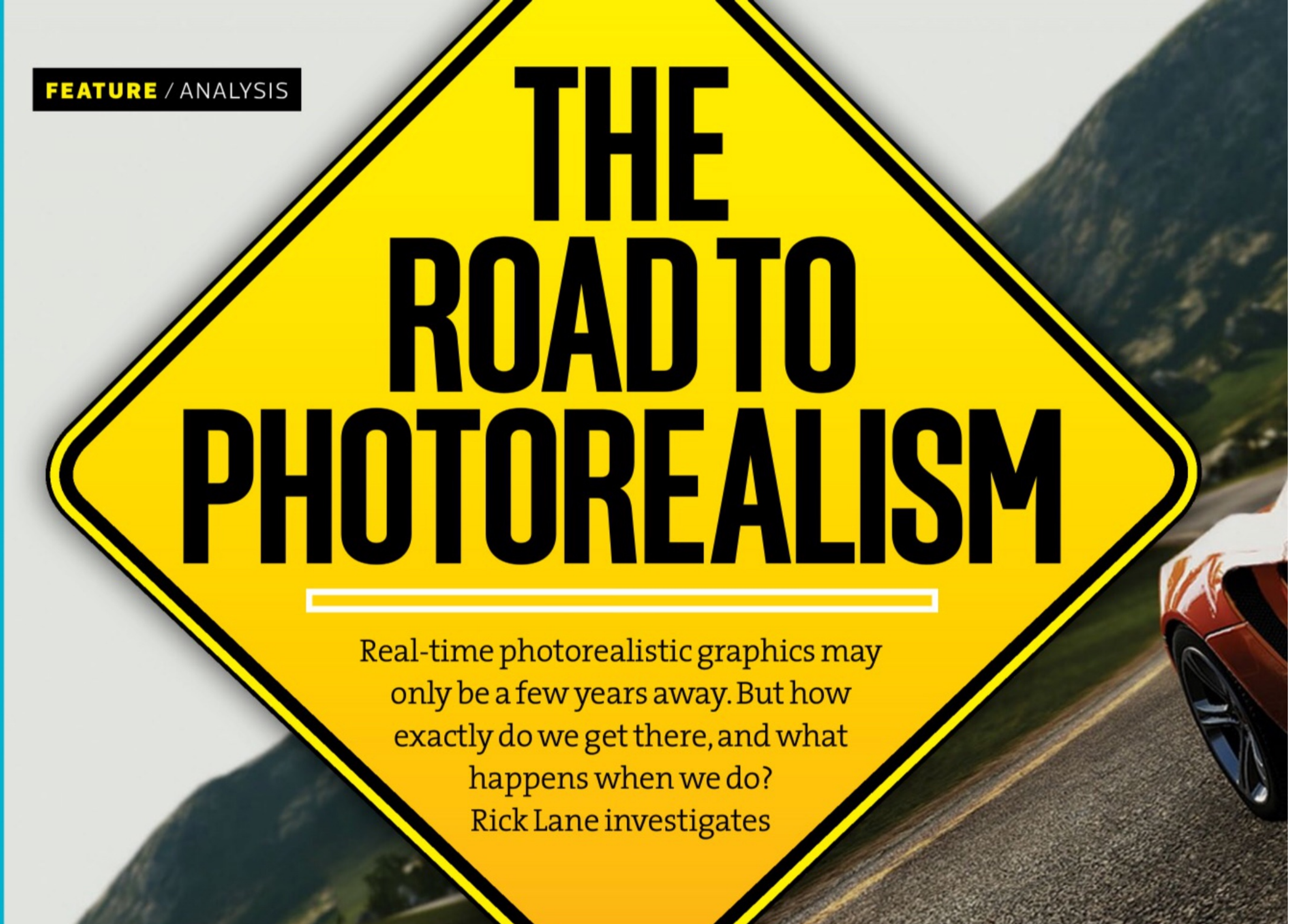


THE ROAD TO PHOTOREALISM

Real-time photorealistic graphics may only be a few years away. But how exactly do we get there, and what happens when we do? Rick Lane investigates

Ever since video game programmers became capable of rendering real-time images in 3D space, photorealism has been considered by some to be the Holy Grail of computer graphics. It's the goal that's driven almost every advancement in visual technology for the past 20 years, if not longer. Like that overused metaphor, it's always had something of a mythical quality to it – a fantastical objective where the importance lies not so much in achieving it, but in the advancements that are made along the way.

Yet unlike Arthur and his knights scouring the medieval land for their sacred relic, it's becoming increasingly likely that the games industry might actually reach this lofty aspiration.

Real-time graphics these days are incredibly advanced, to the point where it's become something of a critical faux pas to discuss how good a game looks because of course it's going to look good. What's more, in terms of how close we've come to that line in the sand, in the summer of last year, Epic Games' Tim Sweeney stated photorealism could happen in as little as ten years, and as you'll see in due course, this may be a conservative estimate.

So what are the remaining obstacles on the road to photorealism? Is it simply a case of more power equals better-looking games, or is there more to the process than meets the eye? Moreover, is it even a road we want to go down, when there are so many other artistic styles and graphical techniques that modern games can embrace?

Photorealism in racing games

But let's first examine where we stand today. One of the most enlightening games in current development is Project CARS, a racing game by Slightly Mad Studios. Project CARS is the latest in a gaming genre that's long been used by mainstream game publishers showing off their latest console or latest graphics tech. Slightly Mad's creative director, Andy Tudor, explained to us why racing games are so often a focal point when pushing toward photorealism.

'Computers have always been great at hard surfaces – glass, metal, reflections and so on. So, since cars are (relatively) inanimate objects, they make ideal candidates for photoreal computer graphics. Then you combine those cars with a racing game that also has lots of technical and mathematical elements, such as physics, forces and engineering – computers just love that stuff. So again, they [racing games] make ideal candidates for replicating realism.'

Computers are great at hard surfaces – glass, metal, reflections and so on, so cars make ideal candidates for photoreal computer graphics, says Slightly Mad Studios' Andy Tudor

In Project CARS, every screw that holds each bit of exposed mechanics is modelled and the cockpit of every car can be explored

Historically, racing games developed realistic-looking cars by cramming large numbers of polygons into every car model. This is why in many racing games from past years, the cars look fantastic, while the track appears sparse and the crowds in the stands seem to be made out of cardboard. This approach still plays a part in modern racing games, but with Project CARS, the focus is more on attention to detail, both on the visible surface and underneath the hood.

'Nowadays we talk about material types, reflections, refractions and abnormalities at the sub-surface level; what the object is physically made from, and therefore how it should react when broken or damaged,' Tudor explains. 'We also go inside the cars now and underneath their hoods, so a lot more minute detail is needed. In Project CARS, for example, every screw that holds each bit of exposed mechanics is modelled and the cockpit of every car can be explored.'

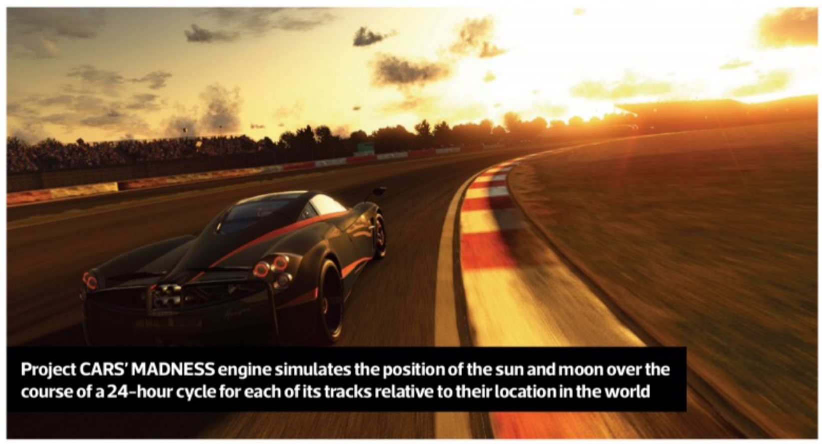
This technique is commonly known as 'physically based rendering', whereby a realistic look is achieved by sourcing material data from the real world in meticulous detail and recreating it in-game, often through scanning photographs of material types and basing in-game objects and locations on real-world objects and locations. The equation is simple: the greater your attention to detail, the more realistic your game will look. 'Our environment artists visit the tracks and take thousands of points of reference for each location, then recreate them digitally as they were in real life using all the tools available to them,' says Tudor.

But the above is only half the battle. The most detailed surfaces will still look flat and dull if they're illuminated in the wrong way. Lighting is a crucial aspect to photorealism. Our ability to see anything at all is a consequence of our brains' ability to interpret light bouncing off objects. Hence, Project CARS extrapolates its environmental simulation from what surfaces look like to how they're lit.

'If it's a bright but overcast day, and you're parked next to a line of trees, you would expect the car to be more brightly lit on the side away from the trees,' Tudor points out. 'We accomplish this effect by using two complete convolutions of the environment map that's used for the vehicle – one sharp one for specular lighting and one maximally blurred one for ambient lighting.'

In addition, Project CARS' MADNESS engine simulates the position of the sun and moon over the course of a 24-hour cycle for each of its tracks relative to their location. 'If you've ever been to a racetrack and watched the sun skimming the hills as you look down a straight, it's a beautiful sight that sticks in your memory. If, when you play the game, the sun is in the wrong place, that memory is jarred, so we believe it's important to make sure it's accurate.' Tudor adds that CARS' day/night cycle is so accurate that their racing-driver consultants use the game to practise on the virtual tracks, so they know at which points on the track the sun's glare will obscure their vision.

Rain in Project CARS – you need to simulate how each type of light is bouncing, refracting or reflecting off other surfaces in the area, and that changes if it's raining



Project CARS' MADNESS engine simulates the position of the sun and moon over the course of a 24-hour cycle for each of its tracks relative to their location in the world

This may make photorealism sound like a simple process: import some realistic-looking surfaces, shine the sun on them, job done. But simulating light is an incredibly complex job. Alongside the direct light from the sun, you also have to simulate the indirect light of the sky and the ambient light of the surrounding area.

Then you need to simulate how each type of light is bouncing, refracting or reflecting off other surfaces in the area, alongside whether it's daytime, nighttime, dawn or dusk, whether it's an overcast day, whether it's raining, whether there are any electric lights adding to the mix and so on and so forth. 'Thankfully, we have a dedicated art team who is willing to spend hours and hours tweaking and adjusting every little value until they're happy with the results,' Tudor jokes.

Right now, Project CARS demonstrates more or less the closest we can get to a photorealistic look in a real-time scenario (CGI in films is obviously far more powerful, but the film industry uses pre-rendered frames, rather than real-time rendering). It achieves this photorealism through intense attention to detail in a series of controlled environments. To go any further requires more powerful hardware, although perhaps not as powerful as you might think.

IN PROJECT CARS, EVERY SCREW THAT HOLDS EACH BIT OF EXPOSED MECHANICS IS MODELLED AND THE COCKPIT OF EVERY CAR CAN BE EXPLORED

'I think Tim [Sweeney] is being a little cautious with his estimate of ten years, or maybe he's looking at a broader perspective than I necessarily would,' says Richard Huddy, gaming scientist at AMD. 'I believe that perhaps we'll get the first real-time graphics that are photorealistic as soon as six years from now, but that will be working with a constrained set of circumstances. That means scenes (or whole games) that take place in fairly simple and constrained environments, such as office buildings, dungeons or even jungles.'

CPU and GPU requirements

A limited number of photorealistic games might be available in just over half a decade, but to get to this stage would still require some evolution of current hardware. In particular, photorealism would require more powerful GPUs capable of performing several tasks. The first is rasterisation of micro-polygons, which are the size of (or smaller than) a single pixel, enabling far greater detail in a computer-generated image. 'The technical requirements for this are in place, but to do the job well, the GPU will need considerably more horsepower and more bandwidth,' Huddy says.

The other major graphical technique that would hugely benefit games is ray-tracing, which performs the complex and difficult job of simulating the way light bounces off objects in one fell swoop. It achieves this feat by tracing the path that light takes through the pixels in an image. Ray-tracing is very accurate and produces highly convincing images, but computationally, it's expensive, and with the exception of a few tech demos, it's currently only used in pre-rendered scenarios, such as films.

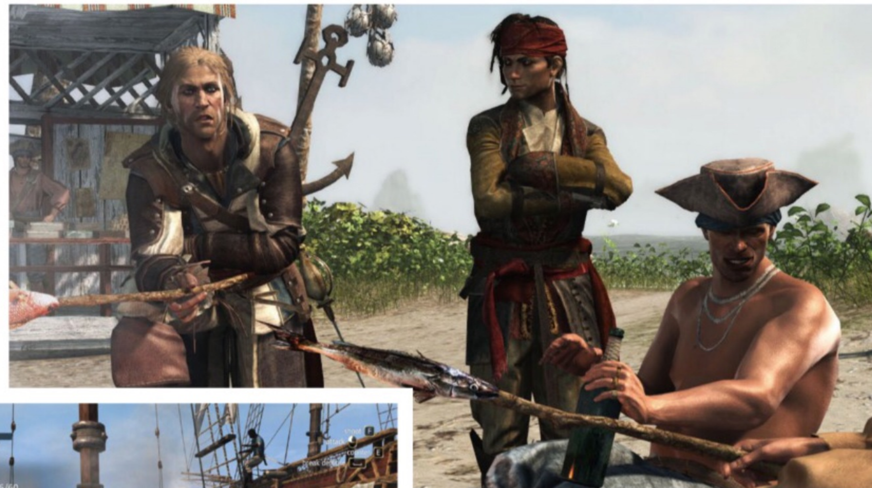
Huddy, however, is optimistic about seeing ray-tracing in real time. 'GPUs aren't strong enough at this [ray-tracing] at present,' he says, 'but we're getting better, and lower latency and more bandwidth remain the single biggest help I can see. Incoherent memory accesses remain a problem, and they're going to shift the bottleneck towards memory latency.'

By comparison, the CPU's requirements to achieve photorealism are much more straightforward. In terms of individual cores, CPUs are rapidly approaching the maximum number of supportable transistors, limiting their single-core potential.

As a consequence, the projected path is simple. 'More cores should do the trick nicely,' Huddy says. 'The trick is to have enough CPU cores to provide sufficient horsepower for marshalling the power of the GPU.'

To that end, AMD is working with other members of the heterogeneous system architecture (HSA) foundation on a new type of system architecture, which the members believe will be a considerable boon to the photorealism prospect.

'With our HSA-enabled architectures, our CPUs treat the GPU as a peer, not as a subservient partner,' Huddy explains. 'With the CPU and GPU both able to consume and create work for each other, a far more efficient machine emerges.'



We spend a lot of time trying to avoid sudden changes in momentum or unnatural weight-shifts, says John Cooper, an animator on the Assassin's Creed series

WE'LL GET THE FIRST REAL-TIME GRAPHICS THAT ARE PHOTOREALISTIC AS SOON AS SIX YEARS FROM NOW

Other visual styles

So, at both a software engine and hardware level, we can roughly predict the route for photorealism. There is one last point worth considering on these topics, however. Although the concept of photorealism is a useful yardstick with which to measure the progress of computer graphics technology, in terms of developing a game, it's ultimately just one visual approach. As graphics have improved, they have also diversified, with many different artistic styles being explored over the years. A good example is cel-shading, used in games such as Borderlands and The Walking Dead. Cel-shading provides a look that's visually very pleasing without being remotely realistic.

AMD is aware of the many graphical styles used by developers, and consequently wants to ensure that the drive for photorealism doesn't come at the cost of flexibility. 'One thing you'll notice about some films is that they take a very artistic interpretation of reality. Films such as 300, Sin City and The Matrix all benefit from playing with reality and breaking the normal rules of rendering,' Huddy says. 'Game designers are just like movie directors and producers in that they have much more in mind than just reality.'

Cel-shading, used in games such as Borderlands, provides a visually pleasing look without being remotely realistic

Regardless, in the past ten years, photorealism has gone from being a fantasy to an inevitability. At least, as mentioned by Huddy, in contrived circumstances. In fact, it might be said that the biggest problem photorealistic games face isn't so much the hardware and software capabilities, but the human factor, and the difficult task of merging the demands of photorealism with the freedom we so frequently experience in modern games.

The real-time factor makes photorealism in games a far trickier prospect than in the film industry. Films can produce extremely high quality CG frame renders because the images are iterated over the course of hours, days and sometimes even weeks.

Games, on the other hand, target a minimum render of 30fps in order to be enjoyable, and this isn't the only issue that comes with real-time rendering. It isn't always possible to predict what the player will do in the game, and therefore how the game will look in that particular instance. As graphics edge closer to photorealism, the easier it becomes to break the illusion, which in turn makes aesthetic demands on other parts of the game.

A good example is the animation of game characters and other aspects of game environments. Jonathan Cooper is a game animator who has worked on multiple high-profile titles, including Mass Effect, Assassin's Creed and the Uncharted series. From an animation perspective, he sees the prospect of photorealism as rather more problematic. 'I believe that years ago, the game animation community realised it was something of a false god,' Cooper says. 'It's a lot easier to make a convincing performance using a character with exaggerated features when you can concentrate solely on acting, instead of worrying about details such as the perfect movement of skin and muscle across a skull, or the most accurate rendering of wetness in the eye.'

Realism isn't just about graphics

The problems that animators face are largely unrelated to technology. Motion-capture equipment has been capable of recording realistic animation for a long time, to the point where the main technological innovations Cooper predicts concern making the motion-capture process more comfortable for actors. 'The results we're getting are so good that we no longer fight with it [the technology] to get it working on our characters. This frees us up to use all our animator know-how on the creative side – improving posing, exaggerating actions and timing, among other tricks that make up for the real actors' limitations.'

Even when those limitations rear their heads, there are workarounds. Good old-fashioned keyframing – manually drawing animations frame by frame, can be used to build animations that are impossible for an actor to perform. Meanwhile, physics-driven animation, in which characters' bodies are moved in real time via dynamically calculated application of forces, rather than recorded animations, is becoming increasingly common, although it still isn't ready to be used for 'realistic' characters. 'For now, we use physics as a tool to supplement animation, such as on cloth or flowing hair, and most recently, to provide extra weight on characters as they make quick changes in momentum,' Cooper says.

Part of the problem is that good animation in games isn't simply about how it looks, but also how it feels beneath the fingers, ensuring characters have enough virtual 'weight' to them, while also ensuring the controls are responsive. This is particularly the case in 'realistic-looking' games such as the Assassin's Creed titles. 'We spend a lot of time trying to avoid sudden changes in momentum or unnatural weight -shifts, while at the same time balancing that with the controls,' Cooper says. 'We can't resort to having crazy high jumps or incredibly reactive locomotion with characters turning on a dime, or performing crazy fast combos during combat.'

The other significant issue is the simple fact that a game's interactive nature makes it very difficult for animators to cover every option for how a character in a game such as Assassin's Creed will move around the game world, increasing the likelihood of a break in the illusion of photorealism. This isn't to say that animators don't try, of course. One trick animators use is parametric blending, where several animations are recorded for one action and blended in playback, depending on what exactly the player is doing. Cooper is also excited by the potential of 'motion graphs', an animation technology we'll be seeing in the future.

'Whereas in the past a game character had a collection of short animation cycles that were created to loop or hit predetermined poses, in the future, large banks of non-looping motion capture will be curated and maintained by the animator, with the player input affecting which sections are played back on the fly,' says Cooper. 'This not only makes characters more responsive, as they can interrupt animations at any point during a move, but the visual quality is also unmatched, as we're no longer seeing noticeable loops or popping between precreated animations.'

The same facial animations on Mass Effect's blue-skinned Asari characters looked instantly more 'believable' than on their human counterparts, says Cooper

Realistic dragons

On top of all of the above is the fact that games regularly feature creatures that aren't realistic at all, such as dragons and aliens. How do you photorealistically animate something that isn't real? 'This is the most fun part of our job!' Cooper exclaims. 'Animators can really let loose their imaginations on non-existent creatures and such. The trick is to always find a real-world equivalent on which to base it and use as reference – from jellyfish to bats to microscopic bacteria.'

Cooper also points out that the lack of a real-life equivalent can make the job of making it seem realistic easier, as it avoids the 'uncanny valley' effect, which makes an avatar that looks almost but not quite human appear off-putting. 'The same facial animations played on Mass Effect's blue-skinned Asari characters looked instantly more "believable" than on their human counterparts,' he says.

Cooper believes we won't see realistically animated characters in games for 10-20 years. 'A while back, I attended a lecture on the creation of the tiger Richard Parker from Life of Pi, and it would take around 30 hours to render just one frame, whereas in games we target 30-60fps,' he points out.

Furthermore, alongside animation, there are other aspects of games that will play a part in a photorealistic effect, such as AI. Your feeling of immersion in a photorealistic game will quickly be broken if the AI doesn't act in a convincing manner. What's more, photorealism could also affect your emotions in a different way when playing games. A first-person shooter might become difficult to swallow if the soldiers you're shooting look and act authentically when you blow their innards out of their back.

The technology to make real-time photorealism possible is may well be closer than you might have anticipated, but making a photorealistic style work in a game requires more than graphics. Every other part of the game must follow suit to prevent players from being put off by a game that jars in and out of realism. Real-time photorealistic graphics could well be on the scene by 2020, but photorealistic games may still be a way off. CPC