BREAKTHROUGH MOBILE IMAGING EXPERIENCES

How Qualcomm® Snapdragon™ processors are transforming photography

At the heart of devices you love

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1 Executive summary

Mobile imaging has changed the way consumers capture and share memories. The smartphone is now our constant companion, and the camera is a key feature that enhances our lives and facilitates communications in ways that previously could not have been imagined. The ability to instantly capture and transmit images has transformed modern life for people everywhere. From offering others a glimpse into our lives, to assisting in productivity and problem solving, the camera conveys what cannot be communicated in words — and with stunning visual acuity.

Mobile is playing an increasingly pivotal role in advancing camera technologies and redefining what is possible in imaging. However, it has been very challenging to offer DSLR-like image quality[1] in the mobile form factor. Unlike DSLRs, the use of large image sensors and thick lenses are simply not feasible for smartphones that need to fit into a pocket. To overcome this challenge, advanced mobile processors have introduced many innovations and increased processing to compensate for the shortcomings traditionally associated with the smaller optical components found in smartphones.

Through its camera and multimedia innovations, Qualcomm Technologies, Inc. (QTI) is leading the way in redefining the visual experience on mobile devices. QTI takes a holistic approach to system design across the SoC (system on a chip) to deliver a superior end-to-end camera solution, while maintaining long battery life and maximizing thermal efficiency.

This paper discusses mobile imaging trends and what it takes to deliver breakthrough mobile imaging experiences. Specifically, it highlights the following points:

1) The rise of mobile imaging
2) How Qualcomm® Snapdragon™ processors[2] support DSLR-like image quality in a smartphone form factor
3) How Snapdragon processors are revolutionizing the mobile imaging experience
4) How QTI is fueling innovation in the camera ecosystem

2 The rise of mobile imaging

Global camera phone sales have surged from under 1 million units in 2000 to 1.4 billion in 2013, and are expected to reach 1.8 billion by 2017 according to a Strategy Analytics report.[3] Today's smartphones are not only eclipsing the camera industry in terms of shipments, they are also becoming as good as (or even better than) traditional point-and-shoot cameras. In a 2014 survey by Qualcomm Technologies, more than 80% of smartphone owners indicated that they love the convenience of their smartphone camera and almost half prefer their smartphone to any other camera.[4] The survey also shows that using a smartphone camera was the main reason why people no longer own DSLRs and

[1] DSLR is the acronym for Digital Single Lens Reflex camera.
[2] Some of the features described in this paper are only available on specific Snapdragon processors. Consult processor specifications for feature availability.
[3] Strategy Analytics, Aug' 13 "Global Camera Phone Sales to Reach 1.5 Billion Units in 2014"
[4] According to a 2014 survey commissioned by Qualcomm Technologies, regarding the most requested smartphone features.

point-and-shoot cameras. Smartphone cameras are increasingly delivering higher-quality photos thanks to increased sensor resolution, improved image processing, and faster response (reduced click-to-capture and shot-to-shot times). And this level of quality is possible even under difficult conditions, such as when taking fast-action shots (e.g., sports photos) or when shooting in low-light conditions. Due to their quality enhancements, smartphone cameras have cannibalized over 50% of usage and ownership of DSLRs. [6] Today, over than 60% of smartphone owners use their smartphone camera for any situation even including special occasions.[6]

The camera has become the most used feature in mobile phones. A recent survey conducted by Strategy Analytics in the U.S. and Western Europe found that 98% of respondents reported having a camera on their phone, and 48% of respondents in the U.S. reported using the camera feature at least once per week.[5] Over half of the surveyed people believe that camera quality is very important in influencing the selection of their next smartphones.[6]

Today, far more images are captured with mobile devices than with dedicated digital cameras. According to the Tomi Ahonen Almanac, more than 90% of all people who have ever taken a picture have only used a camera phone instead of a stand-alone camera.[7] In a 2014 survey by Qualcomm Technologies, around 80% of point-and-shoot camera owners believe that smartphone cameras have the advantage of convenience, portability, ease of use and sharing.[6] Smartphones have in effect democratized professional photography by making it easy and affordable for everyday consumers to capture the right image, edit it on the go, and instantaneously share it. As presented by Mary Meeker, more than 1.8 billion photos are being shared online per day as of 2014,[8] and Flickr, one of the world's most popular online photo sharing services, reports that the three most popular cameras used by its members are smartphones.

Consumer demand for better mobile imaging is voracious, and several other key ecosystem drivers and technology advancements are expected to further accelerate the rise of mobile imaging and the popularity of camera phones.

2.1 Ecosystem drivers

OEMs – Desire to differentiate: To capitalize on the public's growing fascination with mobile imaging, innovative smartphone OEMs are developing super-thin smartphones with superior image quality and advanced features. To differentiate its smartphone offering, Samsung recently has merged its camera and smartphone business units. Microsoft Devices Group, including the recently acquired Nokia Devices and Services business, is using advanced imaging features to differentiate its Lumia-branded Windows Phones. HTC offers a suite of imaging features branded as ImageSense to differentiate its HTC One family of smartphones, including their large pixel sensor called UltraPixel. And Oppo's N3 comes to market with mobile industry firsts, such as a remote control and a motorized 16 megapixel (MP) camera that can automatically track the subject through 206 degrees of movement.

[5] Strategy Analytics, Feb.'13 "Camera Still King, with WiFi the Second Most Used On-Device Feature"
[6] According to a 2014 survey commissioned by Qualcomm Technologies, regarding the most requested smartphone features.
[7] Tomi Ahonen Almanac, "the 2013 Edition of the annual-mobile-industry-numbers-and-stats-blog"
[8] Mary Meeker, May '14, "Internet Trends 2014 – Code Conference"

Application and service providers – Higher service revenue: Camera phones also play a key role in enabling service providers to create appealing services and generate higher revenue. For example, the Firefly feature on the Amazon Fire phone allows users to quickly identify products with the camera, and order them directly from their phone through the Amazon website. On social networking apps such as Facebook, users become more engaged when viewing high quality pictures, which are mainly captured and shared through mobile devices.

OS vendors – More user adoption: To increase user adoption of their platforms, OS vendors are adding camera frameworks and APIs (application programming interfaces) to give app developers and device OEMs access to ever more advanced camera functionalities.

Component Vendors – Higher quality: To deal with fierce competition on pricing and quality vectors, makers of image sensors, lenses, and modules are also innovating as a means of differentiating their products.

Users – Desire to share: The human desire to capture, store, and share visual memories with loved ones, especially in this new age of social media, further accelerates the rise of mobile imaging. Today, more than 60% of smartphone owners upload or share their pictures.[9]

2.2 Technology drivers

Smartphones are making huge strides in improving camera performance thanks to many hardware (HW) and software (SW) advancements and innovations.

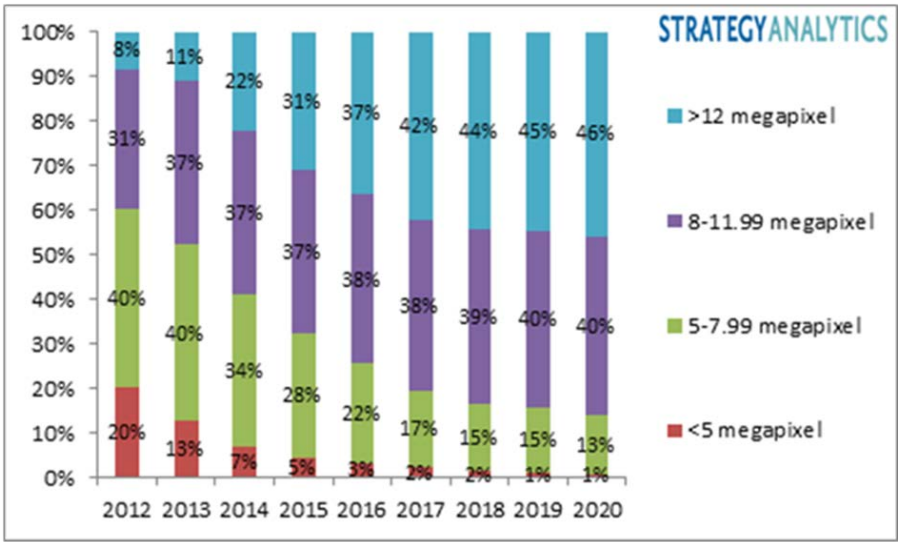
Bigger image sensors: Image sensors consist of millions of light-sensitive spots called photodiodes, which are used to record information about what is seen through the lens. A bigger sensor can gain more information than a smaller one in two ways: larger pixels and/or more pixels. Bigger sensors can produce better images with larger dynamic range, less noise, finer detail, and improved low-light performance. The primary trend is towards the higher pixel counts, though that is not necessarily evidence of better performance.

In the past, smartphones had small image sensors typically of 1/3-inch optical format or smaller. In 2013, Nokia launched the Lumia 1020 Windows Phone with a 2/3-inch sensor, with 4x the light sensing area. The Sony Xperia Z1 has a 1/2.3-inch sensor, which is the same size as sensors found in consumer-level compact cameras**.** Nokia's 6-inch "phablet," the Lumia 1520, which combines a 2/3 inch 20MP sensor with PureView technology, is the latest model to implement a sensor that is larger than what has been the standard to date. And this trend of integrating larger sensors into smartphones is expected to continue in the next generation of devices.

Higher-resolution cameras: Camera technology in mobile devices has dramatically improved, and its resolution has increased significantly. Pressure to increase resolution as well as frame rates will continue. Today, camera sensors for mainstream premium mobile devices already offer resolutions of 16 MP to 21 MP. And the high-resolution trend applies to both still image and video capture. For example, many premium smartphones, such as the Samsung Galaxy S5, Oppo N3, Motorola Droid

[9] According to a 2014 survey commissioned by Qualcomm Technologies, regarding the most requested smartphone features.

Turbo, Sony Mobile Xperia Z3, and others can capture and record 4K video. We expect to see many more 4K-capable devices on the horizon.



Source: Strategy Analytics, Wireless Smartphone Strategies (WSS) services

Figure 1: Smartphone unit forecast for different camera resolutions

The desire to increase sensor size is constrained by the phone thickness, thus increasing camera resolution is expected to come at the expense of pixel size. The shift to smaller pixels (1.1 um and below in the future) results in capturing less light, leading to more noise, worse color, and less dynamic range. Advancements in camera module design and mobile processors help in dealing with the challenges presented by small pixels.

More capable mobile processors: Today's smartphones are required to provide a digital still camera (DSC)-like experience in terms of image quality, resolution, and frame rate, all while fitting in a sleek form factor. Mobile processors need more performance to deal with visual artifacts resulting from using smaller image sensors and lenses. Integrated, high-throughput image signal processors (ISPs) in modern mobile processors help with providing the required high frame rate and resolution. Along with the ISP, other processing engines, such as the CPU, GPU, and DSP, provide more compute performance to support advanced camera features, such as High Dynamic Range (HDR), image refocus, and photo editing.

Image stabilization: Modern smartphones can use several image stabilization techniques to help photographers capture blur-free images and smooth video footage. Optical Image Stabilization (OIS) works by either moving the image sensor or an optical element of the lens in order to counteract camera shake. The Lumia 920 Nokia (launched in late 2012) was the first smartphone that supported OIS and since then several high-end smartphones, such as the Galaxy S5, LG G3, and Google Nexus 5 also support OIS. Electronic Image Stabilization (EIS) and Digital Image Stabilization (DIS) offer techniques to correct shaky motion in video. The motion of the camera is either directly measured using a gyro (EIS) or by estimating the motion from the image (DIS). The view frame is then moved within the wider field of vision (FOV) of the camera, removing the shaky motion in the recorded video.

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Multiple cameras: Modern smartphones can have more than a single front- and rear-facing camera. For example, having multiple rear-facing cameras or camera arrays allows for taking multiple pictures at the same time with different settings, and brings many advanced features into play, such as fast auto-focus, optical zoom-like capabilities, depth mapping and low-light photography. The use of multiple front-facing cameras also enables new user experiences, such as more natural interaction through gesture recognition.

Advanced computational photography: Beyond the camera functionalities provided by the ISP, computational photography (CP) applies image manipulation techniques to enhance and extend digital photography capabilities. It is used for HDR, low-light photography, optical zoom-like image synthesis capabilities, and many other image enhancement techniques. Computer vision (CV) takes this to the next level by allowing a device to "see" or "make connections" to things in the physical environment. CV allows mobile devices to scan the environment and extract meaningful information from captured images — helping make sense of what is around a person in the physical world and deliver contextually relevant information to the user. For example, an augmented reality (AR) app can overlay contextual information in a dinosaur exhibit at a museum by using CV to identify different species and then to virtually illustrate a particular dinosaur in its natural habitat.

3 Supporting DSLR-like image quality in a mobile form factor

DSLR cameras are known for their ability to capture high-resolution photos with pristine image quality, even in conditions with low-light or fast-moving targets. They have burst photography capabilities that allow them to process multiple photos in rapid succession. Speed is critical for both image capture and processing because it enables the user to capture all intended shots. Capturing light and accurately converting it to pixels is the essence of digital photography. DSLRs use expensive, large image sensors and glass optics to capture as much light as possible. However, due to its small form factor and strict power and thermal constraints, a different approach to mobile phone camera design is needed. Large image sensors and thick lenses are simply not feasible for today's sleek smartphones. To mitigate the practical limitations of mobile-specific sensors and optics, the Snapdragon SoC architecture has been designed with advanced image processing capabilities to conveniently deliver new, single-camera and multi-camera imaging experiences with stunning quality.

Snapdragon processors are revolutionizing mobile imaging experiences and offering advanced features and DSLR-like image quality at low power, notably by:

- Designing a superior ISP architecture for remarkable image quality, high throughput, and advanced features
- Taking a holistic approach to designing power-optimized SoCs that take advantage of heterogeneous computing

3.1 Flexibility and differentiation through dual high-speed ISPs

Snapdragon processors are designed to allow mobile cameras to capture the human experience in all its color, texture, and vibrancy at the moment that counts. Snapdragon processors provide unmatched levels of pixel throughput, while maintaining high quality. The dual ISP architecture of Snapdragon

processors allows simultaneous dual, high-quality cameras. The dual ISP also supports compelling features that utilize computational photography, such as instant autofocus, bokeh (aesthetic blur), and dual-camera zoom.

The discussion that follows highlights the *unmatched speed* and *superb image quality* of the Snapdragon ISP.

Unmatched speed: The Snapdragon ISP's Zero Shutter Lag (ZSL) capabilities and dual-camera performance numbers are evidence of QTI's focus on performance. The HW support provided by the Snapdragon ISP is designed to exceed that offered even by high-end DSLRs and DSCs. The Snapdragon 810 processor has a dual-ISP architecture, with each ISP capable of running up to 600 MHz. When the dual-ISPs are configured in tandem mode, they provide up to 1.2 GP/s throughput, offering the ability to capture higher resolution images in real-time, with ZSL. And significantly higher resolutions can be achieved with off-line processing capabilities of Snapdragon processors. The dual-ISP not only allows for high resolution and frame rates, but also supports dual cameras for picture-in-picture, video-in-video, and seamless 4K Ultra HD video encode with high-resolution snapshot. The Snapdragon 810 processor represents a powerful example of this capability, offering simultaneous support for 16 MP burst-shot capture (at an incredible 15 fps JPEG encoded images via ISP #1 – itself running at 30fps full frame ZSL), and 4K video at 30 fps via ISP #2.

Superb image quality: The ISP provides superior color and noise processing through advanced image processing blocks. The full capabilities of the Snapdragon ISP are too extensive to describe in detail here, so this paper will focus on a few of the standout functional blocks that help provide incredible image quality. These advanced capabilities have helped smartphones powered by Snapdragon processors earn unparalleled recognition.

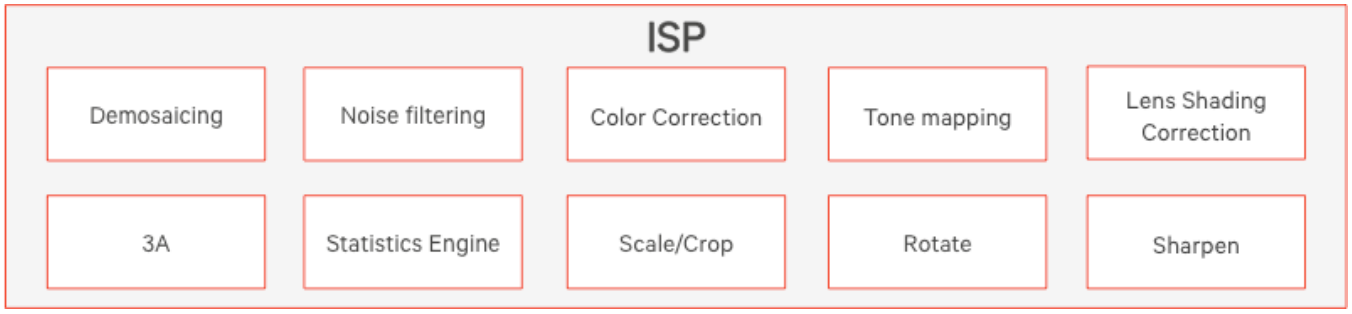

Figure 2: ISP high-level functional block diagram

3.1.1 Exceptional noise filtering capability

Snapdragon processors support sharp, high-quality, high-resolution photos with advanced pre- and post-processing noise reduction features for low-light conditions in both snapshot and video modes. It features advanced Bayer noise filters, as well as HW wavelet noise filtering, to help produce the cleanest possible image, while maintaining the details of the scene.

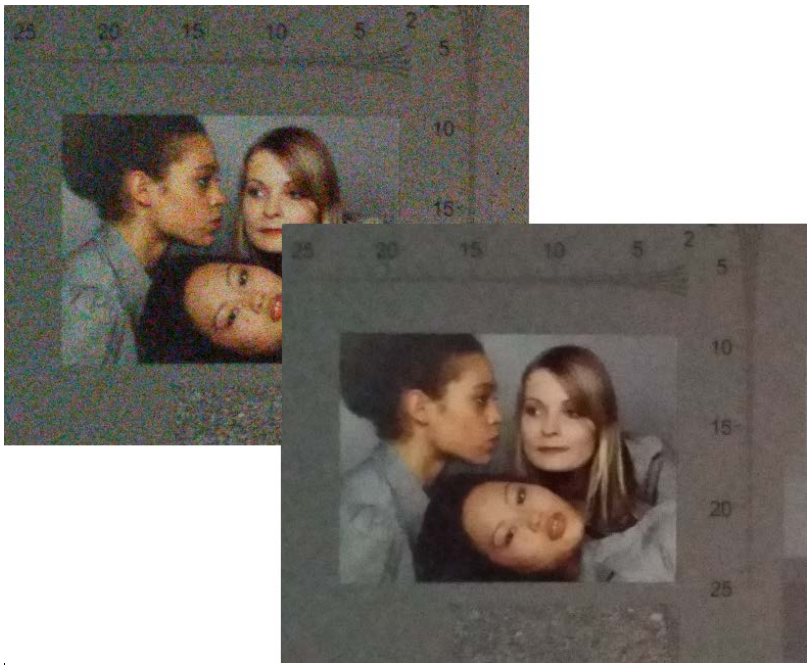

Figure 3: HW wavelet noise filter (on: bottom, off: top)[10]

Snapdragon processors also offer advanced video noise reduction capabilities. Featuring Temporal Noise Reduction, Mosquito Noise Reduction, and Block Noise Reduction, mobile devices powered by Snapdragon support stunning 4K video experiences.

3.1.2 Adaptive Local Tone Mapping (LTM)

LTM technology remaps the tones in a single image to provide a more pleasing appearance. This boosts shadow details so they are more visible, improves contrast and sharpness, and captures a greater dynamic range. LTM is available in both still capture and video modes of operation.

[10] Image Engineering GmbH & Co. KG is producer and copyright holder of the image.

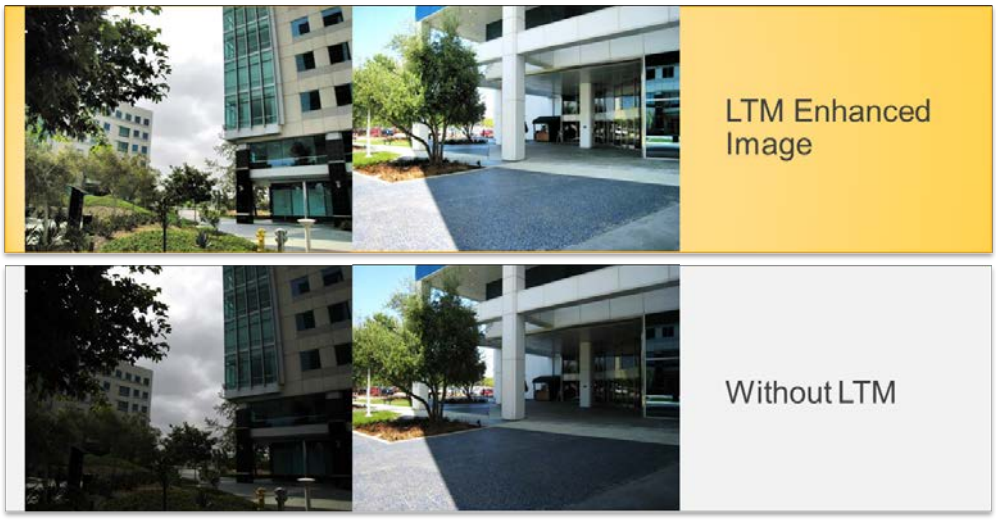

Figure 4: Local tone mapping improves image quality

3.1.3 Advanced lens shading correction

Compact camera module optics are especially challenging in smartphones due to the small form factors. This can cause color non-uniformity and intensity roll-off across the field of view. Snapdragon 800 processors provide an advanced correction block that offers a highly granular mesh correction with a full 4-channel architecture. Each of the four sensor channels are programmable on-the-fly. This supports the update of roll-off parameters based on changing light conditions, along with dynamic tint correction. As every camera that comes off a production line is different, the Snapdragon ISP has the capability to use per-unit calibration to account for the variation between different components.

3.1.4 Advanced 3A technologies

As illustrated below, advanced auto-focus, auto-exposure, and auto-white balance (3A) is a key contributor to Snapdragon processors' outstanding image quality.

Improved contrast auto-focus (AF) for fast, sharp capture

Capturing the moment at the right time with sharpness and detail has traditionally been challenging for smartphones. Contrast AF remains the backbone of a sharp image, either working alone or in concert with technologies that speed the focus convergence. Snapdragon processors support dual kernels and larger kernels, which will dramatically improve contrast AF performance.

Kernel1 provides metrics based on larger regions of the image, which provides a smooth and robust measure for driving the direction of the actuator. Kernel2 provides metrics based on fine detail, which gives good accuracy for achieving the peak focus position. Together, the two kernels allow for a fast and accurate focus search. And the larger kernels allow a more accurate calculation of the image characteristics.

Auto-exposure (AE) and auto-white balance (AWB)

AE and AWB are two of the biggest challenges in the digital imaging world. The scene your camera is capturing is exposed to light, which constantly varies in color and intensity. It is the job of AE and AWB to detect the ambient light characteristics and adjust the camera system to maintain accurate color and brightness.

QTI provides a flexible and powerful solution for AE and AWB that starts with an advanced statistics engine, which determines color temperatures and intensity ranges. These statistics drive sophisticated algorithms that set the gains in the ISP pipeline and image sensor to maintain proper color characteristics, while avoiding excessive saturation or clipping of high and low intensities. For those OEMs seeking to differentiate with their own AE and AWB, QTI provides a flexible API to Snapdragon processors that gives full access to the statistics engine, and control over the ISP.

3.1.5 14-bit ISP for HDR imaging

With its superior ISP technology, QTI is a leader when it comes to superior image quality and high-resolution photography. For example, the Snapdragon 810 has a 14-bit dual-ISP for handling high performance image sensors with extended dynamic range. The auto-exposure algorithms are engineered to ensure the proper hardware configuration to make the most of the 14-bit ISP.

The high bit depth retains detail and fidelity in bright and dark regions, providing great video HDR performance. This is designed to increase dynamic range and fractional precision while reducing artifacts due to compression, leading to stunning HDR performance in your pictures and videos.

3.2 Advanced computational photography through heterogeneous computing

Snapdragon processors provide a flexible heterogeneous computing architecture that delivers high performance at low power; to support breakthrough mobile imaging experiences, such as new CP and CV use cases. The secret to handling such a diverse set of use-cases lies in having a diverse set of processing engines available, and in using the right one for the right task. Besides the camera ISP, Snapdragon processors have other custom-designed processing engines, such as the CPU, GPU, DSP, video, and more.

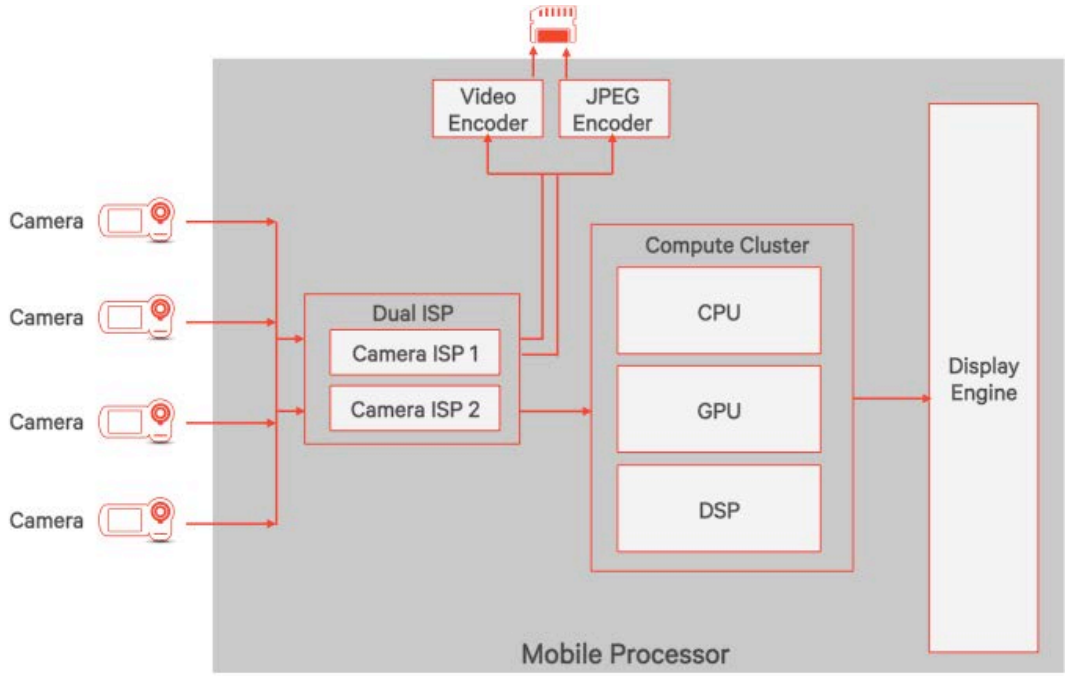

Figure 5 Snapdragon imaging high-level architectural diagram

The CPU is optimal for extreme performance tasks where the algorithm isn't highly parallel and requires branching operations. For example, the CPU is used for Lucas-Kanade Optical flow tracker that performs different operations on different sections of an image based on the local characteristics.

When imaging tasks can be broken into exceedingly parallel tasks, the parallel compute capability of the Qualcomm® Adreno™ GPU is up to the task. For example, the Adreno GPU is used for many post-processing tasks, such as object removal. When real-time performance and programmability at low power are paramount, the Qualcomm® Hexagon™ DSP offers extremely capable processing with excellent power efficiency. The Hexagon DSP excels at many computer vision tasks, such as object detection.

Finally, when low power and real-time response are more important than programmability, some other mobile imaging tasks run more efficiently on fixed-function hardware. For example, implementing YUV conversions and video encoding on dedicated hardware will be the right design choice for power- and thermal-constrained mobile devices.

Proper coordination between the specialized engines is key to providing breakthrough-imaging experiences at low power. For example, Snapdragon processors use an optimal heterogeneous computing approach to coordinate between the ISP, the sensor engine, and the GPU to offer superior gyro-based image stabilization. The ISP produces the frames to be stabilized, the sensor engine processes the gyro information, and the GPU runs the stabilization algorithms.

The combination of powerful heterogeneous compute engines, a state-of-the-art ISP, and advanced system software has made advanced CP and CV functionality feasible on mobile. For example, CP utilizes the compute horsepower of Snapdragon processors to enhance photographs captured. CP

supports many image enhancements such as night-mode shooting, Qualcomm® OptiZoom™ feature, Qualcomm® UbiFocus™ feature, and many more use cases. CV also uses the compute capabilities of the Snapdragon processor to further enhance digital photography, generate depth maps, recognize objects in the scenes, and support many advanced use cases.

Calculating the distance of various points in the scene relative to the position of the camera is one of the important tasks of CV. Depth information can be used for fast focus, object segmentation, refocus, and distance measurement. Acquiring multiple images at different focal points is required to extract depth information. Although a single camera can generate multiple images at different focal points sequentially, a dual-camera can take two images at different focal points simultaneously to eliminate time-based movement in the scene.

Additionally, recognizing an object in a scene is another key task of CV. For example, this comes in very handy when trying to keep the camera in focus on a moving object. The touch-to-track feature allows the camera to "follow" an object in motion, while keeping focus, exposure, and color accuracy without user intervention.

Snapdragon processors apply an optimal heterogeneous computing approach to run the touch to track efficiently, distributing the touch-to-track workloads to the most appropriate processing engines. The ISP produces the images, which are processed by a touch-to-track app. The general object tracker control code is concurrently run on multi-core CPUs, while the object tracking is primarily executed on the DSP. The DSP returns key point information to the application, and the GPU renders the app output to the display engine.

4 Revolutionizing mobile imaging experiences

Snapdragon processors are revolutionizing the mobile imaging experience. These processors support sharp, high-quality, high-resolution photos with advanced pre- and post-processing noise reduction features for low-light conditions in both still and video modes.

According to the December 2014 DxOMark Mobile camera rankings, devices powered by Snapdragon processors take 70% of the top slots in the 20 highest rated phones.[11] This is a testament to QTI's relentless focus on every aspect of the imaging system — from the sensors to post-processing — all with the goal of delivering the best possible user experience to today's informed consumers.

[11] DxOMark Mobile test results are available on www.dxomark.com and in the press

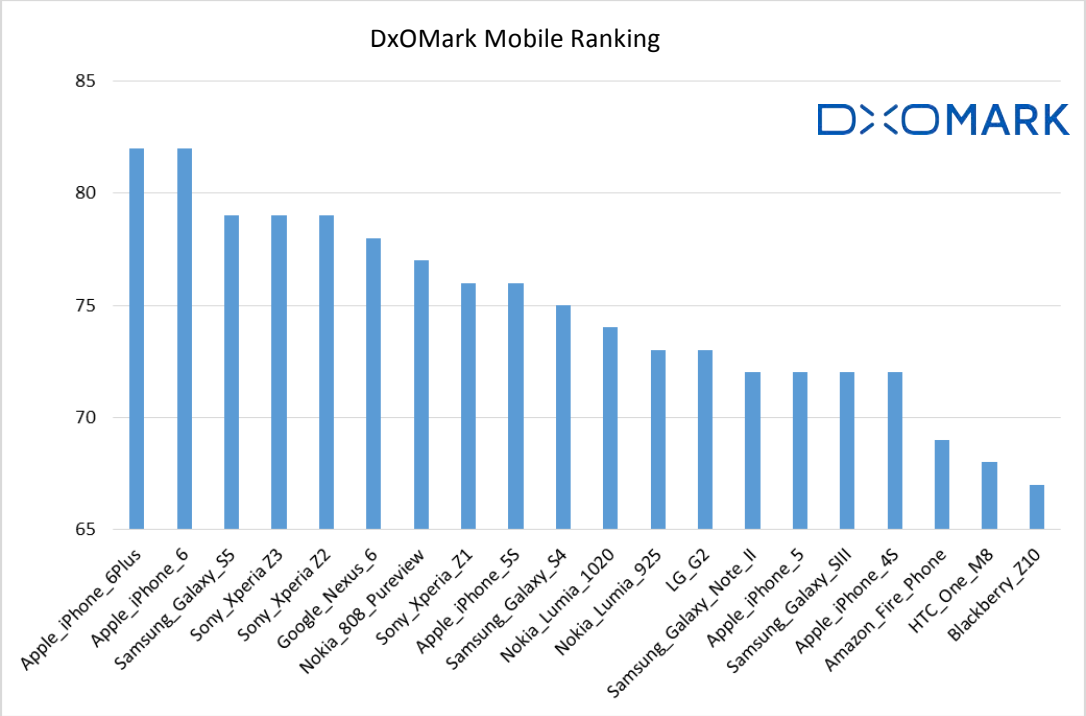

Figure 6: Top 20 highest rated smartphones in DxOMark Mobile rankings

Below are some examples of how Snapdragon processors are transforming mobile imaging experiences.

4.1 Ultra-fast, high resolution capture

Smartphone users want to capture superb-quality pictures that record special moments in all their color, texture, and vibrancy. Speed is critical for both image capture and processing, because it enables the user to capture all intended shots in high resolution. For example, the Snapdragon 805 processor features a 1.2GP/s ISP to provide ultra-fast throughput. This high performance ISP also supports features like ZSL and burst photography, so that consumers can always capture the intended moment. ZSL helps users capture the desired shot, by making the camera ready when the user is ready. For instance, a user can pick up the phone, point, and shoot without perceivable delay. With Snapdragon processors' burst photography capability, consumers can shoot rapid, continuous shots to help capture the moment. As a result, they can snap clear and crisp shots of a fast moving scene like a sporting event. A parent, for example, can now shoot multiple photos instantaneously – thereby capturing that special moment of her child hitting the ball over the fence.

High frame rate photography, enabled by high pixel throughput, has brought the ability to capture events in life that are too fleeting for the human eye to capture without slow motion playback. Snapdragon processors are leading the way with up to 120 fps Full HD video, allowing users to play back videos in slow motion. This allows the user to analyze a golf swing, capture and guide a child in the batter's box, or just have some fun watching rain drops fall.

Due to its high pixel throughput, the Snapdragon 800 processor was the first mobile processor to support 4K video. Today, some smartphones, such as the Samsung Galaxy Note 3 (powered by the Snapdragon 800 processor), are capable of recording a 4K video, and playing it back.

4.2 Optical-like zoom

Unlike DSCs, smartphone cameras are typically not equipped with optical zoom due to size and cost considerations of lenses. As a result, the image captured by zooming in with a smartphone is typically handled by a cropping and interpolation process known as “digital zoom.” This results in an image that is both blurry and highly pixelated. QTI’s OptiZoom technology significantly improves the clarity of images captured using zoom, via sophisticated image processing technology, which enhances the true resolution of the image. This super resolution feature allows the user to “see” beyond the normal limits of a digital zoom. OptiZoom generates this sub-pixel resolution by taking many (12) photos, and processing the micro movements between the many (12) images, to get sub-pixel resolution.

Figure 7: OptiZoom technology provides much greater detail for images captured with zoom

4.3 Photography in tough lighting conditions

Smartphone users want to capture high-quality images under varying light conditions. Poorly lit settings such as nightclub scenes, fireworks shows, or candle-lit venues, are often too dark to shoot without the assistance of flash. Using the flash in many of these settings tends to over-saturate the subject of the scene, which could ruin the picture.

Low-light photography is challenging for all imaging systems, and especially for smartphone cameras. Today’s image sensors, with their small pixels, simply cannot gather enough light to generate a clean image. Advanced capabilities are needed to overcome these limitations.

For instance, the Snapdragon ISP features advanced Bayer noise filters, as well as wavelet noise filtering to generate the cleanest possible image, while maintaining the details of the scene. Large kernels allow the differentiation between noise and edges, preserving the texture and detail of the image.

Beyond the superior capabilities of the ISP, Snapdragon processors also utilize computational photography (CP) and its processing capabilities to capture high-quality images under difficult lighting conditions through other techniques, such as HDR and the Qualcomm® ChromaFlash™ camera feature.

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HDR processing is needed in scenes with a large variation in brightness in order to more accurately represent the range of intensity levels found in “real” scenes, from direct sunlight to faint starlight. This is typically handled by capturing multiple exposures of the same scene, and then using advanced image processing techniques to combine them into one image.

When an object happens to move while these images are captured, it can result in a picture with a duplicated image. Ghost-free HDR prevents this from occurring by analyzing any object motion present in the scene, and intelligently merging the multiple exposures of the scene together, in order to generate a more realistic, ghost-free image with higher dynamic range than is available “naturally” in any single photograph.

No HDR HDR Ghost-free HDR

Figure 8: Ghost-free HDR removes blur from HDR images of moving objects

ChromaFlash is a computational imaging technique where we process two images: one taken with the flash on, and another taken very quickly afterward (with the flash off). It then extracts the best aspects of both. ChromaFlash takes the brightness from the flash image and takes the color accuracy from the no-flash image, to render a well-balanced and low noise picture.

With flash | Without flash | With ChromaFlash

Figure 9: ChromaFlash provides improved brightness and color accuracy for images

4.4 Making professional-quality photography simple for all

With traditional cameras, composing the perfect shot requires patience, timing, and the right eye for detail. Snapdragon processors make it easier for amateur photographers to capture the perfect shot. For example, the blink detection feature analyzes the stream of images for faces with eyes closed, and then displays only the "good" shots with open eyes. Gaze estimation will detect if your subject is looking at front and center of the frame or looking elsewhere. Image stabilization helps minimize the effects of a shaky hand or motion and reduces blurriness and distortions in images. And touch-to-track solves the challenge of keeping the camera in focus and properly exposed on a moving object — without user intervention.

Today, most consumers can easily capture panoramic images on their smartphones. A panoramic image provides a field of view considerably wider than the traditional one-shot version. Panoramic images are popular because they capture more details and give a sense of "being there." To make a panoramic image, devices powered by Snapdragon processors take several shots that capture overlapping sections of the scene, and then seamlessly stitch them together.

4.5 Editing on-the-go

On-board editing tools on many DSLR cameras are cumbersome and generally too basic for most users. Many prefer to transfer their photos to their personal computer where they can easily edit them using more capable tools. The trade-off however, is that desktop-based tools are complex, expensive, and not portable. Today's smartphones, on the other hand, offer a much simpler, less costly, and faster means for creating a professional looking image, including the ability to edit and enhance photos instantly. With many of today's popular photo editing apps on smartphones, it is quite simple to edit or remove objects within photos or create artistic filtering effects.

By utilizing geometric disparity from a dual camera, a depth map can be generated, enabling compelling applications, such as ultra-fast focus, object removal, and applications yet to be imagined. For instance, premium smartphones featuring QTI's object segmentation software allow a mom to instantly remove that annoying "photo bomb" by a classmate that ruined her son's graduation photo.

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Additionally, different objects in a scene are often at different depth positions. Traditional autofocus has difficulty bringing all (or most) objects in-focus in the final image. The Qualcomm® UbiFocus™ feature uses the ISP to "understand" the current 3A settings, disengage the auto focus, and take five separate images at different focal points. It then processes the five images, creating a single "all in focus" image. With UbiFocus, the user has the flexibility to have all of a scene, or only parts of it, in focus.

Front in focus | Back in focus | Everything in focus

Figure 10: UbiFocus allows users to selectively focus the entire scene or portions of it.

4.6 Creating a Digital 6th Sense with the camera

We use the term Digital 6th Sense to describe what happens when apps and devices become so intuitive that they provide us with a whole new ability that goes beyond the five human senses. As mobile devices become more intuitive, they will be able to see and perceive the environment around them, bridging the digital and physical worlds. They will be able to see things in 3D, recognize and make sense of objects, and map the world around them. This will become feasible by incorporating *human-like abilities* into mobile devices, *enabled* by CV, sensor fusion, and machine learning. Below are just few examples of the unlimited possibilities.

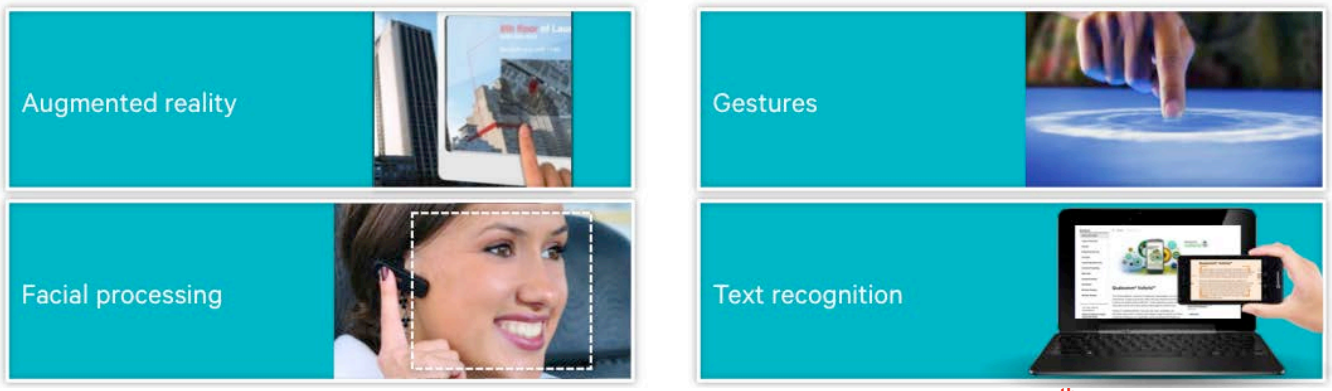

Figure 11: Key computer vision use cases for creating a Digital 6th Sense

Face recognition: Recent advances in CV technologies give mobile devices a human-like ability to handle facial recognition, a capability that will drive many new use cases. For example, mobile devices shared by the family will be able to distinguish between parents and children, unlocking the devices as needed and presenting each with the appropriate apps and individually tailored content. The parents will have access to work email and apps, while the child will have access to age appropriate games and cartoons.

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Localization and mapping: Humans have the ability to recognize objects and map their relative locations in the surrounding environment, allowing them to construct a 3D view of their surroundings. As humans move around objects, they augment the complete picture of their surroundings. Similarly, mobile devices use novel techniques to model an unknown scene into 3D, and to use the model to track the position and orientation of the camera with respect to the scene. This kind of awareness will help in many different ways. For example, the visually impaired will be able to use these technologies to navigate the environment, and when these techniques are combined with machine vision, drones will be able to navigate autonomously, learning when to hover, land, and avoid collisions.

3D object modeling: With CV, smartphones can generate a depth map, which is used as the basis of several compelling applications. Imagine the possibilities of being able to accurately construct a 3D model and print any object you see. For example, the shoe buying experience will be transformed. By using an accurate 3D model of a foot, a consumer can purchase custom-fitted, 3D-printed running shoes that fit perfectly to give an athlete the competitive edge on the track.

Augmented reality: In augmented reality applications, smartphones use CV to continuously analyze the camera feed, recognize and track interesting objects, locate them in 3D space, and then overlay relevant images and information. Qualcomm® Vuforia™ mobile vision platform reinvents the way you interact with the world. For example, it allows users to see how furniture will look in their home before buying it, interact with the toy without opening the box, or play a video game “projected” on their coffee table.

Natural user interaction: Using CV to process gestures is also changing the way we interact with our mobile devices. For example, the smartphone’s camera can detect a hand waving gesture to turn a page in an e-Book, or detect if a person is taking a phone out of their pocket.

Text recognition: Text recognition uses CV to handle complicated tasks like language translation or handwriting recognition. For example, if you are in a foreign country eating at a restaurant and don’t speak the language, your camera phone could accurately recognize foreign characters on the menu, translate them to your native language, and overlay relevant user reviews as part of the process.

4.7 Bringing the power of mobile imaging to other form factors

Low-power, high-performance Snapdragon processors support high-quality imaging for a variety of form factors, including smartphones, tablets, set-top boxes, cars, and more. The first standalone camera to feature a Snapdragon processor is now available for purchase — the LYTRO ILLUM, a light field camera and LYTRO’s software platform are designed to redefine the way we see the world around us. This computational imaging camera with a 40 “Megaray” sensor is an interesting example of how Snapdragon processors are capable of bringing features beyond DSLR to different form factors. It demonstrates the power of the Snapdragon 800 processor, combined with an innovative camera design by Lytro.

> *We wanted to build a professional-grade light field camera that could create richer living pictures, and we wanted to equip it with a lot more processing power. This is precisely where the Snapdragon 800 came into play.* — Kurt Akeley, Lytro CTO.

The LYTRO ILLUM delivers a number of features that were inconceivable not too long ago, but are now possible by QTI's collaboration with Lytro.

Figure 12 : LYTRO ILLUM features a 40 Megaray sensor powered by a Snapdragon processor

Lytro is using light field technology to develop some extraordinary imaging capabilities, such as the ability explore depth in a picture *after* it's taken, and shifting perspective to create interactive *Living Pictures* and 3-D experiences.

While other contemporary cameras are getting more processor intensive, light field cameras demand even greater computational power. The Lytro-developed light field camera is efficiently brought to life by heterogeneous computing using the Snapdragon ISP, GPU, CPU, and DSP. For example, the Snapdragon processor fully utilizes the dual ISP for image processing, the CPU for real-time depth analysis, and the GPU for lens aberration correction.

5 Fueling innovation in the imaging ecosystem

QTI works closely with the leading camera innovators in the HW, SW, and applications sector. The tight coupling of tools, technologies, and innovation combined with QTI's comprehensive understanding of all aspects of the imaging pipeline allows the company to optimize the whole system (end-to-end) so that its customers can produce next-gen camera experiences. This proactive engagement across the ecosystem allows QTI to deliver quality and innovative features unavailable from other SoC vendors.

Delivering the best in image quality requires a well-defined, rigorous development process. And QTI supports its deep customer base in the camera ecosystem with the elements needed for advanced mobile imaging products and experiences, supporting everything from component device selection to documentation, tools, training, and customer/vendor support. QTI also works with a broad range of 3rd party developers, furthering their ability to help OEMs differentiate their products.

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5.1 HW vendor engagement and support

The HW ecosystem for camera includes image sensors, actuators and controllers for focus and stabilization, optics, camera modules, and flash illumination. Each one of these technologies is complex in its own right, and QTI is proactively engaged to harmonize these features and specifications. By working closely with HW vendors, QTI provides a comprehensive library of camera sensors and modules that are fully tuned.

For example, we engaged with IHVs to develop dual-CCT flash illumination. Until now, using camera flash has resulted in poor image quality, with skin tones often appearing bluish. The dual-CCT technique uses LEDs at both ends of the visible spectrum, allowing a better match in ambient light conditions. Working with leading LED component suppliers, QTI defined a process to characterize the spectral response of the image sensor. This information is then used to formulate the phosphors for the 2 LEDs in such a manner that their light output ideally matches the image sensor they are being paired with. This attention to the camera "system" rather than just individual components makes it possible to create natural looking indoor pictures, even when using flash.

Another example of QTI's holistic approach to image quality optimization is in the area of AF. For users, having fast, accurate focus is critical for capturing the moment with fidelity. Working with camera sensor vendors, QTI is now implementing phase detection auto focus (PDAF), a technique that was previously the domain of high-end DSLR cameras. Using PDAF, the camera takes a distance measurement of all objects in the field of view. When combined with a closed loop AF actuator, the camera can quickly set the focus to the correct point for fast, sharp images. QTI is driving the convergence of image sensor, AF actuator, and supporting algorithm capabilities to bring PDAF to mobile imaging.

5.2 Image quality development tools

In support of camera development, our driver development and Image Quality (IQ) tuning tools include Chromatix™ and Chromatix™ Light. Chromatix gives expert users complete access to all the individual functions in the ISP to unlock its full power. Chromatix also has a driver generation tool, which greatly speeds the integration of camera sensors with Snapdragon processors.

Offering higher level abstraction, Chromatix Light is designed to simplify internal adjustments to camera settings including roll-off, AWB, color tint, color correction, saturation, contrast, denoise, sharpness, and AEC control. Chromatix Light makes it easy to explore quick adjustments to IQ, and view those changes live on the target phone.

QTI also offers an objective IQ evaluation tool that automates many of the tests used in tuning development and IQ validation. This tool helps guide camera development down a path that is repeatable and reproducible, giving solid metrics by which to tune.

5.3 Software development tools

Support of the software developer ecosystem is paramount to help ensure the widest range of applications available on the Snapdragon processors. QTI is deeply committed to supporting the application development community. Some key examples are highlighted here.

5.3.1 Android Camera HAL v3

QTI works closely with Google on the integration and delivery of the Android camera Hardware Abstraction Layers (HAL). This tight relationship is vital to QTI's ability to be a leader within the mobile industry in supporting compelling camera apps that not only enhance ease of use, but also provide useful and fun features such as augmented reality, image post-processing, and more.

The Android camera HAL connects the higher level camera framework APIs in android.hardware.Camera to the underlying camera software and hardware. In Android L, the new HAL v3 introduces a new camera stack, and QTI is at the forefront in supporting it.

Version 1 of the camera subsystem was designed as a black box with high-level controls. The operating modes were segmented into preview, still capture, and video. This rigid segmentation made it difficult to implement new, advanced features that required the capabilities of multiple modes or the ability to allow the camera application control over the image sensor and ISP. One such example is burst capture mode, or still capture during video record.

In addition to eliminating the distinct operating modes in favor of a unified view, HAL v3 introduces changes that make it possible for the camera applications to access and control the image sensor and ISP. For example, HAL v3 makes it possible for OEMs and developers to create smart applications that improve image quality by intelligently controlling settings within the camera and ISP to reduce noise, improve dynamic range, enhance color, change depth of field and focus, and more.

5.3.2 Domain specific computer vision library

The FastCV™ library offers a mobile-optimized CV library which includes the most frequently used vision processing functions — for use across a wide array of mobile devices.

Middleware developers can use FastCV to build the frameworks needed by developers of computer vision apps. For example, Qualcomm Connected Experiences, Inc.'s augmented reality SDK (Vuforia) uses FastCV. Developers of advanced CV application can also use FastCV functions directly in their application. FastCV helps developers to add new user experiences into their camera-based apps, such as, gesture recognition, text detection, face recognition, and augmented reality.

FastCV is designed for efficiency on all ARM-based processors, but is optimized to take advantage of Snapdragon processors. Mobile application developers can use FastCV to get the benefits of heterogeneous computing on Snapdragon processors without having to program the processing engines explicitly. This gives developers one of the most widely used, computationally intensive vision processing APIs on mobile, along with hardware acceleration and better performance.

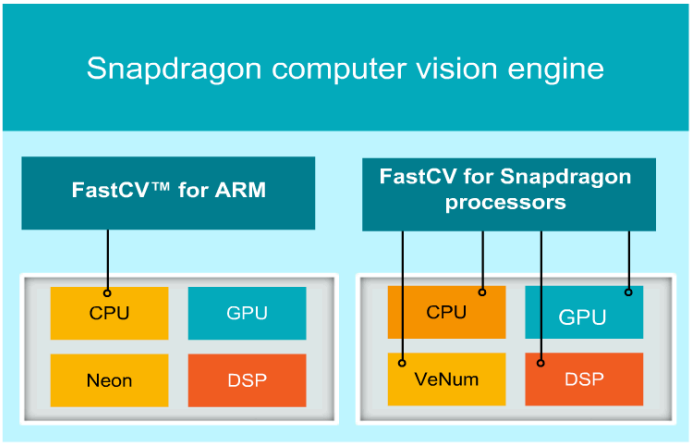

Figure 13: FastCV is optimized for the heterogeneous engines on Snapdragon processors

5.3.3 Heterogeneous computing development tools

For those who are programming directly to the hardware and not using imaging libraries, QTI has created powerful development tools. These tools, including the Adreno SDK, and the Hexagon SDK, are used by OEMs, ISVs, and app developers to optimize the features and performance of their mobile imaging software on Snapdragon processors. By running computationally-intensive applications on the most appropriate heterogeneous engines, developers are able to create compelling imaging user experiences, with high performance and low power.

The Adreno SDK includes tools, emulators, libraries, documentation, samples, and tutorials. The Adreno SDK supports the most common APIs such as OpenGL ES, DirectX, and OpenCL. In addition, the Adreno SDK contains several timesaving utilities, and over 100 samples and tutorials, including 50 advanced shader effects. The Adreno Profiler provides developers with detailed GPU utilization analysis to help them optimize their imaging algorithms for faster frame rates, and longer battery life.

The Hexagon SDK provides developers access to the embedded computing resources on the Hexagon DSP. Using the Hexagon SDK, developers with expertise working in native programming environments can tap into world-class, hardware-enabled multimedia features to deliver premium, interactive user experiences in weeks, instead of the six-to-nine months typically required to provide this level of functionality when using source code modification.

5.4 Development platforms

The DragonBoard™ platform is a development kit based on the Snapdragon processor. Intrinsyc, for example, distributes the development kits based on Snapdragon 805 processor.[12] The kit exposes the Snapdragon processor and lets hardware vendors take advantage of pins, connectors, adapters, and expansion headers to tap into its functionality in their own product development efforts. The DragonBoard development kit is used for developing and prototyping hardware components as well as for developing middleware.

[12] http://www.intrinsyc.com/products/qualcomm/dragonboard-development-kits.aspx

Developers can cover a lot of technical ground with the DragonBoard development kit, including Android, integrated development environments (IDEs), radios, application processors, debuggers, sensors, and displays. It gives developers the opportunity to optimize their apps for a mobile processor that powers millions of advanced mobile devices worldwide.

Mobile development platforms (MDP) powered by certain Snapdragon processors in the form of tablets and smartphones are currently available to developers prior to the launch of commercial OEM devices. Intrinsyc, for example, distributes the development platforms based on Snapdragon 805 processor.[13] These MDPs provide early access to new features of Snapdragon processors and are designed to allow developers to optimize their camera software in advance of the commercial launch of devices with Snapdragon processors. Devices with Snapdragon processors are available across tiers, and developers can select from a wide range of existing commercial devices to complete final testing and validation of their camera solutions.

Figure 14: Snapdragon Mobile Development Platform

5.5 Engineering support

QTI's world-class engineering organization offers a range of training programs and other support functions that are helping drive the growth and evolution of the mobile imaging community.

Figure 15: Snapdragon processors enable premium smartphones with great camera capabilities

QTI works closely with OEMs worldwide, helping ensure that smartphones powered by Snapdragon processors offer superior camera experiences. QTI works on many fronts to support its customers throughout the life cycle of their products, from program kick-off to component device selection, to handling service requests, to providing specialized training, to offering a library of easy-to-use support materials.

[13] http://shop.intrinsyc.com/products/mdp-tablet-powered-by-snapdragon-805-processor

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As part of that commitment, QTI has a large team of customer engineers deployed throughout the world at both customer sites and dedicated support laboratories. These sites incorporate a full complement of imaging, SW, and HW engineers focused on making every device with a camera powered by Snapdragon processors produce fantastic images.

6 Conclusion

Mobile imaging has come a long way, and yet there are still many innovations to come. Today, smartphones offer advanced features and DSLR-like image quality, while getting thinner and more power efficient. QTI is a leader in delivering an industry leading, comprehensive camera solution, not only by taking a holistic approach to mobile SoC design, but also by fueling innovations in the mobile ecosystem. To deliver next-generation imaging experiences within the power and thermal constraints of mobile devices, Snapdragon processors use heterogeneous engines along with its dual ISP to deliver unmatched image processing performance. By working hand-in-hand with the global mobile imaging ecosystem, QTI is fueling innovation and working relentlessly to deliver the world's best camera experience. Creating breakthrough mobile imaging experiences is our passion, and QTI will continue to lead the way.

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