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ORIGINAL ARTICLE

Evolution of 3D mobile games development

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Abstract 3D computer graphics have been an important feature in games development since it was first introduced in the early 80s and there is no doubt that 3D based content is often viewed as more attractive in games than the more abstract 2D graphics. Many games publishers are keen to leverage their success in the console market into the mobile phone platform. However, the resource constraints of mobile phones and the fragmented nature of the environment present considerable challenges for games developers. In this paper we consider some of the current constraints together with current and, probable, future developments both in the software and hardware of mobile phones. As part of this process we benchmark some of the latest and most prevalent software and hardware devices to ascertain both the quality of the graphics produced and the effects upon battery life. Whilst our test results highlight that the current market does indeed present challenges, our research into the future developments highlights the fact we are approaching greater standardization, which will be an important factor for the successful development of 3D mobile games.

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1 Introduction

Mobile games are seen as an important service for many mobile phone users by both the network operators and the games industry. Operators are currently trying to drive up the average revenue per user (ARPU) by encouraging greater use of data services and games are seen as a means in which this can be achieved. The games industry also sees the enormous opportunity for increasing sales and its customer base. Indeed, mobile games already represent 14% of $43 billion total world gaming revenue [1] and many current predictions would suggest that the mobile platform would become the dominant force in the games industry. However, current evidence shows that growth in downloaded games is relatively slow [2] and many traditional games publishers are sighting poor quality of production and too many developers distributing in the market as the primary cause. However, this does not explain why the so-called casual games, such as Tetris, dominate the market. Many mobile games developers cite the fact that there is a general lack of innovation in the market and many traditional console games developers are failing to grasp the innovative opportunities for the social interaction, already a significant element of mobile phone usage, in the design of their games. For example, in June 2006, while speaking about casual games to the Hollywood Reporter, the Digital Chocolate CEO, and founder of EA, Trip Hawkins said:

‘‘companies are treating the cell phone like it was a second-rate game console and I don’t think that’s really doing it justice’’

Part of the problem could be that the games industry has adopted the popular profiles of hardcore and casual gamers [3] to define its audience demographic and these definitions are undoubtedly influencing industry expectations about the mobile gamer.

Hardcore gamers:

- Purchase and play many games.
- Enjoy longer play sessions and regularly play games for long periods.
- Are excited by the challenge presented in the game.
- Will tolerate high levels of functionality in the user interface and often enjoy mastering the complexity.
- Often play games as a lifestyle preference or priority.

Casual gamers:

- Buy fewer games, buy popular games, or play games recommended to them.
- Enjoy shorter play sessions—play in short bursts.
- Prefer having fun, or immersing themselves in an atmospheric experience.
- Generally require a simple user interface (e.g. puzzle games).
- Consider game playing as another time-passing entertainment like TV or films.

It is often assumed within the games industry that casual gamers form the majority of mobile gamers although this may be an over simplification as the nature of the mobile environment is a major contributor to the formation of more casual gaming habits. There is a strong argument that the games industry must establish new definitions specifically for mobile. In an interview for the Game Daily Biz in February 2006, Jason Ford, General Manager for Sprint Entertainment, defined two specific types of hardcore mobile gamer:

''First there are the 'cardcore' mobile gamers. These are people who play casual games in a hardcore fashion. The type that might spend hours and hours trying to get a bejewelled high score but don't own a gaming console''

''Second is the 'hard-offs'. These are your more typical hardcore gamers, who are playing off their normal platform. They're the type more likely to check out the mobile version of a hit console title, because they know and like the brand''

Additionally, at the 2006 CES panel discussion 'future of mobile games', IDG's CEO, Dan Orum, stated that:

''We're seeing an emergence of the 'social gamer', they're like the typical 'hardcore gamer', but with social lives''

The question then is will these mobile casual/social gamers actually care about 3D? From the current evidence from the traditional games industry it is evident that 3D animation will be the initial driver of sales, as it undoubtedly produces a better experience than 2D, but that gaming experience will prove to be the key in ensuring repeat purchases. It is a similar argument as to whether customers wanted colour or monochrome handsets—whilst monochrome can produce the same functional experience once a user has used a colour terminal they are unlikely to change back. Given the large demographic of the mobile phone user base it is highly unlikely that one or two game genres will dominate as they do in the console market but that 3D has a major part to play in maximising the user experience.

Having put the case for the importance of 3D it is useful to examine games that have appeared in the market. It can be seen that until relatively recently many of the games delivered on the mobile phones have been restricted to 2D games, 3D-look-a-like games (not true 3D i.e. isometric) or games with very poor 3D effects. This is because implementing fully 3D-featured titles on mobile phones is a difficult task both in terms of the physical constraints such as small screen sizes, limited processing power, small memory footprints, and critical power consumption, in addition to a lack of dedicated software support. However, improvements are being made all the time as can be clearly seen in Fig. 1, which shows how mobile 3D games have evolved over the last few years with significant reductions in image pixilation and improved image texturing.

The aim of this paper is to consider the general requirements for 3D game development on mobile phones and how the constraints of the mobile phone platform effects these requirements. Further, we will highlight the improvements in software and hardware support for 3D games and illustrate through performance testing the consequences of some of these improvements.

2 General requirements for 3D games

It is commonly accepted that computer games are amongst the most resource intensive computer applications that can be developed; 3D-based games in particular often push both the limits of the hardware and skills of the programmer to their maximum. A 3D computer game requires lots of calculations to perform functions such as object rendering,[1] application of lighting, shading and reflection effects and collision

[1] Rendering is the process of generating an image from a 3D model by means of a software program.

Fig. 1 3D mobile graphics evolution

detection, etc. For these tasks to be accomplished in real time systems have evolved utilising powerful graphics processors, high bus bandwidths and large memory space to achieve smooth and effective 3D object manipulation.

High performance graphics processors facilitate high rates of pixels per second, vertexes per polygon and triangles per second while rendering 3D objects. Whilst a high bus system bandwidth has a huge impact on the vertex per polygon count and fill rates, the higher the bus bandwidth, the faster object rendering will be performed and the less data sent from the CPU to the graphics engine (either in software or hardware), thereby alleviating potential bottlenecks [4].

To allow game developers to obtain the maximum benefit from all these hardware features an efficient interface between the applications and that particular hardware needs to exist. There are many development environments available, with two of the most common being OpenGL[2] and DirectX, [3] but they all aim to produce a development environment that eases programming and maximizes the use of the hardware.

3 Phone constraints affecting 3D game development

It is important to note that both software and hardware development for 3D games has evolved over a number of years; they have not formed part of the mobile device development as its principal function up until now has been as a communications device. To display a 3D game object on a mobile phone screen requires [5]:

1. Rotation and translation of the vertices of the game object's polygons to reflect its orientation and position relative to the camera.
2. The vertices must then be projected onto the camera's XY plane.
3. Each polygon is clipped to remove any regions that lie outside the camera view, and any polygons that lie entirely outside this view are discarded.
4. The resulting polygons are mapped onto the screen.

This sequence of tasks is known as the rendering pipeline and in all four stages of the rendering pipeline a programmer encounters variations of the fundamental problem, which is the need to maintain numerical precision without sacrificing speed. Precision and speed are important factors in making a game world attractive for players. If precision is lost in any of the steps of the pipeline, objects will seem to change shape at random from one display frame to the next, undermining the illusion of solidity. On the other hand, if the processor takes too long over executing any of the steps of the pipeline, the frame rate will fall off, undermining the illusion of smooth movement. Maintaining precision without sacrificing speed is difficult on mobile phones, because the data types and arithmetic operations that make it easiest to maintain precision are also the ones that tend to produce the slowest-executing code [5]. In this section we will explore some of the constraints that particularly affect this rendering process.

3.1 Mobile phone processors

Most mobile phones at the present time run at relatively slow clock speeds, normally between 100 and 500 MHz [4]. They also lack dedicated graphics processors, which means that all speed improvements for the rendering pipeline must generally be obtained

[2] OpenGL (open graphics library) is a standard specification defining a cross-language cross-platform API for writing applications that produce 3D computer graphics.

[3] DirectX is a collection of APIs for handling tasks related to game programming on the Microsoft Windows operating system.

through software [5]. However, data sent from the processor to these software routines could easily become bottlenecked because of the low bus bandwidth available on mobile phones. This will affect the vertex per polygon count and frames per second rates and developers have to be aware of this limitation while programming their games by not overloading the data path [5].

3.2 Fixed point arithmetic

In general most mobile phone processors do not support floating-point arithmetic because of their excessive power consumption and utilise fixed point arithmetic. If floating-point data types are used on mobile applications they will perform extremely slowly since they are implemented in software emulation routines [4].

To get the fastest possible 3D game code it should only use, in order of preference:

- Integer shift operations (<< and >>)
- Integer add, subtract and Boolean operations (&, | and ^)
- Integer multiplication (*)

In other words, in speed-critical code we must represent all quantities (coordinates, angles, and so on) by integers, favour shift operations over multiplications, and avoid division completely. This strategy will give us the speed we want, but it will pose problems in implementation. Further trigonometry functions, such as cos and sin, should use pre-calculated look-up tables [6, 7].

3.3 Screen resolution

Obviously, mobile phones have screens that are tiny compared to those on PCs and games must therefore be carefully designed to fit in the particular device's screen. Generally, if mobile games are to be commercially successful they must sell in very large numbers which means that they should be capable of being run on as many devices, with various screen sizes and colour capabilities, as possible. This is particularly difficult when developing 3D games since it is more complex to export 3D game objects to different screen sizes than a corresponding 2D object [7, 8].

4 Software support for 3D mobile game development

Until recently, interfaces that enabled 3D graphics on mobile phones were limited as no common standards were available, no common engines were used and any developments made were based on personal implementations of graphics APIs. This limitation has been rectified with the introduction of OpenGL ES and M3G. Their relationship to the various operating systems in the mobile arena is shown in Fig. 2.

OpenGL ES is a lightweight well-defined subset of desktop OpenGL, which is optimized by removing some classes and APIs that are expensive for the mobile platform, and introducing smaller data types and support for fixed-point arithmetic [9]. There are three versions for OpenGL ES currently available. The first is v1.0 which was introduced in July 2003 by the Khronos Group and which emphasizes software rendering and basic hardware acceleration for mobile 3D graphics. The Khronos Group is the global association that strives to stimulate the growth of OpenGL ES and other graphics technologies for mobile devices.

In mid 2004, Khronos released its newer version of the API, OpenGL ES v1.1, which emphasizes hardware acceleration. Later in 2005 Khronos introduced the latest version, OpenGL ES version 2.0, which provides the ability to create shaders and write to vertexes using OpenGL ES Shader Language, OpenSL ES [9]. OpenGL ES v1.0 is currently the only version supported by manufacturers. Early in 2004 Nokia was the first to release a mobile phone implementing OpenGL ES, the Nokia 6630. Now, all Symbian- (v8.0 and above) and BREW- (v1.1 and above) based phones implement this API, in addition to some Mobile Linux phones. However, there is an OpenGL ES implementation for Windows CE-based Pocket PCs and smartphones. Microsoft has stripped off its DirectX 3D API (MDX, DirectX Mobile) to suit devices running its newest mobile operating system: Mobile Windows 5.0.

M3G is the first Java-specific standard for 3D graphics on mobile phones. The API is an optional package to be used with profiles like the mobile information device profile (MIDP). It is based on OpenGL ES in low-level and crafted for the J2ME development platform. This implies that any device

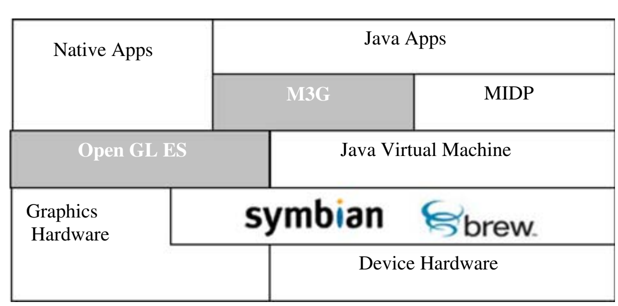

Fig. 2 Software/hardware stack for mobile phones

embedding a J2ME interpreter, given that its profile is aligned with OpenGL ES, will be able to present and render 3D graphics [10]. Although M3G is based on OpenGL ES, the API does not implement fixed-point arithmetic. It uses floating-point arithmetic instead, which causes loss in programming efficiency and extra resource consumption. The first device to support M3G in software was Nokia 6630 and the first to accelerate it in hardware was the W900 Walkman phone by Sony Ericsson released in October 2005 [11].

5 Hardware support for 3D mobile game development

Unlike software APIs and operating systems, hardware architecture for mobile phones is almost similar. The majority of mobile central processing units (CPU), and hence processor instructions set, are based on the ARM technology. All Symbian OS, Microsoft Windows Mobile, Mobile Linux and Savaje[4] support the ARM architecture [12].

There is currently a plethora of companies introducing optimized CPUs for the mobile platforms. In the next subsection we shall mention only those processors that are dedicated for graphics acceleration in general and 3D graphics in particular

With the explosion in the demand for high-quality graphics presentation on cell phones, and the continuous appeal for sophisticated multimedia services, graphics hardware technology providers have leveraged their extensive experience and knowledge to develop new solutions to meet users' and companies' expectations and requirements. The PowerVR MBX graphics processor by Imagination Technologies is developed to meet the growing needs of multimedia applications on power-conscious mobile devices like smartphones. It implements OpenGL ES 1.0/1.1. PowerVR MBX introduces benefits of low memory bandwidth, high image quality, low power demands, fill rate of 300 million pixels/s, throughput of 3.7 million triangles/s [12] and refresh rate up to 37 frames/s [12].

NVIDIA® GoForce® 3D 4800 handheld graphics processing units on the other hand delivers impressive 3D graphics, multi-megapixel digital still images, video capture and playback and extended battery life to advanced handheld devices. The processor is capable of rendering 250 and 5 million triangles/s while a frame rate of 30 frames/s [12]. The Sony Ericsson W900 Walkman phone, mentioned previously, is the first phone to ship with NVIDIA GoForce® 3D 4800 on board.

[4] Savaje is a relatively new fully featured native Java OS.

Other industry leaders like Bitboys, ATI and Qualcomm are concentrating on developing hardware solutions to accelerate 3D graphics on mobile handsets in hardware rather than purely in software.

6 3D performance testing

As was discussed previously, there is a huge variety of mobile phones in the market with very different capabilities and the majority of 3D enabled mobile phones only support software acceleration. In this paper we limit the discussion to those mobile phones that have 3D graphics capabilities supported in software via OpenGL ES 1.0 API. This version is only considered because the next version, OpenGL ES 1.1, is only available on prototype handsets and as yet none are commercially available. In particular the tests will be applied on the following Nokia Symbian-based Series60 smartphones: 3650, N-Gage, 6600, N-Gage QD, 6630 and 6680.

The phones' performance was tested for 3D performance using the Futuremark SPMar04 Benchmark software (http://www.futuremark.com), rather than our own internal tests, as it is widely available and thus the results can be readily verified. The benchmark is a comprehensive OpenGL ES 3D test suite, as shown in Fig. 3, that measures graphics capabilities and includes 2D and 3D modules. The 3D test is an advanced gaming scene that contains models, rendering, camera movement, collision detection, texturing and blending and lasts for 110 s. The 2D section features 2D content bliting and image manipulation, and lasts 30 s. The results of the benchmark demonstrate details of each phone's frame/second rate, texel/second dotting (in millions) and triangle/second rendering features (in thousands).

Despite the fact that tested phones belong to different versions of Symbian OS, and only those of version 8.0 come shipped with the OpenGL ES API, SPMark04 provides within its package an OpenGL ES implementation for all the other devices under test. A DLL[5] file containing OpenGL ES libraries is installed locally when the application is installed. Hence, the tests will run on all phones but will vary in performance according to the hardware with which it integrates.

In addition to performance, we have conducted battery-durability tests that allow us to make conclusions of how long the battery would last on each phone

[5] A DLL is a file containing executable code and data bound to a program at load time or run time. Several applications can share the code and data in a dynamic link library simultaneously.

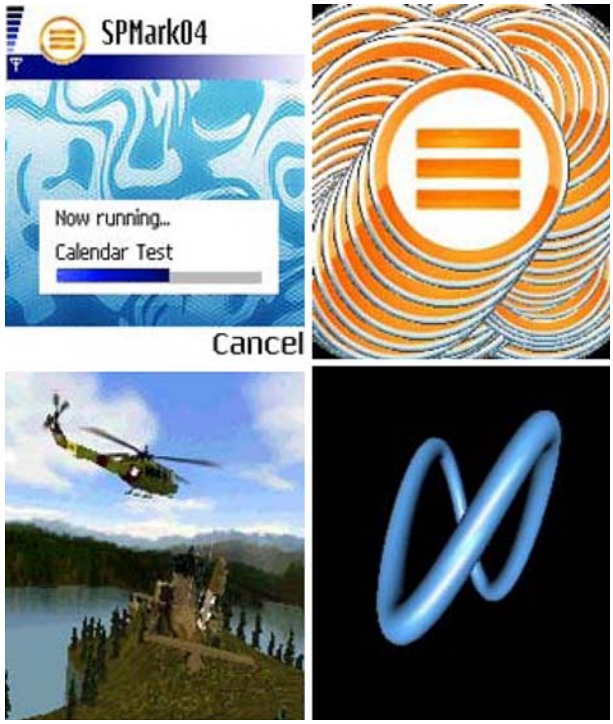

Fig. 3 Screenshots from 3D mobile graphics testing

while rendering animated 3D scenes. This test is performed by continuously running the ''Bubbly Balloons'' demo which is a 3D non-interactive animated game featuring real-time rendering, transformation, texturing, lightening, collision detection and simple models animation. It is developed by Hybrid Graphics (http://www.hybrid.fi) and includes Hybrid's implementation of OpenGL ES 1.0 which means that Bubbly Balloons will run on any of the phones in the same way SPMark04 does.

Table 1 shows the result of the tests on each of the phones previously defined. As expected the results from the three tests (frame/s, M textel/s, and K tri/s) performed on this range of phones clearly show that the devices not supporting OpenGL ES perform poorly when compared to those that do. For example, the performance of Nokia 6630 is approximately twice that of the other models. No results are presented for the 6680 as there is currently no implementation available of SPMark04 for Nokia 6680, however, it is expected to perform similarly to the 6630 but with possibly more improvement due to better resolution features. From the testing perspective it is unfortunate that the implementation of Open GL ES coincided with an increase in processor speed as this will also contribute to the improved performance although the results of the power consumption test do help clarify the situation.

Table 1 3D graphics performance test results

	3650	N-Gage	6600	N-Gage QD	6630	6680
Symbian	v6.1	v6.1	v7.0	v6.1	v8.0	v8.1
CPU (MHz)	104	104	104	104	220	220
Open GLES support	No	No	No	No	Yes	Yes
Frame/s	8.16	8.11	7.72	8.01	14.73	n/a
M Texel/s	1.73	1.73	1.62	1.8	3.26	n/a
K Tri/s	27.2	27.8	26.6	28.1	66.1	n/a
Display colours (k)	4	4	64	4	64	256
Durability (h:min)	04:41	04:42	06:06	06:45	06:52	07:02

From the table it can be clearly seen that OpenGL ES has reduced the power consumed by the phones to render the 3D graphics on mobile phones. For example, the time the Nokia 6600 spent running Bubbly Balloons until its battery died was 6 h and 6 min whilst the Nokia 6680 ran the application for 7 h and 2 min, an increase of almost an hour despite the fact that the processor speed is doubled which would normally be expected to be detrimental to battery life. This increase is most likely the result of the software support for OpenGL ES on the phone, thus confirming the conclusions derived from the 3D tests. One note of caution in regard to these results is that the demo used for the battery life test did not include any user interaction or game play and it is likely that the running time would be considerably reduced when playing ''real'' games.

The table also shows the colour range supported by the phones is also increasing which has further benefits for 3D graphics rendering and battery life as it reduces processor computation when it has to estimate the colours to paint to the screen if they do not exist in the colour table.

7 Future developments

There are many software and hardware companies actively researching for new technologies to improve the 3D experience on the mobile platforms and in this section we shall briefly highlight some of those advances.

The chief complaint among consumers' remain the perceived short operating time of mobile phones, and with the excessive calculations required for 3D graphics, this time will become even shorter. The efforts to reduce energy consumption by battery-powered devices has achieved a relative success on almost all portable electronic devices, including mobile phones, with an increase in efficiency of 10–20% every year. To continue this improvement, mobile device makers may have to combine batteries with other technologies such as superconductors and fuel cells [13], which offer a very promising potential for future mobile phones.

In addition to optimizing power consumption, processing units with faster clock cycles are likely to appear in a short term. The fastest CPU available now on mobile phone is Intel PXA272 with a clock cycle of 520 MHz [14]. It is shipped in O2 Xda IIi, which is a dual purpose mobile phone and personal digital assistant (PDA). When compared to its predecessor Xda, it offers an increase of half an hour in the talk-time and 20 h in the stand-by time [14]. This leap proves that it is possible to reach faster clock cycles for processors on mobile phones while decreasing their power consumption.

Mobile phones dedicated for gaming purposes, such as the Nokia N-Gage series, are expected to incorporate in their hardware architecture graphics processing units like the ones previously described to manage the excessive calculation of 3D games. However, this does not necessarily mean that there will be two processors present in the mobile phone. In the short term, only one processor will be available and it will be responsible of both functional control and graphics rendering. Once graphics processors are introduced alongside the central more clock cycle resources will be freed, resulting in better performance and user experience but this will require advances in chip technology to handle the resultant heat burden.

In terms of software, OpenGL ES is expected to be the standard API for 3D graphics on almost all mobile phones. It is highly likely that all mobile processor manufacturers will provide hardware support for the standard. This is because the consolidating force in PC games was OpenGL and most analysts are predicting that history will repeat itself with OpenGL ES for mobile phones.

8 Conclusions

Mobile games are expected to be one of the most commercially successful applications on mobile phones. With the relentless progress being made in both hardware and software on mobile phones we shall see this technology innovation start to filter down into the mobile phone models purchased by the average person on the street. Once this occurs we are likely to see increasing development of mobile games that incorporate 3D whatever the genre.

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