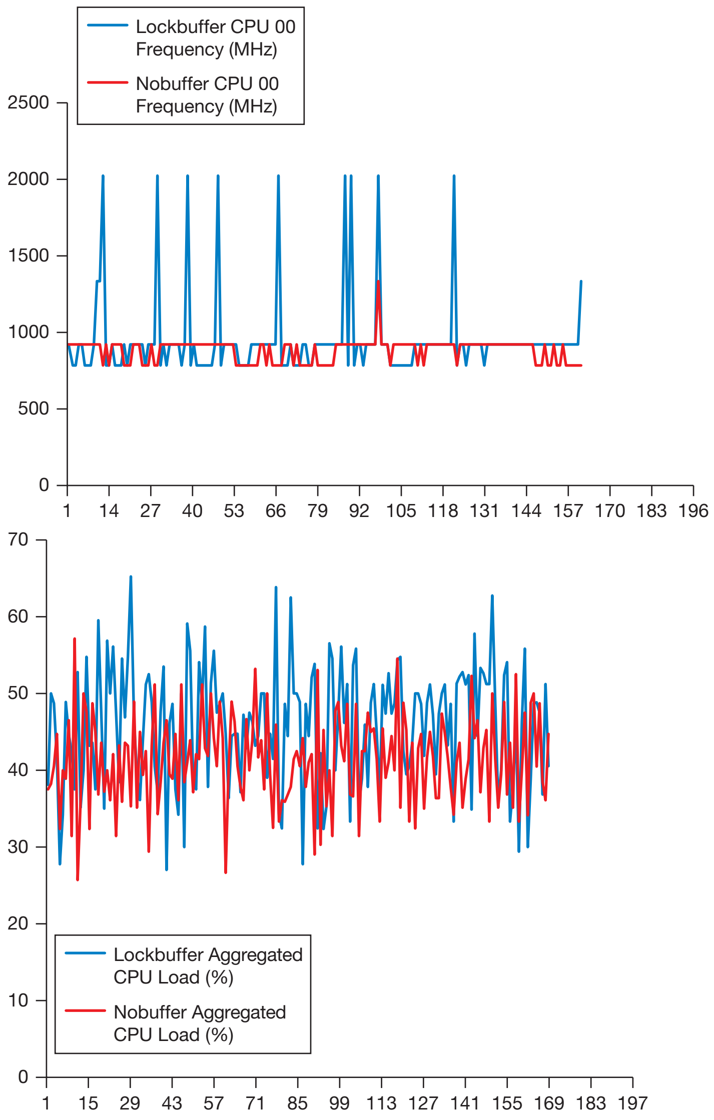


Figure 9: NativeMediaCodec performance comparison (buffer retrieval vs. no access buffer)
(Source: Intel China Ltd., 2013)

doing *memcopy*, CPU frequency will jump to the highest 2 GHz, and CPU usage will increase. But at least only two *memcopy* operations occur (one is from GFX to user space memory, the other is the opposite).

This solution is very simple for the developer. The developer uses MediaCodec just like FFmpeg. The developer can get the buffer and do the same as before with a small performance loss. Developers can implement their special multimedia application even though they do not know OpenGL and OpenCL.

The second solution will be much more complicated but efficient. Google has introduced "SurfaceTexture" from ICS. SurfaceTexture will add a mid-layer between decoder and surface. The decoder now will not render its content directly onto a surface. The content will now copy into a texture and the texture can be rendered by OpenGL. So now developers have another choice if they want to do image post-processing. They can configure MediaCodec with a SurfaceTexture and use OpenGL to do post-processing and use OpenCL to do general-purpose computing on graphics processing units. Although it is a little complicated, "zero copy" will bring out the best performance and for image processing, the GPU will perform much faster than the CPU.

The key code for this solution is listed here:

```
1. use GLES20.glGenTextures to get TextureID
GLES20.glBindTexture(GL_TEXTURE_EXTERNAL_OES,
TextureID);
2. mSurface = new SurfaceTexture(TextureID);
mSurface.setOnFrameAvailableListener(this);
3. when onFrameAvailable, call mSurface.
updateTexImage();
4. Use OpenGL to render SurfaceTexture
```

Summary

There are only two hardware acceleration technologies that can be used on the Android app layer: OpenGL and OpenMax. OpenGL includes GLSurfaceView and OpenGL-ES 1.0 and 2.0 in NDK; it is generally used as a renderer or for multimedia effects processing. OpenMax includes OpenMax-AL in NDK, MediaCodec, and OMX-IL (not Google code, it is implemented by the author). Each technology has a usage scenario and applicable Android version. Up until now, the popular Android versions have been 2.3 and 4.0, so I only cover the versions from Android 2.3 through Android 4.1.

OpenGL is complex but the usage scenario is relatively fixed (video effect and image processing), so I only list a summary of the usage of OpenMax in Table 6.

Android 4.1 MediaCodec is an important update for multimedia apps. It gives apps the ability to process images before encoding or after decoding. While on Android on Intel architecture, the greater advantage is that you can get this

Solution by author (app layer)	OMX-IL	OMX-AL	MediaCodec
2.3 audio			
2.3 video decode			
2.3 video encode	Codec(Intel architecture only)		
4.0 audio		Player (NDK only)	
4.0 video decode		Player (NDK only)	
4.0 video encode	Codec (Intel architecture only)		
4.1–4.2 audio			Codec
4.1–4.2 video decode			Codec
4.1–4.2 video encode	Codec (Intel architecture only)		Codec

Table 6: Summary of the usage of OpenMax
(Source: Intel China Ltd., 2013)

ability even before Android 4.1, and with hardware improvements, hardware acceleration can give better and better effects.

References

[1] VideoLAN: A project and a non-profit organization composed of volunteers, developing and promoting free, open-source multimedia solutions. URL: http://www.videolan.org/vlc/

[2] FFMPEG: a complete, cross-platform solution to record, convert and stream audio and video. URL: http://ffmpeg.org/

[3] Intel Architecture Software Developer's Manual, Volume 2: Instruction Set Reference Manual, Intel Corporation (Order Number 243191)

[4] OpenMAX: OpenMAX™ is a royalty-free, cross-platform multimedia API. URL: http://www.khronos.org/openmax/

[5] OpenMAX IL 1.1.2 Specification, 2008

Appendix A

How to compile tewilove_faplayer x86 version:

1. Modify vlc_fixups.h, delete __cplusplus; it will lead to a compiling problem.
2. Modify \jni\vlc\config.h, and add the macro defined as follows:

```
#define CAN_COMPILE_MMX  1
#define CAN_COMPILE_MMXEXT 1
#define CAN_COMPILE_SSE 1
#define CAN_COMPILE_SSE2 1
#define asm __asm__
```

```
#define MODULE_NAME_IS_i422_yuy2_sse2
#define MODULE_NAME_IS_i420_yuy2_sse2
#define MODULE_NAME_IS_i420_rgb_sse2
```

3. Modify libvlcjni.h, delete yuv2rgb; it's ARM NEON code
4. Modify Application.mk:

```
APP_ABI := x86
BUILD_WITH_NEON := 0
OPT_CPPFLAGS += -frtti –fexceptions
```

5. Delete Android.mk in ext\ffmpeg; we must replace it with the x86 FFmpeg version.

How to build ffmpeg x86 libs:

```
#!/bin/bash

NDK=$ANDROID_NDK_ROOT  #your ndk root path

PLATFORM=$NDK/platforms/android-14/arch-x86

PREBUILT=$NDK/toolchains/x86-4.4.3/prebuilt/
linux-x86

function build_one

{

./configure --target-os=linux \
    —prefix=$PREFIX \
    —enable-cross-compile \
    —extra-libs="-lgcc" \
    —arch=x86 \
    —cc=$PREBUILT/bin/i686-android-linux-gcc \
    —cross-prefix=$PREBUILT/bin/i686-android-
linux- \
    —nm=$PREBUILT/bin/i686-android-linux-nm \
    —sysroot=$PLATFORM \
    —extra-cflags=" -O3 -fpic -DANDROID -DHAVE_SYS_
UIO_H=1
-Dipv6mr_interface=ipv6mr_ifindex -fasm -Wno-psabi
-fno-short-enums -fno-strict-aliasing -finline-
limit=300 $OPTIMIZE_CFLAGS " \
    —disable-shared --enable-static \
    —extra-ldflags="-Wl,-rpath-link=$PLATFORM/usr/
lib
-L$PLATFORM/usr/lib -nostdlib -lc -lm" \
—disable-ffplay --disable-avfilter --disable-
avdevice
—disable-ffprobe \
—enable-asm \
—enable-yasm \
$ADDITIONAL_CONFIGURE_FLAG

make clean
make  -j4 install
}

#x86
CPU=x86
OPTIMIZE_CFLAGS="-march=atom -ffast-math -msse3
-mfpmath=sse"
PREFIX=./android/$CPU
ADDITIONAL_CONFIGURE_FLAG=
build_one
```

After running this script, you can get libavcode.a, libavformat.a, libavutil.a, and libswscale.a; link these libraries to your project as a prelink static library.

Appendix B

Improve the FFMpeg yuv2rgb function from MMX2 to SSE.

Because MMX is 8-bit aligned and SSE is 16-bit aligned, first you must enlarge the data to 16 bits:

1. Modify *swscale_internal.h* and *yuv2rgb_mmx.c*.

```
DECLARE_ALIGNED(8, uint64_t, redDither);

==>

DECLARE_ALIGNED(16, uint64_t, redDither);

DECLARE_ALIGNED(8, uint64_t, redDither1);

DECLARE_ASM_CONST(16, uint64_t, mmx_redmask) =
0xf8f8f8f8f8f8f8f8ULL;

==>

DECLARE_ASM_CONST(8, uint64_t, mmx_redmask1) =
0xf8f8f8f8f8f8f8f8ULL;

DECLARE_ASM_CONST(16, uint64_t, mmx_redmask) =
0xf8f8f8f8f8f8f8f8ULL;
```

2. Now *redDither* and *mmx_redmask* can be used as 8-bit data or 16-bit data.
3. Change the *mov* and *mm* instruction.

```
#if HAVE_SSE2

     #define MM1 "%xmm"
     #define MM "%%xmm"
     #define MOVD "movq"
     #define MOVQ "movups"
     #define MOVNTQ "movntps"
     #define SFENCE "sfence"
     #define SIMD8 "16"

#else
#if HAVE_MMX2
     #define MM1 "%mm"
     #define MM "%%mm"
     #define MOVD "movd"
     #define MOVQ "movq"
     #define MOVNTQ "movntq"
     #define SFENCE "sfence"
     #define SIMD8 "8"
     #endif
```

4. MMX uses the *mm* register while SSE uses the *xmm* register. Because SSE has 128-bit data length (16 bytes), the data offset is 16 when using SSE (SIMD8 is 16).
5. RGB_PACK24 must be rewritten due to the different data length.

```
DECLARE_ASM_CONST(16, uint8_t, rmask1[16]) =
{0x00,0x80,0x80,0x01,0x80,0x80,0x02,0x80,0x80,0x03,
0x80,0x80,0x04,0x80,0x80,0x05};
...
MOVQ"       "MM""red",      "MM"5 \n"\
"pshufb      "MANGLE(rmask1)",    "MM"5 \n"\
MOVNTQ"     "MM"5,           (%1) \n"\
```

I just copy the key code. Here I use *pshufb*; the key idea is using *pshufb* to put each R, G, and B value to right place, and use *por* to get RGB888 data.

Appendix C

The following is the code for a cross-compile script:

```
#!/bin/bash

HOSTCONF=x86
BUILDCONF=i686-pc-linux-gnu
NDK=$ANDROID_NDK_ROOT

TOOLCHAIN=$NDK/toolchains/x86-4.4.3/prebuilt/
linux-x86
PLATFORM=$NDK/platforms/android-14/arch-x86
PREFIX=/home/lym/libjpeg-turbo-1.2.1/android/x86
ELF=$TOOLCHAIN/i686-android-linux/lib/ldscripts/
elf_i386.x
```

```
export ARCH=x86
export SYSROOT=$PLATFORM
export PATH=$PATH:$TOOLCHAIN/bin:$SYSROOT
export CROSS_COMPILE=i686-android-linux
export CC=${CROSS_COMPILE}-gcc
export CXX=${CROSS_COMPILE}-g++
export AR=${CROSS_COMPILE}-ar
export AS=${CROSS_COMPILE}-as
export LD=${CROSS_COMPILE}-ld
export RANLIB=${CROSS_COMPILE}-ranlib
export NM=${CROSS_COMPILE}-nm
export STRIP=${CROSS_COMPILE}-strip
export CFLAGS="-I$PLATFORM/usr/include -O3
-nostdlib -fpic
-DANDROID -fasm -Wno-psabi -fno-short-enums
-fno-strict-aliasing -finline-limit=300 -fomit-
frame-pointer -march=i686 -msse3 -mfpmath=sse"
export CXXFLAGS=$CFLAGS
export LDFLAGS="-Wl,-T,$ELF

-Wl,-rpath-link=$PLATFORM/usr/lib -L$PLATFORM/usr/
lib -nostdlib -lc -lm"

./configure  --enable-shared --host=$HOSTCONF
—build=$BUILDCONF  --with-sysroot=$SYSROOT
—prefix=$PREFIX

make clean

make  -j4 install
```

If an open source has a configure file, generally it can use cross-compiling for Android. I give a common script for the x86 platform. It's a script that I use for *libjpeg-turbo*. It uses SSE to optimize JPEG encoding and decoding.

Benefitting from the long history of the x86 platform, actually nearly all open source has done good optimization on the x86 platform, especially in the multimedia category. A large number of arithmetic functions have been written to SIMD code (FFmpeg , vp8, x264, OpenCV). What you need is to choose the right source and use the right compiling script.

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INTRODUCTION TO GRAPHICS AND MEDIA RESOURCES IN ANDROID*

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Modern mobile apps and operating systems need to take full advantage of graphics hardware. With smooth animation and rich graphics, mobile apps are more intuitive and responsive. This article explores mobile GPUs and provides direction on maximizing graphical acceleration on Android devices. It covers basic mobile GPU concepts and hardware shipping with Intel® Atom™ processors. Then it examines OpenGL ES support, performance, and features for use with 3D graphics. Lastly, it shows how to use Scalable Vector Graphics (SVG) libraries to render resolution-independent 2D graphics. By combining the techniques and knowledge shared in this article, developers will be able to create apps that are more graphically rich, scalable, and that maximize the performance of Android devices.

Understanding Mobile GPUs

It's important to understand how mobile GPUs are evolving.

Originally, mobile devices used software rasterization to generate the final image on the screen. However, the CPU was overtaxed performing rasterization and all the other tasks involved in a modern OS. In Android, the CPU is performing numerous background tasks, handling I/O, and running applications. Combine this with Android's numerous graphical animations and effects used to convey intuitive UI response, and the need for a GPU is apparent.

"…Android's numerous graphical animations and effects used to convey intuitive UI response, and the need for a GPU is apparent."

The Intel Atom processor is designed to maximize performance and battery life on a mobile device. Just as the Intel Atom processor's CPU is specially designed for mobile devices, so is its GPU. A lot of the initial GPU design came from OpenGL* ES.

OpenGL was designed to be run on a desktop. It supports numerous features that are not necessary on a mobile device, such as scientifically accurate operations and high-bit precision. To support full OpenGL on a device would require a lot of extra hardware. That extra hardware takes precious space and power. Enter OpenGL ES. OpenGL ES was designed for mobile devices and removes a lot of the OpenGL features not needed for mobile devices.

OpenGL ES 1.1 only supports fixed function pipelines. As such, GPU designers targeting OpenGL ES 1.1 can create very simple special-purpose GPUs. As mobile devices evolved, this limitation was holding back modern graphical techniques. OpenGL ES was extended to support a programmable pipeline (that is, shaders) with OpenGL ES 2.0. This evolution allowed much more complex visuals included in modern 3D games. However, it also required GPUs to become much more complex.

OpenGL ES 2.0 is the predominate graphics API, but the story doesn't end here. OpenGL ES 3.0 was just released and it brings the possibility of even more complex and visually impressive techniques.

Major Mobile GPU Designs

There are currently two major designs being used by mobile GPUs: deferred and immediate. Deferred mode GPUs wait until all commands for an individual frame are submitted before processing the work. An immediate mode GPU starts working on commands as soon as they are ready. Table 1 shows major GPU vendors and their GPU design type.

"There are currently two major designs being used by mobile GPUs: deferred and immediate."

GPU	Type
Intel® HD Graphics	Immediate
AMD Radeon*	Immediate
NVIDIA GeForce*	Immediate
NVIDIA Tegra*	Immediate
Qualcomm Adreno*	Immediate/Deferred
Imagination Technologies PowerVR*	Deferred
ARM Mali*	Deferred

Table 1: Major GPU Vendors and Their GPU Design Types
(Source: Intel Corporation, 2013)

Advantages of Deferred Mode GPUs

A deferred mode GPU has several major advantages. First, data sent to the GPU can be better organized. This can result in significantly decreased memory bandwidth. Memory usage is a major consumer of power, so limiting memory bandwidth will result in significant power gains.

Since all the data to render the frame is known, the work can be easily divide into smaller chunks. PowerVR is actually referred to as a *deferred tile-based render*. This is because the GPU collects all the commands/data to generate a frame and then divides the work into small *tiles*. A tile is just a square collection of pixels. This collection of pixels is designed to fit into very high-speed caches. If you want to learn more about all the advantages of PowerVR's design, please refer to their documentation.[1]

Deferred rendering does have several limitations. The internal memory and cache on the GPU can only be so big. If a frame has too much data to be rendered, the work needs to be divided among multiple rendering passes. This redundancy results in a lot of overhead and wasted operations. A lot of the optimization tricks for deferred mode GPUs involve avoiding these "glass jaws."

A Note about Defining "Deferred"

The term *deferred* is very overloaded in computer graphics. There are many terms like deferred mode GPUs, deferred renders, deferred shading, deferred lighting, and deferred rasterization. To make it even more challenging, the definitions are not consistent and must be taken in context. Don't confuse a deferred mode GPU with deferred rendering techniques. In general, deferred rendering techniques refer to accumulating scene data into a g-buffer and applying lighting/shading in screen space.

Advantages of Immediate Mode GPUs

Immediate mode GPUs have been the predominant desktop design for decades. A lot of rendering techniques, tricks, and optimizations have been designed around immediate mode rendering. As such, immediate mode GPUs have become very complex and capable.

"A lot of rendering techniques, tricks, and optimizations have been designed around immediate mode rendering. As such, immediate mode GPUs have become very complex and capable."

Since an immediate mode rendering starts processing commands as soon as they are ready, simple tasks can be completed more quickly and efficiently on immediate mode GPUs. Furthermore, they don't run into as many "glass jaws" based on the amount of data passed to the GPU.

However, the years of design for immediate mode GPUs targeted desktops with massive power supplies. This has resulted in designs that maximized performance at the cost of power. This is why deferred mode renders have dominated the mobile market. But research and development in immediate mode GPUs have been driving down power utilization rapidly; this can be seen in Intel HD Graphics included in Intel® Core™ processors.

The Intel Graphics Developer's Guide provides the best information for target Intel® HD Graphics.[2]

Understanding OpenGL ES

The standard API for 3D graphics on Android is OpenGL ES, which is the most widely used 3D graphics API on all mobile devices today. Android uses OpenGL ES to accelerate both 2D and 3D graphics. In early releases of Android, OpenGL ES acceleration was somewhat optional, but as Android has evolved and screen sizes have grown, accelerated OpenGL ES has become an essential part of the Android graphics system.

"…as Android has evolved and screen sizes have grown, accelerated OpenGL ES has become an essential part of the Android graphics system."

There are several major versions of OpenGL ES. OpenGL ES 1.0 and 1.1 have always been supported in Android. OpenGL ES 2.0 was added in Android 2.2. OpenGL ES 3.0 was just recently added with Android 4.3. Today, Android developers can choose to use any version.

Extensions to OpenGL ES

The OpenGL ES feature set is required to be mostly the same across platforms by the Khronos standard documents that define OpenGL ES 1.1, 2.0, and 3.0. That is the purpose of a standardized API. However, GPU developers are permitted to expose special features of their GPU through extensions to OpenGL ES. Khronos maintains an official online registry for OpenGL ES extensions.[3]

The most important extensions to OpenGL ES are available on most Android platforms, such as support for compressed textures and direct texture streaming, but many different formats for compressed textures are in use today with OpenGL ES.

Compressing textures is an important technique for 3D applications to reduce their memory requirements and improve performance, but the various formats in use are defined only by extensions and therefore vary for each platform. The most widely supported format is Ericsson Texture Compression (ETC1_RGB8), but it only supports 8-bit-per-pixel precision and has no support for per-pixel alpha.

"Compressing textures is an important technique for 3D applications to reduce their memory requirements and improve performance,…"

Android applications should never assume that any particular extension to OpenGL ES is available on any particular device. Instead, well-behaved apps will query OpenGL ES for a list of available extensions at runtime. The extension lists can be obtained from the OpenGL ES and EGL drivers with these calls:

```
glGetString(GL_EXTENSIONS);
eglQueryString(eglGetCurrentDisplay(), EGL_
EXTENSIONS);
```

Realtech VR's OpenGL Extensions Viewer app is a useful tool that will perform this query and display the returned list for any Android device.[4]

The OpenGL ES extensions that are available for Android vary significantly based upon the GPU, not because of differences in the CPU architecture. For example, the PowerVR supports exclusive extensions to OpenGL ES such as:

```
glFramebufferTexture2DMultisampleIMG()
glRenderbufferStorageMultisampleIMG()
```

Of course, using these exclusive extensions will limit the portability of your application to Android devices with PowerVR cores. As extensions become popular, more and more GPU companies will adopt them. If an extension is generally supported by most GPUs, it will often be added to the next OpenGL ES specification.

"As extensions become popular, more and more GPU companies will adopt them."

Accessing OpenGL ES through the Android SDK

The Android SDK offers the easiest way to use OpenGL ES in your Android application by using the GLSurfaceView class. This class handles most of the initialization of the EGL, threading, and allocating a surface that OpenGL ES can render to and that Android can display. OpenGL ES can also render to a TextureView object that has some additional capabilities, like transformations and alpha blending, but requires more code to set up and use. The Android SDK provides support for OpenGL ES through bindings for Java* in these packages from Google and Khronos:

- javax.microedition.khronos.egl: The Khronos standard implementation
- javax.microedition.khronos.opengles: The Khronos standard implementation
- android.opengl: Android's API updated to provide better performance

The three versions of the OpenGL ES API that can be used today on Android are: 1.1, 2.0, and 3.0. OpenGL ES 1.0 was superseded by 1.1. OpenGL ES 2.0 offers greater flexibility through shader programming, but is not compatible with legacy code written for OpenGL ES 1.1. Table 2 summarizes the versions of the OpenGL ES API that can be used for application development and the classes that define them for Android.

OpenGL ES 1.0	android.opengl.GLES10
OpenGL ES 1.0	android.opengl.GLES10Ext
OpenGL ES 1.1	android.opengl.GLES11
OpenGL ES 1.1	android.opengl.GLES11Ext
OpenGL ES 2.0	android.opengl.GLES20
OpenGL ES 3.0	android.opengl.GLES30

Table 2: OpenGL ES Support Classes in Android
(Source: Intel Corporation, 2013)

"The Intel Atom processor platform for Android provides full support for applications that use any of these versions of OpenGL ES through either the SDK or the NDK…"

The Intel Atom processor platform for Android provides full support for applications that use any of these versions of OpenGL ES through either the SDK or the NDK (OpenGL ES 3.0 requires a device with Android 4.3 or newer).

Accessing OpenGL ES through the Android NDK

The Native Development Kit (NDK) was developed by Google to help developers achieve better performance in their Android applications by bypassing the Dalvik VM and running C/C++ code natively. Google decided to make the NDK available to all Android developers because it simplifies the process of porting existing applications written in C/C++ and allows the best possible performance in applications that need it the most, like 3D games.

The Android NDK supports all versions of OpenGL ES and provides several example apps. Most applications using OpenGL ES are written in C/C++, and the NDK provides a mechanism for combining C/C++ code with an Android framework, which is based on Java. This is called the Java Native Interface (JNI) and it's becoming the dominate approach for implementing apps that require fast graphics on Android. The NDK supports the JNI for Intel Atom processors beginning with release r6b.[5]

Accessing OpenGL ES through RenderScript

"RenderScript is designed to exploit multiple processors,…"

RenderScript was first introduced in Android 3.0. It is another technology that Google developed to help accelerate computationally intensive algorithms, including graphics, by bypassing the Dalvik VM. But, unlike the NDK, RenderScript code is compiled at runtime on the Android device. RenderScript is designed to exploit multiple processors, but it initially only utilizes the processing cores available on the CPU. As of Android 4.2, RenderScript has been improved to utilize the GPU in addition to the CPU.

RenderScript abstracts the hardware it runs on so that app developers need not be concerned about the CPU and GPU architecture or even how many processors are actually available. RenderScript is a new language based on C99 with support for OpenGL ES built in. RenderScript's abstraction guarantees that it will run on any Android device, including Intel Atom processors.[6]

Optimizing for Intel GPUs

As shown in Table 3, Intel Atom processors designed for Android use either PowerVR GPUs or Intel HD Graphics.

Intel® Atom™ Processor Series	GPU Core
Z2760	PowerVR SGX 545
Z2560/Z2580	PowerVR SGX 544MP2
Bay Trail	Intel® HD Graphics (Gen 7)

Table 3: Intel Atom Processors Designed for Android Use and Their GPUs. (More details about individual processors can be found at ark.intel.com.) (Source: Intel Corporation, 2013)

Optimizing for PowerVR

It's important to refer to Imagination Technologies' documentation on PowerVR. General optimization tips and tricks provided by Imagination Technologies are just as important on Intel platforms as other platforms with PowerVR.

To get a good understanding of the PowerVR hardware, please review Imaginations Technologies' architecture guide.[7]

To get a good understanding of how to optimize for PowerVR hardware, please review Imaginations Technologies' developer recommendations.[8]

Pay close attention to the "golden rules."

Optimizing for Intel® HD Graphics

The Intel Graphics Developer's Guide provides the best information on optimizing for Intel HD Graphics.[9]

"The Intel Graphics Developer's Guide provides the best information on optimizing for Intel HD Graphics."

When targeting mobile GPUs, the optimization advice is very similar between platforms. In most cases, the optimizations suggests for PowerVR and Intel HD Graphics are very inclusive.

There are numerous tools, case studies, article, and tech samples for Intel HD Graphics available on the Visual Computing Source.[10]

Intel® Graphics Performance Analyzer

The Intel® Graphics Performance Analyzers (Intel® GPA) suite is a set of powerful graphics and gaming analysis tools. It helps save valuable optimization time by quickly providing actionable data to help developers find performance opportunities from the system level down to the individual draw call.

To download a free copy of Intel GPA, browse to the Intel GPA homepage.[11]

Texture Compression

"Proper texture compression will decrease download sizes, improve visual quality, increase performance, and decrease impact on memory bandwidth."

It's important to use good texture compression on mobile devices. Proper texture compression will decrease download sizes, improve visual quality, increase performance, and decrease impact on memory bandwidth. However, this is one of the biggest challenges on Android. Since Android supports a wide range of hardware, there isn't one texture format that runs well on all devices. OpenGL ES 2.0 only requires that the hardware supports ETC texture compression. Sadly, this format doesn't support an alpha channel. So developers are forced to support multiple texture formats.

For PowerVR, developers should use PVRTC to compress all textures. For Intel HD Graphcis, developers should use DXT to compress all textures. To reach all platforms, it's best to generate both PVRTC and DXT textures. The inclusion of two texture formats will increase the overall app size. If this is a concern, Google Play allows separate APKs to be uploaded based on OpenGL ES texture formats.

Understanding the Scalable Vector Graphics Library

Scalable Vector Graphics* (SVG) is a family of specifications of an XML-based file format for two-dimensional vector graphics, both static and dynamic (that is, interactive or animated), text or embedded raster graphics. The SVG specification is a royalty-free vendor-neutral open standard that has been under development by the World Wide Web Consortium* (W3C) since 1999.

"SVG images and their behaviors are defined in XML text files. This means that they can be searched, indexed, scripted and, if required, compressed."

SVG images and their behaviors are defined in XML text files. This means that they can be searched, indexed, scripted and, if required, compressed. As XML files, SVG images can be created and edited with any text editor.

SVG files are compact and provide high-quality graphics on the Web, in print, and on resource-limited handheld devices. In addition, SVG supports scripting and animation, so is ideal for interactive, data-driven, personalized graphics.

Using SVG has many benefits. First, you don't need to have pictures in different resolutions, no need to scale. Second, SVG is an XML file, so its size is much smaller than the raster size format for the same image. This also helps to change the picture on the fly.

SVG allows three types of graphic objects: vector graphics, raster graphics, and text. Graphical objects, including PNG and JPEG raster images, can be grouped, styled, transformed, and composited into previously rendered objects.

Native Android applications do not support SVG XML files. But SVG XML files could be parsed in browsers starting with Android 3.0 (see Figure 1). This chapter integrates the SVG-Android open source library into codebase and provides an example application on Intel® architecture Android Ice Cream Sandwich (ICS).

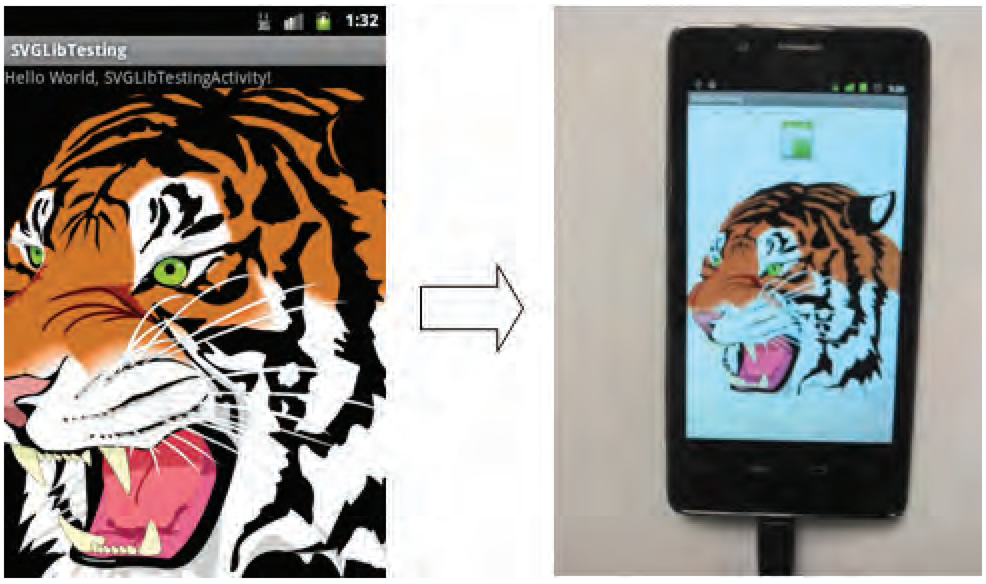


Figure 1: SVG Implementation on Android Device
(Source: Intel Corporation, 2013)

SVG Functionality

The SVG 1.1 specification defines 14 functional areas of feature sets, which are:

- Paths
- Basic shapes
- Text
- Painting
- Color
- Gradients and patterns
- Clipping, masking, and compositing
- Filter effects
- Interactivity
- Linking
- Scripting
- Animation
- Font
- Metadata

SVG Shapes

SVG's predefined shape elements are:

- Rectangle `<rect>`

```
<svg>
```

```
   <rect x="50" y="20" width="150" height="150"
style="fill: red;
stroke: yellow; stroke-width: 5; opacity: 0.5" />
   </svg>
```

- Circle <circle>

```
   <svg >
   <circle cx="100" cy="50" r="40" stroke="black"
stroke-width="2" fill="red" />
   </svg>
```

- Ellipse `<ellipse>`
- Line `<line>`
- Polyline `<polyline>`
- Polygon `<polygon>`
- Path `<path>`

```
      <svg xmlns="http://www.w3.org/2000/svg"
version="1.1">
      <path d="M150 0 L75 200 L225 200 Z" />
      </svg>
```

SVG Library Integration

Create a file named svgandroid.xml to describe svgandroid.jar. Place svgandroid.jar in /system/framework folder and svgandroid.xml in the /etc/permissions folder. Applications will discover the svgandroid.jar library through svgandroid.xml.

Put the following code into the svgandroid.xml:

```
<?xml version="1.0" encoding="utf-8">
<permissions>
<libraryname="svgandroid"
file="/system/framework/svgandroid.jar"/>
</permissions>
```

Use the <use-library> declaration in the AndroidManifest.xml file. This method loads the svgandroid packages. They will not be loaded automatically.

```
<uses-library android:name="svgandroid"
android:required="true" />
```

Set android:required="true". The Android system would not permit an application on a device without this library.

If this application is installed on Android devices without this library, the following error message occurs:

```
Failure [INSTALL_FAILED_MISSING_SHARED_LIBRARY]
```

This element also affects the availability of the application on Market. The Android device could not list this application on Market without the library.

Render a File Using Revised SVG

This section shows how to render a file using revised SVG.

What Is SAX?

SAX (Simple API for XML) is an event-based sequential access parser API generated by the XML-DEV mailing list for XML documents. SAX's mechanism for reading data from an XML document is very different than the one provided by the Document Object Model (DOM). Where the DOM operates on the document as a whole, SAX parsers operate on each piece of the XML document.

Benefits of SAX

SAX parsers have certain benefits over DOM-style parsers. A SAX parser typically uses much less memory than a DOM parser. DOM parsers must have the entire tree in memory before any processing can begin, so the amount of memory used by a DOM parser depends entirely on the size of the input data. The memory footprint of a SAX parser, by contrast, is based only on the maximum depth of the XML file (the maximum depth of the XML tree) and the maximum data stored in XML attributes on a single XML element. Both of these are always smaller than the size of the parsed tree itself.

Because of the event-driven nature of SAX, processing documents can often be faster than DOM-style parsers. Memory allocation takes time, so the larger memory footprint of the DOM is also a performance issue.

"Because of the event-driven nature of SAX, processing documents can often be faster than DOM-style parsers."

Due to the nature of DOM, streamed reading from disk is impossible. Processing XML documents larger than main memory is also impossible with DOM parsers, but can be done with SAX parsers. However, DOM parsers can make use of disk space as memory to sidestep this limitation.

Drawbacks

The event-driven model of SAX is useful for XML parsing, but it does have certain drawbacks.

Certain kinds of XML validation require access to the document in full. For example, a DTD IDREF attribute requires that there be an element in the document that uses the given string as a DTD ID attribute. To validate this in a SAX parser, one would need to keep track of every previously encountered ID and IDREF attribute to see if any matches are made. Furthermore, if an IDREF does not match an ID, the user only discovers this after the document has been parsed. If this linkage was important to building functioning output, then time has been wasted in processing the entire document only to throw it away.

Additionally, some kinds of XML processing simply require having access to the entire document. XSLT and XPath, for example, need to be able to access any node at any time in the parsed XML tree. While a SAX parser could be used to construct such a tree, the DOM already does so by design.

How to Implement the SAX Parser in Android

When implementing the SAX parser, the class needs to inherit *DefaultHandler*. And there are a few methods that need to be overridden when inheriting the DefaultHandler default base class for SAX2 event handlers in Android. These methods include startElement, endElement, startDocument, and endDocument. You can easily see what each function does by its name. For example, startDocument means when the SAX starts to parse the document, it will trigger the event and call the startDocument method. Once the SAX parses any tag of XML file, it will call startElement, so you can get the tag name, attribute, and some other information relevant to the tag. The other methods, endDocument, startElement, and endElement, are self-explanatory.

Why Revise the Original SVG Library?

Since the original library can't render the SVG file with attributes in the group tag (`<g>`), we must add a register to store the style attribute with a `<g>` tag. If there is already a style attribute in the inner render element, the style attribute will replace the one in the `<g>` tag.

We recommend using SAX to parse the SVG file. When we parsing the `<g>` tag, we retrieve the entire attribute into the instance –*g_prop*, which is an internal class of the properties.

```
public void startElement(String namespaceURI,
String localName, String qName, Attributes atts)
throws SAXException
{
......
      }
      else if (localName.equals("g"))
      {
            ......
            pushTransform(atts);
            g_prop = new Properties(atts);
      }
      ......
}
```

```
public void startElement(String namespaceURI,
String localName, String qName, Attributes atts)
throws SAXException
{
      ......
      }
      else if (localName.equals("g"))
      {
            ......
            pushTransform(atts);
            g_prop = new Properties(atts);
```

```
     }
     ......
}
```

When we parse the `<rectangle>`, `<path>`, or any other rendering tags, we need to check to see whether any style is associated with the tag. If there is, we need to get the attributes. The methods doFill and doStroke help to initiate the style of fill and stroke of the canvas. After these methods are invoked, we can draw the parsed element onto the canvas.

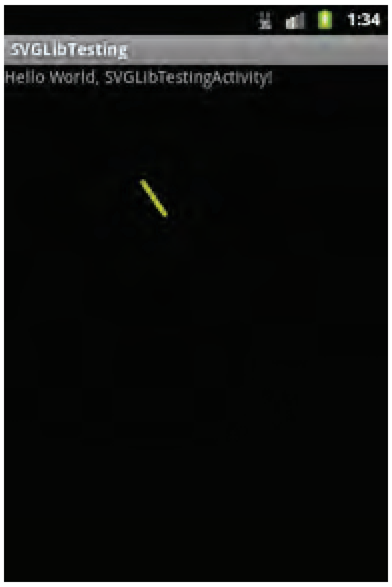
```
Properties props = new Properties(atts);
if (doFill(props, gradientMap))
{
     doLimits(p);
     canvas.drawPath(p, paint);
}
else
{
     if(g_prop != null)
     {
          if(doFill(g_prop, gradientMap))
          {
               doLimits(p);
               canvas.drawPath(p, paint);
          }
     }
}

if (doStroke(props))
{
     canvas.drawPath(p, paint);
}
else
{
     if(g_prop != null)
     {
          if(doStroke(g_prop))
          {
               canvas.drawPath(p, paint);
          }
     }
      popTransform();
}

Properties props = new Properties(atts);

if (doFill(props, gradientMap))
{
        doLimits(p);
        canvas.drawPath(p, paint);
}
else
{
        if(g_prop != null)
        {
                if(doFill(g_prop, gradientMap))
                {
                        doLimits(p);
                        canvas.drawPath(p, paint);
                }
        }
}

if (doStroke(props))
{
        canvas.drawPath(p, paint);
}
else
{
        if(g_prop != null)
        {
                if(doStroke(g_prop))
                {
                        canvas.drawPath(p, paint);
                }
        }
        popTransform();
}
```



Hello World, SVGLibTestingActivity!

Figure 2: SVG Implementation on an Android Device (Source: Intel Corporation, 2013)

SVG XML File with Attributes in the Rendering Tag

The following is an SVG XML file with attributes in the rendering tag (see Figure 2).

```
<path display="none" fill="#FFFFFF"
d="M268.461,471.01c2.526,0,4.575,2.048,4.575,
4.571c0,2.529-2.049,4.576-4.575,4.576
c-2.525,0-4.574-2.047-4.574-4.576C263.887,473.058,
265.936,471.01,268.461,471.01z"/>
```

SVG XML File with Attributes in the Group Tag

The following is an SVG XML file with attributes in the group tag (see Figure 3).

```
<g style="fill: #ffffff; stroke:#000000; stroke-
width:0.172">
```

```
<path d="M-122.304 84.285C-122.304 84.285 -122.203
86.179 -123.027 86.16C-123.851 86.141 -140.305
38.066 -160.833 40.309C-160.833 40.309 -143.05
32.956 -122.304 84.285z"/>
</g>
```

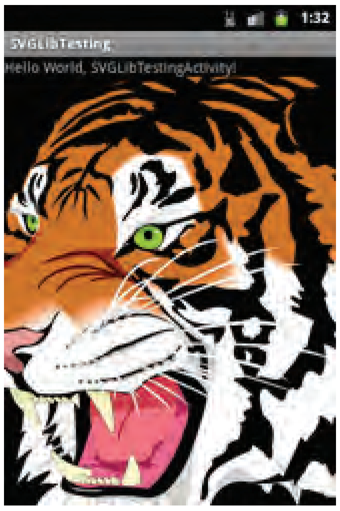


Figure 3: SVG Implementation on an Android Device (Source: Intel Corporation, 2013)

Conclusion

This article provided a brief overview of mobile GPUs and how to best optimize for GPUs included with Intel Atom processors. To create intuitive, responsive, and engaging apps, it's important to understand and master graphical acceleration on Android.

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Orion Granatir works as a senior software engineer in Intel's Personal Form Factor team, a fancy name for "Orion works on mobile video games at Intel." Most of his current work focuses on optimizing for the latest Intel technology (Intel Atom, Intel SSE/AVX, multithreading, processor graphics, and so on). While in this role, Orion has presented at GDC 2008, Gamefest 2008, GDC Online 2008, GDC 2009, GDC 2010, GDC 2012, GDC 2013, and IDF.

Orion is a content tourist and generally beats four or more video games a month. Orion holds a BS in Computer Science from Oregon State University.

Clay D. Montgomery is a leading developer of drivers and apps for OpenGL on embedded systems. His experience includes the design of graphics accelerator hardware, graphics drivers, APIs, and OpenGL applications across many platforms at STB Systems, VLSI Technology, Philips Semiconductors, Nokia, Texas Instruments, AMX, and as an independent consultant. He was instrumental in the development of some of the first OpenGL ES, OpenVG, and SVG drivers; applications for the Freescale i.MX and TI OMAP platforms; and the Vivante, AMD, and PowerVR graphics cores. He has developed and taught workshops on OpenGL * ES development on embedded Linux and represented several companies in the Khronos Group. He is currently a Senior Graphics Firmware Engineer at AMX, LLC.

INTRODUCTION TO INTEL® INTEGRATED PERFORMANCE PRIMITIVES FOR ANDROID* WITH A CASE STUDY

Contributor

Zhen Zhou,
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"Intel® IPP for Android is a software library that provides a comprehensive set of application domain-specific highly optimized functions for Android applications. "

The Intel® Integrated Performance Primitives (Intel® IPP) for Android is a software library that provides a comprehensive set of application domain-specific highly optimized functions for the development and optimization of Android applications. Intel IPP is included both in Intel® System Studio for Android (ISS-A) and in Intel's beta development environment for native Android applications, codenamed Beacon Mountain, supporting application development for various Intel® architectures. By providing a single cross-architecture application programmer interface, Intel IPP permits software application repurposing and enables developers to port to unique features across Intel processor-based desktop, server, mobile, and handheld platforms. Use of the Intel IPP functions can help drastically reduce development costs and accelerate time-to-market by eliminating the need of writing processor-specific code for computation intensive routines.

This article provides an overview of the architecture of Intel IPP for Android, containing signal processing, image and video processing, operations on small matrices, three-dimensional (3D) data processing, and rendering. The author also discusses Intel IPP for Android as a newly added part of ISS-A and Beacon Mountain. Several examples are given to show how to use Intel IPP on Android for applications development and how the performance is improved by Intel IPP. These examples include not only the traditional Intel IPP samples but also OpenCV-based applications on Android.

Introduction to Intel® IPP

Intel Integrated Performance Primitives (Intel IPP) is an extensive library of software functions to help you develop multimedia, data processing, and communications applications for Windows*, Linux*, Mac OS* X, and Android environments. These functions are highly optimized using Intel® SSE and Intel® AVX instruction sets, which often outperform what an optimized compiler can produce alone. Because Intel has done the engineering on these ready-to-use, royalty-free functions, you'll not only have more time to develop new features that differentiate your application, but in the long run you'll also save development, debug, and maintenance time while knowing that the code you write today will run optimally on future generations of Intel processors.

The Latest Intel® IPP Version 8.0

Intel IPP 8.0 is the first step toward an updated vision for the product. This includes GPU support, starting with technology previews (see below). For more information please see http://software.Intel®.com/en-us/articles/Intel®-ipp-80-library-whats-new/.

While use of Intel IPP libraries in Android has been possible since Intel IPP 7.1, we now have alignment with Beacon Mountain (http://www.intel.com/software/BeaconMountain) and improved documentation on using Intel IPP with Android (http://software.intel.com/en-us/articles/using-intel-ipp-with-android-os).

Three Main Parts of Intel® IPP

Intel IPP is a software library that provides a comprehensive set of application domain-specific highly optimized functions for signal processing, image and video processing, operations on small matrices, three-dimensional (3D) data processing and rendering:

"Intel® IPP is a software library for signal processing, image and video processing, operations on small matrices, three-dimensional (3D) data processing and rendering. "

- The Intel IPP signal processing software is a collection of low-overhead, high-performance operations performed on one-dimensional (1D) data arrays. Examples of such operations are linear transforms, filtering, and vector math.
- The Intel IPP image and video processing software is a collection of low-overhead, high-performance operations performed on two-dimensional (2D) arrays of pixels. Examples of such operations are linear transforms, filtering, and arithmetic on image data.
- Intel IPP also provides a collection of low-overhead high-performance functions for small matrices, realistic rendering, and 3D data processing.

Details of Intel® IPP

The Intel IPP software enables you to take advantage of the parallelism of single-instruction, multiple data (SIMD) instructions, which make the core of the MMX™ technology and Intel® Streaming SIMD Extensions. These technologies improve the performance of computation-intensive signal, image, and video processing applications. Plenty of the Intel IPP functions are tuned and threaded for multi-core systems.

Intel IPP supports application development for various Intel architectures. By providing a single cross-architecture application programmer interface, Intel IPP permits software application repurposing and enables developers to port to unique features across Intel processor-based desktop, server, mobile, and handheld platforms. Use of the Intel IPP functions can help drastically reduce development costs and accelerate time-to-market by eliminating the need of writing processor-specific code for computation intensive routines.

Cryptography for Intel IPP is an add-on library that offers Intel IPP users a cross-platform and cross operating system application programming interface (API) for routines commonly used for cryptographic operations.

It is the goal of this article to enhance this situation on mobile devices. The rest of the article is organized as follows:

- Basic features of Intel IPP
- Intel® System Studio for Android* (ISS-A) and Beacon Mountain

- How to use Intel IPP on Android for applications development
- Examples to show Intel IPP fitting with existing C++ developer workflows simply
- Case Study: How to combine OpenCV with Intel IPP and get benefits

Basic Features of Intel® IPP

To sustain a smooth user experience, Intel IPP should be used to fit the significant demand for performance. Like other members of Intel® Performance Libraries, Intel Integrated Performance Primitives is a collection of high-performance code that performs domain-specific operations. It is distinguished by providing a low-level, stateless interface.

Based on experience in developing and using Intel Performance Libraries, Intel IPP has the following major distinctive features:

- Intel IPP functions follow the same interface conventions, including uniform naming conventions and similar composition of prototypes for primitives that refer to different application domains.
- Intel IPP functions use an abstraction level that is best suited to achieve superior performance figures by the application programs.

To speed up the performance, Intel IPP functions are optimized to use all benefits of Intel architecture processors. Besides this, most of Intel IPP functions do not use complicated data structures, which helps reduce overall execution overhead.

Intel IPP is well-suited for cross-platform applications. For example, functions developed for the IA-32 architecture can be readily ported to the Intel® 64 architecture-based platform. In addition, each Intel IPP function has its reference code written in ANSI C, which clearly presents the algorithm used and provides for compatibility with different operating systems.

Intel® System Studio for Android* (ISS-A) and Beacon Mountain

"Intel® System Studio for Android (ISS-A) is a paid set of tools targeted at system developers, available under a nondisclosure agreement."*

Intel® System Studio for Android* (ISS-A) is a paid set of tools targeted at system developers, available under a nondisclosure agreement. It includes Intel Integrated Performance Primitives, Intel® C++ Compiler, Intel® Graphics Performance Analyzers (Intel® GPA), Intel® VTune™ Amplifier, and Intel® JTAG Debugger. The Intel® C++ Compiler for Android* is a Linux hosted cross-compiler based on our standard Intel® C++ Compiler version 13.0. The Intel GPA is a suite of software tools that helps you analyze and optimize your graphics-intensive applications. The Intel® VTune™ Amplifier for Android* is for performance and power analysis of native IA-32 architecture ELF binaries on Android devices. The Intel® JTAG Debugger for Android* OS provides Windows*-hosted and Linux*-hosted cross-debug solutions for software developers to debug the Android kernel sources and dynamically loaded drivers and kernel modules on devices based on the Intel® Atom™ processor.

For native application developers there is a free development framework with a collection of some ISS-A tools, plus third party tools, codenamed Beacon Mountain. Beacon Mountain provides productivity-oriented design, coding, and debugging tools for native apps targeting Android-based ARM and Intel architecture based devices, including smartphones and tablets. The tools are compatible with Eclipse and support popular Android SDKs including the Android NDK. The suite incorporates a number of Intel and third-party development tools such as Intel® Hardware Accelerated Execution Manager, Intel® Graphics Performance Analyzers System Analyzer, Intel® Integrated Performance Primitives Preview for Android*, Intel® Threading Building Blocks, and Intel® Software Manager.

"Beacon Mountain provides productivity-oriented design, coding, and debugging tools for smartphones and tablets. "

Key features of Beacon Mountain are:

- Simple, fast installation of popular Intel developer and third-party tools for creating Android applications
- Compatibility with and augmentation of existing Android SDK and NDK toolkits
- Supports Apple OS X*, Microsoft Windows 7 and 8 host systems

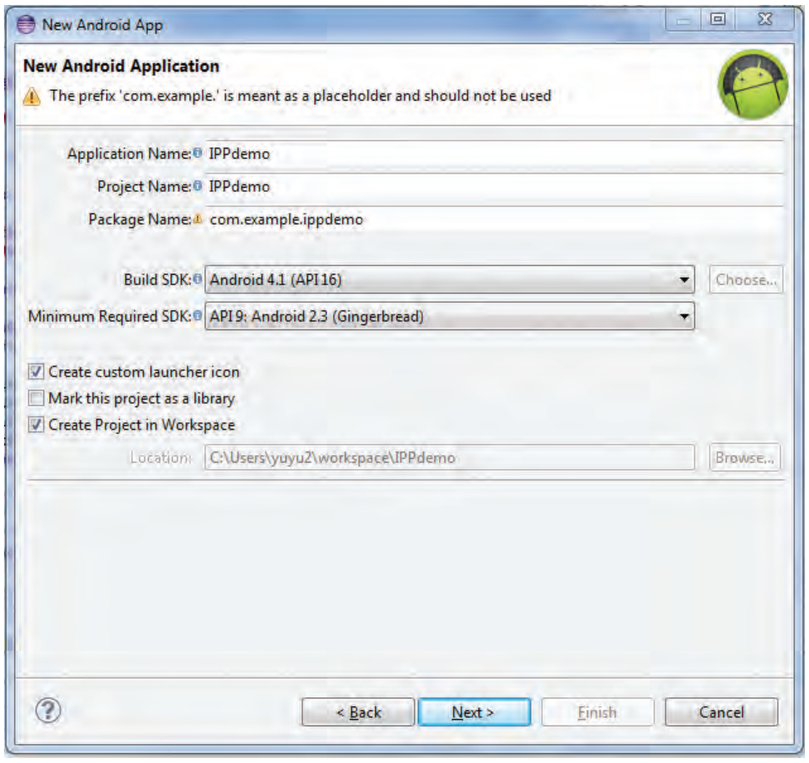
As for Intel IPP, Beacon Mountain has only provided a free preview version until now. To achieve all functions we need and take advantage of the strength of IPP, it's recommended to use the full version of Intel IPP in ISS-A.

How to Use Intel® IPP on Android Application Development

This article shows you a basic way to develop an Android application with Intel IPP. Make sure your development environment is okay and Intel IPP has been installed successfully first. Then follow these steps:

1. Create a new Android Project in Eclipse, as shown in Figure 1.
2. Select the project, press Ctrl+N, and then select Convert to a C/C++ Project (see Figure 2).
3. Create a new folder named "jni" in the project directory and then do as following:
   a. Copy "ipp_android_preview.h", "libipp_android_preview.a", and "ippdes.h", to the "jni" folder from IPP library.
   b. Create "ippdemo.cpp" under the "jni" folder.

```
// ippdemo.cpp
#include <jni.h>
#include "ipp_android_preview.h"
Jstring Java_com_example_HelloIPP_
getVersion(JNIEnv* env,jobjectthiz)
{
     IppStatus fm;
     IppStatus status;
      status=ippInit();
```


New Android App

New Android Application

The prefix 'com.example.' is meant as a placeholder and should not be used

Application Name: IPPdemo

Project Name: IPPdemo

Package Name: com.example.ippdemo

Build SDK: Android 4.1 (API 16)

Minimum Required SDK: API 9: Android 2.3 (Gingerbread)

[✓] Create custom launcher icon

[ ] Mark this project as a library

[✓] Create Project in Workspace

Location: C:\Users\yuyu2\workspace\IPPdemo

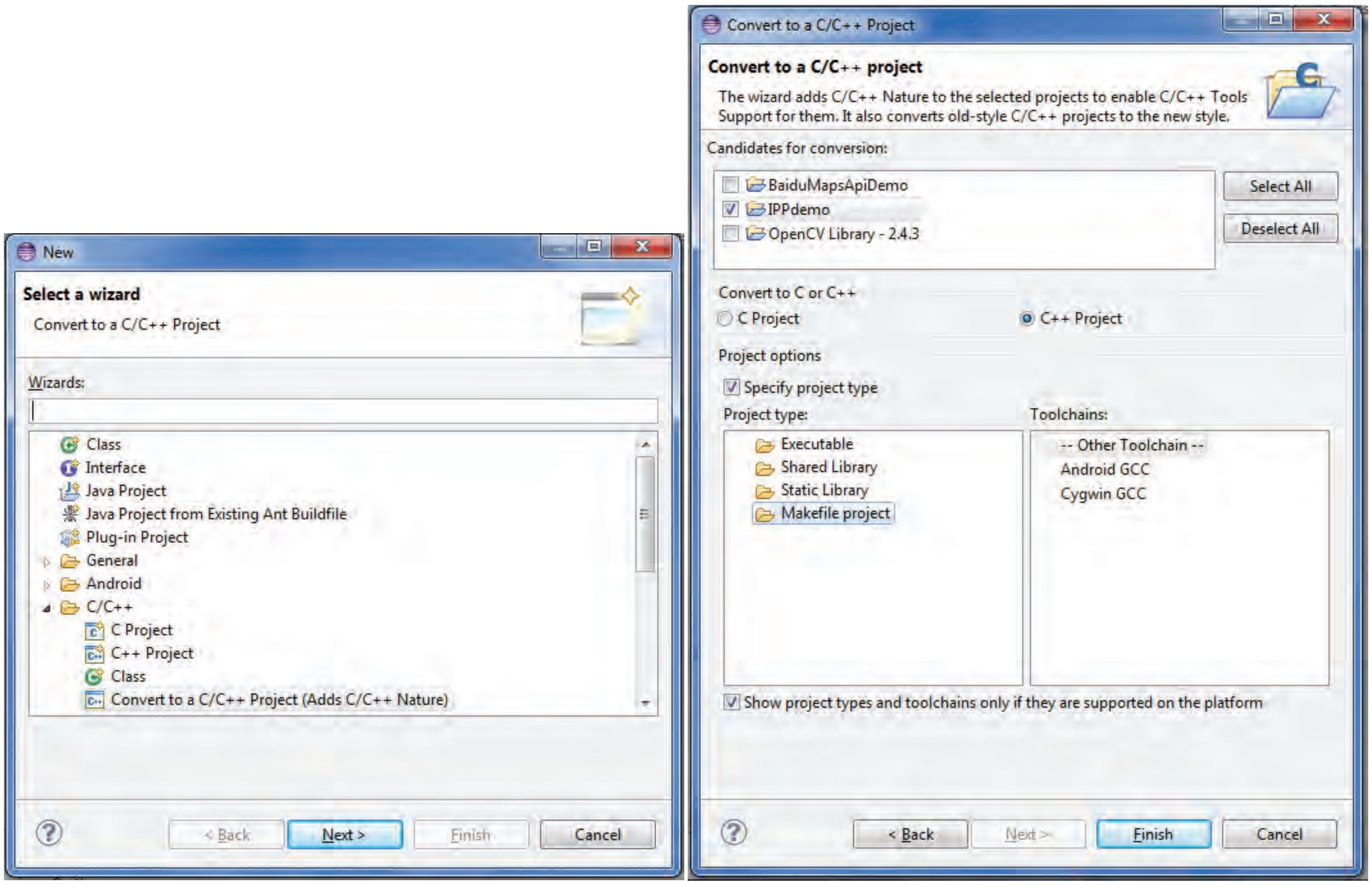
Figure 1: Create a New Android Project in Eclipse (Source: Intel Corporation, 2013)

```
        If (status! =ippStsNoErr){
        return -1;
        }
        lib=ippGetLibVersion();
        Fm=ippGetEnabledCpuFeatures();
        return (*env) ->NewStringUTF (env,lib-Name);
}
```

c. Create “Android.mk” and “Application.mk” under the “jni” folder

```
#Android.mk
include $(CLEAR_VARS)
LOCAL_MODULE:=ipp_demo
LOCAL_STATIC_LIBRARIES:=ipp_android_preview
LOCAL_C_INCLUDES:=.
LOCAL_SRC_FILES:=ippdemo.c
LOCAL_LDLIBS:=-lm -llog -ljingraphics
LOCAL_ALLOW_UNDEFINED_SYMBOLS:=true
Include $(BULID_SHARED_LIBRARY)

#Application.mk
APP_ABI := x86
```


New

Select a wizard

Convert to a C/C++ Project

Wizards:

- Class
- Interface
- Java Project
- Java Project from Existing Ant Buildfile
- Plug-in Project
- General
- Android
- C/C++
  - C Project
  - C++ Project
  - Class
  - Convert to a C/C++ Project (Adds C/C++ Nature)

Convert to a C/C++ Project

Convert to a C/C++ project

The wizard adds C/C++ Nature to the selected projects to enable C/C++ Tools Support for them. It also converts old-style C/C++ projects to the new style.

Candidates for conversion:

- [ ] BaiduMapsApiDemo
- [✓] IPPdemo
- [ ] OpenCV Library - 2.4.3

Convert to C or C++

C Project [✓ C++ Project]

Project options

[✓] Specify project type

Project type: Executable, Shared Library, Static Library, [✓ Makefile project]

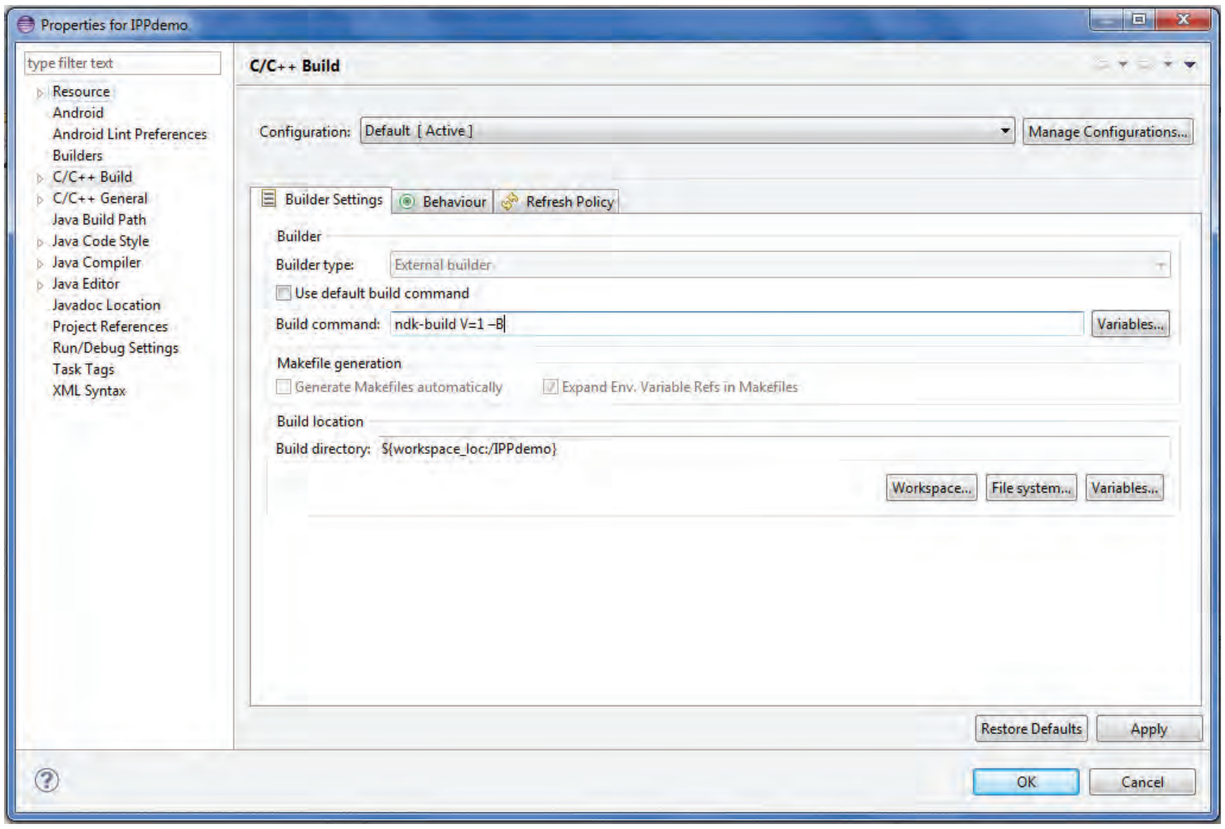
Toolchains: -- Other Toolchain --, Android GCC, Cygwin GCC

[✓] Show project types and toolchains only if they are supported on the platform

Figure 2: Convert to a C/C++ Project
(Source: Intel Corporation, 2013)

4. Configure project properties as follows:
   a. Right-click on the project in Eclipse Project Explorer, add the command "ndk-build V=1 –B" in the Build command field of C/C++ Build for the NDK build (Figure 3).
   b. From the Behaviour tab, set the correct options for building an NDK application (see Figure 4).
   c. Add "includes" for "GNU C" and "GNU C++" under C/C++ General in Paths and Symbols to avoid symbol-resolving issues.
5. Right-click on the project in Eclipse Project Explorer to select Build Project; the NDK project will be built and will generate libipp_demo.so.
6. Dynamically load the libipp_demo.so in the Java code and call the getIPPVersion():

```
//In HelloIPP.java
//Load libipp_demo
Static{
```



C/C++ Build

Configuration: Default [Active]

Builder

Builder type: External builder

[ ] Use default build command

Build command: ndk-build V=1 –B

Makefile generation

[ ] Generate Makefiles automatically
[✓] Expand Env. Variable Refs in Makefiles

Build location

Build directory: ${workspace_loc:/IPPdemo}

Figure 3: Modify the Build Command
(Source: Intel Corporation, 2013)

```
System.LoadLibrary(“ipp_demo”);
}

//Declare native function prototypes
public native String getVersion();
```

7. Run the application on Android devices (see Figure 5).

Examples to Show Intel® IPP Fitting with Existing C++ Developer Workflows Simply

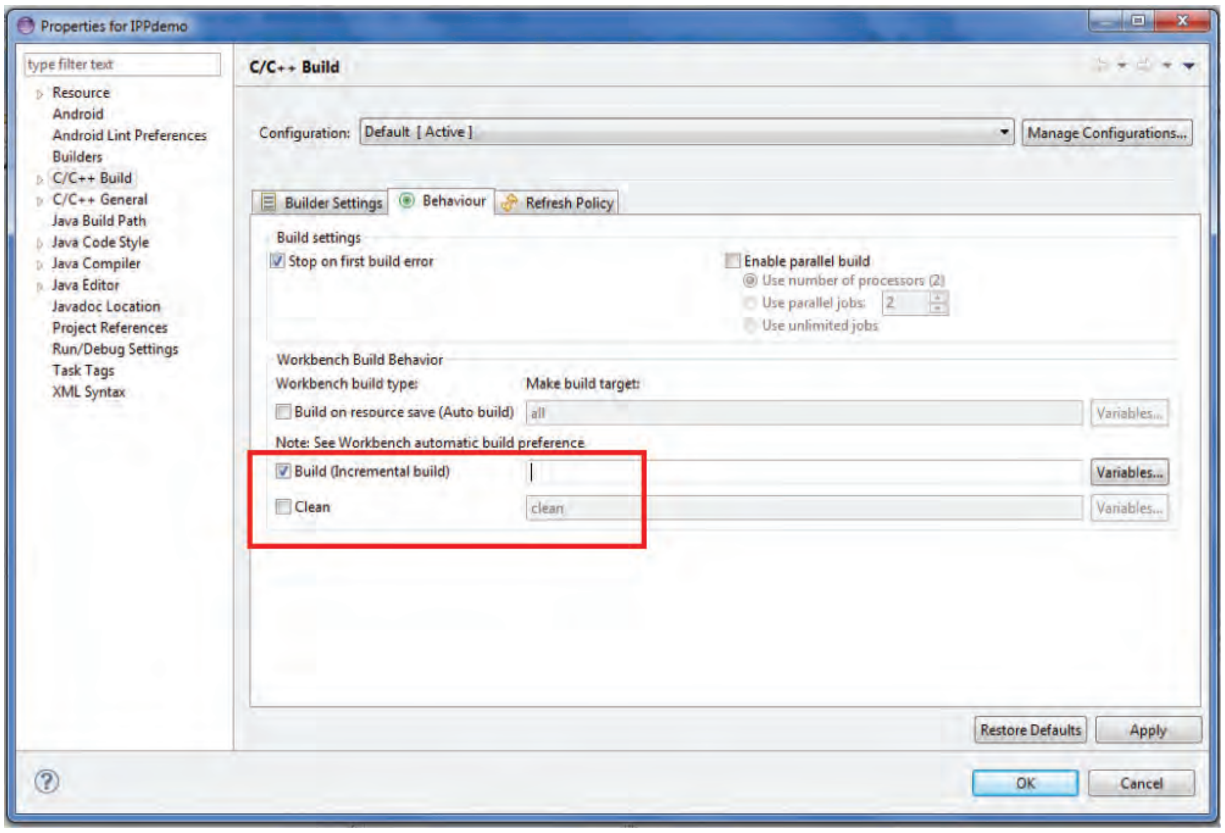
“Intel IPP® is a library of highly optimized algorithmic building blocks for media and data applications, fitting with existing C++ developer workflows simply.”

Intel IPP is a library of highly optimized algorithmic building blocks for media and data applications. The following two examples show Intel IPP fitting with existing C++ developer workflows simply. Both examples implement an image-scaling function. The first example uses the Intel IPP interface in Android and the other one uses the general Android API. The comparison identifies the differences between them.

Example 1: Using an Intel® IPP Interface in Android to Implement an Image-Scaling Function

The code for the first example is shown here:

```
// initialize ipp module and allocate the memory
```



C/C++ Build

Configuration: Default [Active]

Build settings

[✓] Stop on first build error

[ ] Enable parallel build

(●) Use number of processors (2)

( ) Use parallel jobs: 2

( ) Use unlimited jobs

Workbench Build Behavior

Workbench build type: Make build target:

[ ] Build on resource save (Auto build) all

Note: See Workbench automatic build preference

[✓] Build (Incremental build)

[ ] Clean clean

Figure 4: Set the Behaviour Tab
(Source: Intel Corporation, 2013)

```
Status Init(Image* psrc,Image*pdst)
{
      IppiSizesrcSize = { pSrcImage->m_iWidth,
pSrcImage->m_iHeight};
      IppiSizedstSize = {pDstImage->m_iWidth,
pDstImage->m_iHeight};
      ippSts = ippiResizeGetSize_8u(SrcSize,
dstSize,m_interpolation, 0,
      &iSpecSize, &iInitSize);
      m_pSpec = (IppiResizeSpec_32f*)
ippsMalloc_8u(iSpecSize);
      m_pInitBuffer = ippsMalloc_8u(iInitSize);
      ippSts = ippiResizeLanczosInit_8u(srcSize,
   dstSize, m_iLobes, m_pSpec, m_pInitBuffer);
      ippSts = ippiResizeGetBorderSize_8u(m_pSpec,
&borderSize);
      m_templ = *pSrcImage;
      return STS_OK;
}
```

ipp version:8.0.0 (-)

Figure 5: Demo Screenshot on Android Devices
(Source: Intel Corporation, 2013)

Inside the *Init* function, according to the sizes of the source and the destination image, the *IppiResizeGetSize_8u* function calculates how much memory must be allocated for the *IppResizeSpec* structure and initialization work buffer.The *IppsMalloc_8u* function allocates the memory. The *ippiResizeGetBorderSize_8u* function calculates how much memory must be allocated for the border of the image.

```
// Zoom picture according to a selected area
Status ResizeBlock ( Image *pSrcImage, Image
*pDstImage, Rectroi, unsigned char * pExtBuffer = 0)
{
     if(!dstRoiSize.width)
     dstRoiSize.width = pDstImage->m_iWidth;
     if(!dstRoiSize.height)
          dstRoiSize.height = pDstImage->m_iHeight;
     status = Init(pSrcImage, pDstImage);
     ippSts = ippiResizeGetSrcRoi_8u(m_pSpec,
dstRoiOffset,
               dstRoiSize, &srcRoiOffset,
               &srcRoiSize);
      pSrcPtr = pSrcImage->m_pBuffer+srcRoiOffset
.y*pSrcImage->m_iStep + srcRoiOffset.x*pSrcImage->m
_iSamples;
      pDstPtr = pDstImage->m_pBuffer
+ stRoiOffset.y*pDstImage->m_iStep +
dstRoiOffset.x*pDstImage->m_iSamples;
      ippSts = ippiResizeGetBufferSize_8u(m_pSpec,
dstRoiSize,
pSrcImage->m_iSamples, &iBufferSize);
      pBuffer = ippsMalloc_8u(iBufferSize);
      ippSts = ippiResizeLanczos_8u_C1R(pSrcPtr,
pS.rcImage->m_iStep, pDstPtr, pDstImage-> m_iStep,
dstRoiOffset, dstRoiSize, border, 0, m_pSpec,
pBuffer); ippsFree(pBuffer);
      ippsFree(pBuffer);
      return STS_OK;
}
```

Inside the *ResizeBlock* function, the *IppiResizeGetSrcRoi_8u* function obtains the source *ROI(Rect of Interest)* through the defined destination *ROI*.

```
// The key function of resize image
Status ReszieImage(Image *pSrcImage, Image
*pDstImage)
{
     if(!pSrcImage || !pDstImage)
```

```
            return STS_ERR_NULL_PTR;
     Rectroi = {0, 0, pDstImage->m_iWidth,
pDstImage->m_iHeight};
     return ResizeBlock(pSrcImage, pDstImage, roi);
}
```

Example 2: Using the Traditional Android API to Implement an Image-Scaling Function

Resizing the size of the image can also be realized through the use of the Android API. The following code creates a new class called *Zoom*, which extends from the class of *View,* Overriding the *onDraw* function and setting the bounds of the image.

```
public  class Zoom extends View{
     private Drawable image;
     private int zoomControler=20;
     public Zoom(Context context,int index){
     super(context);
     image=context.getResources()
.getDrawable(index);
      setFocusable(true);
          }
          @Override
      protected void onDraw(Canvas canvas) {
              // TODO Auto-generated method stub
            super.onDraw(canvas);
            image.setBounds((getWidth()/2)-
zoomControler,
(getHeight()/2)-zoomControler,
(getWidth()/2)+zoomControler, (getHeight()/2)+zoom
Controler);
     image.draw(canvas);
          }
          @Override
     public       boolean onKeyDown(int keyCode,
KeyEvent event) {

          if(keyCode==KeyEvent.KEYCODE_
VOLUME_UP)
          zoomControler+=10;
          if(keyCode==KeyEvent.KEYCODE_
VOLUME_DOWN)
          zoomControler-=10;
          if(zoomControler<10)
          zoomControer=10;
          invalidate();
          return true;
          }
}
```

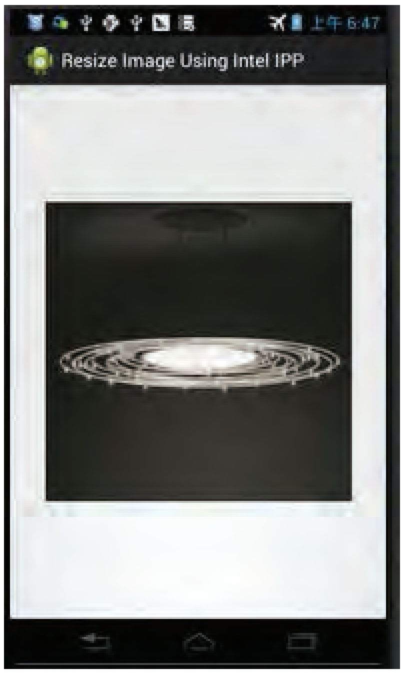


Figure 6: Screenshot of the Resizing Demo
(Source: Intel Corporation, 2013)

Example Comparison

Run these two examples and the results of the image-scaling effects are almost the same (see Figure 6).

Performance analysis by Intel GPA renders the following results, illustrated in Figure 7 and Figure 8.

Summary

Comparing these two screenshots, CPU usage will be smoother when using Intel IPP, and the average performance is increased slightly. We can see that Intel IPP fits with existing C++ developer workflows simply, and the result of using Intel IPP is amazing when compared to the traditional Android applications. So, it's recommended to use Intel IPP to simplify and optimize graphic image processing.

Case Study: How to Benefit from Combining OpenCV* with Intel® IPP

The following case study illustrates how combining OpenCV* with Intel IPP can produce benefits.

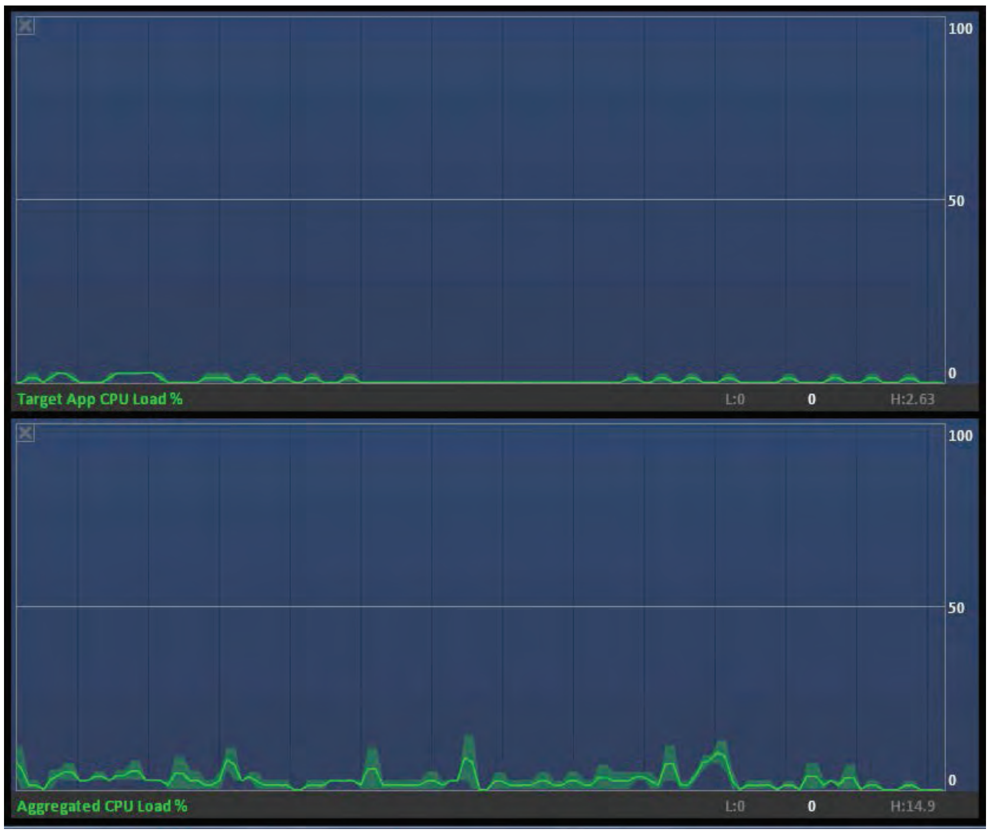


Figure 7: Using the Intel® IPP interface in Android
(Source: Intel Corporation, 2013)

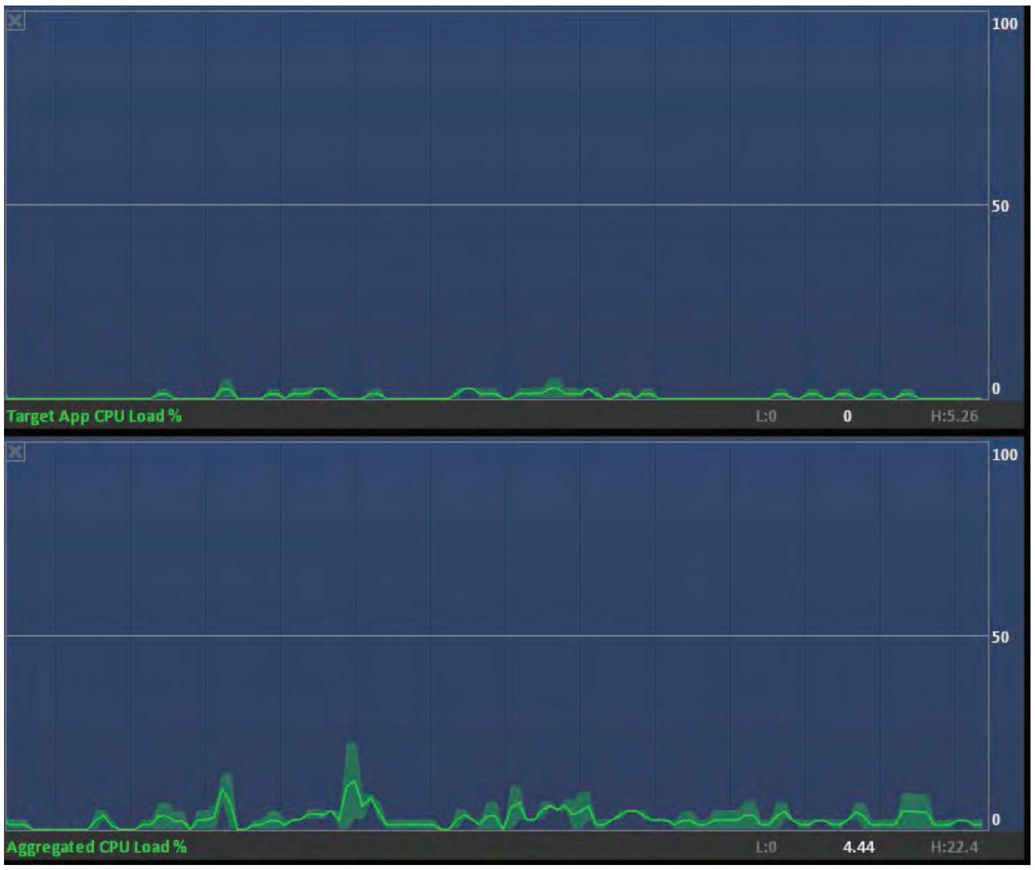


Figure 8: Using the traditional Android API
(Source: Intel Corporation, 2013)

What Is OpenCV*?

OpenCV is an acronym for Open Source Computer Vision Library. The library is a well-known software library in computer vision for both academic and commercial use. It is free, open-source software that provides developers an easy way to input, display, and store video and images, and it also provides over 500 routines for computer vision processing, image processing, face detection and tracking, machine learning, and so on. More information about OpenCV can be found at http://opencv.willowgarage.com/wiki/.

"OpenCV is a well-known software library in computer vision for both academic and commercial use."*

What Is the Relationship between Intel® IPP and OpenCV*?

In early OpenCV* versions, OpenCV was automatically accelerated by taking advantage of Intel IPP. However, starting with OpenCV version 2.0, OpenCV doesn't incorporate Intel IPP by default, thus the performance benefit of Intel IPP functions that are optimized via the Intel® Streaming SIMD Extensions (SSE, SSE, SSE2, SSE3, SSSE3, SSE4, SSE4.1, SSE4.2, and Intel® AVX in the latest versions) instructions cannot be obtained automatically. This article shows how to use Intel IPP for Android with the latest OpenCV for Android version.

"OpenCV is a collection of C functions and a few C++ classes that implement many popular image processing and computer vision algorithms."*

Using the Intel® IPP Library and OpenCV* Library Independently

OpenCV* is a collection of C functions and a few C++ classes that implement many popular image processing and computer vision algorithms. Intel IPP is a collection of highly optimized functions for digital media and data-processing applications. There is some duplication of functionality between the two libraries.

Engineers who develop image/video processing may often use the two libraries in the same application, for example to transpose an image from horizontal orientation to vertical orientation. In our test case we implemented face recognition using OpenCV* for Android and Intel IPP for Android. The following instructions show how to realize that and how to call Intel IPP functions and OpenCV* functions in the Android NDK application.

1. Because OpenCV* provides a user-friendly API and supports about 80 image formats, it is easy to use it to read, write, and show an image file. Load a source image via an OpenCV* function: *cvLoadImage()*.

```
//Load original image via OpenCV* function
IplImage* pSrcImg = cvLoadImage("testimg.bmp", 1)
```

2. Create a destination image via the function *cvCreateImage()*:

```
//Create Destination image via OpenCV* function
IplImage* pDstImgCV = cvCreateImage( cvSize(TARGET_
WIDTH,TARGET_HEIGHT ), pSrcImg->depth,pSrcImg-
>nChannels);
IplImage* pDstImgIPP = cvCreateImage(
cvSize(TARGET_WIDTH,TARGET_HEIGHT ),
pSrcImg->depth,pSrcImg->nChannels;
```

3. Call *cvRemap()* (an OpenCV* function) to transpose the original image

```
//Use OpenCV* function
//Resize image via cvResize
cvRemap(pSrcImg, pDstImgCV, pXMap, pYMap, CV_INTER_
LINEAR, cvScalarAll(0));
```

   or call *ippiRemap* (an Intel IPP function) to transpose the image:

```
//Use Intel IPP function
//Resize image via ippiRemap
ippiRemap_8u_C3R( (Ipp8u*)pSrcImg ->
imageData,srcSize,
pSrcImg->widthStep, roiRect, pXTable, sizeof
(float) * TARGET_WIDTH, pYTable, sizeof (float) *
TARGET_HEIGHT, (Ipp8u*) pDstImgIPP -> imageData,
pDstImgIPP -> widthStep,  dstSize, IPPI_INTER_NN);
```

4. Use an ASM algorithm to realize face recognition:

```
//Implement ASM algorithm via OpenCV function
faceCascade.detectMultiScale(pDstImgIPP,faces,
1.2, 2, CV_HAAR_FIND_BIGGEST_OBJECT|CV_HAAR_DO_
ROUGH_SEARCH|CV_HAAR_SCALE_IMAGE, Size(30, 30));
asmModel.fitAll(pDstImgIPP, faces, 0);
```

5. Link the required static libraries to the Android NDK project in Android.mk:

```
OpenCV*
//Link OpenCV* Static library
//Android.mk
OPENCV_LIB_TYPE :=STATIC
include ../../sdk/native/jni/OpenCV.mk

Intel IPP
// Link IPP Static library
// Android.mk
LOCAL_STATIC_LIBRARIES := \
          lbippi.a \
          lippcv.a\
          lbipps.a\
          lbippcore.a
```

6. Build and run the face recognition applications; they work well on Android (see Figure 9).

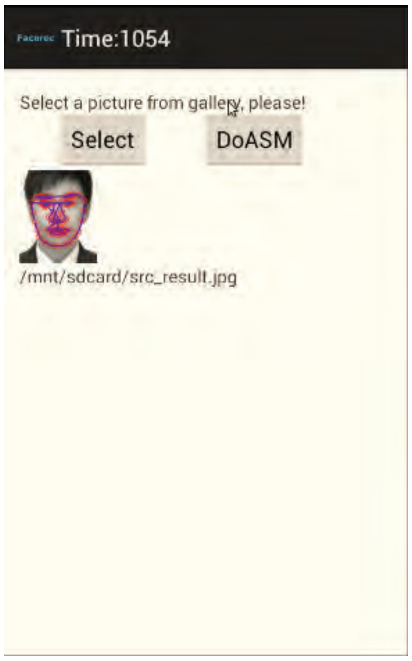

Facerec
Time:1054
Select a picture from gallery, please!
Select
DoASM
/mnt/sdcard/src_result.jpg

Figure 9: OpenCV Demo Screenshot on Android
(Source: Intel Corporation, 2013)

Summary

Developing image/video processing can easily use both OpenCV* libraries and Intel IPP libraries in the same Android NDK application. In this face recognition example, OpenCV* is used to combine with Intel IPP through several simple APIs. The result is acceptable and brings a slight performance improvement. It's easy to take advantage of the strength of Intel IPP in OpenCV-based applications on Android.

References

[1] Intel® Integrated Performance Primitives – Documentation: How to use IPP to develop the program. URL: http://software.Intel.com/en-us/articles/Intel-integrated-performance-primitives-documentation.

[2] What's New in Intel® Integrated Performance Primitives (Intel® IPP) 8.0. URL: http://software.Intel.com/en-us/articles/Intel-ipp-80-library-whats-new/

[3] Beacon Mountain: Beacon Mountain provides productivity-oriented design, coding, and debugging tools for native apps targeting Android-based ARM and Intel® architecture -based devices. URL: www.intel.com/software/BeaconMountain

[4] Intel® Integrated Performance Primitives Reference Manual Document Number: A70805-036US.

[5] Using Intel® IPP with OpenCV: This document shows how to use Intel® IPP with the latest OpenCV as well as how to integrate Intel® IPP into OpenCV. URL: http://software.Intel.com/en-us/articles/using-Intel-ipp-with-opencv-21

[6] Beginning with the Android NDK: This document shows how to develop with the Android NDK using C++ (a Chinese blog). URL: http://www.cnblogs.com/hibraincol/archive/2011/05/30/2063847.html

Author Biography

Zhen Zhou earned an MSc degree in software engineering from Shanghai Jiaotong University. He joined Intel in 2011 as an application engineer in the Developer Relations Division Mobile Enabling Team. He worked with internal stakeholders and external ISVs, SPs, and carriers in the new usage model initiative and prototype development on the Intel Atom processor, traditional Intel architecture and embedded Intel architecture platforms, to extend the Intel architecture computing power and ecosystem from the PC screen to mobile in handheld devices, tablets, and consumer devices. Zhen can be reached at zhen.zhou@intel.com.