

Dissection of the Intel[®] Play[™] QX3[™] Computer Microscope

Lenka Jelinek, Smart Toy Lab (Connected Products Division), Intel Corp.

Geoff Peters, Smart Toy Lab (Connected Products Division), Intel Corp.

Jim Okuley, Smart Toy Lab (Connected Products Division), Intel Corp.

Steve McGowan, Advanced Engineering (Intel Architecture Labs), Intel Corp.

Index words: Consumer Products, Extended PC, Smart Toys, Intel[®] Play[™], Computer Microscope, Imaging, Camera, USB, optics, CMOS

ABSTRACT

“Wow, it can do all that for \$99 (USD)?” is the reaction of many people upon first seeing the Intel[®] Play[™] QX3[™] Computer Microscope in action.

Unlike regular optical microscopes, the QX3 has no eyepiece to look into. Instead it has a built-in camera that sends live video images of specimens or small objects at 10x, 60x, or 200x magnification to the PC via a Universal Serial Bus (USB) connection. The creativity software of the QX3 then allows scientists of all ages to easily view, capture, modify, and share images, videos, and time-lapse movies.

Unlike most commercially available microscope systems that offer on-screen viewing, the QX3 provides photomicrography at an affordable price along with additional functionality. Furthermore, the QX3 was designed for children; this translates into a device that is extremely easy for everyone to use.

So how did we do it? This paper examines the interworkings of the QX3 Computer Microscope, including both hardware and software aspects. It will become clear that a consumer product in the smart toy space is a complex, yet delicate balance between designing for “low cost” and remaining true to the vision of the product.

Intel Play and QX3 are registered trademarks or trademarks of Intel Corporation or its subsidiaries in the United States and other countries.

INTRODUCTION

A smart toy is defined as a plaything that uses technology in some preeminent way. Toys are the tools of play; they reduce the complex world of human culture to forms that children can grasp. So how do we create a smart toy that utilizes technology in a novel, ingenious way but yet focuses *not* on the technology itself, but instead on the *use* of this technology?

This is the challenge that we faced in the Smart Toy Lab in the spring of 1998. The result was the flagship of Intel[®] Play[™], the QX3[™] Computer Microscope.

The QX3 satisfies this challenge in these three ways:

- **Novel:** The major difference between the QX3 microscope and its predecessors is its ability to capture and view digital images and movies. Before the introduction of the QX3, photomicrography was only possible with the most expensive microscopes.
- **Savvy:** The QX3 microscope is easy to use; yet, it takes advantage of today’s video imaging and computer technology.
- **Feasible:** The hardware design fits the cost constraints for a consumer product.

This paper discusses the tradeoffs and decisions behind making the QX3 not only a successful product for Intel Play, but also one of the key learning experiences in Intel’s consumer product design.

Intel Play and QX3 are registered trademarks or trademarks of Intel Corporation or its subsidiaries in the United States and other countries.

CONCEPT EVOLUTION

In many instances of product development, a new concept is a successful marriage of old and new, and sometimes even something blue. The QX3™ Computer Microscope is no exception. The concept of microscopy has been around for centuries; the first microscope is usually credited to Zacharias Jansen in the late 16th century.

Digital microscopy then utilized the power of the personal computer, and its professional applications in such fields as science and medicine are very well established. However, in the children's toy category, with a sub \$100 price point, marrying the microscope with the PC was a unique challenge. A compelling, fun set of features that was acceptable to the target audience, children, was far from a trivial task.

To create a product with an open-ended play pattern was one of the main objectives of the project. An open-ended play pattern allows children to bring their own creativity to the various aspects of the product. Open-endedness not only prolongs the child's interest in the product, but also prolongs the life of the toy. Close-ended play patterns often result in toys that children get bored with and put in the closet. The goal was to create a long-lasting product that did not require the child to follow complicated instructions or rules.

A user-centered design approach was taken when developing the features of the QX3 microscope. Product concepts were generated that were easy enough for a six-year-old to figure out but involved enough so that older children would not get bored with them. This large set of product features was presented to target users in the form of models, storyboards, and software demos. Feedback from children in these tests was a major determining factor for the final feature set of the product.

The very first instantiation of the QX3 concept began as a sawed-off microscope with a digital camera attached to its eyepiece (Figure 1).

The first prototype provided significant learning: it was feasible to combine two off-the-shelf products and get a satisfactory outcome. This was also the first validation of cost implications. At this price point we could deliver this level of product quality.



Figure 1: First prototype

The next important validation came in the form of prototype number two: the hand-held digital microscope (Figure 2).



Figure 2: Hand-held prototype

In the design phase of the project, features were created that improved on the play of the traditional microscope toy. For example, a hand-held mode was developed in which the user could remove the barrel of the microscope from the stand to view specimens that would never fit on a traditional microscope stage, such as a flea on the family dog or the inside of a child's ear. Testing with the target users revealed that this was a very popular hands-on feature.

QX3 is a trademark of Intel Corporation or its subsidiaries in the United States and other countries.

The design at this level also posed challenges: how do we fit the technology into a barrel that is safe yet small enough to fit into the hands of young children? How do we control the light conditions? And finally, would this feature be attractive to kids, not just engineers?

Building an actual prototype allowed us to validate the above questions to a level sufficient for further development. It also taught us another lesson: a prototype in hand is better than pages of engineering assumptions.

Function fitting the form became the reason for another milestone prototype (Figure 3).



Figure 3: Form and function prototype

Since the driving force behind the QX3 concept was not technology per se, but instead the use of the technology by our target audience. Its form in many ways dictated the technical function, at least at the implementation level. A key example was the layout of the Printed Circuit Board (PCB); the originally engineered design did not fit the form specified by the toy designer.

Safety was always an overriding goal of the product's hardware. Competitive microscope toys contain sharp instruments, glass slides, and even metal scalpels. Careful attention to detail was taken to avoid sharp edges on the plastic housing and also to design a product that could withstand heavy use and abuse by a child. Light bulbs on the QX3 are sealed safely behind plastic covers. Plastic

specimen slides were found to be more than adequate in quality compared to the potentially more dangerous prepared-glass slides.

However, the evolution did not stop there. The next section describes the hardware and software features that made it into the final product as shown in Figure 4, along with the tough decisions that went into this difficult and final step.



Figure 4: QX3 Computer Microscope

TECHNOLOGY AGENDA

In the design of both the software and hardware of the Intel® Play™ QX3™ Computer Microscope, those features that could be accurately communicated to the end user via the product's packaging were specifically emphasized. Just because we can build it, doesn't mean we can sell it. This section elaborates on the technical tradeoffs made to create a successful \$99USD toy. Included are the key engineering decisions made to support a viable feature set.

Given that the focus of all the features centers on one main feature, the microscope image on the PC, we needed to ensure that the product leverages the power of the PC and takes full advantage of the monitor for viewing

Intel Play and QX3 are registered trademarks or trademarks of Intel Corporation or its subsidiaries in the United States and other countries.

images. Great care was taken in selecting the best camera sensor at the required low cost.

CMOS Versus CCD

The QX3 microscope uses a Complementary Metal Oxide Semiconductor (CMOS) sensor as opposed to a Charge Couple Device (CCD) sensor. The choice between the two options was a hot topic of discussion during the development cycle. With the entry of the Barbie* Digital Camera and the likes, the image sensor arena in consumer end products was in search of a cheap yet satisfactory solution. Everyone wanted to get the best quality for a minimum price. For the QX3, it eventually came down to cost: CMOS sensors are built upon standard CMOS processes; they have a key advantage of incorporating general-purpose digital logic into the sensor. CCD sensors, on the other hand, are strictly image sensors. The processes that are used for CCD sensors are poor at supporting random logic implementations, which means that the control electronics for CCD sensors are implemented as external circuits. CCDs also require multiple voltage levels, thereby complicating power-supply designs. Both of these issues raised part counts and increased costs.

CCDs do, however, have a wider dynamic range than CMOS sensors, thus they perform better in a variety of lighting conditions, especially in low light. Fortunately, the QX3 does not have to primarily deal with sunlight conditions. Low-light issues were resolved by carefully controlling the lighting environment of the QX3.

Lighting Environment

Power, safety, mechanical, illumination level, and reliability problems arose when illuminating the scene.

The first decision we had to make was regarding the source of the lighting: should we use LEDs or incandescent bulbs. LEDs do not burn out, thus they avoid the issue of providing replacement parts to end users. LEDs also are not made of glass, which circumvents potential safety issues regarding glass shards from a bulb that blew up or shattered from a drop. LEDs, however, suffered from poor luminosity: high-intensity LEDs may look bright, but they output less than 10% of the light from comparable halogen bulbs.

The final decision came down to cost. At the time, white LEDs were first coming onto the market. Our initial quote for white LEDs was \$5; by the end of the project we were able to find white LEDs for \$0.75 each. But, this was still much more than the \$0.17 that we could pay for a

*Other brands and names may be claimed as the property of others.

miniature halogen bulb, similar to those used in small high-performance flashlights. So a decision was made to go with the halogen bulbs despite the design changes that would be required and the challenges that the halogen bulbs would represent.

Power

The halogen lamps that we selected are rated at 5 Volts, but the QX3 runs them at a slightly lower voltage to conserve bulb life and to lower the heat dissipation.

An early design decision was to rely solely on the Universal Serial Bus (USB) connection for all power. There are several advantages to this decision:

1. No need for batteries. This is important for a low cost of ownership from a consumer perspective.
2. No external power brick. Convenience and safety were key.
3. The user must only make a single connection to use the QX3, improving its ease of use.

As a result, the power for the lighting solution was tightly constrained to USB's power specifications. The halogen bulbs that we were looking at were rated at 350 milliAmps, which at first glance worked within our power budget. Unfortunately, an incandescent bulb looks like a dead short until it warms up. The solution was to design a current limit circuit that clamped the bulb current to 350mA; this caused the bulbs to warm up slowly (500 ms.) and prevented the initial current surge. USB power has strict constraints on current surge. Also, given that the maximum available power provided by USB is 500 mA, only one of the bulbs can be turned on at any given time.

Safety

The industry policy for toys is to enclose all glass light bulbs in a plastic cover to contain any shards if the bulb accidentally blows or shatters. The cover was problematic because it retained heat, causing the tungsten filament to evaporate, plating the inside of the bulb, and reducing light output over time. Moreover, if it got hot enough the plastic cover could melt. To minimize the possibility of excessive heating, the software turns off the lamp after a few minutes of no activity. We also attempted to increase the volume of the bulb cavity to allow more heat to dissipate. Finally, we took advantage of the fact that we needed a cover and made it translucent to better diffuse the light.

Mechanical

The mount for the incandescent bulbs needed to be removable so that it could be replaced. While this is not a significant engineering challenge, it is an instance when use of a LED-based light source would have circumvented a design issue. Both the upper and lower bulbs can be

replaced with a small Phillips-head screwdriver. To ensure that the screws were not lost, we employed a captive design that allows them to be unscrewed without falling out of the cover assembly.

Microscopes generally use two different light sources depending on the specimen being observed: top for opaque objects and bottom for translucent objects. It was decided early to allow the QX3 to be removed from the base of the microscope. This feature permitted looking at the surfaces of large objects like ears and noses, versus what could fit on the microscope stage. One lamp was integrated into the microscope and the other into the base.

The top light is well-suited for illuminating opaque specimens such as coins and bugs. It is also a light source when the microscope is used in the hand-held mode, i.e., when the child removes the QX3 body from the base or the cradle as it is also referred to.

Controls were added into the software to allow the user to select either the top or the bottom lamp when the body was in the base. We also added a contact to the base that allowed software to determine when the body was in the base. The software would then switch automatically to the top lamp when the scope was removed from the base.

Illumination

A “Super Bright” white LED generates 0.014 Candle Power (CP) at 20mA, while a halogen bulb generates 0.06CP at 350mA. While a LED is more efficient, it takes many LEDs to generate the same amount of light as a single halogen bulb. Even though it was brighter, the light generated by the halogen bulb was still marginal at high magnifications. The field of view is inversely proportional to the magnification. The diagonals of the field of view are roughly 1.25”, 0.227”, and 0.0625” for 10x, 60x, and 200x, respectively. If we distributed the 0.06CP evenly over the large 1.25” diagonal field of view required by the 10x magnification, then there would be only about 5 percent of that light (0.003CP) that was hitting the small area displayed by the 200x field of view. We had to modify the camera firmware to increase the range of imager integration time to allow proper light collection under all magnifications.

Incandescent bulbs generate light that most people consider white, but as far as the image sensor is concerned it has a distinct red tint. This effect is referred to as the color temperature of the bulb. Firmware changes were required to force the color correction circuitry to its limit, in order to compensate for the color temperature of the light generated by the incandescent bulb.

Additional Lighting Controls

A time-lapse mode in the software supports capturing images at one-second to 60-minute intervals. In the longer

time-lapse modes, the lights will turn off a few seconds after an image is recorded, and turn on approximately 15 seconds prior to taking a snapshot. The early turn on allows the color temperature of the lamp to settle prior to capturing an image, and the short turn-off time conserves bulb life during long time-lapse settings.

CIF Resolution—Striking the Right Balance

For the image sensor we used a CMOS Common Interchange Format (CIF) sensor. CIF sensors were developed for video teleconferencing applications. Their 352x288 resolution is a compromise between image quality and available bandwidth. Three years ago, during the development of the QX3, CIF was the sweet spot for low-cost USB video capture. The wide availability of CIF image sensors helped in obtaining lower pricing.

While the sensor provides CIF resolution, the camera hardware is set up to transmit a subset of the sensor array, 320x240 pixels to be exact, centered in the middle of the array. There were several advantages to using only the pixels in a central Region Of Interest (ROI).

With image sensors, there tends to be a slight degradation in the color quality of the pixels on the perimeter. Our image sensor has 352x288 physical pixels, and it places a Bayer-patterned mask over the individual pixels of the sensor to provide color information. A Bayer pattern covers 4 pixel groups with 1 blue, 1 red, and 2 green color masks, respectively. (The extra green pixel is used to compensate for the increased sensitivity of the human eye for green.) The color value of an individual pixel is computed by evaluating the intensity and color contributions of the adjacent pixels. Needless to say, the color calculations are compromised for pixels around the edge of the array, where there are no adjacent pixels. Pixels along the outer edge are also more susceptible to greater lens distortion. These problems are circumvented by not including the outer-edge pixels in our images.

Another beneficial side effect of using a smaller ROI is an increased frame rate, because there are less pixels per frame to send through the USB pipe.

IMAGE COMPRESSION

The CMOS sensor is integrated with a Digital Signal Processing (DSP) component. The DSP provides additional processing on the sensor’s data, such as compression. In our case, the frame rate was limited by the bandwidth of a USB connection. The maximum throughput on a high-speed isochronous USB is limited to 1.023MB/sec. Most cameras use a lower rate to allow some bandwidth for other USB devices to work while the camera is streaming video.

There is always a tradeoff between image quality and frame rate when it comes to compression. The higher the compression setting, the more frames of data can be sent through the USB; therefore, the frame rate is higher. However, the video compression used by cameras is lossy, i.e., higher compression settings decrease the quality of the image. With no compression, the original quality of the image is preserved, but the frame rate is lower. After careful evaluation of the tradeoffs, we chose to use no compression of the image data for the QX3™ Computer Microscope. This resulted in an image quality that gave the end user the best picture detail. The resulting frame rate was approximately four frames per second, which is slow, but acceptable for the application.

Lenses and Magnification

The QX3 microscope has three preset magnification options: 10x, 60x and 200x. The user can change magnifications by manually rotating a barrel, which contains three lens tubes. Classically, microscopes have “objectives” that rotate into position at the bottom of a long lens tube and replaceable “eye pieces” at the top of the tube. This solution is flexible because it allows a wide variety of magnifications, but it is expensive because multiple lenses are required in each of the actual objectives to condition the light so that it can span the length of the lens tube without distortion. By using a lens tube for each magnification, we were able to optimally position the lenses in the tubes and minimize the lens count.

The “magnification” of the QX3 is the ratio of the field of view on the specimen stage to the size of the image on the monitor. The magnification is comprised of three components: optical, pixel scaling, and digital. The magnifications provided by the pixel scaling and digital components are fixed.

The *optical* magnification for 10x, 60x and 200x is performed via the custom lens system, where the lenses magnify the field of view on the specimen stage by 0.2x, 1.1x and 4x, respectively.

The *pixel scaling* is simply the ratio between the image sensor pixel size and the monitor pixel size. The pixels on a 15” monitor, running at 800x600 resolution are roughly 270x270 μm . When the 9x9 μm pixels of the image sensor are displayed on the monitor, the sensor pixels are “magnified” 30 times.

The *digital* magnification is performed when the 320x240 image is then software interpolated to the final 512x384 pixel resolution that is displayed on the monitor, resulting in an additional 1.6x magnification.

The advertised magnifications for the QX3 assume a 15” monitor. The actual magnification depends on the size of

the monitor. In all cases, the QX3 application forces the video mode of the monitor to 800x600.

The optical magnification is the key to good performance in the QX3. The decision to perform 1.6x software interpolation was mostly for aesthetic reasons. On an 800x600 display, the resulting on-screen image was large enough for user viewing, and it left enough real estate around the Live View window for the application’s buttons and user-interface elements.

From a feature perspective, the 10x magnification was designed to provide as much depth of field as possible for easy focusing with the limited light source and simple optics. The field of view for the 10x magnification was also an important factor in its design. The field of view had to support a specific play feature that tested great with children: the ability to use the microscope to acquire small photographs of friends or family members’ faces, cut them out using the software, and then paste them onto the heads of bugs. Essentially, children wanted to also use the microscope as a scanner.

Also, as objects are increasingly magnified, they become less recognizable, especially to children. The 10x or “wide-angle” magnification allowed children to see giant versions of insects that they could recognize.

The 200x magnification was largely driven by a marketing requirement. 200x allowed the QX3 to compete with other entry-level laboratory microscopes in the marketplace.

Lens System

The lenses were designed for optimum quality, ease of operation, and safety, while remaining within the target range price of a toy.

One of the goals of our lens design was to allow changing magnification with minimal refocusing on the user’s part. Parafoveal lenses do just that: they provide magnification changes without the need for manual refocusing. The QX3 microscope does not have parafoveal lenses, but it was designed to get as close to that functionality as possible. The working distance of all three QX3 microscope objectives lies approximately between 26-29 millimeters, but again, the objectives are not parafoveal with one another.

To achieve parafoveal lenses in the QX3, we would need to add additional factory alignment (axially) and would have to make design and manufacturing changes so that the mechanical system would be robust enough to hold focus while changing objectives. This is not a trivial task. It should be noted that even high-end microscopes aren’t exactly parafoveal at high magnifications.

Based on the tradeoff between cost, quality, and safety, a decision was made early in the design phase to use plastic lens elements instead of glass ones.

Another technology that the QX3 took advantage of was “binary” or “diffractive” optics. When light is refracted through a lens, some colors are bent more than others, causing a rainbow effect around the edges of objects. Typically, lenses are paired to correct this problem. The “binary” feature of the lenses in the QX3 etched virtually invisible concentric ridges on one surface of a lens. These ridges provided a diffraction grating, similar to a Fresnel lens, which acted as if we had placed a second lens in the optical path.

A key goal was to minimize the number of lens elements needed. This was accomplished through the use of our novel lens barrel approach and diffractive optics. The use of a single lens in the higher power objectives was specifically to reduce optical aberrations. The QX3 only uses four lenses, three of which are binary: one for 60x, one for 200x, and two for the 10x magnification.

Having non-glass lenses helped us achieve a stringent safety and reliability compliance. This is significant in areas such as drop testing, choke hazards, etc.

Finally, the lenses were specifically designed for manufacturing, with foolproof assembly techniques. The lenses themselves were manufactured in the United States for best quality control.

Focus Mechanism

The QX3 can be focused in one of two ways. In the cradle mode (where the QX3 body is held by its cradle), the focusing happens by manually moving the stage up and down via a focusing knob. In hand-held mode (where the user holds the QX3 body in the hand), focusing happens by moving the QX3 body closer and farther away from the object until the image is in focus. The hand-held mode is best suited for the 10x magnification setting. Higher magnifications are more difficult to use in this mode since focusing on the object is more sensitive to hand movements/shaking. Most users, especially children, have difficulty holding the QX3 body steady enough to provide a steady picture image. To make hand-held focusing easier, there is a “foot” on the bottom of the body that positions the optics at the proper working distance when the body is standing on a flat surface. Rocking the body on the foot can perform fine focusing adjustments.

The benefits of being able to use the QX3 microscope in the hand-held mode far outweighed the focusing difficulties, hence this design decision. The hand-held mode greatly expands the world that the child is able to examine at the microscopic level. With traditional microscopes, the user is limited to only examining

specimens that fit on the microscope’s stage. The QX3 microscope removed this barrier.

Exposure Control

While the user has the ability to control the lights in the QX3 microscope, direct exposure control is done by the application. The application adjusts the exposure and color balance levels to provide the optimum setting under various lighting conditions. For example, when the QX3 is removed from its cradle (i.e., is in hand-held mode) and the user turns off the light, the application switches to day light color settings and adjusts the gain levels.

SOFTWARE FEATURE METHODOLOGY

One underlying design mantra for the Intel® Play™ QX3™ Computer Microscope is to “harness the power of the PC to make a \$99USD toy yield a \$1000USD play experience.” High-tech software running on the host computer best delivers on this mantra. In early discussions, the potential for heavily algorithmic features became overwhelmingly obvious. Potential features included image stitching and mosaicing, time-lapse microphotography, image processing to improve depth of field, heavy algorithmic image quality enhancements, and object tracking and identification, to name but a few. In these initial engineering-driven discussions, the following criteria, in order of priority, were used:

1. Do the engineers think it is cool?
2. Does it use the latest, cutting-edge technologies?
3. Can we build it?

While we as engineers clearly feel that this will deliver a superior product at the cost of all else, a high-tech product, however, does not imply a marketable product. First, the technology must be easily conveyable in order to sell the product, a common problem with leading-edge ideas. Second, the technology must work solidly: consumers have little tolerance for cool features that are inconsistent and partially usable. Lastly, the appearance of high-tech is often more successful than actual high-tech: low-tech solutions to a stunning feature are more stable and lower risk than high-tech solutions.

Using these observations, an interdisciplinary group of software engineers, toy designers, integration engineers, and marketing representatives revisited the software feature list. This group enforced a greater, more accurate litmus test for feature inclusion, a test that stressed the

Intel Play and QX3 are registered trademarks or trademarks of Intel Corporation or its subsidiaries in the United States and other countries.

unique and targeted use of technology in the eyes of the end user over the complexity of the technology. Thus, the refined acceptance criteria for features were as follows:

1. How does the feature enable and potentially enhance the core feature of the product: the display of the microscopic image on the computer?
2. Is the target audience interested? A significant realization during development was that there was not a single person in the product development team that was a member of our core target audience. Similarly, will the target audience understand it? How hard is it to convey the feature?
3. Can it be implemented to gold quality in time?
4. Will it run on a typical user's computer (i.e., a minimum system configuration)?
5. How much validation effort will it take to ensure a gold-quality solution?
6. What is the "wow" factor? (Note: this does not necessarily imply a highly technical feature.)

This litmus test resulted in a fully functional application that includes: a) a live mode where the user can preview and record still images and movies; b) an image-editing mode complete with common painting tools; c) a "special effects" image filter mode; and d) an image and movie slide-show creator.

With the acceptance criteria enumerated above, we now will examine in more depth, five features and design decisions that were considered for the QX3 software package. Of these five elements, four were included in some form in the final product.

Image Stitching

The software development group for the QX3 included several engineers with image-processing backgrounds. This led to an initial emphasis on highly algorithmic image-processing-based features, including image stitching. The idea was to use the hand-held microscope (or a stationary scope with a motorized stage) to stitch together multiple highly magnified images into an extremely large mosaic super-image. This would potentially turn the microscope into an extremely high-resolution scanner.

Stepping through the engineering-driven criteria list, this feature hit the bull's eye. It was very cool, used the latest image-processing technologies, and could be implemented. For the refined criteria list, however, image stitching performed miserably. The concept is somewhat difficult to convey, and was deemed to be less important to the core 8-14 year-old target audience. Its cutting-edge technology would be difficult to implement to gold quality

in minimal time and would substantially increase the validation effort. Lastly, the algorithm would likely not be usable on our minimum system configuration. As a result, this high-tech feature was not chosen for inclusion.

Time-Lapse Photography

Another featured considered was the ability to take time-lapse movies. Here, the computer takes a snapshot anywhere from every second to every 60 minutes and then compiles the images into a movie. This feature is a great example of a high-tech feature that can be implemented by comparatively low-tech solutions.

The largest risk associated with this feature is the significant validation effort required to ensure that the feature is bug free. First, the validation tests have to run over extremely long periods, tying up valuable testing resources. Secondly, it would be useful to allow the user to use other programs during a long time-lapse recording. This further increased interoperability testing.

In the end, this feature survived in the final product, but was modified to prevent the user from easily using other applications concurrently. This experience proved that validating the implementation of a feature is just as important as the actual implementation of the feature.

Printing

The ability to print from the application is often looked at as fundamentally necessary and entirely *uninteresting* to the engineers. For our target age group, however, the ability to print is essential due to the target age group's desire for possessing tangible evidence of their work. Therefore, the printing capabilities were expanded to include the ability to print stickers and large posters, requiring some image interpolation algorithms to ensure image quality. In this instance, we have a low-tech feature that required significantly more substantial technology for success.

Image Filters

The QX3 software includes a set of filters that can be applied to an image, creating special-effect renderings. The filters include a kaleidoscope, bug's eyes transformations, and other warping image-processing algorithms. Here, each filter effect is a discreet action applied to an image or movie. As a result, validation and interoperability with other application features is minimized, allowing the developers to implement self-contained, high-tech features. As the QX3 has evolved, new optimized filters for the latest processors have been cleanly added as the product has been refreshed.

Middleware

Some of the heaviest lifting for an application often occurs in the “middleware,” or the plumbing of the application. Again, software engineers are presented with the decision on how to architect the application, and how to integrate the application with the operating system. In the case of middleware, the question of high-tech now becomes “how much of the operating system’s new features should we take advantage of?” This is especially problematic when comparing the engineers’ criteria list with the refined product’s criteria list. Here, we have to balance the new capabilities of the latest operating system features with the stability and wider end-user presence of older solutions.

At the risk of accepting a “not invented here” mentality, it may even be acceptable to implement certain new technologies found in the operating system in-house, to ensure that any last-minute bugs can be addressed internally before shipping. Fundamentally, application developers are fairly chained to any bugs pre-existing in the operating system.

For instance, Windows Driver Model* (WDM) streaming was a new technology hitting the mainstream with Microsoft Windows* 98. This infrastructure would have been ideal for use with the QX3. The QX3, however, was initially designed to additionally support the Microsoft Windows 95 platform, which at that time displayed problematic symptoms with WDM streaming. Therefore, we committed to an older VfW-based solution wrapped into the newer DirectShow* framework, part of Microsoft DirectX*, to ensure Windows 95 interoperability. Ironically, the Windows 95 requirement was later dropped after further testing. Subsequent releases of the QX3 are then expected to migrate fully to the WDM solution.

In summary, features and design architectures were best chosen due to a variety of concerns, only a few of which were engineering driven. Many times, high-tech solutions were not the optimal solution. Even the most optimal engineering solutions did not always prove to be optimal for the end result of the product as a whole. Equally distributing ownership feature resolution to a variety of well-respected disciplines resulted in a product that best fulfilled its promise.

FUTURE CHALLENGES

Keeping the technology fresh is an important premise for any smart toy concept. During the product design it was our intent to design scalable hardware and software to assist with future product redevelopments and refreshes.

*Other brands and names may be claimed as the property of others.

The intended use of the Intel® Play™ QX3™ Computer Microscope was always as an end-consumer product. To our fascination, however, it went way beyond our 8-14 year-old target audience. For instance, the QX3 has had wide acceptance from stamp collectors to paleontologists, and from NASA engineers to surgical instrument companies. The potential for widespread use of computer-based photomicroscopy keeps expanding.

The original QX3 was developed three years ago. Given the pace of technological progress, the future opens up possibilities that were not feasible then: ROI digital zoom, better picture with VGA resolution, new optics, better live imaging effects and editing, better focusing, and higher magnification. Some risky image-processing algorithms have also stabilized, thus warranting inclusion.

As the power of the PC increases, so does the potential for the “magic” behind connected toys such as the QX3 microscope. The element of instant gratification is becoming a part of the culture. Three years ago it took a few seconds to apply a filter to an image for a special effect; now it happens almost as instantaneously as the child’s finger hits the function button. Advances such as these will continue to influence smart toys of the future.

ACKNOWLEDGMENTS

The authors express their appreciation of Vareck Bostrom, Phil Doberenz, and Philip Lantz for their insightful feedback in reviewing this paper.

We also acknowledge Michael Davidson at Florida State University for his outstanding Web site on digital microscopy using the QX3, located at <http://www.microscopy.fsu.edu/>

AUTHORS’ BIOGRAPHIES

Lenka Jelinek has been a “versatile engineer” with the Smart Toy Lab since its onset to its end. She was an engineering architect on the QX3 and with passion continues to ideate and innovate smart toys of the future. She holds degrees in Electrical Engineering and Computer Science from the University of Wisconsin at Madison. Her e-mail is Lenka.M.Jelinek@intel.com

Geoff Peters also was an engineering architect for the QX3, and has a master’s degree in Computer Science from Purdue University. His professional interests include semantic video processing, robotics, advanced

Intel Play and QX3 are registered trademarks or trademarks of Intel Corporation or its subsidiaries in the United States and other countries.

computer-human interface design, and any other discipline that yields depth of thought. His e-mail is Geoff.Peters@intel.com.

Jim Okuley has over 10 years experience designing and inventing for the toy industry. He holds a degree in Industrial Design from the University of Cincinnati. He has been an Intel Senior Industrial Designer at the Smart Toy Lab since it started. Jim is also a designer of other award-winning toys such as the Intel® Play™ Computer Sound Morpher and the recently released Intel® Play™ Digital Movie Creator. His e-mail is Jim.Okuley@intel.com.

Steve (“Maven”) McGowan has a degree in Electrical Engineering from Marquette University. His previous experience in designing the optics and electronics for head-mounted display systems was invaluable during the development of the QX3. His e-mail is Steve.McGowan@intel.com.

Copyright © Intel Corporation 2001. This publication was downloaded from <http://developer.intel.com/>.¹

Legal notices at <http://developer.intel.com/sites/developer/tradmarx.htm>.

Intel Play is a registered trademark or trademark of Intel Corporation or its subsidiaries in the United States and other countries.