

Evolution of Physics in Video Games

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Abstract

Graphics and sound have evolved dramatically in video games over the last decade and are at a point where it is getting increasingly hard to improve upon. Physics have been a part of video games since their birth, but have until recently not played a key role. Developers have therefore turned to realistic physics simulations in order to further increase the realism in their games and subsequently the importance and uses of physics in video games has boomed in the last few years. Some games have even incorporated the use of physics into the gameplay with an interesting new dimension of puzzles to solve. However, improved realism comes with the burden of increased computational complexity that needs to find itself a new place away from the main CPU in order to continue the evolution of realism.

1. Introduction

Modern video games have near-photorealistic graphics, cinematic-quality surround-sound and AI that beats world-champions at their own games. There are few areas left to seriously improve upon aside from the gameplay of course. A game can have stunning graphics and amazing sound, but when the game world just doesn't behave in a way that makes sense to you, the immersion is broken.

This is why realistic physics models in video games are important. They transfer real-world behavior that we all know into the game world. Boxes that splinter into a thousand pieces after an explosion, metallic items that create sparks when they collide and walls that you can blow a hole through but look normal otherwise. These behaviors, made possible in today's games thanks to advanced physics models, make a big difference when it comes to immersion.

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Scott Miller of 3D Realms summed up the importance of physics well: “Physics allows for environments and gameplay situations that aren’t scripted” [1]. This is why game players and developers alike are making a huge push for the use of realistic physics in video games.

But all of this added realism comes with the burden of increased load on the main CPU, a device that is not very well designed for real-time physics calculations. Intel, Nvidia and Ageia have all realized this problem and are out to make money from it by hoping to relieve the main CPU of physics calculations, each with their own unique solution [2] [3] [4].

This report will analyze the current trends of physics use in video games, their main applications, key companies and physics engines. It will also discuss the problem of physics’ computational complexity, and the solutions that we are likely to see in the near future.

2. Origins of physics in video games

Physics in video games date all the way back to Pong in 1972 [5], but until recently physics simulations have been extremely crude and done in a way that the player barely realizes that there are any physics calculations happening behind the scenes. Popular uses of physics in the past have been basic gravitational pull and particle systems. Gravity can for example be used to calculate artillery trajectories in games such as Scorched Earth (1991) [6]. Particle systems are commonly used to simulate fire, explosions and smoke.



1 Half Life 2's gravity gun used to throw a grinding-wheel into enemies [7]

This has changed greatly in the last few of years, somewhat symbolized with the release of Half-Life 2 in 2004, which brought extremely realistic physics simulations to the average video game player. Half Life 2 did more than just show off physics with flying boxes; it actually incorporated physics into the gameplay with the Gravity Gun that let the player

pick up and throw objects into enemies [1]. Many of the in-game puzzles also require the use of physics to solve, for example the seesaw that can be turned into a ramp by placing boxes on one end. A level editor was also included with the game for free. It gave the user the ability to experiment and play with the physics engine at will which in turn spawned an entire new community around making weird physical simulations with the game engine [7]. One such community is www.garrysmod.org.

This was the beginning of a new era in video gaming. Most of today's big name first person shooter games have realistic physics simulation as one of their key selling points. A few examples include *Crysis*, *Unreal Tournament 3*, *Quake Wars*, *Call of Duty 4*, *Star Wars: Force Unleashed* and many more. It is quickly becoming an expected part of games, rather than something new and exciting.

3. Modern Day Use of Physics in Video Games

There are endless applications of physics in video games. After all, physics explain how the world goes 'round. This chapter will introduce two of the biggest physics engines leading the market and then cover some of the most frequently used physics techniques in recently released titles.

3.1 Physics engines

Programming realistic physics models is needless to say no easy task, which is why game developers have increasingly opted to use pre-made game physics engines. This allows them both to save time, and make the physics simulations much more realistic than otherwise would have been possible. [1]

Havok is the market leading game physics engine. Over 150 titles have been released using it, including *Half Life 2*, *Halo 3* and *Second Life* [8], as well being used to generate special effects in films [1]. It has broad platform support and aside from the PC, has been used on the XboX 360, PlayStation 3 and Nintendo Wii game consoles amongst others [9].

PhysX is another popular game physics engine with over 140 titles released or in the making, most notably *Unreal Tournament 3* and *Gears of War* [2] [10]. PhysX has similar platform compatibility as Havok but has the unique support for hardware accelerated physics computations using the PhysX PCI add-on card for PC's [11]. In order to make use of the PhysX add-on card the game has to use the PhysX engine for its physics calculations.

The cost of licensing these engines for commercial use is not available to the public, but both of them offer a free downloadable version for non-commercial uses. Both of these engines have support for most of the techniques wanted by developers today, but what sets them apart is the potential hardware support, as detailed in chapter 4.

3.2 Commonly used physics techniques

Even though PhysX and Havok might have the option of using most or all of the techniques mentioned below, today's computers simply can't handle the most realistic simulations possible, forcing developers to make tradeoffs in realism.

Collision detection has been an integral part of video games since the beginning. It involves algorithms to check for collision between two solids. Collision detection can for example determine whether or not a bullet hits a character. Without collision detection, characters could walk through walls and other obstacles unhindered. **Collision response** refers to the simulation of what happens when a collision is detected, such as chain reaction with other collision solids as is evident in ragdoll physics, described below. [12]



2 Classic example of collision detection [12]

Ragdoll physics are a type of procedural animations on creature skeletons that is often used as a replacement for traditional static death animations. Ragdoll physics could realistically animate a person falling down a flight of stairs, or someone getting shot with a shotgun in the torso. For real-time simulations such as video games, a lot of tricks are used to reduce the complexity, such as Halo 2's pre-recording a death animation and constraining the output of the animation to what a physical system would allow [13].



3 Early animation using ragdoll physics [13]

Deformable bodies give objects the ability to shatter, destruct or deform. This could give a player the ability to blow an alternative way through a level using a rocket launcher. Another application of deformable bodies combined with Newtonian physics could give the player the possibility to destroy the support beams of a watchtower occupied by a guard, in order to eliminate the guard. Amongst others, World of Conflict has partially deformable terrain and G.R.A.W. includes the exact



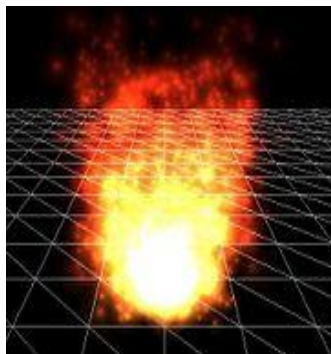
4 Destroyable levels in action in Infernal [10]

same guard and watchtower scenario mentioned above. These examples assume **rigid-body physics**, which in physics are defined by their elements, or “outlines”. [14] [15]

Soft-body physics are also possible, but generally more complex. Soft bodies in physics are ideally defined as an infinite collection of particles that make up the body’s boundary, but obvious tradeoffs are made when soft-body physics are computed in real time, such as in games. With soft-body physics you can for example simulate realistic behavior of hair, clothes, sand and water [16]. Unreal Engine III, used in Gears of War 2, uses soft-body physics for various behaviors, for example the deformation of water when you drop an object into it, and in a very odd tech demo presented at Games Developers Conference 08, the deformation of a giant meat cube as it responded to gunfire. [17].



5 A bouncing ball with a soft body



6 Particle system used to simulate fire [18]

Particle systems is a technique to simulate certain fuzzy phenomena, that are otherwise very hard to reproduce with conventional rendering techniques. Examples of such phenomena that are commonly used in video games and created with particle systems include fire, explosions, smoke, flowing water, sparks, falling leaves, clouds, fog, snow, dust, meteor tails, hair, fur, grass, or abstract visual effects like glowing trails, magic spells. An effect represented with particles can consist of hundreds of thousands of particles that the physics engine needs to keep track of and simulate in real-time. [18]

4. The Upcoming Battle for Physics

Even though what has been described so far sounds pretty impressive, the reality is that there are huge optimizations happening behind the scenes that detract from the realism of the behavior. In modern games, a character is generally presented to the player as a highly detailed 3D model. But to the physics engine, that character could be represented as nothing more than a tall cylinder standing on the ground. This could mean that if you shoot him in the head, the physics engine would not know whether you hit him in the torso or the head, just that you shot him. Modern games usually do not suffer from this specific problem though, but just a few years ago this was a commonly accepted behavior. [19]



7 Interactive worlds with physics [10]

In addition to the fields of physics still left unexplored in the video game domain, for example fluid dynamics and aerodynamics, the increment in accuracy will keep rising. As will the number and complexity of physics techniques included in games. One example is the game Mercenaries II, scheduled for release in the next year. It promises to allow the player to pour petrol on the ground and watch it flow realistically through the environment, before the player can set it on fire and watch the environment burn.

With all of these powerful physics engines, the developers have unimaginable amount of options to use, but they are severely constrained by the power of computers. As is, the physics are computed by the main CPU, the same CPU that is handling graphic and sound orchestration (even though both are hardware accelerated), artificial intelligence, game logic, input devices and many other things.

Before a short intro, the report will describe three possible solutions the problem.

4.1 The 3D Graphics Analogy

Before discussing the future of physics in video games it is worth comparing the evolution of physics in video games to the evolution of 3D graphics in video games because there are striking similarities between the state of physics now and 3D graphics 10 years ago.

3D graphics created a whole new dimension of gameplay. Gone were the days of movement being constricted to two dimensions, or faked to make the user believe he was moving in 3 dimensions. Super Mario 64 (for the Nintendo 64 console) is a good example of the evolution. It was the first game in the Mario series to use true 3D graphics and established a whole new archetype for the “platform games” genre. It sold in over eleven million copies and is the seventh best-selling video game in the USA [20] [21].

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8 Mario 64's breakthrough 3D engine [21]

The improved visuals and computational complexity became an additional burden to the computers, to the point where the power of the main CPU was simply exhausted, and graphics handling was offloaded to special 3D graphics accelerators, like the 3dfx Voodoo, released in 1996 [22]. Gradually, games started supporting hardware 3D graphics acceleration and not before long was a 3D graphics accelerator required to run all new games that used 3D graphics [23].

Physics in video are in a similar state today. All new game engines tout advanced physics models as one of their key selling points and the burden created by the use of physics simulations on the CPU is reaching the point where something fundamental has to change for the evolution to continue [1].

4.2 Participants

Ageia is the creator of the PhysX add-on card, which to this day is still the only available standalone physics processing unit (PPU) solution. It also licenses out the PhysX physics engine, which must be used in games in order to take advantage of the PhysX card [11].

Nvidia, the biggest desktop graphic card manufacturer in the world [24], recently bought Ageia. Nvidia plans to map the PhysX SDK onto their graphics card processor architecture, promising hardware accelerated physics simulations for PhysX titles using the GeForce 8 series cards with just a driver update. [2]

Intel entered the physics business in 2007 with their acquisition of **Havok**. Intel's intentions with the acquisition are to make sure that the CPU, Intel's primary product, serves a purpose in physics calculations. Intel made those intentions quite clear with the cancellation of the Havok FX project that originally promised to offload physics calculations to graphic card processors [4] [25].

4.3 Independent Physics Processing Units

Physics Processing Units, or PPU's, are as previously mentioned, independent add on cards for PC computers, in the form of a PCI or PCI-Express card. A PPU would have a completely dedicated processor designed especially for physics. In theory, this is the best option for physics simulations, but in practice it is a horribly bad option.

It is good because the hardware would be completely void of any other workload whatsoever, able to focus completely on the physics calculations. The processor would be designed specifically with physics calculations in mind, making it more efficient and streamlined than general purpose CPU's [26].



9 BFG Tech's PhysX card [37]

It is exceptionally bad because it would require every player to buy one of these add-in cards in order to play the game. If this were to happen, it is guaranteed that more than one card would be released, and we would have a conflict of standards on our hands. But the fact is that very few people are going to go buy a PPU card if it is required to play a game. This causes game developers to be reluctant to spend time on developing games for the hardware because so few can actually make use of it. This is the same exact problem 3D graphics had a decade ago, and the war over standards and inclusion in games took years to settle.

Nvidia bought Ageia because it was a competition and because it owned the PhysX engine, not because it was interested in the PhysX card. We will most likely not see another PPU card in the near future, because of the drawbacks listed above. The market is simply too hard to penetrate.

4.4 Graphics cards

This might seem like an odd venue for physics calculations, but in reality it is an excellent one. Modern GPU's such as Nvidia's GeForce 8800 GTS are capable of much more than just drawing pixels on your screen. They have incredible processing power at their disposal, although their design is specialized for graphical processing. The GeForce 8800 GTS has 128 shader processor units, each clocked at 1.6 GHz [27]. The raw processing power coupled with the fast on-board GDDR3 memory and PCI-Express 16x interface has pushed people towards using the GPU for more than just graphics.



10 EVGA GeForce 8800 GTX [23]

General-purpose computing on Graphics Processing Units (GPGPU) is a recent trend focused on using GPUs to perform non graphic related computations rather than the CPU.

Tests have shown that a GPU can perform certain tasks over 100 times faster than a CPU [28].

Physics calculations are by nature massively parallel [29] and could perform amazingly well on a GPU because of its high number of processors, but there is one big drawback; in modern video games the GPU already tends to be pushed to the limit as we are already using the GPU for graphics. Physics calculations would cut into our graphics processing power unless the current graphics card designs were modified to include a special PPU.

With Nvidia's purchase of Ageia, it is clear that they plan on making the GPU the future home of physics calculations. Further proof of that can be seen by their most recent commitment; making PhysX an open standard for everyone to use, even their fierce competitor, AMD/ATI [30].

4.5 Multi-Core CPU's

Today, any new mid to high end PC, and even notebook, will have at least a dual core CPU. Quad core CPU's are also available in the same price range, with a slightly lower clock rate, but few see the point of buying them as games rarely make use of more than one core. Despite that, the evolution of CPU's seems to be heading towards increasing cores, rather than higher clock speed. Intel even recently stated that they hope to reach 32 cores per chip by 2010 [31], falling far from their original goal of 20GHz CPU's by 2010, as projected in 2003 [32].



11 Intel's flagship CPU

This leaves a lot of unused computing power, and the average consumer asks themselves why it isn't being used for physics, since physics simulations are apparently challenging enough to warrant a special add-on card (PhysX). However, with Intel's previously mentioned acquisition of Havok [4], it is clear that they want the future place for physics to be their multi-core CPU's.

Havok has already taken a big step towards making use of additional cores, with its HydraCore technology, which aims to distribute the workload of the Havok physics engine between as many cores as you have in your system, even if it is just one [33].

4.6 The Microsoft Factor

It is possible that this battle for the burden of physics will be decided by one swift press release from Microsoft. History has shown that Microsoft is exceptionally good at standardizing and stabilizing technologies. It has done so with its Direct3D, DirectSound, DirectInput and the Windows operating system family.

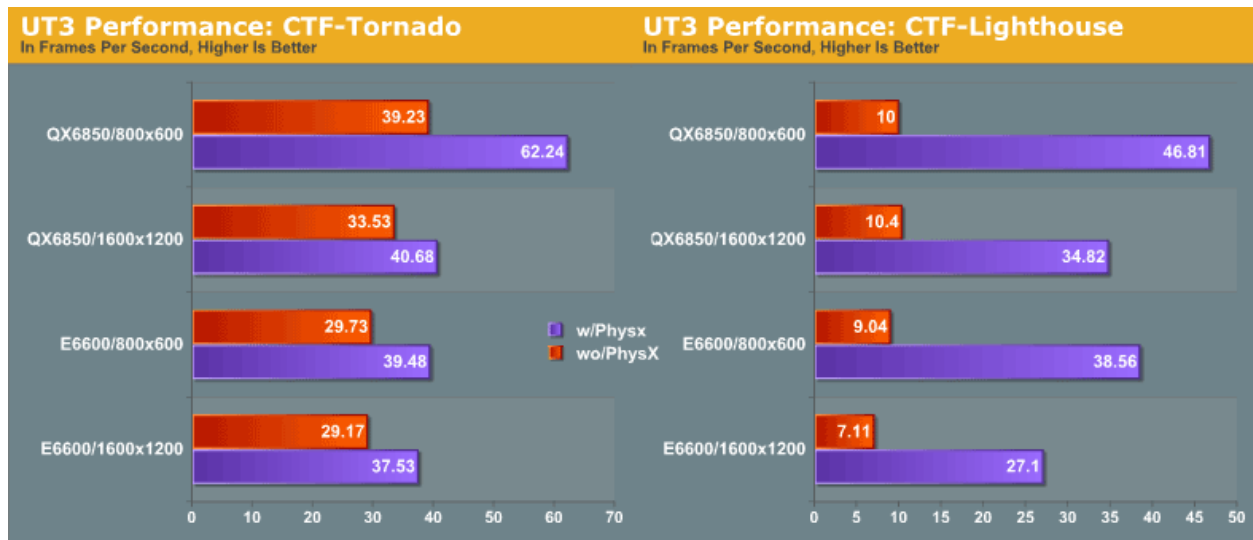
Microsoft is supposedly developing DirectPhysics, software that could stabilize the entire field when released and make it possible for smaller game development studios to incorporate modern use of physics without paying for the use of a market leading physics engine. No announcements have been made so far, aside a few online job postings looking for people to work in the DirectPhysics team [34], but it is something to look out for. [35]

5. The Impact of Specialized Hardware

Neither Intel nor Nvidia have implemented a hardware accelerated physics solution using CPU or GPU as of yet, but Ageia's PhysX PPU is readily available, giving us the option to take a look at the real world performance gains of using hardware acceleration for physics.

Anand at AnandTech benchmarked the PhysX card in its latest flagship title, Unreal Tournament 3 (UT3). UT3 offers support for hardware accelerated physics with a PhysX card, but is also designed not to need one.

Since UT3's hardware PhysX support is optional, the game's stock levels take a very conservative stance to the use of physics, ensuring that the average gamer can easily play the game. Ageia however made two special UT3 maps that make a heavy use of physics, designed especially for the PhysX hardware. Shown below are Anand's benchmark results from these 2 special maps.



12 PhysX UT3 benchmarks [36]

As show in the benchmarks, it is evident that the use of a PPU is beneficial. However, the performance gains of having PhysX hardware in the UT3 stock levels were marginal, from 0 to 8% [36].

While the PhysX card clearly delivers a performance boost when it is challenged, it does not do so in a definitive way unless it has tailor made levels, hardly making it worth the purchase for the average gamer until games are released that make a better use of it.

6. Conclusion and Final Thoughts

As shown, it is quite evident that the evolution of physics in video games is set to bring us an unprecedented realism in the future games to come. Some interesting techniques that we are likely to see in the near future are completely deformable worlds and fluid dynamics with breathtaking precision.

Advanced physics models, even if they were computationally free, can cause problems which could hinder the immediate adoption of such techniques. For example, imagine that without a PPU we could only handle 100.000 particles at once, but with a dedicated PPU we could handle 100 million. That leaves us with the gigantic problem of actually rendering the 100 million particles with our graphics card!

So far the heavy users of video game physics have mainly been first person shooters. But with the increasingly simple integration of physics, thanks to pre-made physics engines such as Havok and PhysX, we will soon see other game genres follow in the footsteps of first person shooters. Role playing games and puzzle games are two genres that would be very interesting to see incorporate modern use of physics.

Developers will still need stay cautious towards their implementations because the physics field is changing extremely rapidly and will likely see major changes in the next two years with the dawn of hardware accelerated physics being brought to the masses. In what form the hardware acceleration will be, I won't say, but it's coming, sooner than many might think.

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