Hi! Thank you for coming this morning to this year's Advances in Real-time Rendering.

My name is Natalya Tatarchuk, some of you know me as "Natasha" and I am CTO at Activision.

So normally I begin with this slide where I start from "welcome and welcome back" and remind folks that Advances has been fortunate to be a yearly program where we bring together talks from both the latest and greatest productions, indies, and developers focused on real-time rendering techniques, largely grounded in the video games needs but of course not limited to that – over the years we've talked about algorithms that have since been used in AR and VR, or architecture visualization, film generation and so much more.

But this year is the 20th anniversary so perhaps you could indulge me in walking with a bit of a look back, how did this program come to be, what have we accomplished over these two decades, what's happening around us – in games, in the hardware ecosystem, and – most importantly – where are we headed?

Now I will tell you – I don't believe in forecasts being accurate. All the articles about how so and so predicted the exact trend of the future decades ago exhibit enormous survivor bias. Yet, look-backs though do tell us what stood the test of time [love the SIGGRAPH papers "test of time" awards btw!]

So how did it all begin?

Well, in 2005 I found myself frustrated. Because – and yes, these were the early years of the internet, but it was really really hard to find any resources on real-time rendering. SIGGRAPH has been running since 1974 yet there were scarce if any publications on real-time rendering.

And when I say I was *frustrated*. I mean it - not the polite kind of "wouldn't it be nice if..." frustration.
I mean the kind you feel when you know the answers *exist*, but they're scattered in studios, locked in production vaults, trapped in late-night conversations and debug logs,
never making it to the people who could use them.

I was deep in the trenches, trying to solve real-time graphics problems and I kept hitting this same wall: there was no place - no real, open, pragmatic forum - to talk about *how* production graphics were actually made to work. In video games, and for other real-time applications. I was deeply sad about the state of that.

And then there was a magical moment in 2005.

I came to the SIGGRAPH that year, with a few of my colleagues back at ATI. I loved going to the SIGGRAPH courses (this is before we got production sessions). Many of them, especially production-oriented – grounded in film productions, were so far removed from what we could afford to do in a frame in real-time. And by "real-time" I mean – 30+ fps on commodity – consumer – hardware.
I found that going to those sessions was certainly interesting and thought-provoking, but far from immediately applicable to what I was doing at that time.

And yet there was a moment ...

I wandered into a session.
Pixar was talking about *Finding Nemo*. They weren't just showing the glossy shots.
They were peeling back the curtain - explaining how they lit underwater scenes,
the tricks they used, the shortcuts, the compromises. They were talking about texture
sampling hacks they used for rendering their beautiful corals.

It was honest, it was concrete,
and you could *feel* the knowledge being passed from one creative team to the next.

I walked out of that room thinking,
"Why can't we have this for real-time graphics?
Why can't we talk, in the open, about what we're actually doing?"

They were describing effectively a texture sampling hack – that was immediately
applicable to the work we were thinking about [gooey materials algorithm]. It sparked
my imagination – what if we also were to talk about what we're doing and invite others
to share what they are working..? But how do we do this at SIGGRAPH – a course not
about research, not about film production... but about real-time rendering – but really
leaning into constraints of video game productions and real-time challenges.

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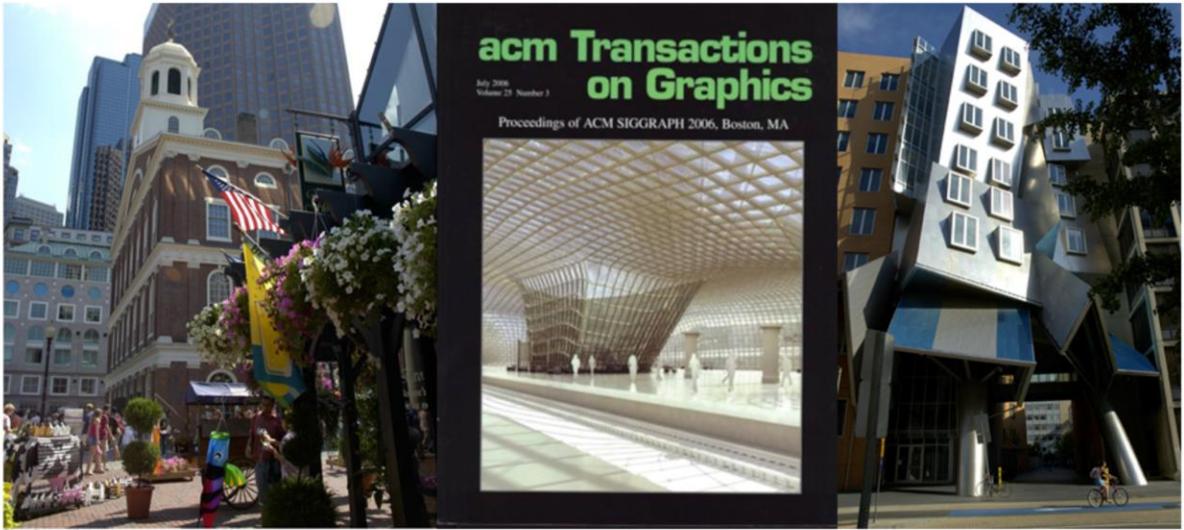
That's where Advances was born - in 2006, out of my own frustration.
Not as a grand, top-down initiative.
Not because someone told me to.
But because I needed it - and I knew I wasn't the only one.

We didn't want a course that was just research papers.
We wanted a space where game developers could share real production methods - warts and all.
A place to talk about what *works*, what *doesn't*, and most importantly - *why*.

We wanted to reward the careful explainer *and* the bold experimenter, because both are essential to pushing this field forward.
We wanted to reward those who dare to talk about what failed. Why it failed?

So, you could say Advances was born out of my frustration out of the lack of a good forum for sharing ideas about real-time rendering but then inspired to create a place where we could foster a new community – community of folks who want to share their approaches in that space.

That was the promise at the start, and honestly - it still is.
Every year, Advances is a room full of people who are driven by the same thing - not just the love of beautiful pixels,
but the curiosity to ask: "How does it *really* work? And how can we make it better?"
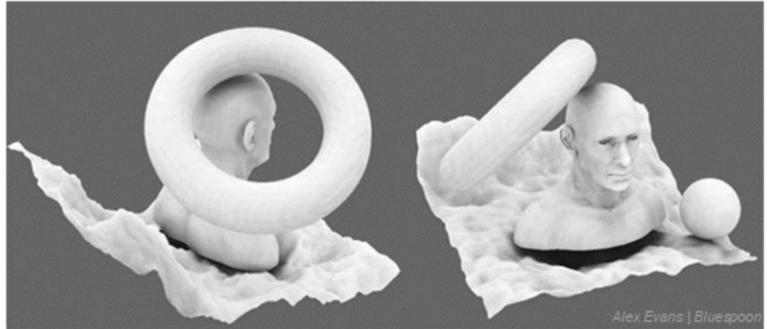
Alex Evans joined the first course, to share his truly inspiring and innovative lighting algorithm which completely blew many of our minds – it allowed 3D scenes to be displayed with approximate global illumination including ambient occlusion and sky-light effects at real-time rates. It was fast, it was scalable for even scenes with decent geometric complexity, and barely relied on precomputed data. And it could support animated sequences – and it was just plain beautiful.
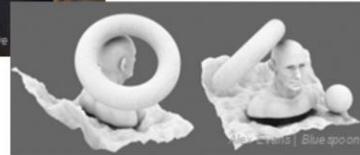
We also had Jason Mitchell from Valve share the approach they used for shading in Half Life 2, CounterStrike and more to efficiently combine the soft realistic lighting of radiosity with the reusable high frequency detail provided by normal mapping and to generate well-lit characters. This was also one of the first talk about using HDR in real-time in games and color grading that they used across the Source engine titles

We were off to the races!!

And before I go much further – I just want to remind people – be agents of change. [this little girl totally looks like me, right?!].

Seriously though – Advances was actually a really strong moment to remind me – be the change you want to see.

And so - it began.

While it smells of hubris – this isn't.

Advances did happen because I decided to be the agent of change, to build the forum I wished had existed when I was struggling. And once that door was open, others rushed in to share, to teach, and to learn. Be the agent of change! ☺

And the other thing I tell people when they ask about the origin and strategy of Advances is the same thing I tell them when talking about innovation – the power of small steps. In many ways this is just math – compound interest exists not just in finances, but in most initiatives.

I go back to Ichiro Suzuki, a baseball player I've grown to admire in my time in Seattle. Ichiro, who was a locals' favorite, was recently inducted into the Hall of Fame for Baseball..
And he gave what I consider – and Seattle Post Alley agrees – one of the greatest Hall of Fame speeches ever – seriously you should go and read it. It's crazy inspiring. Or watch it on YouTube: https://www.youtube.com/watch?v=urrlUiQXguY
But what he talked about is the power of small steps. It resonated with me on the deepest level.

"Building up small things is the only way to achieve something extraordinary."
This profound statement was shared when Ichiro reached the milestone of 4,000 hits in his career spanning Japan and the United States. When asked about his next goal, his response was equally memorable: *"My goal is to get the 4,001st hit."*
And that idea - *"Building up small things is the only way to achieve something extraordinary"* - is the heartbeat of Advances.

This course wasn't built in a single sweeping motion. It started with a few talks, a few speakers willing to share, a few honest conversations about what worked and what didn't.
Then the next year, we added another set of talks. Another set of voices. Another collection of techniques tested in production. We kept stacking those moments - like hits in Ichiro's career - until, before we realized it, we weren't just holding a session.

And in a way, we were curating a living archive of real-time rendering as it evolved, year after year.
Each presentation, each slide deck, each hard-earned lesson became another "hit" in the record books [to use Ichiro's terminology, of course].

Twenty years later, the extraordinary thing isn't just the big breakthroughs - it's the compounding effect of all those small steps, those incremental, generous contributions by literally hundreds of developers – the Advances speakers. (can you believe we have now 145 speakers over the years?!)

Ichiro was focused on the *next* hit. We've always been focused on the *next* frame - on the next insight that will make that frame faster, more beautiful, more real. Make better workflow for artists.
That's how Advances was built. That's how it endures.

We've come a long way from then, and there are many avenues of learning now,

including even new conferences, numerous developers' blogs, which is so wonderful.

Still, I am happy that we get to continue to bring new content to Advances this year - new every year. And there have been a few other Advances spun up - a few years ago there were Advances in animation and rigging; Advances in Neural Rendering, and even Advances in Real-Time Rendering of *Sound!*

From the very beginning, the goal for Advances has been simple - and I've learned that simple goals, when pursued with consistency, can build something extraordinary.

ADVANCES GOALS

Share	**Share pragmatic lessons from production with the community**
Learn	Learn from production-validated, battle-tested efforts
Explore	Explore early experiments to help the field thrive and move forward faster together

We wanted to grow the real-time graphics community by sharing *pragmatic lessons* from real productions.

Not just the shiny final shots - but the experiments, the prototypes, the "we thought this would work and it didn't" moments.

We've never shied away from early experiments - as long as they were rooted in practical production thinking.

Because our communal knowledge grows *faster* when we see the edges of an idea, when we understand *why* something failed, just as much as when we celebrate a breakthrough.

And for us, it's always been about implementation-centric knowledge sharing. We aim for talks that don't just show you the results but walk you through the guts of a technique - clear, reproducible algorithms, the tradeoffs, the constraints, the "watch out for this if you ship on console" warnings.

The goal is to help you *build intuition* for what's really going on under the hood. Because intuition is what lets you take someone else's idea and adapt it to your own production realities.

But the technical depth has always been matched by something just as important: **creating a safe space to share -** not just the wins, but the missteps.
In game development, it can feel risky to talk about what *didn't* work.

But here, we've learned that those stories are often the most valuable.
Because when someone stands on our stage and says, "We tried this, and here's where it broke, and here's why," they're giving the entire community a shortcut around the same pitfalls.
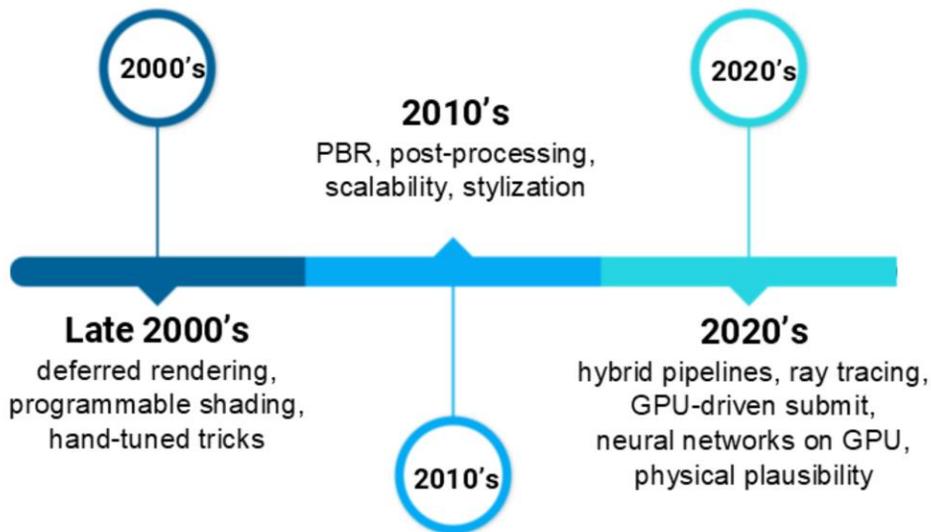
That only happens when people trust the room.
When they know they won't be judged for taking a swing and missing.
When first-time speakers feel just as welcome as veterans with decades in the field.

It's not about gatekeeping; it's about lifting each other up.

That culture of openness - the willingness to share *all* the lessons, both the triumphs and the failures – I hope this is what makes Advances more than just a technical course.
It's what makes it a living, breathing record of how our field truly moves forward.

EVOLUTION OF REAL-TIME RENDERING

2000's

2010's
PBR, post-processing, scalability, stylization

2020's

Late 2000's
deferred rendering, programmable shading, hand-tuned tricks

2020's
hybrid pipelines, ray tracing, GPU-driven submit, neural networks on GPU, physical plausibility

2010's

Real-time rendering used to mean squeezing every ounce of power from fixed-function hardware to hit 30fps. It was about deeply pragmatic engineering - clever hacks, performance tricks, doing more with less. And it still is... but the canvas has grown.

Now, real-time rendering spans high-fidelity cinematic output at 60fps or more, across an explosion of platforms - consoles, cloud, mobile, VR, AR. The bar for interactivity and visual believability is higher, and so is the complexity.

But one thing hasn't changed: every frame is still built under a promise that it will respond to the player, that their interaction matters. That's the core of real-time - and it's why the field remains so creatively and technically exciting.

Real-time rendering is the art and science of making pixels respond instantly to interaction. It's about delivering beautiful, believable frames fast enough that the viewer can feel immersed - and in control. At its heart, it's a promise: that the world on screen will react to you in the moment.

Twenty years ago, real-time meant racing against the clock - pulling off visual tricks within milliseconds on hardware that demanded every ounce of optimization. It was about smart compromises and technical storytelling. (I mean, we still race against the clock.. The frame rates only have gotten 2-3x higher..)

Today, the definition has expanded. Real-time rendering spans physically-based lighting, unified physically-based volumetrics, hybrid raster-ray pipelines, GPU-driven submit pipelines, explosion of compute-shader-based techniques with more and more progress toward general programming, and starting proliferation of machine learning on GPU - all working together to build experiences that look cinematic and feel alive.

But the soul of it hasn't changed: it's still about delivering meaning through motion, with speed and responsiveness at the core.

For newcomers, I'd say this: real-time rendering is a mindset as much as a technique. It's about creativity under constraint and building worlds that invite participation - not just observation.

I want to take a quick look – how did the landscape change? What are the differences between where we started in 2006 to now?

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...ESPECIALLY WHEN IT COMES TO TASTES AND ECONOMICS...

ADVANCES IN REAL-TIME RENDERING IN GAMES
+ CELEBRATING 20 YEARS
SIGGRAPH 2025
Vancouver+ 10-14 August

	2006 SNAPSHOT	2025 SNAPSHOT
Key social media platforms	myspace a place for friends, You Tube, twitter, facebook, flickr	TikTok, YouTube, X, facebook, Instagram, reddit
Household economics	Value of a $1 purchase in 2006 $1.00 → National average retail gas price $2.62/gal; Real median US household income $71k → National average home selling price $304k	Value of the same purchase in 2025 $1.59 → National average retail gas price $3.25/gal; Real median US household income $81k[1] → National average home selling price $504k[2]
Top grossing film *(global box office)*	PIRATES OF THE CARIBBEAN DEAD MAN'S CHEST — Global box office: $1.07B, Prod. budget: $200M, DISNEP (USA)	NE ZHA 2 — Global box office: $2.22B, Prod. budget: $80M, 光线影业 ENLIGHT PICTURES (China)

SIGGRAPH 2025 Advances in Real-Time Rendering in Games *course*

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A lot. If we just look at how things have shifted even in terms of player tastes and economics, a few things worth highlighting:

In terms of the "Eyeball Time" – the competition has changed significantly.
In 2006, social media was emerging - MySpace, early YouTube - mostly static posts or long-form video.
Today, platforms like TikTok, Instagram Reels, and YouTube Shorts dominate attention spans with short-form, algorithm-driven content.
This shift means our games are competing not just with other games, but with high-frequency, addictive micro-content engineered for maximum engagement.
Rendering and gameplay have to *earn* every second of player attention.

In terms of *Economics* – the value equation has shifted.
A dollar in 2006 buys $1.59 worth in 2025 - our budgets stretch less for the same rendering investments.
Hardware and toolchains have evolved, but so have player expectations - photorealism, massive worlds, and cinematic quality are now baseline, not premium.
The cost of achieving that bar has risen, even as we work within fixed or slower-growing budgets.

We also see a major shift from West to a Global Palette – with strong preference for *localized preferences*.
In 2006, pipelines often assumed a default "Western" visual standard for characters, environments, and styles.

Today's market demands authenticity across cultures - diverse hairstyles, skin tones, fashion, architecture, and environmental cues.

Titles like *InZoi* highlight how deeply regional aesthetics can influence player engagement and expectations.

Rendering tech must adapt, providing flexibility to represent global diversity without sacrificing fidelity or performance.

Does this have any Implications for Rendering? Yes. Absolutely.

We must design pipelines to deliver *cultural flexibility*, *economic efficiency*, and *visual impact* strong enough to hold attention in a fragmented, attention-scarce market.

This is not just about pixels - it's about strategic rendering choices that keep us relevant in a world where taste, economics, and attention are in constant flux.

When we think about WHAT we create, we've gone from prioritizing the ubiquity of western standards to seeing an increase in localized and diverse preferences. This evolution in taste has highlighted shortcomings in our rendering toolkits and posed challenges such as rendering a diverse set of hairstyles and the life-like skin tones for various ethnicities.

Taking a step back and looking at how players game has evolved – we've seen a rise in portability.

Between Nintendo's move to hybrid, the rise of mobile PC gaming and streaming, and the 800 lb gorilla in the room, the smartphone boom – gaming has been evolving for more mobility since 2006.

On one hand this is supported by technical advances, Moore's Law I'm looking at you.

This also means there is a need to optimize rendering pipelines as games built for the latest consoles and high-end PCs need to run on devices with less hardware capabilities. And we also have to mind power and temperature optimization as well, uncommon for many console techniques.

...WHICH HAS BEEN ECHOED THROUGHOUT GAMING

ADVANCES IN REAL-TIME RENDERING IN GAMES + CELEBRATING 20 YEARS — SIGGRAPH 2025 Vancouver+ 10-14 August

	2006 SNAPSHOT			2025 SNAPSHOT		
Top NVIDIA GPU *(i.e., top of market)*		NVIDIA GEFORCE 8800 GTX	MRSP $599		GEFORCE RTX 5090	MRSP $1,999
Top AMD GPU *(i.e., mid market)*		ATI RADEON X1950	MRSP $449		Radeon RX 9070 XT	MRSP $599
	Gen 7 Launch Prices			**Gen 9 launch Prices**		
Current Gen consoles		XBOX 360	$400		XBOX XIS	$500 |$300
		PLAYSTATION 3	$600	$500		PS5	$500	$400
		Wii	$250		NINTENDO 2 SWITCH	$450

						As of May		
Top selling game in the US		Madden NFL 07 EA Sports	➡	Base $59.99	Deluxe $69.99		Mon. Hun. Wilds Capcom	➡ Base $69.99	Deluxe 1 $89.99	Deluxe 2 $109.99

SIGGRAPH 2025 Advances in Real-Time Rendering in Games *course*

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At the same time, while the cost of a top-end GPU has tripled over the last 2 decades while cards for majority of the gaming consumer customers has remained relatively flat.

Consoles have followed this trend by remaining an affordable way for gamers to access high quality graphical performance at a fraction of PC prices.

That said, in Gen 9, we've seen console prices increase mid-generation while the price of games has not risen enough to offset inflation highlighting the tough economic conditions the gaming industry faces.
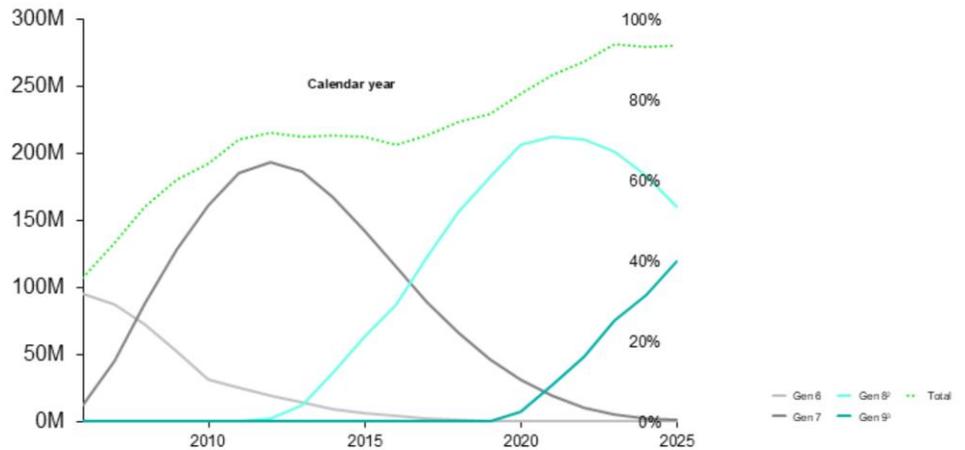
While there has been growth in the overall console install base as you can see here, ...
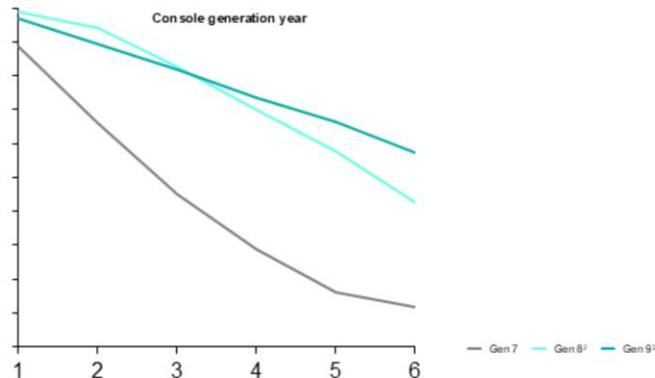
... **more players are playing on "past-gen" consoles in Gen 9 than Gen 8 or Gen 7**.

This highlights the overall performance strength of Gen 8, as players today are still able to enjoying games on last-gen hardware. It also speaks volumes about the impact of improvements in Gen 9 games over Gen 8; or rather, the lack of large impactful improvements.

Shuhei Yoshida, the former President of Sony Interactive Entertainment Worldwide Studios, recently said in an interview on the Kit & Krysta podcast, "...moving from PS4 to PS5, somehow the technology is similar, but the [game] budgets are still increasing. I saw some analysis or estimate of one same franchise released during PS4 era and PS5 era generation double the budget."
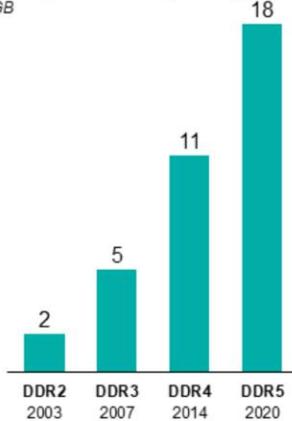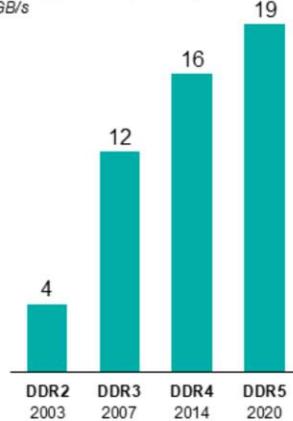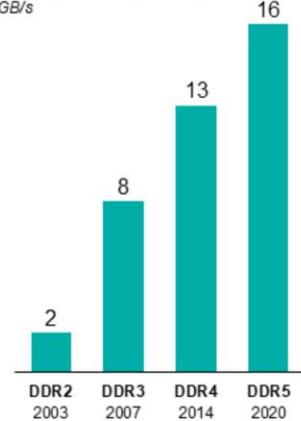
If we look at the components of our gaming devices, starting with RAM, we see that RAM specifications have broadly improved between DDR2 and DDR5. Not only can we store more information at runtime, but we can also do so quicker.

VRAM ON CONSOLES HAS PULLED AWAY FROM AVERAGE PCS SINCE GEN 8 LAUNCH
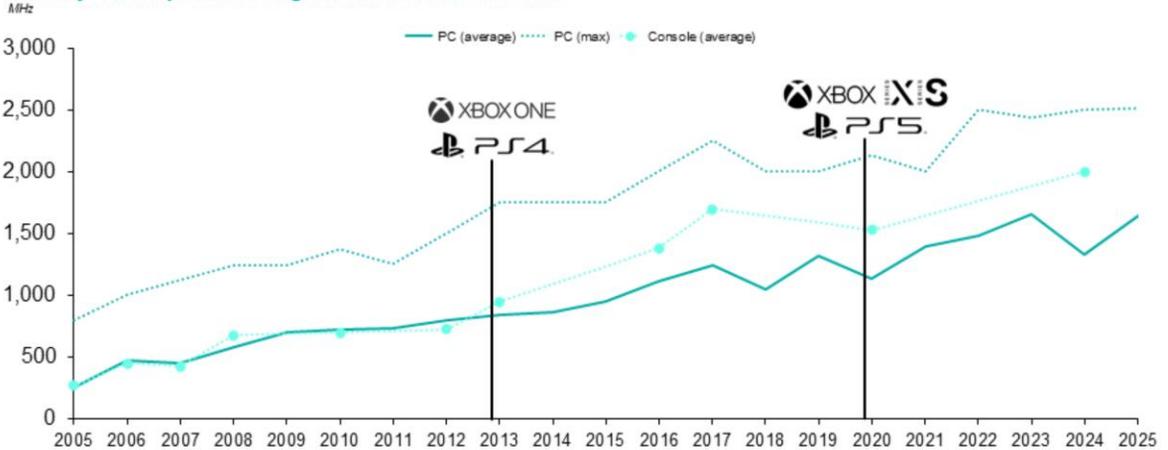
Amount of VRAM among annual new GPU releases
GB of VRAM
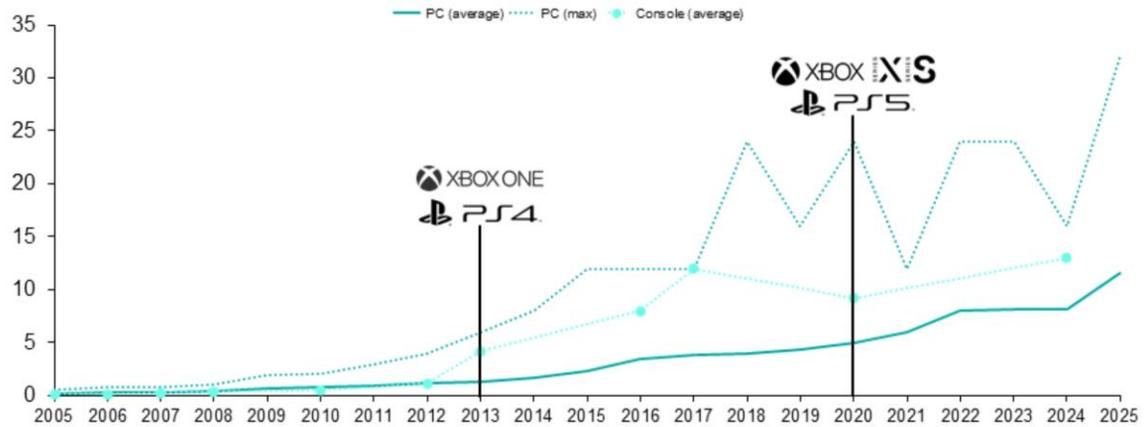
Looking at the GPU – the trend VRAM has followed system ram with cards today having much more memory than in 2006. Interestingly, starting with Gen 8, we started to see GPU specs on console have better specs than the average PC GPU.

With top PC GPUs remaining ahead of consoles, we've begun to see three distinct quality targets forming: the highest render targets for the best GPU, the standard target for the console core, and a lower target for the PC masses.

The trend is identical for memory clock speeds....

...and processor clock speeds. Though the gap between consoles and average PC GPUs is less pronounced.

All these GPU specs come together to paint a picture of rapid growth over the last 20-years.

2025 GPUs perform over 100x better than 2006 cards in some benchmarks.

That said, the rate of relative improvement for new cards has been slowing over the last 5 years.

Step change performance is harder to come by, and incremental gains are hard fought.
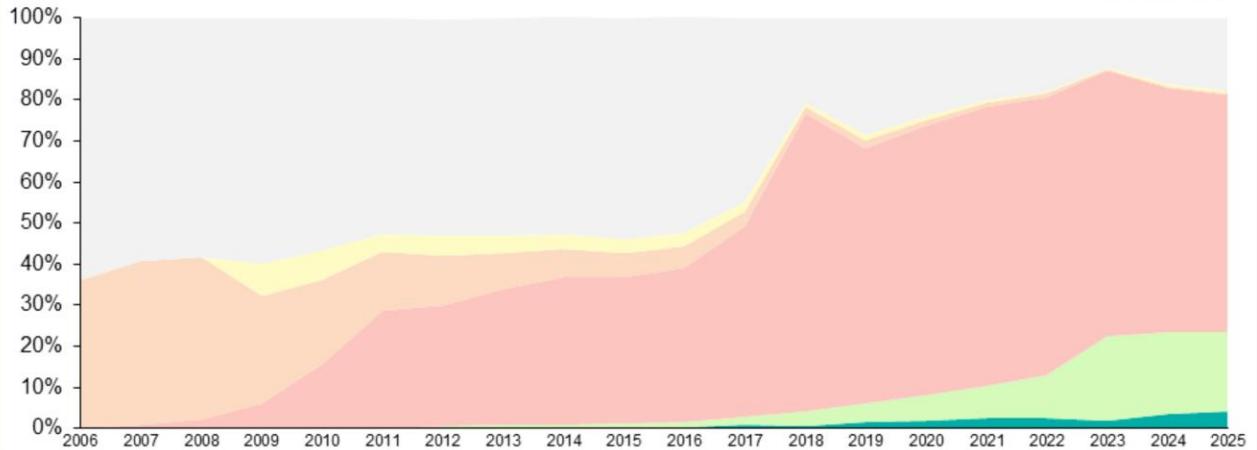
At the same time, despite these gains in GPUs, at least on the PC front, we're seeing a delay in the adoption of monitors capable of leveraging these powerful GPUs.
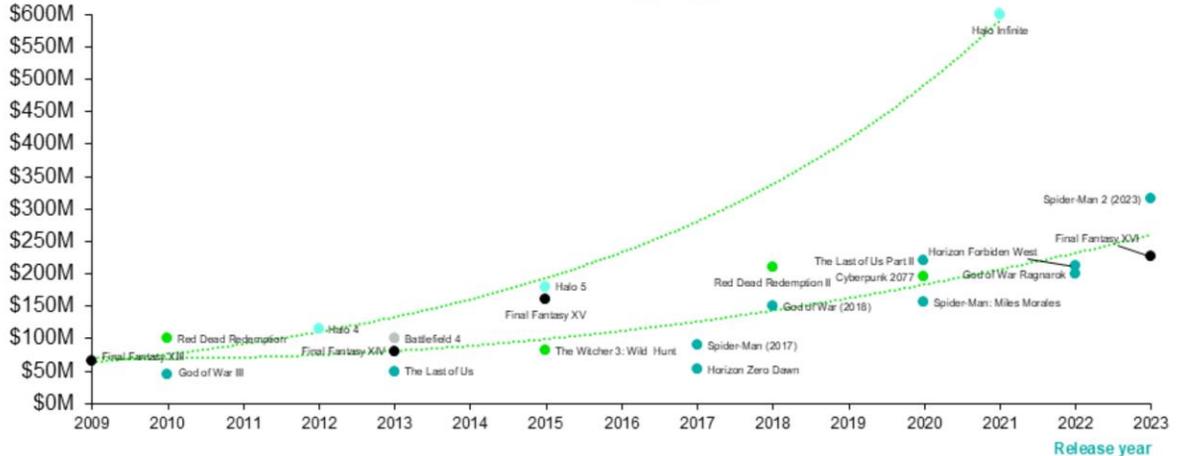
Most gamers are still using 1080p monitors with 1440p a distant second. 4k? Less than 5% of gamers use a 4k monitor as their primary monitor.

DEVELOPMENT BUDGETS HAVE BEEN GROWING UNSUSTAINABLY IN THE AAA SPACE

Estimated development costs (excludes marketing and publishing costs). Unadjusted millions of USD. Chart of estimated development costs by release year (2009–2023) for various AAA games. Notes: Quadratic fit for non-Xbox entities, $R^2 = 0.75$; Exponential fit for Xbox entities $R^2 = 0.999$. Source: Epyllion (Sony, Wedbush, CMA / IDC, LA Times, CD Projekt, NRC, Keywords, GameFile, Epyllion analysis), CNN, EA, press search, AP Strategy analysis

Yet we always strive to build the best and that's reflected in our development budgets.

As a note, these figures are estimated figures that have been, for the most part, consolidated by the Epyllion group.

Ultimately what we see over the 2009-2023 period is the budgets of AAA games growing at unsustainable rates.
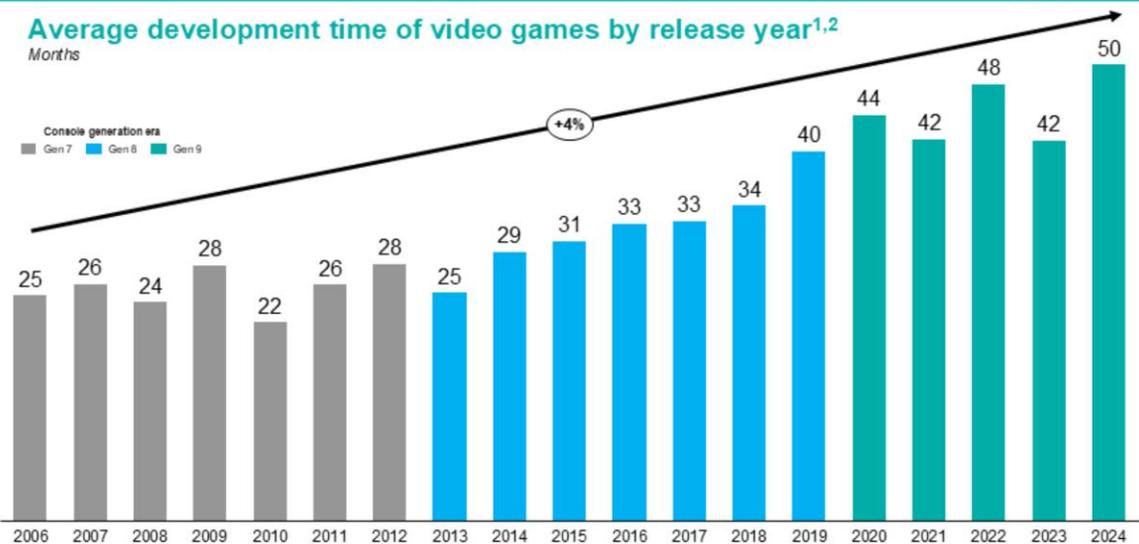
Part of the budget growth can certainly be attributed to growing team sizes. It takes a village to raise a child, and it takes an army of developers and support staff to ship a AAA game.
All that fidelity and huge range of content takes time to build, test and ship, and continue to update.

Part of the increase is that it just takes longer to make a AAA game. Sometimes it feels like we've moved away from the elegant and ingenious solutions of the early 2000s, the smoke and mirrors, to try and fully simulate and solve our game's various challenges, as a slew of deeply interconnected features and system, which in turn creates a new set of problems for us to solve.

DIGITAL STORAGE CAPACITY HAS GROWN EXPONENTIALLY CAUSING SHARP PRICE DECLINES

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Average capacity of retail computer memory
Terabytes of storage
— Disc Drive — SSD

Average price of retail computer memory per GB
USD per gigabyte
Disc Drive pricing   — Disc Drive — SSD   SSD pricing

$0.29
$18.06

$0.02
$0.05

Source: John C. MaCallum (2024), AP Strategy Analysis

Calendar year   Calendar year

This is reflected best in drive storage. The cost per GB is down to pennies for both disc drives and SSDs while their storage capacities are now measured in TBs. This means we often fall back to shipping games with massive footprints to accommodate larger assets. But at this point, footprint is one of the biggest AAA existential problems.
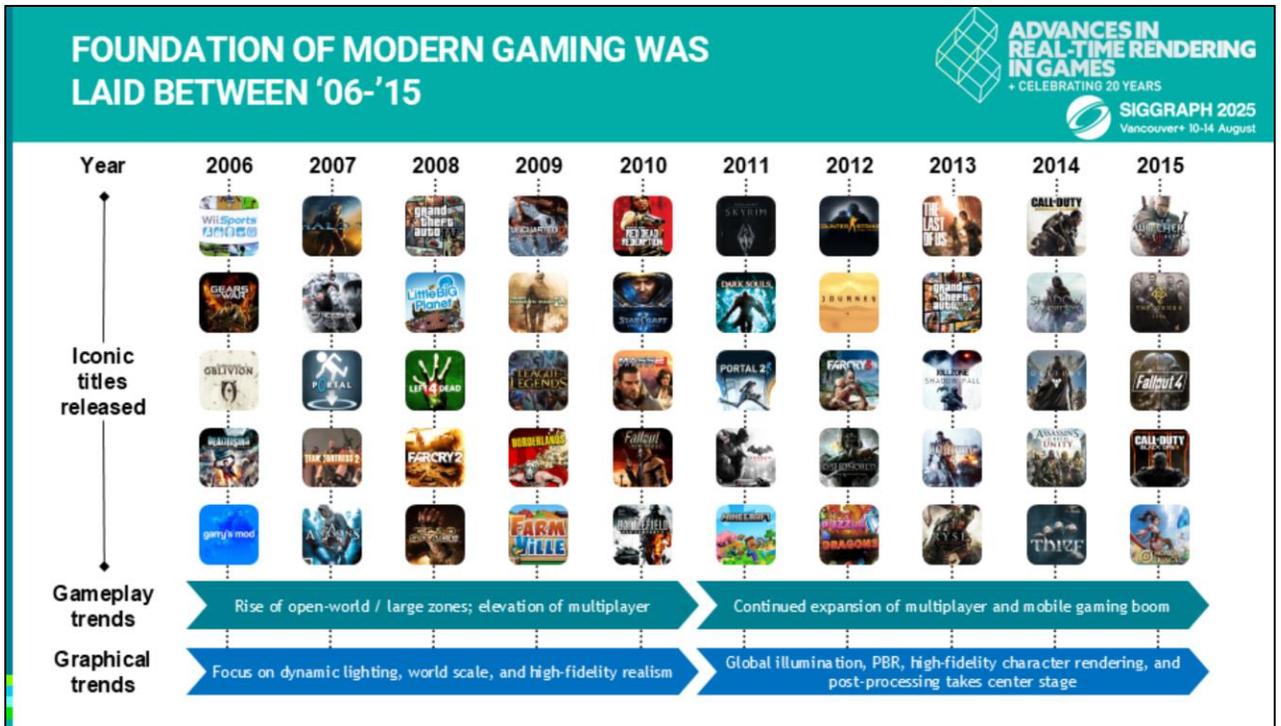
A lot has changed over the last 20 years. Hundreds of games have been released. And of course, everyone has their list of favorites / most impactful titles – here is our, potentially controversial, take.

Over the last two decades, the games industry has transformed through waves of technological, design, and cultural shifts. We've seen the rise of open-world and large-zone environments, the elevation and continued expansion of multiplayer - both competitive and cooperative - and the mobile gaming boom reshaping player demographics. Graphically, the focus has shifted toward dynamic lighting, world-scale realism, and physically based rendering, with global illumination, high-fidelity characters, and advanced post-processing becoming the visual baseline.

This period has been defined not only by technical breakthroughs but by genre-defining titles that pushed boundaries in gameplay and storytelling. From *Wii Sports* democratizing motion controls to *Gears of War* raising the bar for HDR pipelines, from *Crysis* redefining visual benchmarks to *Minecraft* cementing sandbox creativity, each year brought innovations that stuck.

Trends emerged around emergent open-world design (*Skyrim*, *Red Dead Redemption*), the growth of live-service ecosystems (*League of Legends*, *GTA Online*), and the fusion of genres (*Destiny, Rocket League*).

Perhaps most striking is how these advancements fed into one another: reactive

environments in *Far Cry 2* influencing later sandbox realism, the Nemesis System in *Shadow of Mordor* shaping AI expectations, or clustered shading and PBR becoming standard pipelines across studios.

Looking back, the last twenty years have been a story of compounding innovation - where each technical step forward became the foundation for the next generation's creative leap.

_____-

During this decade we saw a rise of Rise of open-world / large zones; elevation of multiplayer and Continued expansion of multiplayer and mobile gaming boom. In terms of graphics we saw a Focus on dynamic lighting, world scale, and high-fidelity realism and global illumination, PBR, high-fidelity character rendering, and post-processing takes center stage

Everyone has their list of favorites / most impactful titles – here is our, potentially controversial, take:
- 2006
  - Wii Sports: foundational for motion control games at home, highlights the "fun" in games, without Wii Sports there is no Switch
  - Gears of War: high-lights advances in Unreal Engine 3, one of the first games to have HDR pipelines, helped set standards in cover based third-person shooters
  - Oblivion: open-world first-person RPG that set a standard for sandbox RPGs to come
  - Dead Rising: combined open-world sandbox design with narrative meta structures
  - Garry's Mod: highlighted that mods can be a real premium game; creates a platform for exploration in source engine; opens the doors for things like Rust and eventually PUBG

2007
- Halo 3: the pinnacle of the franchise that combined crisp gameplay with an epic conclusion to one of gaming's most storied trilogies
- Crysis: can it run Crysis will forever be a meme, yet it was an impressive achievement of graphical fidelity
- Portal: physics-based puzzles and focused innovation
- Team Fortress 2: whether intentionally or not, almost every hero shooter today can likely trace its roots to TF2
- Assassin's Creed: showed an evolution in open-world game design with its crowds and parkour

2008
- Grand Theft Auto IV: the next title in the GTA franchise improving scale and narrative
- Little Big Planet: console UGC and incredible innovation for graphical fidelity in

cinematic postprocessing, materials, and dynamic GI
- Left 4 Dead: one of the greats for online co-op shooters; focused innovation for graphics effects like flowing water and damage
- Far Cry 2: Introduced reactive environments (dynamic fire, weapon degradation), foreshadowing modern sandboxes
- Dead Space: Set horror-game lighting and HUD-integration standards with its diegetic interface and dynamic

2009
- Uncharted 2: Seamlessly blended blockbuster set-pieces with gameplay, redefining action-adventure pacing.
- Call of Duty Modern Warfare 2: Modern realistic weapons with incredible gunplay
- League of Legends: Brought the free-to-play business model to the west in force, live-service MOBA model and laid esports' financial foundations.
- Borderlands: the quintessential looter shooter – brought the loot chase from the likes of Diablo and WoW to the first-person shooter genre
- FarmVille: social casual games were never the same after this

2010
- Red Dead Redemption: Married cinematic story arcs to an emergent, NPC-driven open world in the frontier.
- StarCraft II: Set the gold standard for RTS balance, ladder design, and esports infrastructure.
- Mass Effect 2: Strengthened character attachment via cinematic loyalty missions and choice consequences.
- Fallout New Vegas: Set a standard for narrative driven games that often still gets referenced today
- Battlefield Bad Company 2: Popularized destructible environments in multiplayer FPS

2011
- Skyrim: Set the bar for open-world RPGs with its emergent gameplay systems, breadth of content, and depth of choices for players
- Dark Souls: Sparked a new era of environmental storytelling and "Soulslike" design, redefining difficulty.
- Portal 2: Showcased how co-op puzzles and sharp dialogue could deepen a minimalist core concept; advanced the concepts of physics-based puzzles introduced in the first title
- Batman Arkham City: arguably the pinnacle of the Arkham series, combining open world exploration with fluid combat, also showed the industry how to not make a GOTY cover
- Minecraft: while in alpha since 2009, the full release in 2011 cemented the title as the king of sandbox survival games – digital LEGOs

2012
- Counter-Strike GO: competitive shooters and esports, highlights simplicity of design

can create an evergreen play loop, also loot boxes and knives
- Candy Crush Saga: Match-3 puzzle games on mobile and the use of analytics to drive engagement and monetization
- Far Cry 3: Evolved the formula for emergent open-world FPS (first-person-shooter) design (outposts, hunting, charismatic villain).
- Dishonored: Immersive sim title of critical acclaim – showed how even linear games can promote a sandbox feel, how games can react to player choices
- Puzzle and Dragons: Gacha games on mobile

2013
- The Last of Us: Raised narrative standards, fusing survival-action with emotional character arcs in a blockbuster.
- Grand Theft Auto V: Multi-protagonist storytelling and built GTA Online into an enduring live-service with free updates; the sandbox real world setting high lighted to the world that players want to role-play
- Rust: multiplayer sandbox survival that continues to grow; foundation for many games in the genre
- Battlefield 4: the pinnacle of levelution and mass destructible environments in multiplayer settings
- Dota 2: one of the 2 MOBA giants, set a standard for game balance, and showed a cosmetic only business model with all features unlocked could be viable; foundation for some of the largest prize pools in esports history

2014
- Hearthstone: Proved digital card games could thrive on simplicity and a polished F2P model, fueling esports.
- Shadow of Mordor: Introduced the Nemesis System - dynamic, personalized NPC hierarchies that reshaped AI design.
- Destiny: Blended shooter mechanics with MMO progression, birthing the "shared-world shooter."
- Mario Kart 8: Elevated kart racing with deluxe physics and HD visuals, revitalizing a beloved franchise on new hardware.
- Dragon Age Inquisition:

2015
- Witcher 3: Open-world storytelling with side-quests rivaling main-plot depth.
- Rocket League: Merged sports and vehicular action into an intuitive, esports-ready phenomenon.
- Fallout 4: combined base building / UGC with the open-world rpg formula
- Bloodborne: Evolved the Souls formula into faster paced combat and Gothic design, influencing action-RPG pacing.
- Honor of Kings: Brought core games to mobile; popularized MOBA on mobile

From 2016 onward, the industry accelerated toward a "live, connected, and everywhere" model.

Genres crystallized around persistent content and live-ops cadences - *Overwatch* defined the hero shooter, *PUBG* and *Fortnite* ignited the battle royale phenomenon across PC, console, and mobile, while *Pokemon GO* proved location-based AR could sustain global live events.

Open worlds evolved into richer sandboxes, blending systemic interaction with high-fidelity art direction, as seen in *Breath of the Wild*, *Red Dead Redemption 2*, and *Marvel's Spider-Man*.

Technical showpieces pushed cinematic fidelity (*Uncharted 4*, *God of War*), leveraged SSDs for seamless streaming (*Ratchet & Clank Rift Apart*), and brought hybrid rendering techniques like real-time ray tracing to mainstream audiences (*Control*).

By the late 2010s and early 2020s, the lines between platform and genre blurred. Major IPs adapted to free-to-play models (*COD Warzone*, *Apex Legends*, *Genshin Impact*), while indie and mid-size studios redefined what could capture mass audiences (*Hades*, *Valheim*, *Vampire Survivors*). The emphasis on emergent systems and replayability reached new heights - *Elden Ring* merged Souls-style challenge with open-world exploration, *Tears of the Kingdom* expanded sandbox creativity with robust physics, and *Baldur's Gate III* set new benchmarks for systemic narrative and player agency.

Recent years have shown both the democratization of high-end visuals and the rise of global development powerhouses. *Black Myth Wukong* demonstrated China's AAA capabilities, *Alan Wake II* shipped with full path tracing, and small teams like those behind *Expedition 33* proved that innovation in genre and technology isn't limited to the largest studios. Asynchronous, cooperative, and cross-platform play have become table stakes, while the focus has shifted toward games as evolving worlds - shaped as much by the player community as by the developers.

_____

- 2016
- Overwatch: Defined the hero-shooter genre and live-ops cadence - seasonal events, character drops, rapid balance.
- The Division: Blended cover-shooter mechanics with MMO loot loops in a shared urban warzone; laid the foundation for extraction shooters with its Dark Zone PvP mode
- Uncharted 4: Pushed cinematic fidelity and seamless one-shot cameras in action-adventure.
- Persona 5: Brought the JRPG to the mainstream; Showcased how JRPGs could blend stylized art direction, social-simulation systems, and turn-based depth for global appeal.
- Pokemon GO: Proved AR + geolocation could drive global player gatherings and sustainable live events with the perfect mix of IP and gameplay.

2017
- Fortnite: Combined a stylized aesthetic, survival game building, and later-added BR rules to create one of the most popular games in the industry
- PUBG: Ignited the battle-royale explosion, reshaping multiplayer priorities industry-wide.
- Breath of the Wild: Redefined the Zelda experience with an open-world, non-linear campaign, and emergent physics gameplay balanced with survival systems in a player-friendly way
- Free Fire: Bringing the BR craze to mobile
- Destiny 2: evolved the FPS MMO experience

2018
- God of War: Rebooted a legacy series with a one-shot camera, deeper narrative, and refined combat loops.
- Red Dead Redemption 2: Pushed simulation, pacing, and NPC detail in open worlds to unprecedented realism and depth.
- Marvel's Spider-Man: Raised traversal and city-scale LOD streaming to new heights in open-world superhero games.
- Super Smash Bros Ultimate: the pinnacle in platform fighters

- Sea of Thieves: Created a multiplayer sandbox supporting emergent gameplay and structured seasonal / narrative content

2019
- Sekiro: Overhauled Souls combat with posture/parry systems, pushing skill ceilings in action design.
- Control: Brought hybrid real-time ray tracing to a blockbuster audience, accelerating RTX adoption.
- Apex Legends: Combined hero shooters and respawn mechanics with the BR model; evolved the FPS ping system and popularized sliding across all shooters; showed that a AAA publisher and developer could play in the F2P BR space.
- CODM: brought the Call of Duty experience to mobile
- COD MW19: revived the Call of Duty franchise, set the current tone and trajectory of the franchise

2020
- COD Warzone: combined Call of Duty action and gunplay with the BR formula showing that existing AAA franchises have a F2P lane
- Hades: popularized the action roguelite; set the standard for design choices in almost all action-oriented roguelites
- Genshin Impact: one of the first AAA mobile first cross-mobile-pc-console experiences; combined Breath of the Wild like world design with simple hero-ability-based action combat and gacha collection systems
- Animal Crossing New Horizons: showed the world the demand for casual social experiences for gamers
- Cyberpunk 2077: combined FPS, RPG, and deep narratives with an incredibly high graphical fidelity world although the game was incredibly broken at launch

2021
- It Takes Two: narrative co-operative gameplay with forced split screen (Even if playing across network); unique business model that emphasized the teamwork of the game
- Valheim: brought the survival crafting genre mainstream with a simple narrative, simple graphics, but rich world and setting that encouraged exploration
- Ratchet and Clank Rift Apart: semi-open world action adventure game that modernized and old franchise; leveraged the PS5's SSD to rapidly stream in levels for on-the-fly world swapping
- Returnal: Blended roguelike structure with AAA production values and seamless procedural-level streaming.
- Forza Horizon 5: Brought arcade racing to the open world; delivered dynamic global weather, photogrammetry ground-cover, and 60 fps cross-platform racing.

2022
- Elden Ring: Merged open-world freedom with Souls-style challenge, redefining scale and exploration.
- God of War Ragnarok: Iterated blockbuster narrative–combat fusion, proving sequels

can both refine and expand mythic scope.
- Pokemon Scarlet/Violet: brought open-world and non-linear design to the mainline pokemon franchise
- Horizon Forbidden West: Advanced open-world visuals with underwater biomes and diverse ecosystem simulation.
- Vampire Survivor: Sparked a minimalist "survivor-like" subgenre, showing simple loops can captivate masses.

2023
- Hogwarts Legacy: created a game that fulfilled the childhood fantasy of many millennials
- Baldur's Gate III: Raised CRPG expectations for agency and systemic narrative, marrying tabletop depth with AAA polish; set the standard for how the world responds to player actions
- Starfield: combined Bethesda's RPG standards with better shooting mechanics; expanded scope by combining algorithmically generated planets with handcrafted ones
- Marvel's Spider-Man 2: Refined traversal and narrative in a two-character open world, pushing high-density streaming further; leveraged the PS5's SSD to enable fast travel to any location on the map
- Tears of the Kingdom: Expanded emergent sandbox building across multi-layered maps; leveraged a physics engine that supported almost any player decision

2024
- Helldivers 2: Redefined co-op spectacle with cascading world events and low-friction player impact on persistent war
- Black Myth Wukong: the first AAA PC/Console breakout hit from China showing what a new / young team can be do with today's technology
- Palworld: Viral early-access hit that hybridized creature collection, survival crafting, and shooter mechanics.
- Astro Bot: showed that someone besides Nintendo can create a best-in-class platformer with incredible breadth of complex and fine-tuned feature and fun gameplay
- Alan Wake II: First AAA game to ship with full path tracing for all lighting and reflections (https://www.tomshardware.com/features/alan-wake-2-will-punish-your-gpu)

2025 (through mid-year)
- Death Stranding 2: advanced asynchronous gameplay and advanced the combat and stealth systems of the first game
- Schedule I:
- Monster Hunter Wilds: expanded on the open zone nature of the prior title; added cross-platform play to the franchise
- Split Fiction: expanded upon the forced split-screen co-op model with an industry relevant narrative and a wide assortment of game genres packaged as narrative levels

- Expedition 33: highlighted what small teams can deliver with modern technology; highlighted how genre innovation is not limited to AAA players

When I look back at the last twenty years of Advances, I don't see a neat academic timeline.
I see a climb - hand over hand, step by step - through constraints, crunch, and craft.
Every milestone we've shared here wasn't born in a lab under perfect conditions.
It was forged in production, in messy builds, in late-night debugging sessions.

What ties these moments together is that they weren't theoretical exercises.
They were hard-won solutions to impossible problems.
Someone in a studio somewhere hit a wall, and instead of accepting "that's just how it is," they found a way through. – I mean this defines game development doesn't it?!
"You have to implement skin rendering. Make it awesome. It has to work on PC, 360, PS3 and ... you have 3 weeks" (true story).

Every year, Advances has been a place where these battle scars get shared - where a technique that was duct-taped together in one game gets refined, optimized, and adopted in dozens of others.
And that's the real climb - not just the evolution of rendering techniques, but the evolution of the *mindset*:
from "Can we do this?" to "How can we do this *better*?"
from protecting knowledge in silos to sharing it openly, so the next team starts one step higher than the last.

I want to do a quick walk down some of the techniques introduced or covered in

Advances – some of the algorithms that made a big difference over the years. Now this is not an exhaustive list – I actually started breaking this down and every year had stand out contributions, but … we only have a short span of time to cover, so this is sort of the smaller collection. An example but it's not the totality of all the techniques that matter.

But because it wouldn't be right – whether they did or not, I will not include anything that I worked on – so if you were a coauthor of mine in this course, I'm sorry, it sucks for you – I won't mention any of our techniques.

And .. I'm going to do this in no particular order.

2015 was a crazy year for Advances. I still remember this course as such a strong line up, one talk after another.

Volumetric lighting in real-time games is notoriously tricky small-scale effects like dust or explosions are often faked with particles, while large-scale fog is handled with crude post-process passes. Dust behind a car, smoke from an explosion, big sweeping fog layers - traditionally, they've all been handled separately. Particles here, a quick post-process there... and none of them really "see" the same lights. These layers rarely talk to each other, making cohesive lighting hard to achieve.

In 2015, **Sebastien Hillaire talked about Frostbite's new unified, physically-based volumetric framework**. It ties together all volumetric elements - dust, smoke, fog - into a single cascaded extinction volume, and use voxelization method to project particles onto it in an elegant way, generating a simple volumetric shadow map that can then be used to cast shadow from any light, according to every volumetric element in the scene. Sebastien also described a solution to render the final participating media.

Now, let's talk about one of my favorite examples of taking something notoriously expensive and bending it to our will - **screen-space reflections**.

SSR has always been a bit of a troublemaker - great for selling realism, but tricky to make stable, performant, and physically correct, especially when materials vary in roughness and normals.

Tomacz Stachowiak from the Frostbite team came in with a new algorithm that nailed it: it respects the microfacet BRDFs, faithfully reproducing specular elongation as needed, keeps the look consistent with the rest of the PBR pipeline, and does it without melting your GPU. It was awesome!

The Real-time Volumetric Cloudscapes of Horizon: Zero Dawn

Abstract: Real-time volumetric clouds in games usually pay for fast performance with a reduction in quality. The most successful approaches are limited to low altitude fluffy and translucent stratus-type clouds. For Horizon: Zero Dawn, Guerrilla need a solution that can fill a sky with evolving and realistic results that closely match highly detailed reference images which represent high altitude cirrus clouds and all of the major low level cloud types, including thick billowy cumulus clouds. These clouds need to light correctly according to the time of day and other cloud-specific lighting effects. Additionally, we are targeting GPU performance of 2ms. Our solution is a volumetric cloud shader which handles the aspects of modeling, animation and lighting logically without sacrificing quality or draw time. Special emphasis will be placed on our solutions for direct-ability of cloud shapes and formations as well as on our lighting model and optimizations.

Presenters: Andrew Schneider (Guerrilla Games)

Then **Andrew Schneider** began a series of talks that blew us all away... with little whisps.. Of clouds. Ok, seriously though – some of the most stunning and impressive efforts of replicating nature

Most game cloud systems at that time traded quality for speed, sticking to low-altitude, fluffy stratus clouds because they're cheaper to render.

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But Guerrilla had bigger ambitions for *Horizon: Zero Dawn*. **Andrew** and the team wanted the whole sky - every type of cloud you'd see in nature, from wispy cirrus high above to the heavy, dramatic cumulus rolling across the horizon. And they wanted them to evolve, to light accurately with the time of day, and to run at just 2 milliseconds on the GPU.

What they delivered is a volumetric cloud shader that hits all of it - modeling, animation, and lighting - without losing quality or blowing the frame budget.

And they didn't just make clouds look right; they made them *directable*. Artists can shape and choreograph the formations they need for a scene, while the lighting model and optimizations keep everything grounded in realism and performance.

It's one of those talks that reminds you: even the sky isn't the limit when you're blending art, science, and stubborn determination.

SIGGRAPH 2022 VANCOUVER+ 8-11 AUG — Advances in Real-Time Rendering in Games course

Nubis, Evolved: Real-Time Volumetric Clouds for Skies, Environments, and VFX

Abstract: Real-Time volumetric clouds in games have seen broadening adoption over the past several years. Many of the new applications use systems based on or similar to our approach, Nubis, which was introduced in 2015 in the Advances in Real-Time Rendering course. Nubis could produce a variety of cloud types in various lighting conditions for use in dynamic volumetric skyboxes that could render in under two milliseconds on the PlayStation 4 for the game, Horizon Zero Dawn. With the arrival of the new PlayStation 5 hardware and the sequel title, Horizon Forbidden West, we were able to push Nubis further into the game experience. In addition to improving our rendering approach for volumetric cloudscapes for use in skies, we started to use volumetric clouds to create environments such as clouds that the player could fly through. Additionally, we began to use them as VFX elements such as fast spinning superstorms with internal lighting flashes. In order to extend Nubis in these directions, several open problems in real-time volumetric cloud rendering had to be mitigated or solved. Rendering cloud environments up close, especially flying through them, can easily become computationally expensive. We will present a new cloud modeling and rendering approach that delivers performant and detailed results at 1080p resolution without the use of temporal upscaling. VisualFX are often synonymous with speed and lighting effects – two things that temporally upscaled clouds on a budget cannot do easily. We will present a way to mitigate temporal artifacts in fast-moving clouds and a near zero cost method to add internal lighting effects to clouds. Finally, we will explain how these three approaches are integrated and unified into the new Nubis Cloud System. As a bonus, we will offer a look at some future work.

SIGGRAPH 2025 Advances in Real-Time Rendering in Games *course*

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And he continued to build on the approach more and more, advancing the cloud rendering in his talk at the 2022 Advances, and

SIGGRAPH 2023 Advances in Real-Time Rendering in Games course

LOS ANGELES+ 6-10 AUG

Nubis³: Methods (and madness) to model and render immersive real-time voxel-based clouds

Abstract: In less than 6 months, we developed a highly detailed and immersive voxel-based cloud renderer and modeling approach. The Nubis voxel clouds act as traditional volumetric skyboxes, which support a time-of-day cycle when viewed from the ground, while also supporting high frame rates and atmospheric gameplay when explored on the back of a flying mount in the sky. To achieve these goals, we solved or mitigated several open problems in immersive volumetric cloud rendering with solutions such as ray march acceleration using compressed signed distance fields, fluid simulation-based modeling of clouds, a method to up-rez dense voxel data that avoids memory access bottlenecks, light sampling acceleration, and new methods to approximate cloud-specific lighting features like dark edges and inner glow. This talk covers these subjects in detail and offers a glimpse into our reasoning for leaving behind the now widely adopted 2.5D methods of real-time volumetric cloud rendering, which we introduced in our 2015 and 2017 Advances in Real Time Rendering Course Talks, in favor of the benefits and opportunities presented by voxel-based clouds.

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… and 2023. We've flown a long way through the clouds with this set of talks!

Real-time global illumination has been one of the holy grails for a while – and still is, because even though our computing power continues to leap bounds, so does the complexity of our content.

I remember when **Anton Kaplanyan,** at the time at Crytek, shared **the light propagation volumes approach** they have developed - it caught interest of many.

He introduced the method that uses spherical harmonics irradiance volumes to approximate the light field, point-based volumetric rendering for diffusion, and a novel light propagation step to push that light through the scene. This was a thought-provoking approach that spurred many a follow up in this space, though we're still trying to solve RTGI with efficiency.

SIGGRAPH 2024
DENVER+ 28 JUL — 1 AUG

Advances in Real-Time Rendering In Games

Neural Light Grid: Modernizing Irradiance Volumes with Machine Learning

Abstract: Irradiance volumes and their variants have been used in video games for over two decades. While more advanced, real-time global illumination systems have been presented, they are only practical on most high-end hardware. The diversity of hardware used by players, particularly low-end mobile GPUs, still creates a need for a robust, high-quality solution that can be universally used across all supported platforms, without requiring to re-author the lighting setup. Despite the popularity, the basic problems associated with irradiance volumes have not been fully mitigated: to avoid leaking artifacts various hand-tuned heuristics are used, but they are often insufficient and require manual fixes.

This talk will present how modern machine learning methods can be used to eliminate these artifacts, while keeping the performance of the algorithm acceptable even on very constrained platforms. We will show how we took the idea of utilizing machine learning to improve precomputed lighting through multiple experiments, reshaped it, reframed it, reformulated it, to finally form a solution that shipped to multiple millions of players of the *Call of Duty: Warzone* and *Call of Duty: Modern Warfare 3*.

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Just last year, which was also a standout set of talks, one talk really stood out – **Michal Iwanicki's talk about Neural Light Grid**.

Michal took the challenge of embracing truly diverse set of hardware that players experienced Call of Duty on, particularly the low-end mobile GPUs, and asked himself a question – how does one still create a robust, high-quality solution that can be universally used across all supported platforms, without requiring to re-author the lighting setup or exploding the memory or disc footprint?

He leaned into modern machine learning which ran on GPU to come to the rescue, eliminating crucial artrifacts, while keeping the performance of the algorithm acceptable even on very constrained platforms.

But he also took us on the journey of his idea of using machine learning to improve precomputed lighting through multiple experiments, reshaped it, reframed it, reformulated it, to finally form a solution that shipped to multiple millions of players of the *Call of Duty: Warzone* and *Call of Duty: Modern Warfare 3*.

Stepping back, In 2007 **Martin Mittring from Crytek** did an incredible talk about a bag of impressive techniques that **CryEngine2** packed – which was one of the most innovative engines at the time for high-fidelity games. While Martin's talk covered a whole lot of details, from the unified rendering pipeline, dynamic lighting and shadowing systems, and advanced material framework that supports complex shader combinations, what really caught a lot of people's attention was a little technique called ...
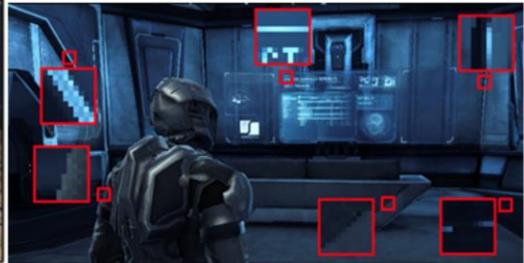
<**click**>

... SSAO which became a standard for every game engine out there and spawned a huge number of subsequent improvements and innovations.

Advances in Real-Time Rendering in Games course

Real-Time Global Illumination and Reflections in *Dust 514*

Abstract: This talk will present a method for approximating the first bounce of diffuse global illumination, and obtaining the approximate point hit by a reflection ray. The method is fast enough to be affordable for current console games; it is shipping in *Dust 514* by CCP, for the Sony PlayStation 3®. The method works by dividing the scene into layers and building a height field imposter for each layer. The imposters are updated at runtime, and therefore dynamic changes to lighting, shadowing, and materials are supported. Performance details, quality problems for the method and its use in *Dust 514* will be covered, as well as some of improvements possible with a larger rendering budget.

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TAA has been one of the definitive improvements to the quality of rendering in games, and there were a number of contributions that really helped it shape.

Hugh Malan, interestingly enough, in the GI and Reflections talk in SIGGRAPH 2012, introduced amongst several topics, improvements to the antialiasing pipeline in their engine – doing a mix of temporal accumulation with subpixel jitter and upscaling.

They rendered the scene on PS3 at 1280x720 as usual, including postprocess, and then it's upscaled to 1920x1080p. The upscale took 3ms but it replaced the 1.4ms FXAA pass, so the net cost is 1.6ms.

This was a huge improvement for practical TAA, and I wanted to highlight it here.
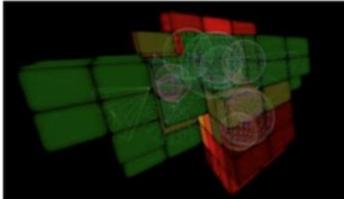
In 2012, Emil Persson and Ola Ollson talked about their approach for using clustered shading for an improved efficiency of lighting computation, which scaled better with complex scenes, without as many heuristics and hacks, and provided a unified solution that worked well with transparency, MSAA, variety of materials including custom BRDFs and lighting models and more.

Back to 2015.

Another stand out talk was by **Ulrich Haar and Sebastien Aaltonen from Ubisoft** where they talked about **Ubisoft's shift to GPU-driven rendering moving scene management and culling almost entirely off the CPU**. That was such a huge moment of innovation!

In *Assassin's Creed Unity*, that meant batching by material instance, pairing it with mesh clustering, and pushing culling to the GPU for dense urban scenes. RedLynx took it further with a clean-slate pipeline using async compute, indirect dispatch, and multidraw to render hundreds of thousands of unique objects at 60 FPS, entirely GPU-driven.

And how can we not talk about **Alex Evan's famous DREAMS renderer talk**!! This was the quintessential Advances talk – the story of struggle, the story of creativity, the story of exploration, of wins and losses, and the story of beating PS4 into submission to generate entirely different representation and frame management. Alex continued to dive deeper into signed distance field to devise multi-resolution point clouds and exploring how compute shaders could apply to generate the rendering of the scene in this alternative representation.

.. and How could we forget the introduction of Froxels??

And the same year, signed distance fields got more love – in another talk by **Dan Wright from Epic Games** who used them to compute occlusion from dynamic scenes, such as dense vegetation scenes, in a way that was performant on Gen8.

Lumen: Real-time Global Illumination in _Unreal Engine 5_

Abstract: Lumen is _Unreal Engine 5_'s fully dynamic global illumination and reflection system, scaling from next generation console games to high-end PC visualizations. This talk will dive into how Lumen works, from software ray tracing with signed distance fields, to virtualized surface caching, hardware ray tracing, final gathering, and reflections. We'll also show how Lumen solved indirect lighting in a large-scale procedural city in '_The Matrix Awakens_', including an emissive-only night mode.

Dan proceeded to build on these techniques further and evolve them, along with other contributors - **Krzysztof Narkowicz and Patrick Kelly**, toward building Lumen - _Unreal Engine 5_'s fully dynamic global illumination and reflection system, scaling from next generation console games to high-end PC visualizations. They covered the deep guts of the complex underlying system that is Lumen in a 2022 advances talk.

Abstract: In this session, the author will present a technique to simulate subsurface scattering for human skin that runs in a performance similar to a simple bloom shader. Previous real-time approaches simulate it by approximating the non-separable diffusion kernel using a sum of Gaussians, which required several (usually five) 1D convolutions. In this work we decompose the exact 2D diffusion kernel with only two 1D functions. This allows rendering subsurface scattering with only two screen-space convolutions, reducing both time and memory without a decrease in quality. A technique to render ambient subsurface scattering will be also presented. The author will also show our latest advances in photorealistic eyes rendering, including realistic reflections, view and light rays' refraction, caustics, ambient occlusion, eye redness, assets modeling and tear fluid representation.

In 2012 **Jorge Jimenez** took the world of character rendering by storm by introducing **screen-space subsurface scattering running as a series of separable Gaussian kernels in a shader**. That was a major breakthrough that made a fundamental difference in our ability to do sophisticated characters in games, where the cost scaled with the size of the characters' faces on the screen, which was a very performant and scalable approach. Jorge shipped this in Call of Duty for the characters there and we shipped this in Destiny, and many other titles also shipped with this.

He also talked about incredible complexity of eye shading and introduced a sophisticated set of techniques to deliver truly high-quality eye rendering at game-friendly performance in an artist-friendly setup.

And there is so much more, from

- the **2.5D tricks of LittleBigPlanet for dynamic GI and high quality DOF** by *Alex Evans* in 2009,
  https://advances.realtimerendering.com/s2009/index.html

- to **Sample Distribution Shadow Maps** by *Andrew Lauritzen* in 2010
  http://advances.realtimerendering.com/s2010/index.html

- To **Physically based lighting in Call of Duty: Black Ops** by *Dimitar Lazarov* in 2011
  http://advances.realtimerendering.com/s2011/index.html

- To **TAA** from *Brian Karis* in 2014
  https://advances.realtimerendering.com/s2014/index.html#_HIGH-QUALITY_TEMPORAL_SUPERSAMPLING

- To **VOLUMETRIC FOG: UNIFIED COMPUTE SHADER-BASED SOLUTION TO ATMOSPHERIC SCATTERING** by *Bart Wronski* in 2014
  https://advances.realtimerendering.com/s2014/index.html#_VOLUMETRIC_FOG:_UNIFIED

- To **Precomputed lighting in *Call of Duty: Infinite Warfare*** by *Michal Iwanicki and Peter-Pike Sloan* in 2017
  https://advances.realtimerendering.com/s2017/index.html
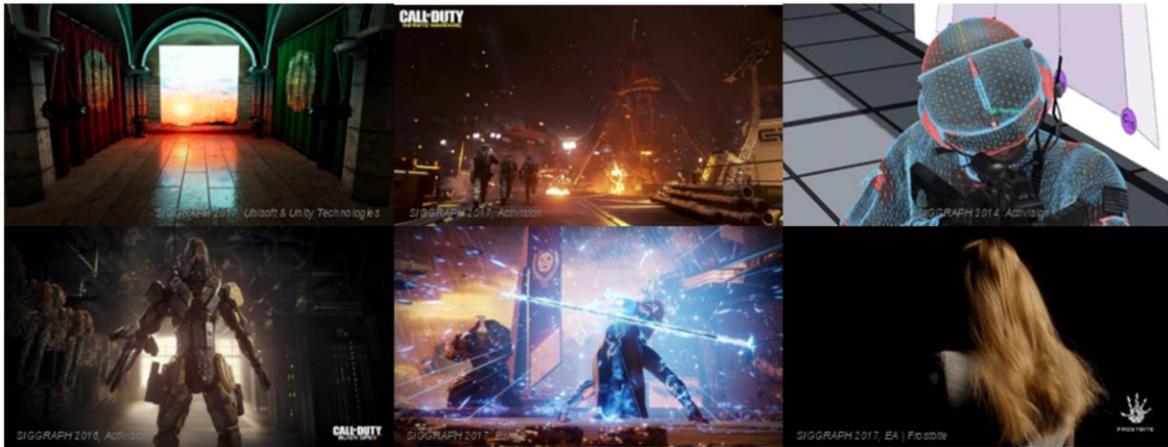
- To **Compute-shader based implementation of subdivision surfaces in Call of Duty Ghosts** by *Wade Brainerd* –in 2014
  https://advances.realtimerendering.com/s2014/index.html#_TESSELLATION_IN_CALL

- To **Real-time area lighting with Linearly transformed cosines** from **Stephen Hill** and **Eric Heitz** in 2016
  https://advances.realtimerendering.com/s2016/index.html

- To **Filmic SMAA: Sharp Morphological and Temporal Antialiasing** by **Jorge Jimenez** in 2016
  https://advances.realtimerendering.com/s2016/index.html

- To **Destiny GPU particle architecture** by **Brandon Whitley** in 2017
  https://advances.realtimerendering.com/s2017/index.html

- To improvements to **Improved Culling for Tiled and Clustered Rendering** by **Michal Drobot** in 2017
  https://advances.realtimerendering.com/s2017/index.html

- To **Strand-based Hair Rendering in** *Frostbite* by **Sebastian Tafuri** in 2019
  https://advances.realtimerendering.com/s2019/index.htm

- And so much more..

(I Stopped at 2020s..)

So what are the Trends? What's Shaping Today Will Shape Tomorrow

- **The Quiet Majority is Growing** – The fastest-growing segment of players is non-competitive or lightly competitive gamers, long under-served by AAA/AA studios. Historically, most big-budget efforts have focused on competitive, GaaS-heavy titles. This is a market gap - and an opportunity.

- **Tools Are Leveling the Field** – Accessible, non-proprietary, high-quality development tools are empowering small, young, and even inexperienced teams to deliver work on par with seasoned studios. This shifts the competitive edge toward gameplay innovation, distinct art direction, and strong narrative.

- **Graphical Ceilings Are in Sight** – For photorealistic styles, current tech can convincingly simulate ~80% of the real world. The remaining 20% - subtle imperfections, nuanced motion, complex interactions - s far harder to achieve and, for most players, less perceptible.

- **Simulation is the Next Battleground** – With fidelity already high, focus is moving to richer, more complex simulations that can still run at 60+ FPS, enhancing immersion and "game feel."

- **Designing for Shareability** – In an age of digital distribution, streamability and short-form content potential are core to design decisions. Game loops, art style,

and graphical quality now need to consider how they'll play in a TikTok or YouTube clip as much as in a 4K screenshot.

IS DISRUPTION ON THE HORIZON?
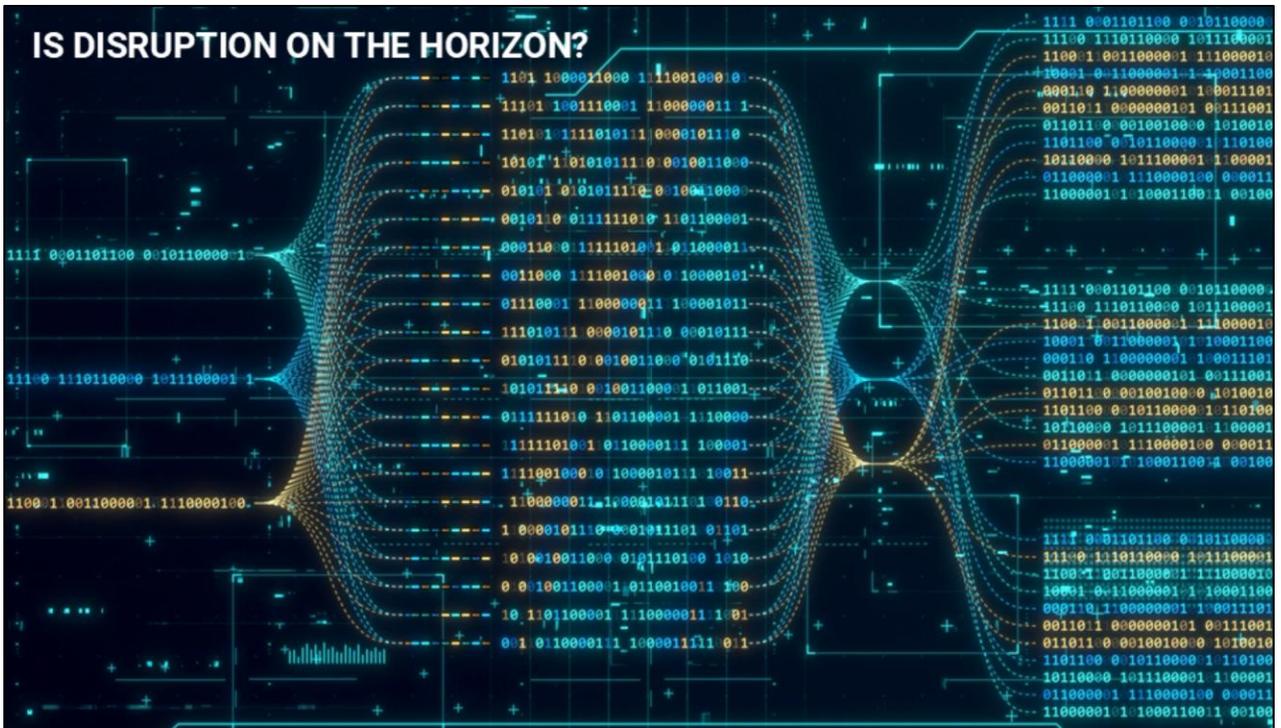
And we would be foolish not to talk about AI. Or as NVIDIA shared recently in their presentation: "AI has shaped graphics, Graphics is now shaping AI".

Right now, AI is playing a supporting role - and it's a very powerful one.

We're seeing ML-driven denoisers, super-resolution, and frame generation make their way into real-time pipelines. These tools help us push fidelity further without paying the full cost in milliseconds.

At Advances, we've focused on practical applications of AI - those that ship in games and help teams solve real problems.
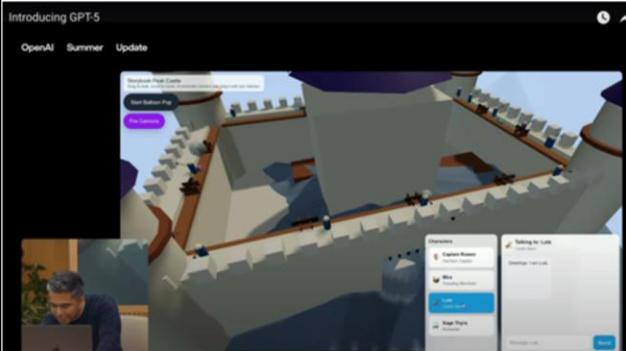We've steered clear of the hype and leaned into the real: how does this help your renderer? Your artists? Your game? That grounded perspective is where we'll keep focusing on the right things.

But nevertheless, there are things worth paying attention to – who knows where the disruption will come from?

[OpenAI: ChatGPT 5.0 Announcement] [Google DeepMind: *Genie 3* introduction]

There are some interesting and exciting frontiers being explored by AI companies – whether vibe coding a game like OpenAI just showed in their most recent ChatGPT 5 announcement or the persistent world creation using Genie 3 shown by Google DeepMind in their Genie 3 unveiling.

Of course, we're not yet at the place where these tools are replacing robust production pipeline [just try to fix a single bug in the vibe code project by ChatGPT and see what happens when it blows up its memory...] but still the progress is relentless and powerful, and it'll be interesting to see how this shapes our field.

Frame from https://www.youtube.com/live/0Uu_VJeVVfo?si=7ZjrJy83HikWfEWq&t=3838
https://deepmind.google/discover/blog/genie-3-a-new-frontier-for-world-models/

NEXT DECADE OF ADVANCES?

Adobe Stock | #628805364

That said, I, for one, continue to believe there is plenty of juice still left to squeeze in the GPU pipeline and the execution using shaders and I hope we'll keep seeing the evolution of general programmability on GPU because we need more to deliver these powerful game worlds that our players want. WE'RE HARDLY DONE INNOVATING IN GFX :)

So - here's to the next decade of Advances!

Adobe stock library: https://t4.ftcdn.net/jpg/06/28/80/53/240_F_628805364_MpDbC81UdkGed3F3ZGATpFseYAXCeVw1.jpg

CURIOSITY MADE CONCRETE

So, in conclusion – as I mentioned, I am a believer in the power of small steps.
So - with this, thank you for staying w/ me through this celebration of **curiosity made concrete** – which is how I think about the enormous pile of knowledge and practical lessons that Advances is for me.

It's hard to believe but there are 145 speakers in Advances including this year. I want to offer my sincere, heartfelt thanks to ALL of the folks who worked tirelessly on their presentations, worried about whether the techniques are right, whether the diagrams are accurate, whether the fonts aren't screwed up and the clickers are working but most of all worried whether they really solved something that made a difference. And I believe they did.

For many folks, Advances has been their first time sharing work on a global stage. That's an incredible moment – and I always wanted it to feel encouraging, rigorous, and honest. Our goal is to leave people better equipped to share, to collaborate, and to keep pushing the field forward.

But besides that, I believe that by sharing the true path of innovation in production, Advances helps folks entering the field to learn what are the latest techniques, so that they can use that as a jumping off point for relevancy, for standing on the shoulders of those before them to keep the innovation going.

So – thank you to all that contributed to that.

THANK YOU, LEONA CAFFEY!!

I also want to take a moment here to thank Leona. Many of you may not have had the fortune perhaps to meet or work closely with Leona Caffey – but she is a key part of the backbone that truly has the knowledge of what makes SIGGRAPH work, and she carries the connective tissue for SIGGRAPHs throughout the years. Simply put, I believe that if it wasn't for Leona, there simply would not be the 20 years of Advances – without her support, whether it is the organizational details or the connection or the general approach of finding a solution, despite the obstacles. I am deeply grateful to her and all her tireless work on behalf of SIGGRAPH and want to share my thanks to her!

To all SIGGRAPH chairs
(Ginger Alford – SIGGRAPH 2025 Chair)

To all SIGGRAPH courses and General Program Chairs
And all SIGGRAPH volunteers

SIGGRAPH 2025 Advances in Real-Time Rendering in Games *course*
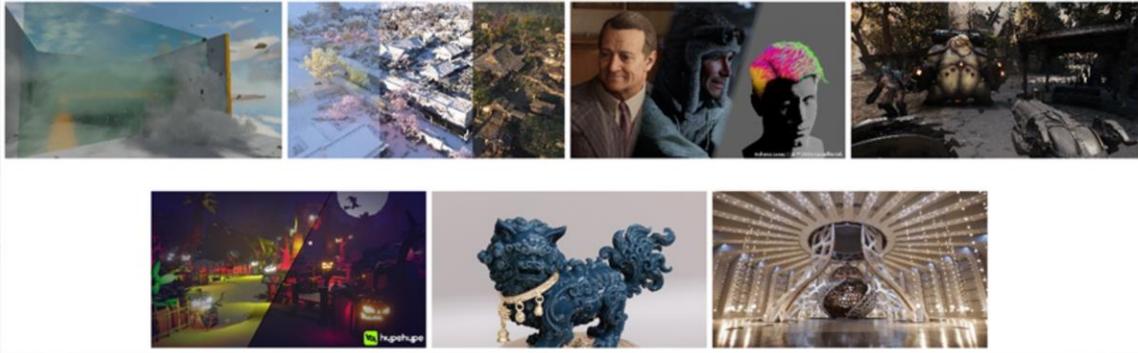
ACTIVISION. 99

Advances also wouldn't be possible without the support of all the 20 SIGGRAPH chairs, the 20 courses chairs, and general program chairs. Super grateful for their support over the years!

That was the 20 years that led to today's course.

But what's on our program today

New content!!! Entirely new content.

At the heart of the principles behind the choices for Advances talks is *production-driven innovation*. Each year we strive to deliver completely new content, and this year is no exception - we have a full slate of new content with the latest and greatest techniques

In the first part of the course, after this retrospective we'll dive into the world of order-independent transparency, open-world ray tracing, and hair and fur rendering..

The next talk will be by Michal Drobot.

Rendering transparent objects and effects in real-time with high performance remains a significant challenge in game development. This talk explores the journey of the *Call of Duty* rendering engine as it transitioned to order-independent transparency (OIT) while supporting active game releases.

Michal will share the road of exploring existing established algorithms and discovering the challenges for the unique requirements of the Call of Duty franchise's needs where both content creation ease, and visual accuracy is critical for gameplay and performance is paramount. This led to the development of a novel OIT technique: *Adaptive Voxel-Based Order-Independent Transparency (AVBOIT)* and Michal will share the details about this approach.

Luc LeBlanc and *Melino Conte* from Ubisoft will share technical insights from *Assassin's Creed Shadows*, built with the Anvil engine and set in feudal Japan. This title features a custom ray-traced global illumination system designed for large, dynamic open worlds. The talk explores the algorithms, pipeline choices, and performance considerations, along with challenges such as translucent geometry, dense vegetation, and specular reflections under tight development timelines.

STRAND-BASED HAIR AND FUR RENDERING IN *INDIANA JONES AND THE GREAT CIRCLE*

ADVANCES IN REAL-TIME RENDERING IN GAMES
+ CELEBRATING 20 YEARS
SIGGRAPH 2025
Vancouver+ 10-14 August

SERGEI KULIKOV
MachineGames

Indiana Jones © & ™ 2025 Lucasfilm Ltd.

SIGGRAPH 2025 Advances in Real-Time Rendering in Games *course*

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Strand hair systems are quickly becoming more widely adopted in video games.

Strand-based hair systems offer high visual fidelity and faster asset creation but face performance challenges, particularly on lower-end hardware. This talk details the performance-focused design, GPU optimizations, and problem-solving that enabled *Indiana Jones and the Great Circle* to ship at 60 Hz using strands as the sole method for human hair rendering.

PART II

ADVANCES IN
REAL-TIME RENDERING
IN GAMES
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Welcome and Introduction to Part II
Natalya Tatarchuk (Activision)

Fast as Hell: idTech8 Global Illumination
Tiago Sousa (id Software)

Stochastic Tile-Based Lighting in HypeHype
Jarkko Lempiäinen (HypeHype)

Real-Time Subsurface Scattering via Hybrid ReSTIR-Path-Tracing and Diffusion
Tanki Zhang (NVIDIA)

MegaLights: Stochastic Direct Lighting in Unreal Engine 5
Krzysztof Narkowicz (Epic Games) and Tiago Costa (Epic Games)

Closing Notes for Advances in Real-Time Rendering in Games, 2024
Natalya Tatarchuk (Activision)

Tiago Sousa from id will share details about the idTech8 and how id Software transitioned from a pre-baked global illumination to a "fast as hell" real-time solution, enabling *DOOM The Dark Ages* to achieve 60 HZ or higher on all platforms.
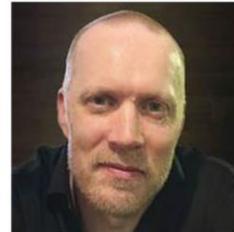
In the talk that follows Tiago Sousa, Jarkko LEMPIÄINEN will introduce stochastic tile-based lighting in HypeHype, which is cross-platform UGC gaming platform. It uses this a novel algorithm to deliver consistent, fully dynamic lighting with shadows across devices from low-end mobile GPUs to high-end PCs. Jarkko will share the intuition behind the design of the method, pragmatic considerations for performance and how the method combines big-tile Stratified Reservoir Sampling with small-tile resampling to maximize GPU coherence and efficiency, enabling scalable high-performance lighting even on constrained hardware.

The following talk from NVIDIA will introduce a hybrid real-time subsurface scattering approach that blends brute-force volumetric path tracing for single scattering with a new physically based diffusion profile for multiple scattering, achieving near path-traced quality without typical diffusion artifacts. By integrating ReSTIR for efficient sample reuse, the method delivers high-fidelity translucency for complex materials at interactive frame rates, enabling lifelike results in games, virtual production, and other real-time applications.

In the final presentation of the course, Krzysztof Narkowicz and Tiago Costa from Epic Games will talk about their take on the multi-lights rendering problem, the Unreal Engine 5's Megalights method – a new stochastic direct lighting path, which enables artists to place orders of magnitude more dynamic and shadowed area lights than they could ever before. They will share the design considerations that are critical to make it work on the current gen consoles and support for RT ray tracing to enable high fidelity soft shadows from variety of light types

CONTINUE THE CONVERSATION

ADVANCES IN
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Live Discussion on Social Media

#rtradvances

@ceruleite.bsky.social

https://mastodon.gamedev.place/@mirror2mask

mastodon

We'd love to know what you thought about the course and the talks in each session! Share them on social media or via the evaluations. Please share your thoughts using these tags

LIVE Q&A ON DISCORD

Post your questions on Discord!

Each talk will have a separate channel

Questions will be relayed to the speaker live by
the moderator during the Q&A portion of the talk.

We encourage speakers to answer any additional
questions in Discord *after* the Q&A session.

Many Thanks to **Michael Vance** for the
Discord management & organization

Please use your <u>real name</u> on Discord.

Please begin your question with **QUESTION** to aid moderators.

This year we are going to continue the initiative we started last year with REAC and
Advances – Discord discussions! (Thanks to Michael Vance from Activision for his server
management and setup!)
There is a channel for each talk.
Please post your questions on Discord throughout the talk - questions will be relayed to
the speaker live by the moderator, and after the course.
Please use your real name on Discord.
Please begin your question with QUESTION to aid moderators.

And this year we have an evaluation form that you can fill out at any point - please do. Your thoughts about the course and how it could evolve in the future, what works, what could be fortified help shape it over the years - please let us know!

CONTINUE THE CONVERSATION: CONTENT

ADVANCES IN REAL-TIME RENDERING IN GAMES
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Look for slides & videos on the Advances website and YouTube channel!

Course Web Page and Slides
http://advances.realtimerendering.com

Advances YouTube Channel

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We have a packed program today. But don't worry - after the conference, we will post all the content on Advances website - QR code on the left. And we are hoping to receive the videos down the line from SIGGRAPH and post them on the Advances YouTube as well.

Photo by Priscilla Du Preez CA on Unsplash

THANK YOU

- Matt Lim
- Rob Jones
- Peter-Pike Sloan
- Pete Shirley

- Michael Vance
- Michal Drobot
- Michal Iwanicki
- Sebastien Lagarde

- Steve McAuley
- Matthew Graham
- Mallory Bockwoldt

I want to extend my thanks to Matt Lim and Rob Jones who helped with the strategic analysis of the industry over the last two decades.

The trends that I shared today were strengthened by the discussion w/ these fine folks who generously shared a great deal of their thoughtful ideas with me on these and Activision Viz dev folks for their help on the slides design.

LET'S ADVANCE!

SIGGRAPH 2025 Advances in Real-Time Rendering in Games *course*
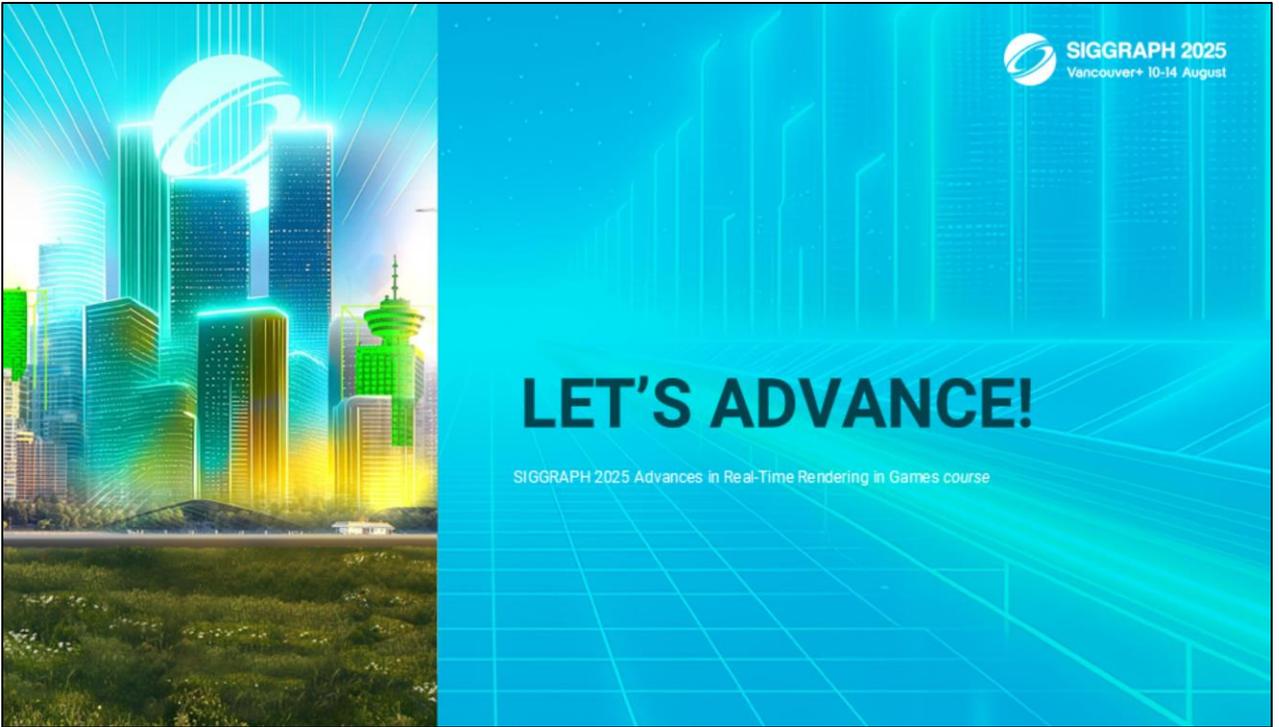
So, without further ado – let's get into the talks!

SIGGRAPH 2025 Advances in Real-Time Rendering in Games course