THE VIRTUAL PRODUCTION FIELD GUIDE

VOLUME 2

By Noah Kadner
Presented by Epic Games

EPIC GAMES

UNREAL ENGINE

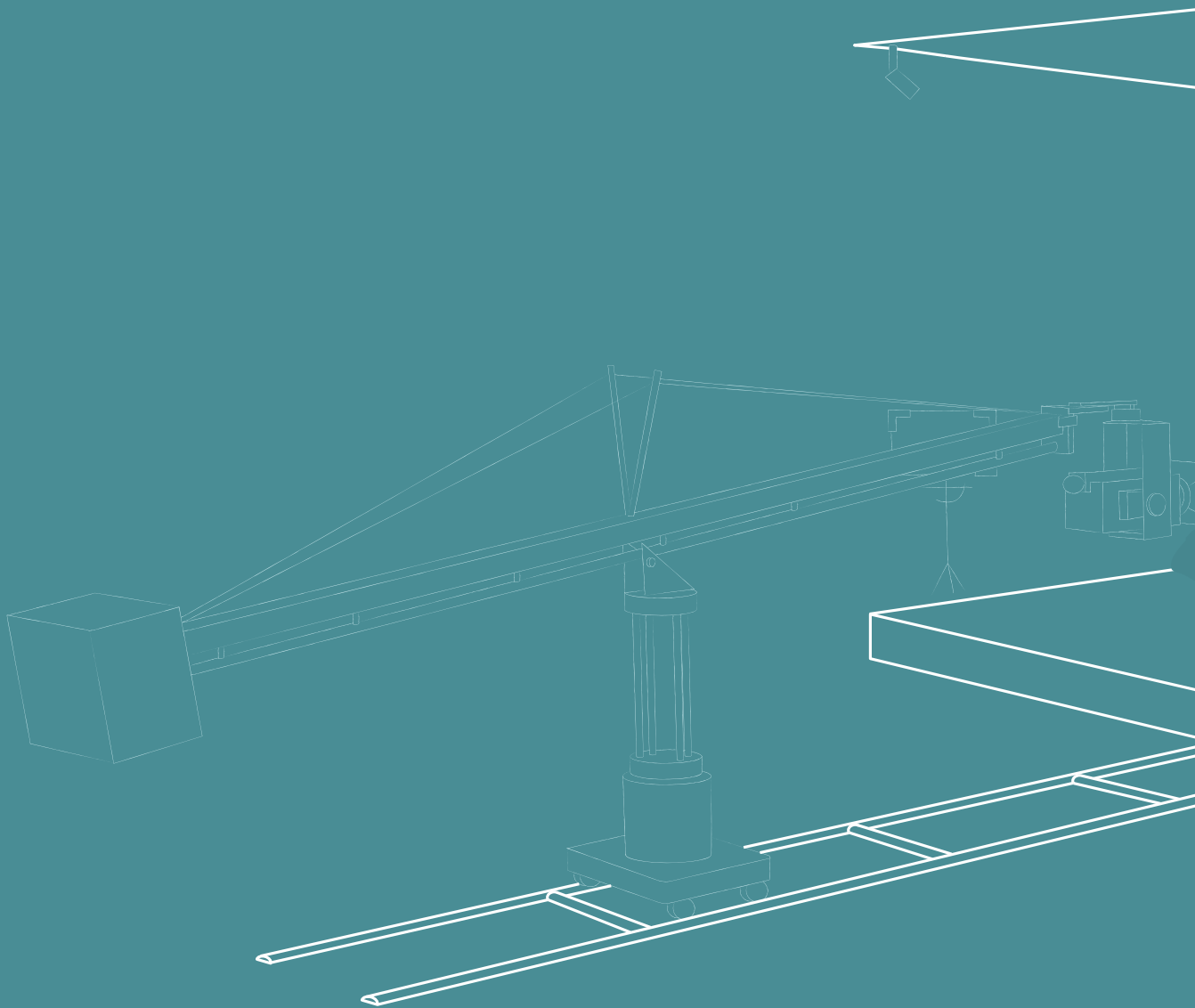**The Virtual Production Field Guide**
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About the Author
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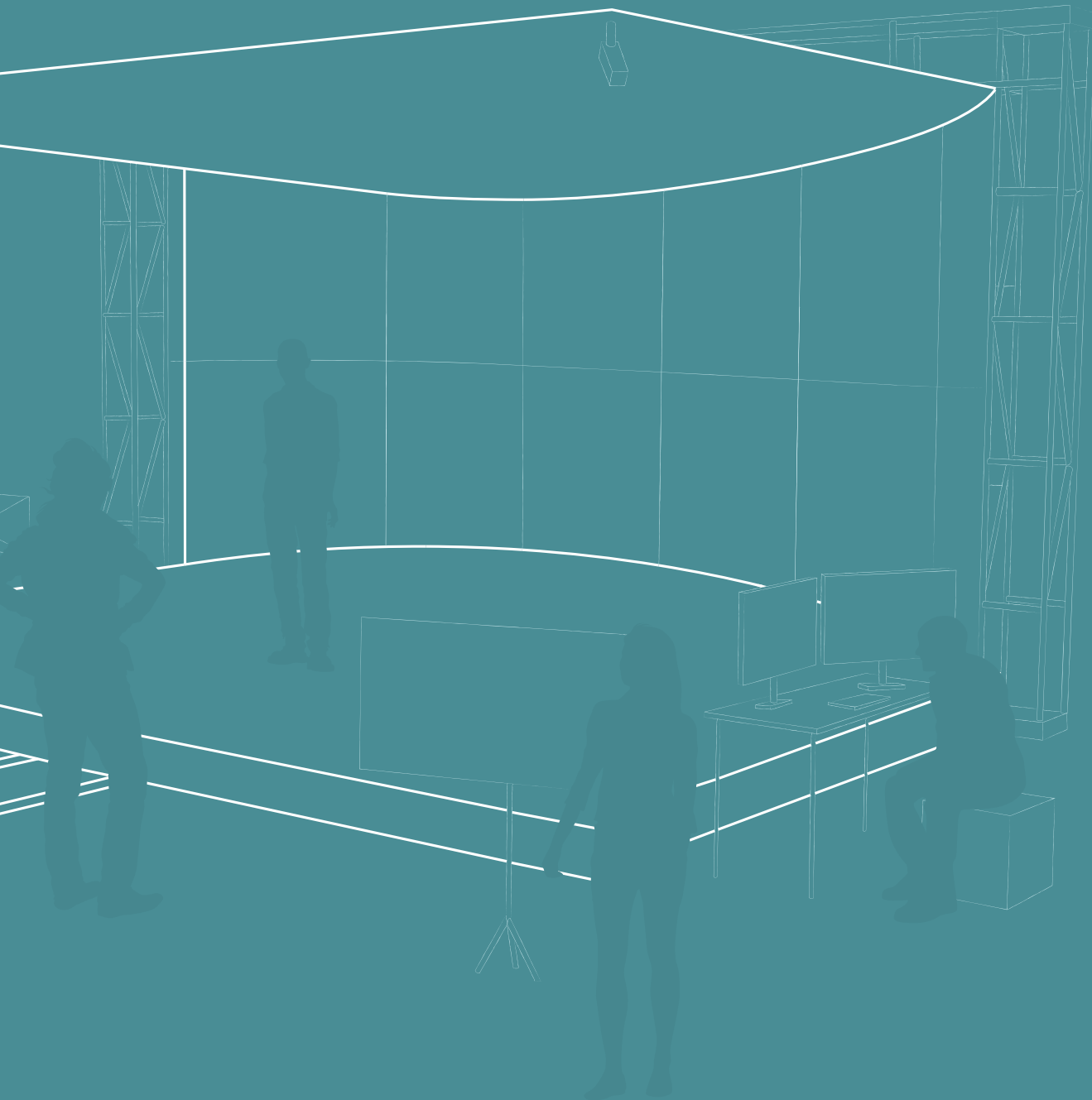
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CHAPTER I

Introduction

What's Changed since the Last Volume?

Welcome to the second volume of the Virtual Production Field Guide. We designed the Virtual Production Field Guide series for anyone interested in or already producing projects using virtual production (VP) techniques. When we say *we*, we're talking about the team here at Epic Games, creators of Unreal Engine.

We hope you've had a chance to read the first volume, as it explores the foundations of virtual production, which this second volume expands upon. Before we dive in, let's review what's changed since our last publication rolled off the virtual presses.

Remote collaboration has become the way. Disruption has always been a part of filmmaking, and technology and market forces have constantly led to change. Alongside the technology, we have the industry's response to the COVID-19 pandemic, with new production safety requirements for reduced crew size and social distancing. Real-time technologies bring new opportunities for remote collaboration, and the desire to get everyone back to work while adhering to these requirements has significantly accelerated a revolution already in progress. In today's climate, remote collaboration has become more critical than ever, challenging the ways we work while also creating a new paradigm that can bring lasting benefits. We'll explore those benefits, and also profile several creatives to learn about their experiences with remote collaboration.

More high-profile virtual productions have been completed. In our previous volume, we alluded to a number of milestone projects in the pipeline that we weren't at liberty to discuss. Now, some of those have been released. One of the most significant projects is the Disney+ streaming series *The Mandalorian*, which achieved new heights in virtual production and LED wall technology. We'll do a deep dive into the workflow of *The Mandalorian*, along with a number of other significant projects, and also interview their creators.

Virtual production workflows have evolved. General production methodologies evolve regularly, and virtual production evolves at an unprecedented rate. We'll explore the latest developments and learn from innovations and challenges in the trenches. Veterans of film and television are leveraging real-time technology to collaborate across previously siloed departments and bridge expertise across the spectrum of filmmaking.

Image courtesy of MELS Studios

Unreal Engine has evolved. New technologies like real-time ray tracing and HDRI have increased image fidelity and realism. In June 2020, Epic Games presented a preview of the technologies coming in Unreal Engine 5, the next major evolution of the engine. Features of great potential utility to virtual production include Nanite, Lumen, and Lightmass 2.0.

Nanite is a micropolygon rendering engine that can handle ultra high-detail 3D models without degrading real-time performance, which means you can reuse the same high-quality model for previs, real-time animation, and final-quality renders. Lumen is a real-time global illumination solution that dramatically improves lighting realism. Lightmass 2.0 creates complex lighting maps for highly realistic effects such as area shadows and diffuse reflections.

How This Book Works

Prerequisites

In order to get the most out of this book, we'll assume you've already read the first volume of the Virtual Production Field Guide, or that you're conceptually familiar with one or more aspects of virtual production. That knowledge as a prerequisite will be of great value to you as we get into the nuts and bolts of how virtual productions are created.

All of that is to say that we will be describing workflows in broad terms. Where applicable, we'll point you to more detailed white papers and other resources with step-by-step instructions. Virtual production has been around for a while, especially in the form of visualization. However, implementation of some of the newer and more technologically complex forms of virtual production, such as LED wall and in-camera visual effects cinematography, may require additional support beyond the scope of this guide. We'll point to additional resources wherever we can.

To support large-scale virtual productions, we cannot recommend highly enough the many systems integrators and consultants with broad experience in these advanced areas. These include companies like Lux Machina, Magnopus, The Third Floor, Happy Mushroom, Digital Domain, DNEG, and Weta Digital, to name a few. You'll hear from many of the principals at these companies within this guide; they welcome your inquiry for further information regarding your own projects.

Interviews

We've interviewed a large cross-section of creative professionals at various parts of the pipeline and in different positions. The experts we spoke with include directors, cinematographers, producers, visual effects supervisors, animators, compositors, Unreal Engine artists, systems integration specialists, and more. A common theme you'll hear from many of these individuals is enthusiasm for how positively real-time technology impacts their workflow.

We've asked these creatives how they use virtual production in their pipeline. We've also asked them how the global pandemic has impacted their projects and pushed remote collaboration to the forefront. In the interests of readers who are aspiring to a career in virtual production, we've also asked for career advice. Finally, we've asked them to extrapolate where they see real-time and virtual production evolving in the future. We hope you'll find their answers as insightful and inspiring as we did.

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> One benefit of this technology platform is that content creators can see a version of their work quickly, and immediately see the impact of their decisions. And that early iteration is much closer to the final vision.
> "
>
> Dane Smith
> Vice President
> The Third Floor

Deep Dives into Virtual Production Workflows

In addition to the interviews, we'll also look at a variety of virtual production workflows. We'll first outline the major components of each workflow, then examine how each workflow is accomplished. We don't intend this guide to be a set of instructions but more of an overview of all the moving parts involved and an invitation to take the next step and integrate real-time into your workflows.

Considering the current era in which this guide is being written, we'll first look at remote collaboration and how the right virtual production practices can make it more productive and inclusive. We'll examine virtual scouting sessions and virtual cinematography, and see how these two areas can be accommodated entirely remotely and as a shared experience.

Next, we'll look at the many different flavors of pure visualization. We'll explore pitchvis, previs, techvis, and stuntvis. We'll look into the history of how these iterative forms were born out of more traditional planning techniques like hand-drawn storyboards and animatics. Game engine tools greatly accelerate not only the efficiency of visualization but also the degree of engagement with real-time visuals that are far closer to final quality than ever before.

We'll move next into the crossover between production and virtual production, examining cutting-edge techniques like LED walls with tracked cameras and real-time in-camera green screen compositing. Live compositing with tracked cameras has been possible for a number of years, but the quality of in-camera imagery has become higher than ever due to advances in Unreal Engine itself, GPU and CPU technology, and real-time display technology.

Many of the creatives we'll talk to and projects we'll examine throughout this guide relate to high-profile blockbusters. We want to stress that this is not the sole domain of these tools. Big-budget films often push revolutionary technology forward, which then proliferates and gets democratized for access to filmmakers at any level.

Unreal Engine is a perfect example of this democratization by virtue of its availability, being free to download and use. All the techniques we cover in this guide can be accomplished with minimal investment. Our goal is to be as inclusive and empowering as possible and encourage the use of real-time power for all.

Finally, we'll look at the ecosystem of virtual production service providers. Many of them, such as The Third Floor and Halon Entertainment, have been around for over a decade, offering virtual production before the term was even coined. And while you may not be familiar with some of the names of the companies, you're most likely familiar with their work.

Virtual production has created a wealth of new opportunities both creative and economic. Pause to consider the many new areas a virtual production requires. The virtual art department is one such example, as it develops and manages the real-time assets critical to new workflows. On-set service providers oversee tracking and display systems in support of the main production. Virtual backlots of assets that can be repurposed and resold constitute another area waiting to be further explored. We believe the surface has just been scratched for an entirely new industry complementing the existing production infrastructure. We also see an increased role and greater opportunities for traditional production departments to participate in virtual production as the physical and virtual worlds continue to overlap.

Who This Book Is For

In our first volume, we recommended the Virtual Production Field Guide to creatives and department heads who were either brand new to virtual production or interested in learning more about a particular workflow. Our readers included producers, directors, cinematographers, production designers, visual effects supervisors, and more. We have the same creatives in mind for this second volume, but now we'd like to expand that audience.

Studio executives will find plenty of information in this guide to help incorporate the benefits a virtual production workflow brings to filmmaking. We believe that massive benefits and economies of scale can be reaped from virtual production at the studio production level. The best part is that much of the existing personnel and infrastructure can be reconfigured to take advantage of virtual production techniques.

Visual effects supervisors and facilities stand to gain from embracing virtual production through tighter iteration and more focused filmmaker feedback. Real-time workflows move away from offline versioning, where filmmakers have to compartmentalize their feedback. Instead, virtual production's online and even real-time versioning unlocks rapid iteration with shared visuals much closer to the ultimate goal.

Virtual production also offers a holistic approach to sequences as environments versus the more traditional shot-by-shot method. The result is increased filmmaker engagement and satisfaction while delivering assets that can be amortized over additional scenes. By leveraging virtual production workflows, sequences can be captured as freeform exploratory footage versus being locked into the specific shot / frame count methodology of traditional visual effects. This potentially moves production from a shot-based approach to a footage-based one.

Although virtual production has come into sharper focus recently, its aspects are not foreign to visual effects studios. Whether you're doing previs, techvis, postvis, stuntvis, mocap, or other forms of virtual production, it's familiar. What's changed is the increasing crossover of the physical and virtual worlds as game-engine software and GPU hardware have evolved to enable accurate emulation of the real world.

We're also aiming to inform producers how to leverage the various components of virtual production for their projects. An important distinction regarding budgeting is that some disbursement occurs earlier because detailed visual development happens at the start of pre-production instead of post-production. We will also discuss virtual production's impact on budgeting—including shifting allocations between departments and timing of expenditures—and managing concurrent workflows versus siloed linear workflows. The most crucial impact is how virtual production can empower filmmakers to be more creative and collaborative and, as a result, lead to a better final product.

Finally, we're hoping to interest and educate aspiring newcomers to virtual production. One theme you'll repeatedly hear throughout this guide is that there's a great demand for personnel with virtual production experience. The skills required for virtual production are multidisciplinary: a traditional, on-set filmmaking and storytelling foundation, combined with real-time and 3D artistry. Just by reading this far, you've already given yourself a competitive advantage.

Let's get started.

"

For LED wall technology, there's an amazing amount of potential for live environments and location-based experiences.

"

Jon Favreau
Writer, director, producer, and actor

Epic Games' Goals and Vision

Unreal Engine is a creative platform and a collaborative sandbox. Although the original purpose of Unreal Engine was for the creation of video games, its evolution into a virtual production tool is the result of a concerted effort on the part of Epic Games. That effort centers on a set of goals and a vision of Unreal Engine as a creative platform and a collaborative sandbox. Epic Games has an ever-growing number of production and post-production experts in its ranks to help guide this effort. These experts spend a great deal of their time dreaming about and envisioning Unreal Engine's possibilities for creating groundbreaking entertainment experiences. They also spend a lot of time listening to filmmakers and users in the trenches to develop the tools they need next.

Iteration, improvisation, and creativity

Iteration is a well-known term in agile software development, referring to the cycle of reviewing and refining a project. Iteration exists in traditional filmmaking, but is often complicated and can be expensive due to the many different moving parts required to deliver a single shot in a form that can be effectively reviewed by the director. This situation introduces a catch-22 that puts the budget at odds with the iterative aspect of creativity. In a traditional pipeline, by the time a shot is at a point where the director can evaluate it, considerable time and effort have been put in. Once the director is reviewing it, excessive iterations can be frustrating and negatively impact the schedule and budget.

Real-time workflows alleviate the iteration bottleneck by making extensive iteration not only possible, but enjoyable and cost-effective. They accomplish this by delivering imagery at a level of visual fidelity much closer to final, and in much less time, than with a traditional pipeline. The result is more akin to agile development, with time to iterate and discover the best version of a story through collaborative experimentation and even happy accidents.

Consider, as an analogy, the process of improvising music. It's much easier and more agile to improvise a song with the four most interested virtuoso players versus an entire 100-piece orchestra. Save the larger group for when the concept is nearly complete, and they will enhance the clarified vision. Making movies this way is also possible if the vision that's shared with both the smaller and larger groups has sufficient fidelity. This is where real-time virtual production comes into its own: by easily scaling from a small group of creatives at the start of development to include the much larger group of the full production crew.

A toolset and workflow

Virtual production bridges the physical and virtual worlds to make the creative process more transparent. It moves a creative toolset back into the hands of filmmakers and away from the domain of technicians and engineers. Instead of working in silos, creative departments can work collaboratively and bring their particular expertise to the project. Real-time virtual production facilitates this by being accessible to anyone who wants to get involved. All you need to do is download the software and begin experimenting.

Image courtesy of Animism

Virtual production should not feel foreign

This is a hands-on renaissance designed to bring the creative process back in camera and into the hands of the filmmakers. Along the way, creatives use a cinematographic vocabulary to describe their processes, regardless of whether they're referring to a physical or virtual space. Though the technology is cutting edge, the concept behind LED wall / in-camera visual effects harkens back to the dawn of film. Pioneering filmmakers like Eadweard Muybridge and Georges Méliès broke ground in a similar way, using the optical technology of the era to capture imagery in camera that could not exist in the real world. Virtual production accomplishes the same creative goals and makes a shared, in-camera vision possible at a higher level of fidelity and interactivity than ever before.

A focus on creative collaboration from previs to post

The best people bring their best ideas when they're fully empowered, and virtual production enables a thriving, image-based iterative process between department heads. Virtual production leverages both the benefits of game engine / real-time technology and the iterative nature of software development.

Game-engine technology is capable of simulating real-world physics, meaning assets created in the engine can have a one-to-one relationship to the real world. A virtual world lensed by a virtual camera will produce the same image as the corresponding real-world lens, even to the point of precisely matching shadows if you define the virtual time of day. Production designers can spot technical construction issues in sets before building them. Cinematographers can arrive at a location having already simulated their lighting equipment's precise effect on a given scene.

Considering game-engine technology as just another render portal ignores its unique benefits for filmmakers, such as extensive simulation and programming logic. For example, instead of manually setting and adjusting animation keyframes, you can develop custom scripts that automatically react to changes within a virtual scene. Procedural instead of ad-hoc creative tools drive these unique workflows.

Image courtesy of Rebellion

You can also develop highly modular creative assets and reconfigure them via parameters to fit various uses. For example, a retail store and product configurator could be repurposed to become a backlot asset configurator for a virtual studio. Unreal Engine's node-based Blueprint visual scripting system makes sophisticated interactivity straightforward to set up and easy to reuse.

An intense focus on creative collaboration is critical to reducing iterative friction for top-level creatives. By making the creation of complex imagery more interactive, creativity can flow freely. Ideas can be more deeply explored and shared without the traditional time or cost penalties.

Interoperability with other digital content creation tools

Because game-engine technology is designed to create games and other applications, it's built from the core for maximum interoperability. This makes it a perfect companion for virtual production and its chief goals of enabling collaboration and preventing creative silos.

As a game engine, Unreal Engine leans into its gaming roots just as much as it embraces virtual production. It supports import from and export to many of the critical 3D asset creation formats such as FBX, Alembic, and OBJ. This means a modeler working in another 3D application such as Maya or Houdini, or a production designer working in SolidWorks or even SketchUp, can easily integrate their work into an Unreal Engine scene. A scientific researcher can bring in a physically accurate simulation for deep visualization; even machine-learning models can be integrated into Unreal Engine for a variety of new applications.

Unreal Engine also supports a wide range of still, audio, and video formats, together with a variety of live data, including motion capture data, camera/lens tracking data, lighting systems, and more. Such interoperability also includes support for newer file formats such as Universal Scene Description (USD), which attempts to preserve maximum fidelity when assets and scenes are ported between different applications. All this functionality can be even further enhanced via Unreal Engine's plugin system.

These examples of uses and functionality reinforce Epic Games' vision for Unreal Engine as both a highly extensible platform and a powerful creative sandbox.

Interview:
Virtual Production for Studios - Girish Balakrishnan

Girish Balakrishnan is the Director of Virtual Production for Netflix. Before joining Netflix, he worked in a similar capacity at Technicolor. Balakrishnan's credits include **The Jungle Book**, **The Lion King**, and **Ready Player One**.

Can you talk about your role and how Netflix thinks about virtual production as a studio?

Girish Balakrishnan: We see virtual production as a method of creative problem solving enabled by new production technology. It connects all parts of the production process, reduces blind spots, and promotes a more advanced culture of planning. Historically, individual flagship titles were the only ones that could access these workflows. At Netflix, we feel strongly that virtual production should be accessible to everyone, anywhere, at any budget.

In my role as director of Netflix's virtual production department, I'm responsible for the studio's engagement with virtual production methodologies across our content slate and industry-wide. Our team assesses content early in development and works directly with filmmakers and facilities to deploy virtual production across all types of content—series, features, unscripted, animation, etc. By standing as our own department within physical production, we can influence production planning before titles are greenlit, ensuring they have the budgets, schedules, and knowledge required to tackle the creative challenges.

For virtual production to scale, we need to drive the industry to develop open and accessible standards. Through NLAB, our virtual production R&D initiative, we partner with technology leaders, like Epic Games, to standardize pipelines and battle-test emerging tools that can aid in democratizing these workflows. By working with the industry in lockstep with our productions, we provide filmmakers with premier access to the teams behind the tech and a feedback loop culture that drives innovation forward.

The studio uses techniques such as virtual location scouting, visualization, performance capture, on-set camera tracking / compositing, and interactive lighting for a range of content from indie films to blockbuster titles. It has been one of the most eye-opening experiences joining Netflix, working with filmmakers in places like Korea, Spain, and Brazil, and exploring these new technologies together.

Where does Unreal Engine fit into your pipeline?

Balakrishnan: As a studio, we are less interested in building in-house pipelines for virtual production but rather keen to work with facilities to leverage real-time engines like Unreal Engine as a core fabric of their workflows. The partnership with Epic has successfully enabled us to use Unreal Engine for all sorts of virtual production applications, from world-building and real-time previsualization in the virtual art department, to final-pixel rendering and in-camera VFX for both animation and live-action content. Epic is an important partner of the NLAB initiative, helping aspiring artists and supervisors on our titles tap into game engine tech's power and partnering on several R&D endeavors to move this technology forward.

How has the current world condition affected remote collaboration workflows?

Balakrishnan: Virtual production, as a concept, has been elevated into the production zeitgeist. There has been an acceleration of adoption, normalization, and cultural synergy surrounding virtual production across the industry, at a pace unseen before. As our filmmakers and artists have moved to at-home environments, virtual production has allowed for a whole new creative collaboration level. Video calls and remote reviews are effective 2D modes of communication but don't provide the spatial context and creative connection one would expect from reviewing 3D content.

To solve this, we swiftly connected three independent productions with Epic to accelerate the development of a new method of collaborative filmmaking, from home. This unlocked the ability for our studio to connect a DP in New York with VFX artists in London, a director in Los Angeles with an art department in Japan, and performance capture talent with in-house animation supervisors—all working together in Unreal Engine. Effective remote collaboration workflows have the ability to broaden the opportunity for the industry with talent across the world.

Image courtesy of Matt Kasmir/Netflix

How challenging is it for creatives from the traditional production side and the virtual production side to form a common working terminology?

Balakrishnan: Changing the culture of production is challenging. As these workflows become a more pervasive part of the filmmaking process, studios and crews will need to have a baseline understanding of their new roles. By demystifying the technology through education and using common terminology, we can build stronger physical production and creative engagements pre-production, on-set, and with our colleagues in VFX. Language is important, and those of us working in virtual production need to come to alignment on the fundamentals—only then will we be able to scale together.

Do you have any advice for someone interested in a career in virtual production?

Balakrishnan: Virtual production will become just production in the near future, and as that transition occurs, the need for technical literacy in physical production and animation roles will increase. Every department will tap into virtual production in some capacity and hire crew to support it, from production design with the virtual art department to editorial with real-time engine editing, camera with virtual cinematography, locations with scanning and virtual location scouting, sets that blend physical landscapes into immersive LED volumes, and costumes with VR sculpting and design. Understanding at a high level how the pieces move and having a finger on the pulse of where the industry is heading, while having strong domain expertise in any one area, will prove crucial to your success working in virtual production.

Interview:
Producer - Christina Lee Storm

Producer Christina Lee Storm founded Asher XR, a provider of strategic development, planning, creation, and implementation for virtual production, mixed reality, AR, and VR content. As Vice President at DreamWorks Animation, she led the Advanced Creative Technology group, driving the studio's motion capture and real-time technology initiatives and business strategy, and advocating for the future of content creation. Storm's credits include **The Artist**, **Life of Pi**, **Life After Pi**, **How to Train Your Dragon: The Hidden World** (including three VR experiences), **Trolls World Tour**, **Abominable**, and **Solitary**. Since this interview, Christina joined Netflix as the Manager of the NLAB Virtual Production initiative.

What is the producer's role in virtual production?

Christina Lee Storm: As a leader over the entire project, the producer casts vision. It's crucial as producers that we help walk our director and key creatives through the process. Part of the adoption of technology into a project is to create the most collaborative and inclusive environment where the tools don't dictate the art, but enhance the filmmaking process. As a producer, I look at it as creating a highly collaborative, creative sandbox that allows my key creatives to mine the magic where happy accidents can happen with my heads of departments, who can work all together in real time.

It used to be that the producer's role was very siloed with one's specific expertise (for example, story development, casting, or physical production). Due to the evolution of technology, filmmaking, and our creative appetites, we've been able to push the visual and artistic boundaries on projects like never before. Today's producer needs to lean into technology, and understand the full range of production tools, simply because our audience's visual tastes have matured.

Virtual production requires producers to understand how best to dissect the creative needs, understand which parts of virtual production and technology can be unlocked, and then roll the creative needs into a proper budget. Technical proficiency and work experience with computer graphics and real-time technologies are important, as one should understand how to make the most out of virtual production tools.

Is virtual production more beneficial for the potential cost savings, safety reasons, or both?

Storm: Before COVID-19, the approach towards virtual production was, "How much will I save by using virtual production?" In a post-COVID world, there are even more factors to consider such as safety measures for production, reducing travel, and quarantine, and remote work that virtual production can offer to productions today.

We can make some assumptions that savings lie in reducing production travel (lodging / per diem) and equipment costs, and reducing company moves. For example, if we have a scene set in Morocco, depending on what the scene entails, there's the potential to not travel hundreds of crew members and cast to the physical location. There are viable options to obtain that same location and set through technology.

In a post-COVID-19 production environment, your cast and key crew will have to travel, and fly, but may be subject to quarantine for upwards of 14 days depending on COVID-19 guidelines. Where you can send a much smaller virtual art department to capture the location, allowing people to stay where they are locally and work on a stage, it reduces risk and increases safety.

A small team shooting LiDAR offers less exposure to risk in today's COVID-19 world. It offers savings on travel and expenses versus productions traditionally having many people sent out on location for a shoot. In addition, if a production can reduce company moves from location to location because the location is on one stage, the production benefits greatly.

Some unions have expressed reservations about limiting crew sizes because jobs would be lost. How do you see that playing out?

Storm: Crews are very much still necessary to get the work done. It's an evolution of a different kind of work, but it still needs an experienced crew to get the work done at the highest level of excellence. Virtual production will not thrive if it excludes any kind of expertise. Also, a worldwide population of CG artists isn't represented by a union, but is critical to how we make movies today. The foundational core of real-time technology requires all areas of expertise and skill sets to lean in, work together, collaborate, and iterate.

Image courtesy of DreamWorks Animation

The inverted virtual production methodology calls for preparing assets for camera versus deferring final imagery until post-production. How does this approach affect the producer?

Storm: I don't know anyone who wants to make their movie in post. Preparing assets for camera creates an opportunity for filmmakers to see a closer representation of their project during production when all keys and heads of departments can be together. Having all of your departments together seeing final imagery, that's game-changing.

Better preparation earlier in the process will help filmmakers iterate during the pre-production visualization process. Filmmakers will get what they ultimately want—their art and their story up on the screen—reducing the guesswork that tends to happen at the end of the current filmmaking process, and sometimes delivering weeks before the release of a film.

What should producers consider as specific to virtual production in terms of planning?

Storm: I recommend that producers take a holistic view and make every effort to break down siloed departments or mindsets. Take that line that divides production and post in your budget and remove that, move your post

departments earlier, step back, and look at your project holistically. It requires people to shift their mindset of downstream departments and fold them into an earlier collaborative workflow. The foundation of real-time rendering means that we've decreased the traditional "wait time." This advancement now allows traditional productions (both live-action and animation) to have their CG experts serve the project similarly to the way their cinematographer and production designer do. Producers should utilize their virtual art department as early in the process as possible.

Producers can bid virtual production work as an environment or a scene, similarly to how we budget locations in physical production. There is a cost per location. The complexity of budgeting physical production is the savings of shooting out different scenes at one location or area. This is slightly different with virtual production, as the bidding will be based on the environment and asset.

Are traditional films stuck in a more compartmentalized workflow when compared to virtual production?

Storm: Yes, that is why there's a lot of reuse and waste currently happening in the filmmaking process. Human nature is to work in the areas we're comfortable in. Innovation takes courage and inclusion.

There is a near-term future in the filmmaking process where assets are created in prep and used through final imagery. Those same assets can be repurposed for ancillary content, including AR, VR, and short-form content. Imagine how much content and story can be created from those initial assets. Imagine how many labor-weeks can be saved from not having to rebuild assets from scratch. Imagine what creatives can do in the sandbox by leveraging the brain trust from its initial IP.

As a producer, my job is to remind people that we desire to create something collaboratively that infuses awe and wonder. The next generation of diverse producers will lean into the most disruptive time of content creation and content distribution.
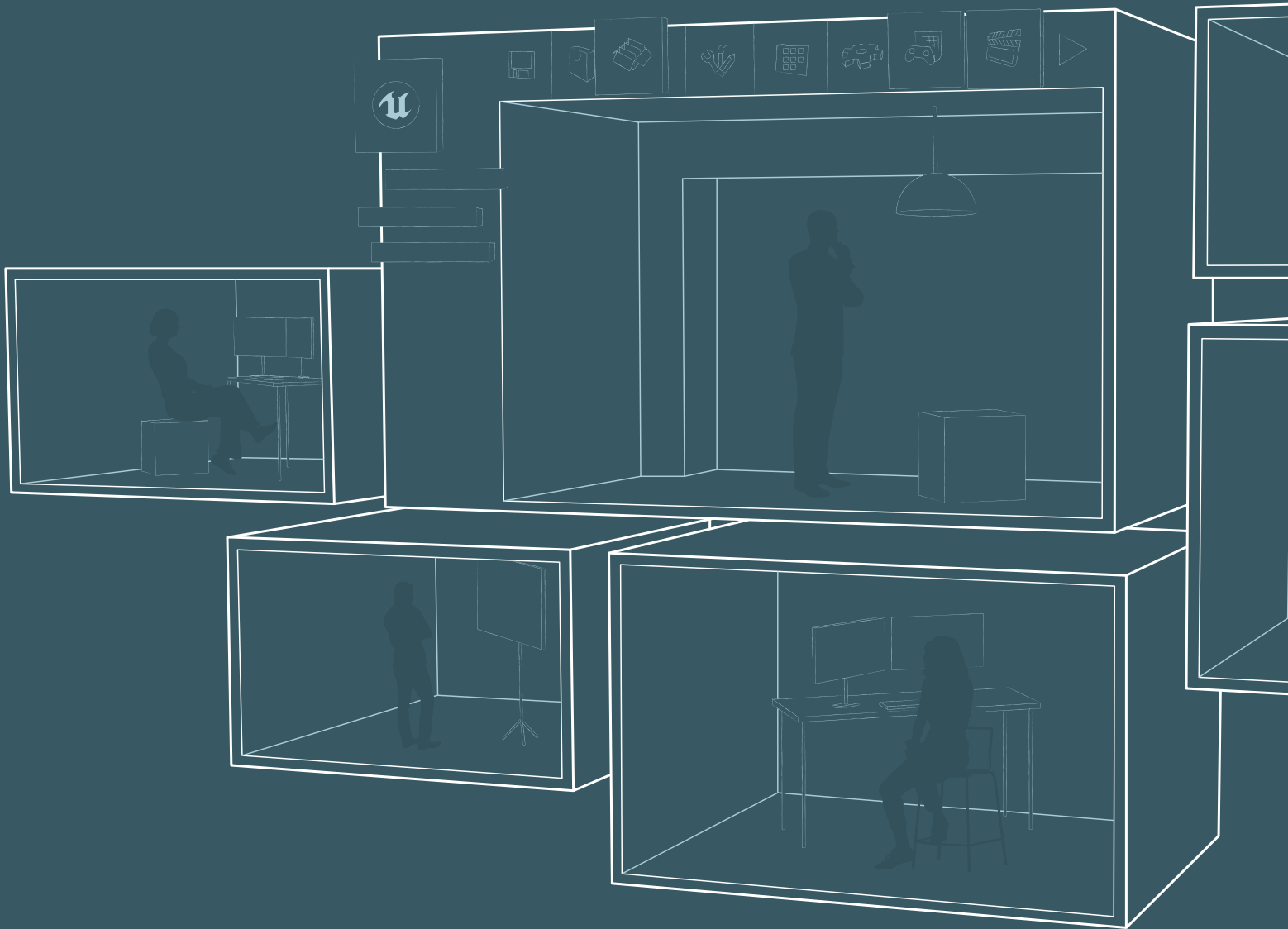
CHAPTER II

Virtual Production Workflows
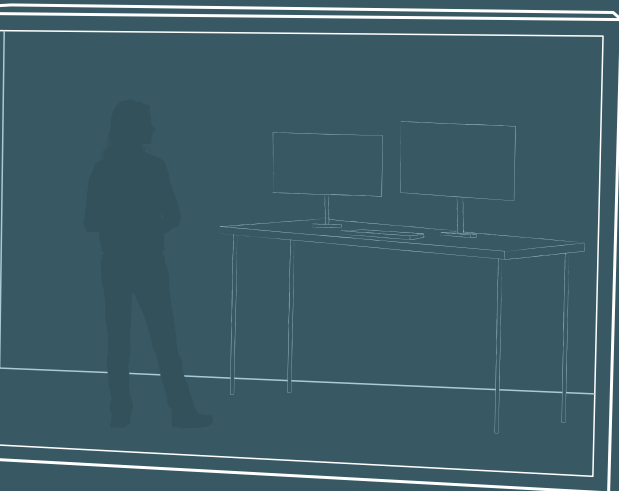
Virtual production is an all-encompassing set of techniques that begin in development and can be used all the way through to the final product. It is a bridge between the physical and virtual worlds. Another critical aspect is the development of reusable assets throughout the production process. The traditional segmentation of filmmaking labor into pre-production, production, and post-production phases transforms into a continuous workflow.

Remote Collaboration

Remote collaboration is a virtual production workflow that eliminates the limitations of the participants' geographic locations. It can be leveraged seamlessly either via a local area network (LAN) or mesh virtual private network (VPN). There's plenty of precedent for remote collaboration on movie sets. For example, in 1993, Steven Spielberg directed *Schindler's List* on location in Poland while simultaneously reviewing *Jurassic Park* edits and visual effects with a relatively primitive satellite TV connection.

In the era of COVID-19, remote collaboration has become more prominent than ever. The benefit of a game engine designed specifically to facilitate decentralized, multiplayer sessions becomes especially clear in this situation. Unreal Engine itself is the nexus of many of the following components.

Components

Perforce Helix Core

Remote collaboration can involve the contributions of dozens, even hundreds of artists and technicians within a single project. Anyone who has ever collaborated on a document of any sort over email or online knows dealing with different versions of a shared project can be incredibly challenging. Unreal Engine addresses this issue through its support of Perforce Helix Core version control software.

In a more traditional visual effects pipeline, creative work happens on a per-shot, linear basis. An animator will pass off their work to a lighter who will pass it off to a compositor, and so on, all without the surrounding scene's context. This workflow makes the process of tracking progress and versioning extraordinarily challenging and time-consuming. With Unreal Engine, because animation, lighting, camera movement sequences, and other scene components all live together in the same project, every collaborator can see and modify any aspect of the sequence.

Perforce automatically tracks and manages all these changes. It resolves any conflicts between individual contributions and keeps a complete version history via check-in/check-out IDE methodology. Any changes to a project can be reviewed and reverted if desired.

Additional benefits include robust protection for intellectual property. Perforce is also highly scalable, so projects can quickly move from pre-production to full production on the same platform. Perforce streamlines the process of remote

> "
> Perforce makes it much easier to collaborate. It makes it easier to find the assets you need to work on. And it lets you see if someone else is working on a particular file.
> "
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> Philippe Rebours
> Technical Account Manager
> Epic Games
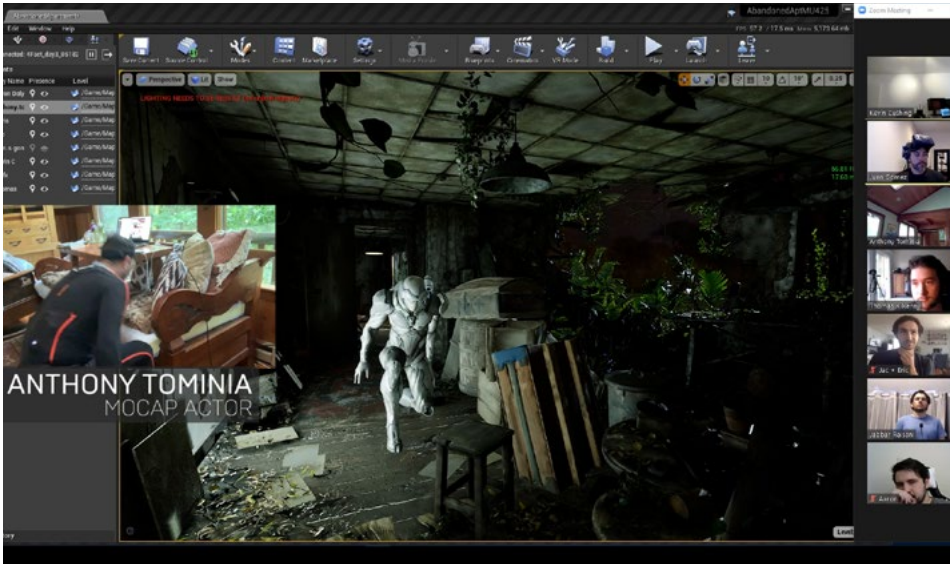
collaboration at the project management level, making working together agile and efficient. Unreal Engine also integrates with other version control systems as determined by a production's specifications.

Security Considerations

Because the protection of intellectual property is a high priority for productions, robust network security is critical for remote collaboration. Many existing products and services can deliver the setup and configuration of firewalls, VPNs, and other network security. Because each facility has unique network topology and protocols, coordination with existing IT resources and infrastructure is essential for security and scalability for IP contained within remote sessions.

Asset Sourcing

The creation of assets for use in projects often requires significant travel for large numbers of people in order to capture the desired locale or reference imagery. In many cases, content already exists that either works as-is for the desired project or can be repurposed to fit. Using existing assets offers significant cost and time savings while reducing both travel and the project's physical footprint.

Assets may include models, reference imagery, textures, and more. They can be created via photogrammetry and LiDAR, from reference imagery, completely digital, or a combination of methods. Assets designed specifically for Unreal Engine are typically tuned for real-time performance with optimized levels of detail and textures. Unreal Engine asset providers include the Unreal Engine Marketplace, the Quixel Megascans library, and Sketchfab.

Remote Collaboration in Unreal Engine

Unreal Engine offers two primary methods of remote collaboration: Multi-User Editing and the Collab Viewer template. Each technique provides highly customizable ways to work as a team in the same location or from anywhere in the world.

Multi-User Editing connects multiple instances of Unreal Engine across a LAN or VPN, each sharing the same project. Though initially designed for usage within the same location, such as on an LED stage, Multi-User Editing also performs well across the internet via a mesh VPN. It offers the highest degree of collaboration because every participant has full control over the project.

The Collab Viewer template is designed as a simplified remote review and collaboration tool for users unfamiliar with the engine via an executable file they can run without needing to install Unreal Engine. The settings in the template enable participants to share an environment across the internet. During the session, participants can manipulate elements and make annotations within the 3D space. The Collab Viewer template also comes complete with all the settings required for server/host configuration and is customizable with additional features for any desired workflow. To see this workflow in action, take a look at this video.

Physical Presence

In an era of social distancing and remote collaboration, we often need to consider the question of which crew members need to be physically present versus remote. Careful coordination and planning can deliver the smallest physical footprint while providing all the necessary functionality to create content. Much of the general pre-production work, such as scouting, set design, footage review, and so on, can also be effectively conducted online through video conferencing and multi-user sessions.

Video Village versus Video Conferencing

Video village is an element common to traditional production where feeds from cameras throughout a set get piped to a central viewing location. Remote collaboration dramatically expands the concept of a video village. Video conferencing solutions such as Zoom, Skype, and Webex, combined with remote collaboration workflows, provide an array of connections from both active participants and production support for an in-depth context for any shared scene.

Image courtesy of Diamond View Studios

"

The results of any one person's exploration can be shared with others, and sets and physical locations can be visited as often as needed without leaving the house.

"

Robert Legato
ASC Visual Effects Supervisor/
Cinematographer

Workflows

Virtual Scouting

Virtual scouting is a way to visualize a virtual location or set so crew members can explore spatially and devise a shot plan. It presents a shared experience, enabling an improvisational, collective approach to virtual shot design just as filmmakers employ on their physical sets. The interaction typically takes place in an HMD (VR head-mounted display), although a tablet or a computer screen can also be used. Virtual scouting can include repositionable props, virtual cameras with lenses, and camera supports for accurately planning shots, defining set builds, or planning entire sequences without building a single flat. Virtual scouting empowers filmmakers to determine which portions of sets need to be built out for their desired shots, as well as reduce or eliminate building areas that the camera will never see. To date, many projects have utilized virtual scouting in their pre-production processes, such as *Game of Thrones* and *The Lion King*.

Virtual Cinematography

Virtual cinematography simulates a real-world camera's characteristics, including optical properties, camera format, aspect ratio, movement, and more. Camera movement can be generated in a variety of ways including procedurally, via traditional keyframing, various input devices such as game controllers, or using a virtual camera (VCam). With VCam, the engine's camera movements are parented to a real-world proxy object, such as a real camera or any tracked object. VCam is a perfect combination of the realism created by the manipulation of physical objects with the limitless visual possibilities of the virtual world.

There are a variety of solutions available for VCam tracking. Unreal Engine includes a virtual camera plugin that, in combination with the free URemote app, enables an iPad to control the movement and orientation of a Cine Camera within the engine. Another cost-effective option is the HTC Vive Tracker, which can be connected to both cameras and objects within Unreal Engine.

The next step up is a professional optical and encoder-driven tracking solution such as MoSys, Ncam, OptiTrack, StYpe, and Vicon, or a custom solution using any of a variety of input devices. All aim for the goal of translating human camera operation into the virtual world. These capture techniques serve two purposes: to provide a more realistic movement to virtual camera moves, and to enable cinematographers and their crew members to have direct, one-to-one interaction with virtual cinematography.

Digital Humans/Crowd Creation

Digital humans can serve a wide variety of purposes in both visualization and in final imagery. In previs, digital humans are used to show camera framing and movement, and to work out stunts and blocking. During production, digital humans can be incorporated for crowds, digital doubles, and stunt work/action design, and even to act as primary talent.

The utility of virtual humans takes on an extra dimension when viewed through the prism of remote collaboration. Performers can deliver their movement from remote locations via mocap suits, and crowd scenes can also be easily simulated. Replacing performers with virtual characters can provide a comparable visual appearance while minimizing risk to the performers themselves.

Unreal Engine comes with a Digital Humans project to demonstrate some of its capabilities in this area. Recent improvements to Unreal Engine also include

hair rendering and simulation to further enhance the realism of digital humans and crowds. Digital humans can be animated via keyframes or simulation, or driven directly via performance capture. The Live Link Face app offers an entry into the arena of facial animation. For a higher level of performance and fidelity, Cubic Motion and 3Lateral (now both part of the Epic Games family) offer professional-grade facial tracking and digital human solutions.

Remote Studio Facility

To comply with the pandemic's heightened safety standards, many studio facilities have shifted to a remote workforce model, where most crew members work from home. Remote studios leverage video conferencing and virtual production techniques to present a crew experience as close as possible to that of a full, in-person crew. Although the safety factor is new, broadcast studios have long deployed remote equipment like robotically controlled cameras and intercom systems for news and sports productions. When viewed in light of new production safety standards established by the many guilds covering production in the United States and throughout the world, the utility of remote studios becomes clear.

> **"**
> Driven by new deep learning techniques, realistic digital humans and characters will soon be around us in a wide variety of forms, from virtual assistants to deep fakes. The way we interact with technology will never be the same.
> **"**
>
> Darren Hendler
> Director, Digital Human Group
> Digital Domain

Image courtesy of Digital Domain

Interview:
Visual Effects - Robert Legato, ASC
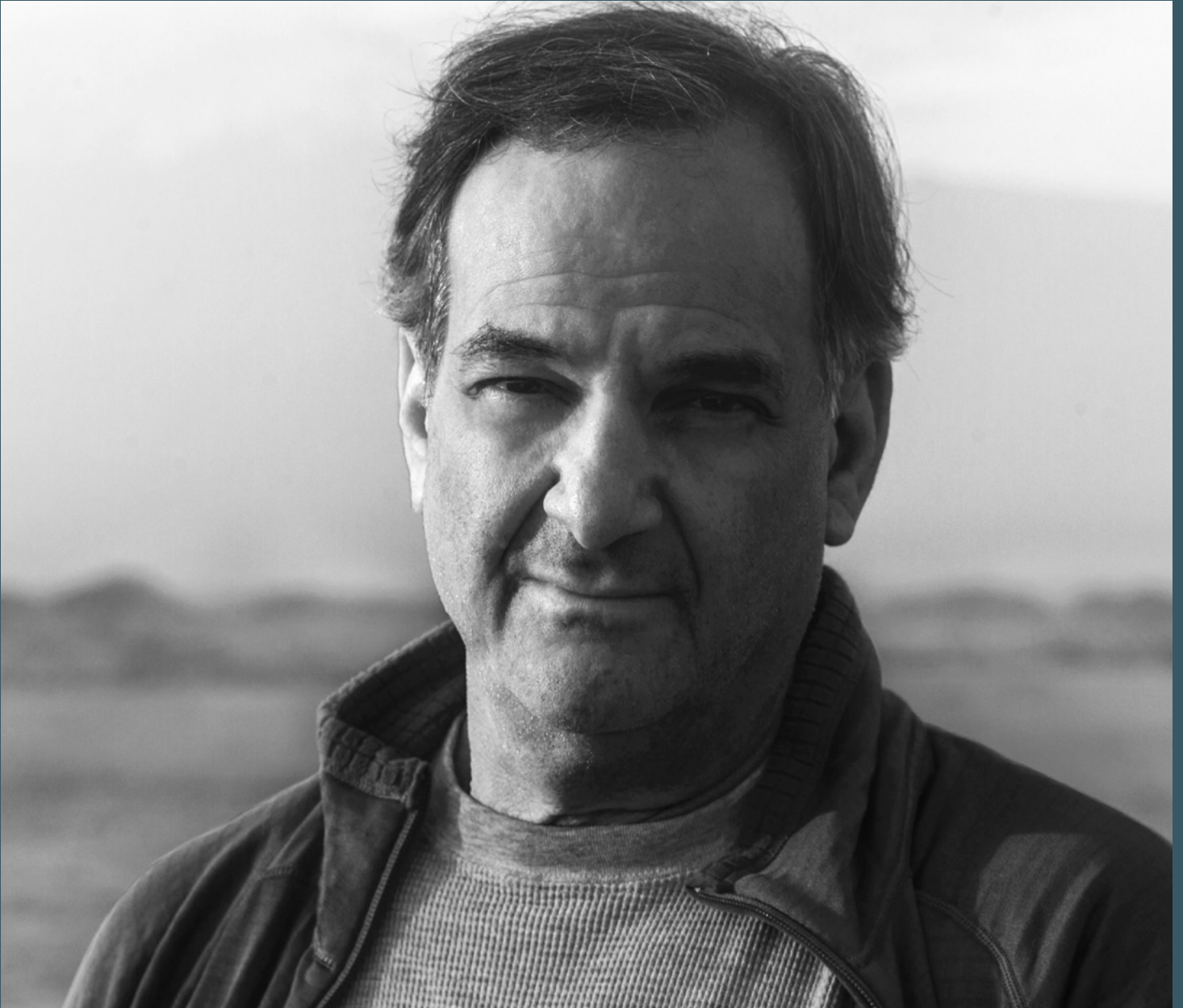
Visual effects supervisor Robert Legato, ASC, is a virtual production pioneer. His credits include **Titanic**, **Avatar**, **Hugo**, **The Jungle Book**, and **The Lion King**. Legato has earned three Academy Awards and two Emmy Awards for his work.

What are some of the operational differences between a traditional project and an LED wall virtual production?

Robert Legato, ASC: The first thing to overcome is the initial expense of building an LED wall because not everybody's doing it just yet. It becomes much simpler to realize the many advantages afforded to any production once a wall's already up. If somebody already had a wall built and you came in for your few days' shoot with your completed game engine model, the flexibility and economy would become very clear, not to mention the ease of shooting.

It's going to replace the one-off sets, which are a waste for a lot of reasons. In the one or two days you photograph a one-off set, you have had sufficient stage space for weeks of construction, pre-lighting, and set dressing. Once shot, the set can't be torn down until it's confirmed that you have everything you need. The process starts all over again for the next one once your set and all its dressings are returned. It can conceivably take six weeks of stage rental for just a day or two of actual shooting.

Now, you can construct the same set on the computer to be just as photorealistic. You still need the people who typically visualize blueprints and elevations to construct a virtual set from the same drawings you might use on a standard movie set; you still need the same set dressers and art directors to choose the furnishings you need, and gaffers to light the set, but they would now just use a computer as a different medium to achieve the same end result. If you have several sets ready to shoot, you can photograph them on the same day and not worry about moving on before seeing dailies. You can always recall the same scene months later for retakes or new ideas.

The extra bonus is that you can be in five different sets in a couple of hours, and shoot out an actor who you only have for two or three days, with the same quality as if you built all the sets or locations you were going to shoot for real. You can make the same high-quality movie faster.

The artists who've been designing real sets, furnishing them, and doing all these various tasks for years can do the same thing on a virtual set. It still needs to look like

somebody who knew what they were doing dressed the set, lit it, and photographed it. The jobs you're doing are similar to traditional roles, but the device you're using is not.

Lately, we discovered that you could work remotely pretty well, and people can be on their laptops in their living rooms, collaboratively creating content for a scene.

Can you talk about new departments necessary for virtual productions?

Legato: They're sort of the same, and you can have a combination. The virtual art department is not just the virtual art department; it's the actual art department. They may build a partial set, build all of the set, or do it all virtually, but it still gets designed on the computer by the production designer.

Even old school designers have adopted that because of the ease of working. Now you're incorporating a game engine like Unreal Engine, and you're designing assets for the final output.

It's the same thing with the camera department. We prevised everything on *The Jungle Book*, even down to the motion capture acting of Mowgli. We created a virtual camera department that became the camera department. I did the second unit on the film, and we would leapfrog so I would shoot on my set, and Jon Favreau and Bill Pope would shoot on their set.

On *The Lion King*, we did the same thing with Caleb Deschanel, and we developed virtual tools for our camera department. We had a real dolly grip that Caleb brought from his live-action shoots. We had Henry Tirl, who's a phenomenal Steadicam operator.

I'm doing previs on a movie for Michael Bay. He's heavily influencing the camera placement, the lens choices, and the camera moves in his usual directing style. He took to remote collaboration immediately, because it was the same idea. He could grab a vid stick in VR, walk around and aim the camera exactly the way he wanted, and start moving objects around. He'd say, "That's exactly the shot I would've done, or will do, when we shoot this live."

Is it difficult to form a common terminology between traditional visual effects personnel and real-time specialists?

Legato: It's a challenge with visual effects in general when departments don't understand other departments well enough. Once they hand off work as a relay race to the next group of people, they haven't thought about their problems and the ultimate solutions that they handed the baton to. Most people who operate a camera don't edit, but you'd be a much better cameraperson if you learned how to edit. Even if you're not a great editor, you'd still know why you're shooting something and what would make it easier or more creative for an editor to construct a scene.

I'm fairly strict when I set up a show because even though it may be visual effects-oriented, the artists may have never photographed anything live before. So they don't necessarily set things up to take advantage of what natural live photography gives you.

Also, if a VFX technical director designs a previs tool he has never used before, it may actually hinder instead of helping the cameraman because it causes them to work in a totally foreign way. That will absolutely interfere with and frustrate the natural creative process.

So it's key to have a traditional effects foundation and be ready to embrace innovations and new techniques.

Legato: Yes, you need to be open-minded and not afraid of the technology. Everybody who works in production requires particular knowledge of the subject matter. You become steeped in something you would never have if you didn't do that movie. When I worked on *Apollo 13*, I became very knowledgeable about how spacecraft mechanics worked to do a better job on the effects scenes. Same thing with *Titanic*.

Caleb is an artist who embraces what he doesn't know and then makes it work for him as if it wasn't an impediment at all. That's the kind of people you want to work with—the people who know the tradition extraordinarily well and embrace new tools to create timeless imagery.

How has virtual production evolved?

Legato: For me, it started when I worked on *The Aviator* and came up with the concept for virtual cinematography, which I presented to Jim Cameron. Then he decided to do *Avatar* that way because he could step inside the computer instead of just looking at a screen. While it wasn't actually stepping into it via VR, it was very promising and allowed Jim to bring the computer camera out on a stage floor with him so he could operate it freely.

We created a hybrid system where you could walk around with a real camera, put marks on the ground, put C-stands up, and create a virtual set to mimic a real set. You could build interactive set pieces out of wood and with various props to create a physical volume corresponding to a CG set.

I've done previs on every movie. For example, I had a previs unit when I was doing *Hugo*. As we were shooting scenes, I'd be one or two shots ahead of the main unit camera, designing how we would get the final result. I could see the set in its entirety, not just the partial set we had on stage, to design the shot properly and then break it down so we could shoot the individual pieces knowing exactly what the final shot would look like.

On *The Jungle Book*, we did it essentially the same way with our virtual sets, very *Avatar*-like, with a couple of improvements on virtual cinematography. But we were still dealing with looking at the virtual world only through the camera portal.

Then the Vive headset came out, and we totally redesigned *The Lion King* as a VR shooting experience. So now, VR scouting becomes very similar to live-action scouting—we build the entire world as if it were real, and simply walk around in it. Your brain picks up on it really fast, and you become comfortable in that environment.

Even if you need to do a live-action scout in VR, you don't have to send everybody to Grand Central Station anymore. People can be in VR, and they don't even have to be in the same city. They can walk around, and the director can talk

Images courtesy of Paramount Pictures

to them and say, "If you put a crane up there by the stairs and you look back, and this is what the shot looks like, that's what I want to do."

The director doesn't even have to leave their apartment to conduct a really informative and valuable collaborative session. You just build all the assets in the game engine, and you can hop from one location to the next and talk about all of it with your key crew. Eventually, when you go to the location, you know exactly where everything goes, where everything is, and you planned out your day very efficiently.

How do you see virtual production evolving in light of the need for remote collaboration?

Legato: I find it interesting working remotely because sometimes you don't need somebody there 12 hours a day to only help you for a few minutes. You may only need them for an hour. Usually, if you're on a high-pressure stage, you just bring everybody. So the fact that you could just call up somebody and they could pipe into your computer and fix your problem—they don't have to be anywhere that's not convenient to them. You don't need 30 people on the stage anymore.

It'd probably keep many people busy, and they wouldn't have to move to Vancouver, or Montreal, or London—they

don't have to move anywhere. They could all be in the place that they enjoy being the most and still work successfully. I used my iPad on Google Hangouts all day long while working on the shots I needed to do for the movie I was working on. Then every once in a while we'd say, "We need this person to check out a problem we're having, something's not working." The person would pop in and see my screen and say, "Oh, I know what you're doing wrong. You have to do this."

The person would fix it, and get to go back to whatever he or she was working on. It wasn't terribly different than if they were there in person, because if you have a problem on the set you'd bring the same guy over, he'd go and look over your shoulder, he'd sit down a little bit, work his magic, and then he'd leave. But he's in the building all day long. We had a teleconference with the director in his edit suite, and I could see what he was doing, and he could see what I was doing. All we need is a 15-minute conversation instead of a two-hour meeting.

Not that you never need to meet in person, but certainly you can plan and previs remotely. One could definitely make an animated movie this way. You could easily send a small sound crew over to Tom Hanks' house and record him at his leisure. You'd remotely monitor the session and then, with his dialogue in tow, collaborate with the animators and do every other function remotely as well, including color correction. It doesn't have to be so centric to a building anymore. That'll be the bonus that comes out of this, I think.

It's a lot better now that we commonly have teleconferences and VR. If everyone adopted this, it would eliminate much of the unnecessary plane travel for a three-hour meeting. When I worked on films with Marty, it would cost a fortune to fly me out to New York and put me up in a hotel. Then I'd meet with him for literally three hours, and I would go back home again. That was three days of valuable time for a three-hour meeting. I think the virus is forcing that concept into being now. As a result of these forced advantages, we have literally no reason to go back to 100 percent of what we did before.

Interview:
Digital Humans - Darren Hendler

Darren Hendler is the Director of Digital Domain's Digital Humans Group. His job includes researching and spearheading new technologies for the creation of photoreal characters. Hendler's credits include **Pirates of the Caribbean**, **FF7**, **Maleficent**, **Beauty and the Beast**, and **Avengers: Infinity War**.

Can you talk about your role at Digital Domain?

Darren Hendler: My background is in visual effects for feature films. I've done an enormous amount of virtual production, especially in turning actors into digital characters. On *Avengers: Infinity War* I was primarily responsible for our work turning Josh Brolin into Thanos. I'm still very much involved in the feature film side, which I love, and also now the real-time side of things.

Digital humans are one of the key components in the holy grail of virtual production. We're trying to accurately get the actor's performance to drive their creature or character. There's a whole series of steps of scanning the actor's face in super high-resolution, down to their pore-level details and their fine wrinkles. We're even scanning their blood flow in their face to get this representation of what their skin looks like as they're busy talking and moving.

The trick to virtual production is how you get your actor's performance naturally. The primary technique is helmet cameras with markers on their face and mocap markers on their body, or an accelerometer suit to capture their body motion. That setup allows your actors to live on set with the other actors, interacting, performing, and getting everything live, and that's the key to the performance.

The biggest problem has been the quality of the data coming out, not necessarily the body motion but the facial motion. That's where the expressive performance is coming from. Seated capture systems get much higher-quality data. Unfortunately, that's the most unnatural position, and their face doesn't match their body movement. So, that's where things are really starting to change recently on the virtual production side.

Where does Unreal Engine enter the pipeline?

Hendler: Up until this moment, everything has been offline with some sort of real-time form for body motion. About two or three years ago, we were looking at what Unreal Engine was able to do. It was getting pretty close to the quality we see on a feature film, so we wondered how far we could push it with a different mindset.

We didn't need to build a game, but we just wanted a few of these things to look amazing. So, we started putting some of our existing digital humans into the engine and experimenting with the look, quality, and lighting to see what kind of feedback we could get in real time. It has been an eye-opening experience, especially when running some of the stats on the characters.

At the moment, a single frame generated in Unreal Engine doesn't produce the same visual results as a five-hour render. But it's a million times faster, and the results are getting pretty close. We've been showing versions of this to a lot of different studios. The look is good enough to use real-time virtual production performances and go straight into editorial with them as a proxy.

The facial performance is not 100 percent of what we can get from our offline system. But now we see a route where our filmmakers and actors on set can look at these versions and say, "Okay, I can see how this performance came through. I can see how this would work or not work on this character."

Image courtesy of Digital Domain

How challenging is it to map the human face to non-human characters, where there's not always a one-to-one correlation between features?

Hendler: We've had a fantastic amount of success with that. First, we get an articulate capture from the actor and map out their anatomy and structures. We map out the structures on the other character, and then we have techniques to map the data from one to the other. We always run our actors through a range of motions, different expressions, and various emotions. Then we see how it looks on the character and make adjustments. Finally, the system learns from our changes and tells the network to adjust the character to a specific look and feel whenever it gets facial input close to a specific expression.

At some point, the actors aren't even going to need to wear motion capture suits. We'll be able to translate the live main unit camera to get their body and facial motion and swap them out to the digital character. From there, we'll get a live representation of what that emotive performance on the character will look like. It's accelerating to the point where it's going to change a lot about how we do things because we'll get these much better previews.

How do you create realistic eye movement?

Hendler: We start with an actor tech day and capture all these different scans, including capturing an eye scan and eye range of motion. We take a 4K or 8K camera and frame it right on their eyes. Then we have them do a range of motions and look-around tests. We try to impart as much of the anatomy of the eye as possible in a similar form to the digital character.

Image courtesy of Digital Domain

Thanos is an excellent example of that. We want to get a lot of the curvature and the shape of the eyes and those details correct. The more you do that, the quicker the eye performance falls into place.

We're also starting to see results from new capture techniques. For the longest time, helmet-mounted capture systems were just throwing away the eye data. Now we can capture subtle shifts and micro eye darts at 60 frames a second, sometimes higher. We've got that rich data set combined with newer deep learning techniques and even deep fake techniques in the future.

Another thing that we've been working on is the shape of the body and the clothing. We've started to generate real-time versions of anatomy and clothing. We run sample capture data through a series of high-powered machines to simulate the anatomy and the clothing. Then, with deep learning, we can play 90 percent of the simulation in real time. With all of that running in Unreal Engine, we're starting to complete the final look in real time.

Image courtesy of Digital Domain

What advice would you give someone interested in a career in digital humans?

Hendler: I like websites like ArtStation, where you've got students and other artists just creating the most amazing work and talking about how they did it. There are so many classes, like Gnomon and others, out there too. There are also so many resources online for people just to pick up a copy of ZBrush and Maya and start building their digital human or their digital self-portrait.

You can also bring those characters into Unreal Engine. Even for us, as we were jumping into the engine, it was super helpful because it comes primed with digital human assets that you can already use. So you can immediately go from sculpting into the real-time version of that character.

The tricky part is some of the motion, but even there you can hook up your iPhone with ARKit to Unreal Engine. So much of this has been a democratization of the process, where somebody at home can now put up a realistically rendered talking head. Even five years ago, that would've taken us a long time to get to.

Where do you see digital humans evolving next?

Hendler: You're going to see an explosion of virtual YouTube and Instagram celebrities. We see them already in a single frame, and soon, they will start to move and perform. You'll have a live actor transforming into an artificial human, creature, or character delivering vlogs. That's the distillation of virtual production in finding this whole new avenue—content delivery.

We're also starting to see a lot more discussion related to COVID-19 over how we capture people virtually. We're already doing projects and can actually get a huge amount of the performance from a Zoom call. We're also building autonomous human agents for more realistic meetings and all that kind of stuff.

What makes this work well is us working together with the actors and the actors understanding this. We're building a tool for you to deliver your performance. When we do all these things right, and you're able to perform as a digital character, that's when it's incredible.

Interview:
Digital Humans - Nathalie Bergeron

Nathalie Bergeron is Vice President of Operations and Business Development at Cubic Motion. Previously, she worked at other technology companies such as Foundry and Apple. Bergeron oversees client relationships, strategic partnerships, and creative and technical team initiatives for the Americas.

Can you talk about Cubic Motion and how it fits with Unreal Engine?

Nathalie Bergeron: We've had a strong relationship with Epic for many years, and we've built many demos of high-fidelity digital humans. Siren is a good example from GDC 2018. We've also worked with Ninja Theory. Many of our service clients work with Unreal Engine. Last year, Cubic released its first product, Persona, a hardware and software solution for live performance capture.

Persona is a live performance capture system that allows you to transfer a complete scripted or unscripted performance from an actor directly to a digital character. We're excited about some of the projects that we're undertaking with the 3Lateral team and the Epic team.

Can you give more details about Persona?

Bergeron: We start with a training session, which gets the range of motion from the actor and the script. Then we take that data and build a bespoke tracker and the solver for that asset. Finally, we return the equivalent of a configuration file to the client.

There's a hardware portion with a helmet and a front and side head-mounted camera system. The side camera gets some of the rolls of the lips and the jaw motion, which can be a little bit harder to get from a single front camera. There's also a small on-body PC that the actor is wearing under a belt, which tracks and solves in real time.

The on-body PC sends the capture data to a desktop PC running Persona as a monitoring application, then you stream the live performance directly into Unreal Engine. If you don't want to see your character live, you can still use Persona for purely offline capture, but most people use it for the live aspect. Once you have an identity logged into your system, you can switch your character pretty much in real time.

The system runs completely wirelessly as well, so, there's no cable running around, and the actor becomes an animation studio by themselves. We've tested four characters simultaneously, but in theory, you could have more characters running. We're exploring our next contribution heavily within Epic, and working out how the next generation of Persona will look.

Is there a learning curve for actors new to mocap?

Bergeron: On a recent shoot, we had an actress doing facial mocap for the first time, so she was nervous. She put on the suit, and she said it was a very smooth process for her. If the device you're wearing is comfortable enough, at some point you forget you have it on your head and you just become your character.

I think actors in mocap suits are very resilient by nature because they have to wear them for hours at a time. It seemed to be easy for everyone I've worked with, or they never complained. It's a testament to their talent and the technology that it is now easier for actors.

How do you handle performance capture for non-human facial anatomy?

Bergeron: You have the likeness of the actor and the likeness of the model. When you have a stylized character, there's a little bit more of a creative process required. So you go back and forth to try to polish and get the performance that you need. It all requires technical ability and a very good artistic collaboration with the other team members to make sure that you obtain the performance you want, even if it's not a human performance.

Image Apex Legends: Live from Mirage's Holo-Day Bash at The Game Awards | Respawn Entertainment & The Mill

Image Apex Legends: Live from Mirage's Holo-Day Bash at The Game Awards | Respawn Entertainment & The Mill

How challenging is live performance capture versus capture for post-production?

Live performance capture requires very robust tracking to avoid snapping as the character performs. It's done with a mix of manually training the system to recognize certain poses and having machine learning tools to train the model.

When we collaborate with a character that is not human at all, it's more of a black-box solution. We're taking advantage of machine learning to drive some of the results. There's also that interaction with the client to ensure that we get the result they want.

Is it possible to do performance capture via remote collaboration when teams can't be in the same physical space?

Bergeron: It's not the best scenario, because ultimately we want to have multiple actors and tracking together in the same space. But if that's the only option available, we want to continue to push things forward. I've attended shoots remotely on Zoom with 12 people. Suddenly, you have many people attending, and you have to give basic guidance. For example, if you're doing a video clip, you cannot rock the head left or right too much.

So, they have to give a more reserved performance because of that constraint, but it's still possible to get data. In the case of a very high-end film, there's not an easy way around having people on a stage. In recent weeks, we've seen some of our clients go back to a mocap volume and shoot with the head-mounted cameras. Epic has also been pushing the next generation of hardware solutions.

Are there uses for facial animation beyond movie characters?

Bergeron: Yes, our clients are talking about projects now that are not limited to facial animation just for a movie character, but also maybe for an episodic content piece. Then they will carry that animation through all of these media. We're also hearing more about people confined at home and wanting to become characters.

Do you have any advice for someone interested in a career in digital humans?

Bergeron: Animation is a great field to be in at the moment, with lots of great schools available. You should look for a school that offers or is looking to include virtual production in their curriculum. You should also be incredibly curious and always want to learn more. You look at the work, watch the movies, and take many classes to stay up to date with the process because it's changing very rapidly.

I've seen several heavy, expensive hardware revolutions where only one person could be on the machine. Then all of a sudden, it's democratization, and everybody can do visual effects on their laptop. I feel now we're on the verge of this next revolution with real-time engines that are putting us back to collaboration where we can have a vision.

Where do you see digital human technology evolving next?

Bergeron: The quality of digital humans will continue to grow to a point where it will be challenging to differentiate what's real and not real. We'll have social events in places
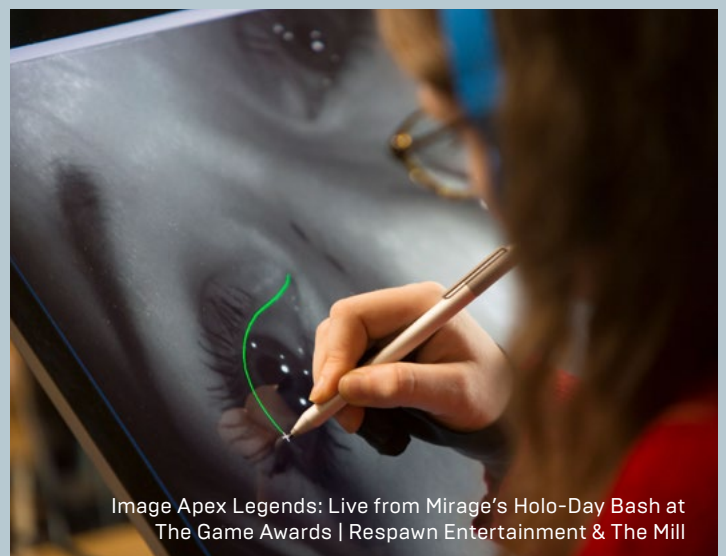

Image Apex Legends: Live from Mirage's Holo-Day Bash at The Game Awards | Respawn Entertainment & The Mill

like *Fortnite*, where the characters that we're looking at are digital humans. In addition to games and other real-time experiences, digital humans will also be more present in our day-to-day lives.

We'll see them when we go to the shopping mall and the like. They will also become less expensive and more accessible. We're building a world where digital humans will appear to be part of our society to a point where it will be difficult to differentiate.

Visualization

Visualization is the original form of virtual production and perhaps the best known to date. It encompasses all the different phases in which having a shared vision complements the production cycle. Visualization includes pitchvis, previs, techvis, stuntvis, and postvis.

In this section, we'll examine the typical hardware and software components behind most forms of visualization. We'll also look at each major visualization workflow and how it's accomplished. Finally, we'll continue our interviews with creatives and service providers of the various types of visualization.

Components

Unreal Engine

Unreal Engine itself is one of the primary components in many visualization workflows. Visualization can, of course, be created in any animation application or through the more traditional methods of hand-drawn animation, storyboards, or animatics. None of those other methods offers the combination of speed, visual fidelity, one-to-one correlation between virtual and physical worlds, and deep collaboration of Unreal Engine.

VCam/Simulcam

Virtual camera (VCam) and simulcam are often significant components of many different visualization techniques. Although more traditional layout techniques are often used to generate movement for visualization, VCam leverages virtual production much more effectively.

Image courtesy of Nviz

Camera movement is one of the most critical aspects of the creative vision. Few directors or cinematographers seek basic camera movement. In contrast, expert manual camera moves can make images look more realistic, help tell the story, and contribute to audience engagement. By bringing actual human camera and object movement into the virtual world, a much closer to final creative vision can be achieved earlier. So, providing realistic camera movement at the previs or pre-production stage can engage creatives much sooner, which aids collaboration.

Simulcam, likewise, continues the through line of visualization into production through real-time compositing of virtual elements into the live-action frame. This is especially key when digital elements such as set extensions or CG characters need to interact within a shot. This simultaneous visualization of live action and CG elements in camera greatly enhances the filmmakers' ability to optimize shot framing and overall composition.

Interface

Various interfaces may also be deployed depending on the type of visualization. These may include motion capture suits, head-mounted cameras, mobile devices, tracking systems, camera/dolly encoders, and more.

Remote Sessions

Virtual production has often led the charge in leveraging **remote collaboration techniques**. The COVID-19 pandemic greatly accelerated this predilection. Remote sessions can range from something as simple as a Zoom call between creatives, to a remote multi-user collaboration session. Remote teams can effectively accomplish all of the key phases of visualization.

Conversion of Existing Traditional Assets

The ability to **convert and repurpose existing traditional assets**, including 3D models, textures, and other visuals for use with Unreal Engine, brings additional benefits to visualization workflows. Rather than losing time and money by recreating existing work, assets in formats such as Alembic, FBX, and OBJ can be brought into Unreal Engine with very high fidelity from other modeling and animation workflows. The feature and performance advances on the horizon in Unreal Engine 5 will enable there to be much less tradeoff between model complexity and real-time performance.

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The main benefit [of Simulcam] is to give the camera operator and director the ability to get an understanding of what the shot's going to be like.

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Hugh Macdonald
Chief Technology Innovation Officer
Nviz

Workflows

Considering visualization as the beginning of production rather than an intermediate phase is a tenet of effective virtual production. By embracing visualization from the opening moments of a new project, creatives can be engaged much earlier and more collaboratively via easier interactivity and iteration. Visualization becomes the clear, common language uniting all of the disparate elements within a project.

Pitchvis

Pitchvis, as the name implies, often occurs before a project is officially greenlit. It's designed to gain stakeholder buy-in by demonstrating the intended look and feel of a project before a major investment has been committed. It has even been used to re-pitch projects in mid-production that may have been discontinued due to budgetary, creative, or other concerns. The film *The Call of the Wild* is one such example—after the project was halted, pitchvis put it back into production. (See the interview with director Christopher Sanders for more details on this project.)

Pitchvis, as a workflow, typically leans hardest on the engine because there may be very few existing assets from a project in its embryonic stage. Still, pitchvis can incorporate many other key visualization components such as VCam, remote collaboration, and asset conversion. With Unreal Engine designed as an end-to-end production platform, content developed during pitchvis can be repurposed throughout a project.

Previs

In the new, real-time paradigm, previs can now be thought of as the beginning of production. In cases where pitchvis hasn't been utilized, previs is the first chance for creatives to present and share specific imagery they have in mind for the production, and with assets that can be used throughout production. In the past, previs has been relegated to only a subset of the production, with perhaps the director working with a few artists to explore concepts in a static medium. Real-time previs offers a more fluid and interactive experience.

Because the potential quality of imagery is much better and the development time much shorter, more departments can be involved earlier, including production design, editorial, art direction, cinematography, and even acting in the form of performance capture. By providing more agility and agency to all departments earlier, the overall production can be more efficient and exploratory in its initial efforts, and at a much lower cost than the full production phase.

Images courtesy of The Third Floor, Inc. and © 2019 Marvel
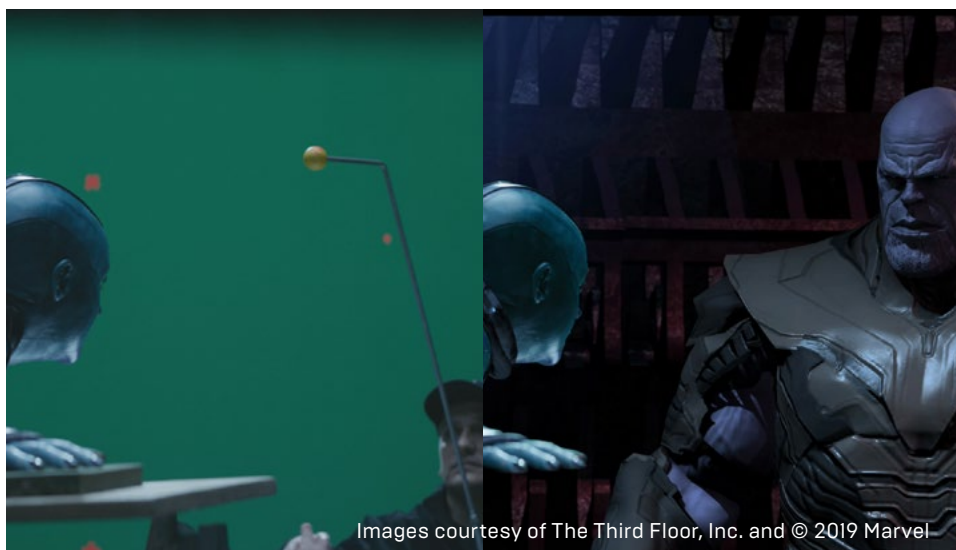
Techvis

Techvis is used to work out the precise technical requirements of practical and digital shots before committing to crew and equipment on the production day. Techvis can be used to explore the feasibility of shot designs within the confines of a specific location as well as blocking involving virtual elements. It can also be used to determine how much of a physical set is required versus digital set extensions. Finally, it is useful for working out safety considerations and mitigating risk.

Stuntvis

Stuntvis is techvis for physical stunt work and action design. Because Unreal Engine incorporates real-world physical simulation, high accuracy can be achieved in designing shots. Action designers can choreograph shots with precision, and get creative and continuity buy-in of stunts. With physically accurate stuntvis, stunt crews can rehearse and execute simulated shots, resulting in much higher efficiency during production, which can mean fewer shooting days. Stuntvis enables ever more spectacular stunt work while maintaining a high safety level for stunt personnel.

Postvis

Postvis combines incomplete shots from production with additional visualization. Visualization's goal is to provide a clear creative vision to all collaborators. Postvis provides the filmmakers' vision to the visual effects team, as well as a more accurate version of any unfinished shots for the editor as they assemble their edit.

Interview:
Visualization - Kris Wright and Hugh Macdonald

Kris Wright is the CEO and Hugh Macdonald is the Chief Technology Innovation Officer at Nviz in London. Nviz is a longtime visualization studio whose services include previs, techvis, stuntvis, postvis, simulcam, graphics, and final imagery. Nviz's credits include **Devs**, **Avenue 5**, **The Witcher**, **Solo**, **Life**, **Hugo**, and **The Dark Knight**.

How long have you been incorporating Unreal Engine into your work?

Hugh Macdonald: Unreal Engine has been in our previs pipeline for about three years and in the simulcam pipeline for the last year. Prior to that, we were using Ncam's own renderer, which uses MotionBuilder. We did a job last year that was heavily prevised in Unreal and we did simulcam on set with it, including facial motion capture of CG characters. We did postvis in Composure in Unreal Engine as well.

What led to your adopting Unreal Engine for virtual production?

Macdonald: It was a combination of having previs assets already existing in Unreal Engine plus the visual fidelity, the control that you get, and the need to do facial motion capture. We felt Unreal was the way to go for this project, because of Epic's film experience coming from people like Kim Libreri. Kim gets the visual effects world. Epic is a company that understands the different sectors and different challenges. Having a CTO who really knows our world inside out is really encouraging for what it could mean for the engine in the future.

What are you typically visualizing with simulcam?

Macdonald: Eighty percent of the time, it's environments. It might be creatures or vehicles in the background, but most of the time it's environments. The main benefit there is to give the camera operator and director the ability to get an understanding of what the shot's going to be like.

So you might be framing a character in the foreground and there's going to be a big CG building behind them. Without simulcam, you might cut off the top of the building or have to shrink the building in that one shot just to make it look right. The key is the ability for everyone on set to have an understanding of exactly what the shot will look like later, over and above the previs and the storyboards.

What kind of data do you need to make simulcam work?

Macdonald: We record all the camera data and tracking data, which includes the camera's location within the world. So you know in post where the camera was and how that syncs up with the animation that was being played

Image courtesy of Nviz
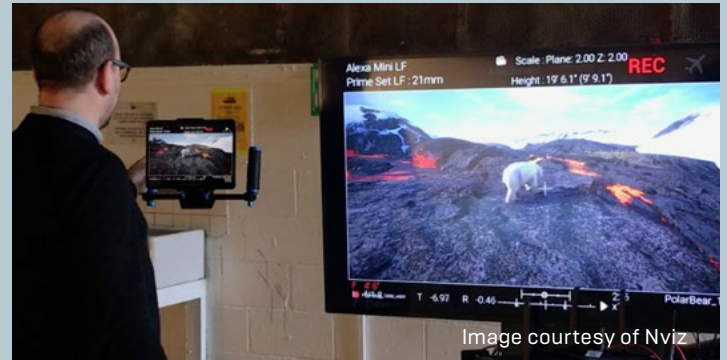
back at the time to the original footage. We also generate visual effects dailies as slap comps of what was filmed with the CG that was rendered.

How do you track the set itself?

Macdonald: It doesn't require any LiDAR or pre-scanning. We use Ncam, which builds a point cloud on the fly. Then you can adjust the position of the real world within the virtual world to make sure that everything lines up with the CG. It's a slightly more grungy point cloud than you might get from LiDAR, but it's good enough to get the line-up.

On a recent project, we had a single compositor who would get the CG backgrounds from the on-set team and the plates from editorial and slap them together in Nuke. Generally, he was staying on top of all the selects that editorial wanted every day, to give a slightly better quality picture.

Kris Wright: And because it's quite a low-cost postvis, it was invaluable for editorial. Some of that postvis stayed in the cut almost until the final turnover. So it was a way to downstream that data and workflow to help the editorial process, it wasn't just about on-set visualization.

How does switching lenses affect simulcam?

Macdonald: With Ncam, the lens calibration process will get all the distortion and field of view over the full zoom and focus range including any breathing. If you switch between lenses, it will pick up whatever settings it needs to for that lens. If a new lens is brought in by the production, then we need about twenty minutes to calibrate it.

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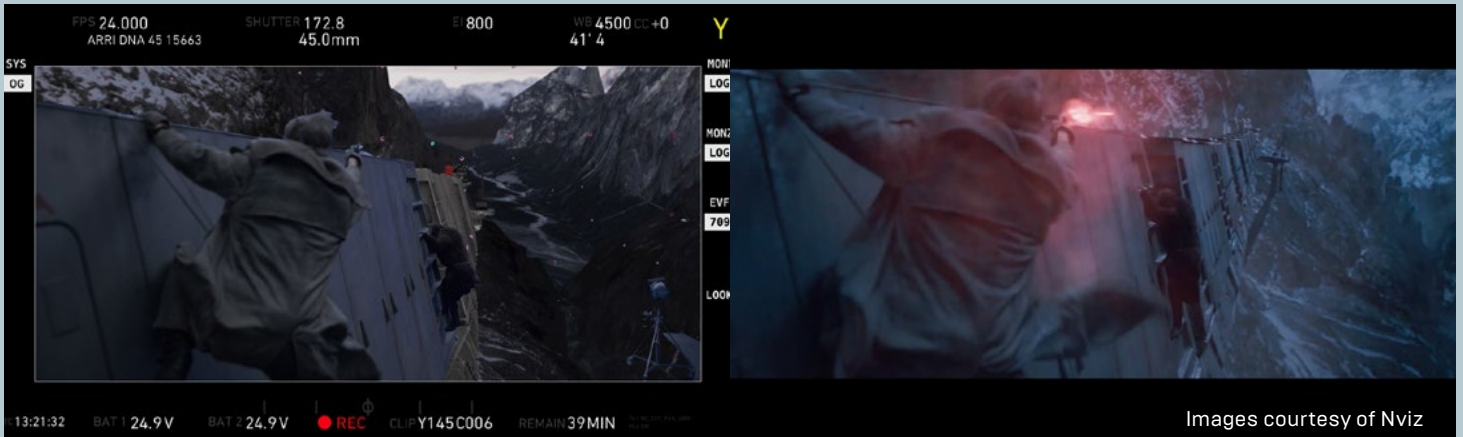
Images courtesy of Nviz

How has your workflow adapted to the increased need for remote collaboration?

Macdonald: We currently have the ability for a camera operator or a DP or director to have an iPad wherever they're located, but have all the hardware running a session in our office. You can have a virtual camera system tech controlling the system from wherever they are. Then you can have a number of other people watching the session and discussing the set at the same time.

We see remote collaboration as very important even without everything going on with the current lockdowns, for example, in a scenario where the clients can't get to our office because they're on a shoot elsewhere and it's too much hassle. To be able to do this remotely, to have multiple other people—whether it's the effects supervisor, previs supervisor, editor, or anyone else— watching the session and able to comment on it and see what's going on with an understanding for it, this gives us much more flexibility.

Wright: The current solutions that I've seen are people on a Zoom call or Google Hangouts saying, "Oh, can you move the camera a bit here? And now there." We wanted to iterate on from that. Everybody has an iPad, which they can now shoot all visualization and previs with. We try to keep it as low-footprint as possible and software-based. Literally, you go on a phone, we'll put on the software and this is what you need to download. Everybody else can view it in a virtual video village.

Where do you see your workflows with Unreal Engine evolving in the future?

Macdonald: The visual fidelity coming in UE5 is going to be amazing and a massive leap forward. More people are going to embrace in-camera visual effects like those in *The Mandalorian*. It's going to become more accessible to more productions. We're going to start seeing a lot more dramas and period pieces using the technology.

There are going to be a lot more live events productions using it, such as concerts. What's been announced is about the visual fidelity of the lighting and the geometry. Unreal Engine is going to get used more and more for seamless effects.

Wright: One of the really exciting things is the application base. We find the virtual art departments now embracing this, and production designers are now using VCam to show their sets before they even go to previs. I've even heard of grips and gaffers bringing people into virtual sessions to move assets around. Epic's really doing this right, and has seen the bigger picture: not only the image fidelity, but also how this tool, because of its real-time aspect and iterative processing, can help decision-making across all parts of filmmaking.

Interview:
Pitchvis - Christopher Sanders

Christopher Sanders' credits as a director include **Lilo & Stitch**, **How to Train Your Dragon**, and **The Call of the Wild**. He also worked as a character designer, storyboard artist, and visual development artist for several Disney animated features, including **Beauty and the Beast**, **Aladdin**, **The Lion King**, and **Mulan**. On his live-action directing debut, **The Call of the Wild**, Sanders used groundbreaking previs and performance capture techniques powered by Fox VFX Lab to create Buck, a completely CG-animated dog.

How does directing performance capture within a live-action film compare to directing a fully animated feature?

Christopher Sanders: I started in very traditional animation. When I came to Disney, we were stepping into the CAPS system, which was computer ink and paint. Up to that point, there were still artists drawing, and cleaning up drawings, by pencil. The only difference between that and cel painting was that those drawings were being scanned and colored in a computer. So, I've gone all the way from traditional paint on hand-drawn cels to computerized painting on scanned drawings to fully CG models. It's been incredible for me, because we have so many new tools.

The basics have remained the same. It's all about character, movement, and story. On something like *The Call of the Wild*, there are no voices. On *The Lion King*, you've all got these beautiful voices, and you're doing the acting twice. You have actors come in, and you're directing those actors. Then you take those voices into an animation department and act it for a second time.

The Call of the Wild was one of the more subtle, interesting, and elusive projects I've ever worked on. Within a few seconds or minutes of watching one of these creatures, as beautifully as they were animated, you could tell these are not real dogs. I knew from the beginning that we could never fool anyone's eyes, which wasn't the point. The real goal was to present characters believable enough for people to invest in and fall in love with.

There was never a set rule as to how anthropomorphic they should be. We always played it by ear. In general, when Buck and the other dogs were in the presence of a human being, we throttled back and made them more realistic. But, when Buck was in a purely animal environment with wolves or with the other dogs, we could push the throttle more. We could put the pedal to the floor and go much more anthropomorphic.

We never actually did any motion capture for Buck's performance. Humans are too different physiologically from dogs, so their movements don't translate. Instead of motion capture, we did performance reference with Terry Notary. Terry stood in for Buck when we were shooting, giving the actors someone to act with, perfect timing with, and block out a physical space we could later drop the animated Buck into. It was critical because our humans needed something to interact with. He gave us rough timings.

There's a scene where Harrison Ford as Thornton is out in front of his cabin in the wilderness and out comes Buck. Buck's holding Thornton's hat, and he wants to play. So, Thornton gets up, and he starts to chase Buck. The final hat is exactly where it was in Terry's mouth, and Terry was doing all the acting, running, moving, and dodging. He was hard to catch, and Harrison was able to chase him. Now we can take that rough acting and timing, and we can put our animated Buck into place.

Were you able to previs the entire film?

Sanders: In feature animation, we do storyboards, which are sometimes very elaborate series of drawings. Then we add voices and sound to them. We make a one-to-one scale model of the film. If the film is an hour and a half, we have an hour-and-a-half story reel. Eventually, a shot done with drawings is removed, and a piece of rough animation is dropped in its place. That animation will go through iterations and will be updated and improved until it is a final, lit shot.

We did the same thing with the previs. It allowed us to look at the film to plan our shots, and even make story changes. That's one of the most valuable things of all. You can look at the story ahead of time. I can't tell you how many times we were like, "Oh, we're missing something here, we need to add this moment."

With previs, you're able to save a lot of work and money. Otherwise, you'd shoot and then have to throw things out. It was a wonderful learning curve that everyone was going through with Buck as a character. Previs is like a story reel for us, and I don't think you can have too much of it beforehand; the more, the better.

> **"**
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Does having a tool working in real time make exploring concepts easier?

Sanders: The value is, you get a visual out of it quickly that you can use for timing. It's the discussion. Sometimes in talking with the artists, revelations happen, and you learn things. The story is always evolving and coming into focus. The main thing I do as a director is attend to the story.

Movies and stories are more sculptural and dimensional than you would think. There's a depth and nuance to them. There is a visual component, and then there's the emotional component. You're attending to the emotional wavelengths while you're also attending to the visuals.

How do you reconcile the degree of control you have in previs versus the unpredictability of a live-action set?

Sanders: The first thing I learned is that live-action production is all about the prep. If you could scrunch a whole movie production down into a day, from the stroke of midnight until about maybe 8 PM is all prep. Then, from 8 PM to 10 PM, you're shooting. After that, it's all editing.

When you ultimately walk onto the set, that's the moment of truth. There's always going to be negotiation, adaptation. It all went smoothly, and there was only one moment that I felt frustrated. I had envisioned this moment where Buck's sled was leaving town and Harrison was going to almost miss the mail.

When we got on set, we realized that the blocking wasn't going to work. So, now suddenly, the sled had to stop before it crossed Harrison. I felt that without the cross, the scene wouldn't work, but Harrison didn't want the sled to pass him. I was trying to negotiate something that told the audience that Harrison was late and missed the mail, and yet the sled was compelled to stop before it passed up Harrison. It didn't make sense to me, since I'd seen it in my head for many months the other way around.

Our cinematographer, Janusz Kamiński, came over to me and said, "You compromise the moment you walk on a set. It's going to be fine, and it's going to work." So, we stopped the sled before it passed Harrison, but negotiated a very short walk for Buck, only about six feet, and preserved the most important thing, which was the critical transfer of the letter by our hero dog. Visually, it worked, and Janusz was right about finding a way to save the moment. It was more like Harrison saw it, and it played beautifully on screen.

There are harrowing moments when you shoot live action, but there's magic to it as well. The wonder of it for somebody who comes from animation is that most of it is complete by the end of the day. In animation, things stretch on for years instead of just being able to say, "Oh, it's in the camera—it's done."

Interview:
Visualization - Dane Smith

Dane Smith is Vice President of longtime visualization studio The Third Floor. His credits include **The Mandalorian**, **Game of Thrones**, and **Avengers: Endgame**.

How has visualization and its role within production evolved?

Dane Smith: For years, digital visualization has offered significant benefits for proving ideas and approaches, whether in the early phases as previs or pitchvis, during prep or production using techvis, or visualizing with postvis following the shoot. What started as a solution for selected challenges is now widely relied upon to roadmap entire projects creatively and technically, sometimes shot by shot. 3D visualization has become standard to many workflows, and something to which budgets and resources are specifically reserved.

As time went by, we started to see these very ambitious films and major blockbusters spend more time in preparation, focused on what would need to happen on stage, and how that could be optimized. This has led to expanded use of visualization, not just to help define what might happen action-wise from point A to point B but to inform the specific shooting layouts and combinations of equipment used on the day. More than that, the 3D assets, environments, and pre-animation that had been built during previs or techvis could be used to directly support the production work on stage or set.

The motion of a CG dragon, already blocked in a previs file, could be played back to the practical buck rig. The choreography and timing approved by the creative team in the 3D simulation of a complex shot could be reproduced accurately and reliably "on the day" from that file. From helping drive virtual eyelines to seeing characters or backgrounds displayed live on set or in virtual or augmented reality, visualization has become essential throughout both development and production, including virtual production. Through postvis, where shots are rapidly prototyped using the actual filmed plates, visualization helps depict and inform the vision deep into final finishing and delivery.

So, we've seen visualization become an enabler across the entire process, not just in the beginning. And the capabilities and value that visualization provides for creative iteration and technical innovation are further accelerated through the speed and immediacy of pipelines that can work in real time.

How has the current need for remote collaboration affected projects?

Smith: The pandemic has accelerated interest in virtual approaches and methods that facilitate social distancing and reduce the carbon footprint. People are reluctant to travel. One of the advantages of virtual production is that parallel processes can happen simultaneously in different locations. Globalization of the filmmaking pipeline provides benefits and challenges that virtual production can capitalize on. Developments like this were already happening before the current state of the world, and the pandemic has accelerated these trends and is helping drive interest in innovation.

What visualization teams do by nature is already virtually based. They construct shots and environments in the virtual sense every day to represent ideas as those ideas move towards execution and completion. Visualization artists inform plans and shoots before anyone builds or films the content for real. And they routinely work remotely from a studio or facility home base.

The expansion of this more classic virtual sandbox is extremely relevant in this moment, and for the future. Now, we can take imagery of a real location or the design for a proposed set and turn that into an immersive environment that the director, DP, and production crew can explore and frame for, individually and from anywhere.

The results of any one person's exploration can be shared with others, and sets and physical locations can be visited as often as needed without leaving the house. The capabilities of real-time tools, running on the desktop, are already being used for applications like virtual scouting and virtual camera blocking and will provide some important x-factors.

What are some of the key benefits and challenges of a real-time pipeline?

Smith: One benefit of this technology platform is that content creators can see a version of their work quickly, and immediately see the impact of their decisions. And that early iteration is much closer to the final vision.

Image copyright HBO and courtesy of The Third Floor, Inc.

But more importantly, you can build consensus and clarity around creative goals, which inevitably adds to production value.

Through now widely adopted techniques like previs, we're able to very effectively communicate the original vision to stakeholders, including department heads, vendors, and crew. A challenge for realizing the vision through real-time workflows and virtual production is fielding the team with qualified people who can execute a clearly defined creative and technical goal.

In traditional production and post-production workflows, each phase's demands and turnarounds are such that shots may deviate from the original intent as they evolve across the process. In real-time production scenarios, the risk of compromise is greatly reduced.

Once you've been invited into that world, it's tough to accept anything less. And to drive all of that, the talent pool is needing to expand and evolve as well.

What would you recommend a person interested in a career in visualization to study?

Smith: I'm going on ten years of teaching at the Gnomon School of Visual Effects, and I've watched the goals of students shift from film and television as their desired focus to gaming and, most recently, real-time content creation. This new discipline requires understanding how to create and ingest assets into an engine, driving visual content in real-time. There's a degree of programming and engineering required that wasn't asked of many artists

before. In a way, we're back to the earlier version of the visual effects ecosystem, where a greater emphasis on programming is useful.

So those skills are very different than, say, the skills of a traditional VFX artist. This desire to create in real-time is empowering content creators to iterate. And in traditional visual effects, with the emphasis on post-production, you may not have the same degree of flexibility that virtual production provides.

How many of your projects use Unreal Engine and real-time methods versus more traditional tools?

Smith: At The Third Floor, we complete approximately 100 projects a year. A half-decade ago, we had a single project deeply invested in using this technology. Now a majority of our productions are seriously exploring working in game engine and the virtual production toolset. After that first project, the process became more agile. Our talent pool grew, and costs were reduced. Half of the productions coming in the door at that point would ask about game engines.

Still, many would retreat—mainly because they realized they would have to have entered the process earlier or made decisions differently going into the job. But client exposure and education have continued to build, and a growing subset of crew that has been exposed to virtual production has created greater demand.

Is real-time as big a game-changer for filmmaking as CG animation or digital cameras?

Smith: I think it's bigger because we're at an all-time high demand for content, partly because of COVID-19. The spectrum of projects that can use this technology runs the gamut. It's democratized production in a way that seems more rapid than earlier digital milestones.

The transition from film to digital was a little slower, and the early adopters were in that game because of cost efficiencies and speed. Real-time is happening in both camps at the same time. The high-end content producers want it because of the beautiful results, and the more budget-conscious productions want it because their menu of options is larger.

In-Camera VFX

In-camera visual effects are among the most exciting and sought-after virtual production techniques. These can be broken down into two categories: live compositing and live LED wall cinematography.

In live compositing, physical objects are photographed and composited with virtual elements in real time. Objects are separated via traditional green/blue compositing or via depth sensors. In the past, in-camera effects could be created via front or rear-screen projection. Today, LED wall cinematography is at the cutting edge of virtual production, where real-time virtual elements are combined optically in camera via LED screens arranged in volumes.

In this section, we'll highlight the key hardware and workflow components for in-camera visual effects. We'll also look at the physical and technological factors impacting shot success. Finally, in our interviews, we'll speak to the creative team behind *The Mandalorian*, one of the most high-profile and successful LED wall applications to date.

Components

Unreal Engine

Unreal Engine plays a crucial role in in-camera visual effects by generating final-quality environments, characters, objects, lighting, and more in real time. Unreal Engine also incorporates live camera tracking to accurately reproduce the physical camera's corresponding perspective on the display as the camera moves. The ability to calculate perspective in real time makes live LED wall cinematography with a freely moving camera possible.

Hardware Overview

A key component to successful LED wall cinematography is LED display technology. LED walls are comprised of interlocking LED panels or modules combined into a large virtual screen via video processing hardware and software. Systems integrators such as Lux Machina (see our interview with Lux's Philip Galler) specialize in the unique hardware and signal flow requirements for in-camera VFX. They work alongside hardware manufacturers and software developers to source the optimal display technologies and video processing requirements for each production. While LED display technology is the solution we're focusing on in this guide, there are also scenarios where projection is preferred.

Video I/O hardware is another critical component to connect cameras, monitors, and LED displays to the computers driving them. Unreal Engine supports 4K, 8K, and even 12K video I/O hardware from Blackmagic Design and AJA. Additional plugins are available for other hardware brands and protocols such as NDI.

In addition to the display and video I/O hardware, powerful computers are required to generate and output real-time imagery from Unreal Engine. The software is designed to run across a variety of computers. For optimum performance, especially on a large LED volume, multiple workstation/server class systems are typically required. High-end CPUs and GPUs, large amounts of RAM, and sufficient room for expansion cards such as video I/O and other related peripherals are also critical.

The Brain Bar

The brain bar is a nickname for the nerve center of a virtual production.
Think of it as an air traffic control center or TV control room for real-time image display, camera tracking, LED output, real-time color grading / compositing, and related operations. Typical personnel within a brain bar include the main Unreal Engine artist, camera tracking experts, display / video I/O experts, content loaders, compositors, IT experts, network specialists, and LED screen technicians. The brain bar can be set up on-site or offstage in an adjoining building, within an OB [outside broadcasting] van, or entirely remotely, which is highly advantageous for social distancing requirements.

Essential elements within the brain bar include powerful desktop computers, video I/O and processing, and networking infrastructure. Though off-the-shelf components can often be integrated, specific productions may require some customization of software and hardware. Finally, various scripts can be used to control all connected machines from a unified interface. To learn more, see these specific hardware recommendations.

On-Set Roles

The combination of real-time engine technology with live video production creates several on-set roles that we don't see in traditional production. Some of these new roles might not appear in the credits because real-time, in-camera visual effects are relatively new to the movie business. Some should be considered as areas of responsibility and tasks instead of specific job titles. Primary among these new roles is that of the **virtual production supervisor.** This role is similar to a traditional visual effects supervisor but includes real-time on-set duties for in-camera visual effects. The visual effects supervisor oversees the virtual production supervisor and has ultimate responsibility for

both the wall content and the more traditional visual effects shots. (See our interview with Clint Spillers for more information about the virtual production supervisor role.)

Virtual camera supervision includes camera tracking and streaming to Unreal Engine via Live Link integration. **Content supervision** includes the brain bar, and making sure the current load has all its components loaded and functioning. **Virtual production technical direction** includes the preparation of upcoming scenes for the engine supervisors and any additional requirements for scenes as needed.

Content loading encompasses the conveyance of real-time scenes as they exist in Unreal Engine onto the screen itself in the proper orientation and scale. The scene content projected into the LED volume is often referred to as a *load*.

Another new on-set task is live compositing, which is often combined with virtual set color correction. This task includes specific video I/O tasks such as matching the color tint of a particular aspect of a load to a corresponding live-action set element or layering additional components into a scene. The work often involves traditional compositing software such as DaVinci Resolve and Adobe Photoshop. Several new assistant roles also evolve out of the specific needs of each production. (See our interview with Charmaine Chan for more details about live compositing.)

Another critical point about crewing: the specific roles and responsibilities may vary based on each crew member's experience, and expertise, and on the size and scope of the production. The most important consideration is that all of these demands are addressed in some form when assembling a VP team.

Multi-User Capabilities

One of Unreal Engine's key strengths, especially in an era of physical distancing, is its multi-user abilities. Because the engine is designed to create multi-user games within a multi-user development environment, a lot of collaboration features are baked in. This has plenty of benefits for in-camera visual effects workflows.

Virtual scouting is a form of remote collaboration that benefits virtual production. You approach a virtual scout just like a real scout, surveying a location to discover your favorite areas and shots, deciding where set dressing and location enhancement may be required.

"

Unreal Engine has a feature called Multi-User Editing where we can have multiple computers working on the same Unreal project. It's like a big *Fortnite* game, but within the full Unreal Engine.

"

Matt Workman
Cinematographer and Founder
Cinematography Database

With virtual scouting, you also gain superhuman abilities to instantly teleport to any location on the site, changing camera lenses on the fly to quickly establish potential camera setups for your production, and with the bonus of accomplishing the scout remotely and safely. All your camera/lens combinations from the virtual scout can easily be labeled and saved within the 3D scene for future reference.

Display Technologies

Because LED wall workflows photograph the display directly, the display technology must be taken into careful consideration. The nDisplay plugin synchronizes a scene across multiple displays via networked computers and determines the overall scene rendering. nDisplay sends the correct section of the Unreal Engine scene to each render node and its connected display. It handles all of the render distribution, pixel mapping, synchronization, genlock, timecode, asset balancing, and geometry warping to create an image that looks correct to the eye and the camera, regardless of the size or shape of the individual displays. For more information on how nDisplay works, see this white paper.

The volume used in the production of *The Mandalorian* and similar LED wall productions is comprised of a matrix of individual LED modules. Depending on the specific model, these panels can be either rigid or flexible for curved surfaces. Via the use of trusses and other physical supports, a nearly limitless variety of geometric configurations is possible. Generally, the more enveloping a volume is—for example, encompassing a front screen with side panels, a ceiling, and panels behind the camera—the higher the level of interactive lighting and realistic reflection.

LED module arrangements are well suited for large-scale volumes but can present issues for smaller volumes. The physical pixel density of the screens prohibits a camera from focusing directly on the wall itself because of the moiré effect. Moiré occurs when there is insufficient resolution in the source image relative to the camera sensor, resulting in a visible interference pattern. Because LED modules contain pixel-sized LED lights, focusing directly on a screen will cause moiré. This varies based on the number of LEDs the camera sees. Generally speaking, the higher the number of LEDs per camera sensor pixel, the less of a chance of moiré. For smaller-scale, closer-to-camera applications, micro LED and OLED monitors are potential alternatives.

For example, the HBO series *Run* created the exterior views for a static train car set using 83-inch OLED monitors outside each window. (Learn more about *Run* in our interview with Sam Nicholson, ASC.) Because the pixel density of
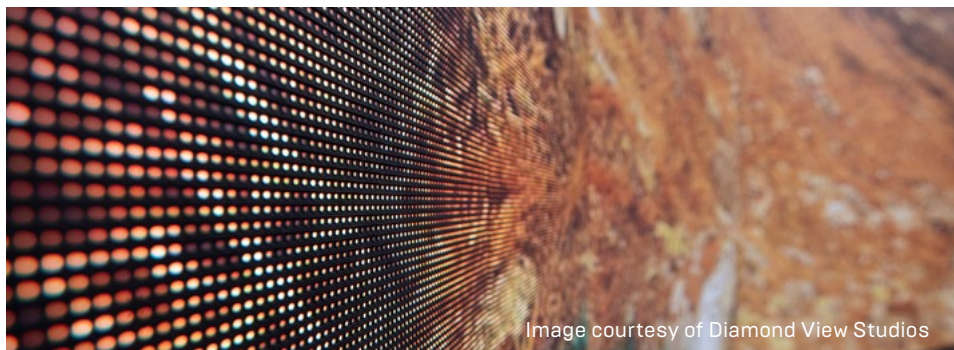
Image courtesy of Diamond View Studios

OLED monitors is much higher than that of LED modules, the camera could be much closer to the monitors without revealing any undesirable moiré patterns.

Traditional laser and LED projectors can also be used for in-camera visual effects. These systems were among the first to be used for in-camera effects before LED wall technology had sufficiently matured. Productions such as *First Man* and *Solo: A Star Wars Story* used projectors with large, curved screens for in-camera effects shots, although the footage was typically pre-rendered and not real-time.

The onscreen image of these various display technologies, including LED walls, micro LED/OLED monitors, and traditional projectors, is the most visible part of the equation. Another critical aspect is the reference lighting itself, which significantly enhances the realism of the shot. It can be derived as reflective and emissive lighting from the display technology.

Additional lighting can be created via larger pitch / offscreen / floating LED panels and by movie lights optionally connected to scenes via DMX control. Projectors can even be used as special animated lighting sources like moving shadows.

Camera

Professional camera equipment with high-quality optics is a vital part of in-camera visual effects. Because moiré patterns can result from having an LED wall in sharp focus, a shallower depth of field helps combat this. Large-format image sensors and cinema lenses are best suited for guaranteeing a sufficiently shallow depth of field.

Careful synchronization between the camera's shutter and the LED wall's refresh rate is another critical consideration, otherwise the resulting image can have visible scan lines and banding.

Finally, extra care must be taken to ensure that the linear scene color and luminance values in the virtual scene are properly represented on the LED wall. The content on the wall should appear as the real world would, with no additional look applied, since that will be applied within the production camera. Unreal Engine supports OpenColorIO configurations to enable users to apply the necessary transforms for color management during asset approval and final shooting.

Tracking

Real-time tracking is a truly unique aspect of modern virtual production. The concept of live LED wall cinematography is very similar to the use of rear projection, dating back to the early days of filmmaking. Camera tracking combined with real-time rendering allows the perspective shift or parallax in the LED wall to match the movement of the camera, thus delivering imagery that, to the camera, appears identical to a real, three-dimensional location.

Unreal Engine's Live Link plugin connects various external sources directly into the engine. It can be used to connect a physical camera in the real world to a virtual camera within Unreal Engine. The physical camera need not be an actual camera; it could simply be a camera proxy, like a box, designed to convey real-world movement into virtual cinematography as was done extensively on *The Lion King*.

Live Link can also connect to other items in Unreal Engine, giving physical control to virtual objects. It can be used to control lights, characters, props, and more.

Tracking Systems

Tracking systems can be divided into inertial, optical, and encoder-based solutions. Sensor-based solutions range from basic solutions like the HTC Vive puck, which is tracked via lighthouses (modules that use laser scanning to locate the puck) and an IMU (inertial measurement unit) initially designed for virtual reality gaming headsets, to the more sophisticated tracking solutions used for *The Mandalorian*.

Outside-in optical tracking systems employ an array of stationary infrared cameras surrounding a volume. The cameras look for designated markers within the volume and calculate their position in 3D space by comparing the overlap seen by multiple cameras. Examples of outside-in solutions include OptiTrack, Vicon, and BlackTrax.

Another form of optical tracking is inside-out, feature-based optical tracking. This involves a computer vision and time-of-flight depth-sensing array placed on the camera that generates a 3D point cloud of the surrounding environment and calculates the camera's position in relation to that reference using machine learning. The technology is similar to Xbox's Kinect gaming system. Ncam is one of the best-known examples of feature-based optical tracking. It has the advantage of efficiency by working without markers, tracking lighthouses, or other preset references.

Marker-based optical tracking includes an infrared sensor placed on the camera, which looks for a pattern of markers. Examples of optical tracking systems using markers include Stype, MoSys and Lightcraft Previzion. These systems generally work well in large, self-contained stages but can be more challenging to deploy outdoors or in situations where placing markers is not practical.

Encoder-based tracking systems use magnetic and/or optical encoders to communicate the movements of tripod heads, dolly wheels, crane fulcrums, and other camera support devices and determine the camera's relative position and motion. Examples of integrated encoder solutions include StypeKit, Egripment, and Technocrane. Custom solutions are also possible with a variety of components. These systems often require more initial setup and calibration to relate the camera's position relative to the virtual world but also offer increased precision.

Lights, objects, and actors can also be tracked for various purposes. For example, an interactive stage light can be connected to a tracking sensor so that its physical position is correlated one-to-one with its virtual counterpart and connected to DMX lighting control within Unreal Engine. As you move the physical light, it samples and matches the virtual environment to provide a greater degree of integration between the physical and virtual.

Tracking actors relative to the camera also has many uses. For example, during *The Mandalorian* production, some shots were determined to be too complex or challenging to achieve entirely in-camera on the LED wall. In this case, the filmmakers tracked the actors' positions and placed green screen halos directly behind them, closely tracked to their movements while keeping the rest of the Unreal Engine scene in the periphery of the screen. It gave the filmmakers the flexibility of a clean green screen for post compositing, while still preserving the interactive lighting from the non-green-screen portion of the frame.

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With Ncam, the lens calibration process will get all the distortion and field of view over the full zoom and focus range including any breathing.

„

Hugh Macdonald
Chief Technology Innovation Officer
Nviz

Virtual Production Gear

This table includes some of the key infrastructure needed to produce in-camera visual effects and other virtual production workflows.

Stage and virtual production	
LED Display Wall	LED modules, processors, rigging, high-end workstations
Brain Bar	High-end workstations, video assist
Tracking	Inertial, optical, and encoder-based solutions
Networking Infrastructure	Used for production and editorial to move media/loads. For data-intensive workflows like mocap, an isolated network with high bandwidth switches is needed
Sync/Timecode	Genlock and time code hardware required to keep all acquired data in sync and lined up
Lens Data	Tracking of focus, iris, and zoom to determine lens distortion, field of view, camera nodal point

VAD	
Workstations	Windows workstations as per artist demands
VCam	Virtual camera system
VR system	Virtual scouting system

Workflows

Live compositing and LED wall cinematography are two major workflows for in-camera visual effects. Live compositing leverages much of the traditional compositing workflows. It adds live, real-time, perspective-matching imagery to deliver effects shots that the camera operators and crew can see and react to during a take.

The Jungle Book is a recent example of a live compositing workflow. One downside is that the actors are still on the green screen or blue screen stage with little visual feedback and immersion. The lighting is also more challenging due to the green or blue screen spill, and doesn't include an LED wall's emissive and reflective qualities.

LED wall cinematography takes on-set virtual production and live compositing significant steps forward by replacing both the green screen and the compositing with an LED wall. Benefits of the LED wall include greater immersion for the actors and crew, and more accurate, believable cinematography due to the emissive and reflected light coming from the LED wall itself.

Live Compositing

Live compositing is a form of real-time visual effects where tracked, live-action green screen cinematography is composited live with perspective-matched, computer-generated imagery. Many off-the-shelf live compositing solutions exist for use with Unreal Engine. Zero Density's Reality Engine and The Future Group's Pixotope are two examples of live compositing solutions that combine Unreal Engine scenery with green screen cinematography. Unreal Engine itself also offers Composure, a highly capable live compositing solution.

Live compositing can also be complementary to LED wall cinematography. A production may determine a specific shot is too complicated or is not ready to be captured in camera on the day. In this case, the camera frustum can be turned green to composite provisional footage into the camera viewfinder and monitor. The interactive lighting from the area outside of the frustum still enhances the subjects. It's also much easier to composite in post, due to the reduced green screen spill.

Image courtesy of Anvil

LED Wall Workflow

LED wall cinematography is a combination of traditional live-action and real-time virtual production techniques including camera tracking, real-time virtual scene output, physical set dressing, and traditional movie lighting. Although the LED walls themselves produce significant lighting, movie lighting still has its place in effects that LED walls alone can't reliably produce, such as hard sources like the sun. (See our interview with Greig Fraser, ASC for more of the specifics on how cinematography and lighting interact on an LED wall-based virtual production.)

The key to successful LED wall cinematography is preparing real-time assets, just as you would a real location or a physical set before shooting. The assets should also be optimized for the volume's specific performance characteristics and any cinematographic requirements such as high frame rate. They should be thoroughly vetted and approved by all the key department heads and stakeholders, just as they would vet a real location.

The brain bar is the mission control center for the LED volume. Its personnel are in charge of staging and displaying all content, facilitating external remote control, and capturing production data including scenes, takes, and related elements. External remote control is enabled through a REST API, where crew members outside the brain bar can remotely manipulate imagery via tablets and other devices. Careful production data tracking is critical to ensuring everything remains organized and readily accessible throughout production and post-production.

Factors Affecting In-Camera Success

Many factors affect a successful LED wall in-camera shot. The size of the volume and how close the scene is to the LED wall play a role. Pixel density is another key consideration—the screen should be of sufficiently high resolution to avoid moiré patterns, with a 2.8 mm pitch generally considered as the minimum viable density for in-camera content. Moiré can also be mitigated optically via lenses with very shallow depth of field to keep the screen out of focus. The resolution of the assets to be displayed on screen should be carefully considered to avoid any visible seams or other resolution artifacts.

The viewing frustum is another important aspect of in-camera visual effects. The frustum is the region on the LED wall representing the camera's field of view. When displaying to an LED wall, Unreal Engine renders the frustum at the highest possible quality, while the area outside of the viewing frustum is typically displayed at a reduced resolution. This helps deliver the maximum

visual quality to the camera while still providing interactive lighting and reflections from the non-frustum area. The frustum is often rendered larger than the camera's field of view to account for camera movement faster than that of the frustum, due to any latency of the virtual camera location tracking and rendering relative to the physical camera.

Image courtesy of Diamond View Studios

Latency is a critical consideration for successful in-camera visual effects. Latency in this case generally refers to the delay between the production camera movement and the virtual camera rendering on the screen. If the camera movement and screen perspective aren't synchronized closely enough, it can cause a visible lag between the camera's movement and the frustum. Various factors such as rendering speed and synchronization, image processing, networking hardware, video I/O hardware, and LED matrix specifications all impact latency. Minimizing the total system latency while maintaining stability is essential to producing the best possible production experience.

LED wall cinematography is technically complex, but the rewards for successful execution outweigh the challenges. A thorough understanding of the technical and artistic aspects, along with plenty of preparation, is crucial to making it work. As the interviews in this section attest, with a skilled and production-savvy team, LED wall virtual production is a game changer.

Interview
In-Camera VFX - Jon Favreau

Writer, director, producer, and actor Jon Favreau began his career as an actor in indie films like **Swingers**. He later became a highly successful director of films including **Elf**, **Zathura**, **Iron Man**, **Iron Man 2**, **The Jungle Book**, and **The Lion King**. A longtime proponent of virtual production techniques, Favreau created, wrote, and executive produced **The Mandalorian**.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

What was your motivation to push virtual production forward and how did you know it would work?

Jon Favreau: Whenever there's a meaningful innovation, it has a lot of different contributing factors. I had a feeling there was a better way to do visual effects, especially set extensions. Every time I set out to do a film, there's often quantum leaps taking place in the meantime. You want to check in with the smartest people in the business and learn about new breakthroughs.

Elf was all in-camera and there was some blue screen in *Zathura,* but mainly for set extensions. We were working mostly with practical sets on gimbals and motion-control miniature work. For *Iron Man*, I was more open-minded about CGI. I don't think anybody ever set out to make a bad CG movie, it just turns out that way sometimes. Working with ILM on *Iron Man* really made me trust them with hard surfaces and I started to buy the photorealism of certain things in CG.

By the time we did *Iron Man 2*, I was getting frustrated with the fact that we were building these big sets with blue screen and then building everything in CG as well. It felt like a lot of redundancy. One of the ways to save money and be more efficient would be to not pay for things twice.

Later, I was developing a movie that never got made called *Magic Kingdom*, which was basically about Disneyland coming to life, with a lot of fantasy CG elements. I met

with Robert Legato to pick his brain after he had worked on *Hugo* and done such impressive set extensions. The question became how small of a footprint could you have in production. Those conversations eventually led to us working together on *The Jungle Book*.

On *The Jungle Book*, we did a lot of blue screens and very small sets. Through using simulcam, we figured out a way for the camera operator to have a monitor with a live composite of what the actual set would look like. The problem was, there was a lot of latency, so the operators would never actually look at the composite image while they were operating.

The other issue was that it took forever to move the blue screens around and relight. We had limited hours and school breaks because our main actor was a kid. It also took a lot of effort to make the performance feel immediate because you were in this blue box looking at references for eye lines, like tennis balls. So I kept talking to other crew members about how we could build a better stage.

One day Andy Jones, the lead animator who also had been working on a VR project called *The Blue*, was going over to a VR startup in Venice. I asked if I could tag along and I got to experience VR with the Vive headset. It was really exciting and I got to thinking—this works so much better than the expensive, photographic motion capture gear.

Images courtesy of Walt Disney Studios

So for *The Lion King*, we built a virtual production suite with MPC and Magnopus, and Disney was our partner. We created an environment like we did for *The Jungle Book,* but completely virtual. We took the best of animation and the best of production and developed a pipeline where I got to direct as I was used to in live-action productions.

While we were in post on *The Lion King*, I pitched *The Mandalorian* to Kathy Kennedy at Lucasfilm and she was into it. That's when we started to look at the combination of what we had done on *The Lion King* and what we had done on *The Jungle Book*. By then there was a lot of murmuring about real-time rendering, and Epic had done some *Star Wars* demos using Unreal Engine. They were right on the verge of ray tracing, and the hard surfaces were really looking good.

One of the great things about using Unreal Engine for filmmaking is that it's not incumbent upon the filmmakers to justify the research expense. Since Epic makes the

majority of their revenue through their games, we're really piggybacking on innovations that are monetized through gaming. So, to use those tools in an industrial capacity and also help Epic do research for their next generation of cinematic tools was a really great partnership.

We started with a big roundtable full of all of these people who had a slightly different idea of where everything was going, like Kim Libreri who had worked with ILM. We had people from Magnopus. Rob Legato was also consulting on this and saw a lot of potential. There was also Rob Bredow and Richard Bluff from ILM and people from my company, Golem Creations.

At first, the idea was to use LED screens for interactive light and very accurate, quick-to-set-up green screens. You wouldn't have to light the green and it would be perfect photographic green. Then, we started to wonder if we could get final pixel with the screens. We were going to use anamorphic lenses with more falloff focus-wise.

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These inexpensive technologies democratize the learning process for filmmaking, and you don't have to wait for a budget or permission.

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By the time we actually filmed Season 1, we were experimenting with creating content for those environments that you could do in camera. It's just gotten better and better. And now with all of the limitations in filming and travel, it's really offering a lot of solutions, a lot quicker than we thought it would catch on. You're going to see a lot more adoption of this technology.

How do you prepare directors to work with the volume for the first time?

Favreau: I made an arrangement with the studio for a lot of time for pre-production versus most television shows. I take the directors into a VR toolset very similar to what we used on *The Lion King*. We designed the sets together and looked at the artwork and storyboards together. Instead of rehearsals, they do a pre-production filming within the virtual world in VR with their crew.

After that, we have a cut that we can comment on. By the time they hit the real set, we've already gone through test runs, we've already made the show once together, and we've agreed upon a basic edit. They're prepared for it because they've already been there and shot it virtually. Then, we're there helping and trying to be good teachers and mentors. It makes it very exciting for us because we're not just making a show but we're making a new pipeline.

How does an LED wall impact your working relationship with the cinematographer?

Favreau: The more you understand what you're going to do, the better the results are going to be. What's nice about looking at the entire image is there are certain things that a DP is going to prioritize. If they're shooting a person in front of an empty green screen, they're going to concentrate all their effort on lighting that person.

So, you might have a very attractive leading character that the DP will light beautifully and backlight, and make the image look amazing. Now, that human is going to be talking to a CG character and it's going to inherit that lighting. This bear or alien is going to have the most unforgiving light that you can have for CGI.

If you'd had a real costume on the set, the DP would have prioritized making the fake thing look real, and let the person get the less flattering light because they can take it. In the case of *The Jungle Book*, Neel Sethi is going to look good in any light and the bear is going to look fake in front light and good in backlight. DPs are artists who like to look and select and choose and construct and compose. So if you can give them all of those tools, they can accomplish what you hired them to do.

How challenging is the mindset of doing visual effects in camera versus deferring to post-production?

Favreau: If you walk through Pixar or Disney Animation, you will see rooms and rooms of projects and teams of people working on films that are not yet being made. On the other hand, lots of live-action moments come out of random sets of circumstances that you capture in the moment. Animation is trying to develop spontaneity in post-production over months and years.

I learned to leave room for both with *Iron Man* because a lot had to be planned well in advance to know what we were going to build and how it was going to be budgeted. But when Robert and Gwyneth were on the set, I ran it like an independent film and left room for improvisation and spontaneity. And so it's trying to strike that balance using the technology.

Once you develop that environment, you stick people in a space that's digital because it's really right there. You may as well be in an independent film set. You can let them do whatever they want as long as they don't go outside of what was planned. It's also having the nonlinear approach where you could always go back and pull a set back up and film some more. That's a safety net that you don't have in a normal live-action film, so it emboldens you to take greater chances.

What advice would you give to someone starting a career in filmmaking?

Favreau: You got to make your own stuff. If you're going to be a storyteller, you better be telling stories. Whether you're making movies on your phone, writing scripts, or animating—you should be doing it. Maybe one of the things you're working on now will be your big break.

You don't have to wait for anybody's permission and now you can even self-distribute. I worked with Donald Glover and he was putting stuff on YouTube before anybody really knew what that was. And it was his entrée into that world. So I don't think there are any boundaries right now. As long as you're creative and motivated, don't wait for somebody to tell you.

The second thing is a lot of these tools are inexpensive or coming down in price, with stuff you can do on your phone or your laptop. Even VR is getting inexpensive very rapidly. Tools that we had to build custom for *The Lion King*, you get a lot of out of the box now with Unreal Engine. Back when I was doing *Swingers*, you had to rent media for an Avid and you had to get your film developed, and it was hundreds of thousands of dollars to make even a tiny thing.

Now you can do it for very little, just using your friends and phones. These inexpensive technologies democratize the learning process for filmmaking, and you don't have to wait for a budget or permission. I encourage people to get going and they'll either figure out they don't want to do it or they'll get much better at it.

Where do you see virtual production evolving?

Favreau: As with any technology, the price point is going to come down and it's going to be easier to set LED volumes up. There's room for many different techniques but the story has to be the king. Oftentimes when something new comes around, people use it in ways that it's not optimized for. There's always been a dance between technology and storytelling. So as long as the filmmakers understand what it's good for and how to use it, it can be a very effective tool.

That's part of what I'm really enjoying with *The Mandalorian* because as an executive producer, I get to work with a lot of new directors. We get to teach people how to use this tool and then we innovate off of what they do with it. And they go off and use it for their own projects in other places. It's a natural and organic way for a new technology to proliferate.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

What new forms of entertainment do you want to see in the future?

Favreau: When it's safe for everybody to go out again, I think we're a communal species and we want to experience things together. The immersion of VR is really cool but there's sometimes a sense of isolation in doing it alone in your room. As we get more into group experiences in VR, it could become much more communal.

For LED wall technology, there's an amazing amount of potential for live environments and location-based experiences. You see artists using these technologies to create the same impact that they might have used lower-tech solutions for, but now it opens up the imagination. I also think about live theater, where they already do a little bit with projections. If you had video walls, it's a perfect environment for a set if you could do it in a convincing way.

It's not one technique replacing the other. It becomes a synergistic solution if you understand the technology and you have a foundation in the old techniques. The best compositors or matte painters have to have an eye for light, surfaces, and reality.

Sometimes, you want to use a hammer, nails, and a paintbrush. And sometimes, you want to use pixels and a mouse. The best solutions are always where you use both together in a way where the matte line blends and you don't know where they are. There's a tradition of what we do that comes out of illusionists and magicians going back to Georges Méliès.

You're creating an illusion and you have to use all the tools available. But always remember that if the audience isn't delighted, or surprised, or fooled, or intrigued, all of it is for naught. It's all about that experience of blowing people's minds and showing them a good time.

Interview
LED Wall Cinematography - Greig Fraser, ASC

Director of photography Greig Fraser, ASC's feature credits include **Zero Dark Thirty**, **Rogue One**, and **Dune**. He received an Academy Award nomination for his work on **Lion**. A longtime proponent of LED technology for cinematography, Fraser shot the pilot and several episodes of the Disney+ TV series **The Mandalorian**, for which he received an Emmy Award.

What led your push into LED wall cinematography?

Greig Fraser, ASC: I suspect there's going to be more proponents of it once people get into the volume and get a chance to fully explore what it's good for. I think only a small portion of what we do as filmmakers is best served on a virtual stage. But when you do it right, it looks unbeatable and it gives the director a lot of opportunities they may not have ordinarily had in the normal film process.

How has the need for remote collaboration affected your work?

Fraser: There's talk about film sets in the future being smaller, which I don't think is a bad thing. A more intimate set is fantastic and the more that can be done on the computer, the better. This is why the whole production is so successful, because the DP has their fingers in the cake mix for the whole process.

That used to be the way stuff was shot. In the '60s and '70s, what you shot in camera was what you got. And so the cinematographer could go home at night going, "All right. Well, that rear screen projection scene driving down Mulholland Drive looks the best that it can possibly look because I made it so." Whereas the whole blue screen world now is you basically go home having shot an actor in front of a blue screen, and you cross your fingers and hope it'll look how you want it to look.

Does it serve your purposes as a cinematographer to have everything ready on the shoot day versus deferring imagery to post?

Fraser: It completely does. Typically, you get your cinematographer in for four weeks of prep, or on a big movie, it might be eight weeks of prep. Then you wave goodbye to the cinematographer and you say hello to all the visual effects people. This way, the cinematographer has much more say in what the lighting and framing are overall. So it's time well spent, and hopefully makes the backend easier and simpler.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

Were you as a cinematographer able to directly interact with Unreal Engine?

Fraser: I learned how to control certain key things, like, for example, where does the sun rise, and where does the sun set? Or what is the height of the sun in a particular scene? I learned how to move a virtual camera through space so I could line up shots. Obviously, I couldn't program it directly, but having some control was very useful for me.

What advice would you give to a fellow cinematographer about to embark on their first LED wall project?

Fraser: The thing with the design of the backgrounds is that it's a little bit of a crossover between the production designer and the DP. You've got to have a symbiosis. I would also recommend that they understand the limitations of the LED wall. It's good for soft light but not great for anything that involves hard, direct light. Some of it's about seeing concept art, and some of it's about seeing if you are able to determine if it's going to be a successful load or not.

If you go out into the middle of a desert in the middle of the day and take a photo of yourself, you'll have direct sunlight on your face. That's what we've been using 18Ks to simulate for years. What you might not notice is all the ambient bounce from the sun hitting everything around you. It's very hard to recreate that look in the volume because you can't light the ground. Otherwise, you start getting spills and you start having lighting angles. So, there are limitations to the LED wall, but there are also fantastic pluses with it as well.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

> **"** ... the cinematographer has much more say in what the lighting and framing are overall. So it's time well spent, and hopefully makes the backend easier and simpler. **"**

What are the limitations to the current LED screens and how can they evolve?

Fraser: They need to have a better range to go really, really dark and really, really bright. Right now, you can dial down the brightness of an LED wall. But once it gets to 30 percent, it starts to block up and you lose detail in the shadows. So your loads need to be relatively low contrast to go onto the wall. Once we get LEDs that have a bigger range and a smaller pitch, so there's no problem with moiré, that's when I think that you're going to be getting into the holy grail.

How critical is color science?

Fraser: The perfect example is the desert. You put some sand on the ground for real. And then you've got sand beyond that. Those two colors have to be identical, otherwise you'll see the seam and it looks like a high school art project. It's a really fine balancing act of changing the color of the wall that you see and the color of the wall that you don't see, but it's creating the light on the ground. So, that's where the art comes from it and where our friends at ILM are very, very good at what they do.

How do you see virtual production evolving?

Fraser: I don't know if I could see anything that would blow my mind more than what I've seen already. That said, I think now it's just a series of evolving ideas. Even on *The Mandalorian* where we knew we wanted to push the technique, there was always a certain amount that we needed to shoot on the volume because we only had a backlot, a volume, and a stage available to us. I think that a production might have, in addition to a big virtual stage as we had, a smaller one with a series of panels that they can move and manipulate.

Rather than building a set out of wood, the background of the set might be built out of LED panels and then the set is projected onto the LED panels. Meaning that you can recycle and reuse those LED panels hundreds of times. With a set, you're building walls and facades, you use it once, you knock it down, and you throw it away. There are ways to actually use LEDs as a smart way to reduce, reuse, and recycle, without reducing the quality aesthetically.

Interview
In-Camera VFX - Philip Galler

Philip Galler is co-CEO at Lux Machina Consulting. Lux focuses on in-camera visual effects, real-time mixed reality, and the future of filmmaking and live broadcast. Lux was responsible for integrating the LED screens used on **The Mandalorian**. Galler's credits include **Oblivion**, **Solo: A Star Wars Story**, **Star Wars: Episode IX - The Rise of Skywalker**, and **Top Gun: Maverick**.

What's the typical process your clients go through from the initial meeting to ready to shoot?

Philip Galler: The first thing we do is check their timeline for a couple of reasons. Our availability is tight, but also, we want to confirm all of the needed hardware and talent resources are available. Ultimately content is, and will continue to be, king. It will always be about who makes the best-looking content and how it best gets represented on a screen.

We go through the client's creative, including any storyboards, pitchvis, or techvis. We sit with the director and the DP and talk them through deploying the LED wall and how much coverage they might need. We then design a wall that we think fits the needs of the majority of the show, and have a conversation with them about any potential compromises on budget and quality in some cases, depending on the specifics and the plan for post-production.

Once they move forward, we go to engineering and get the LED wall structure engineered if needed. We work with the virtual art department to make sure they're building the content correctly. We test all the content at our volume in Los Angeles.

We build any tools that are exclusive to the show itself. Then we wait for content to get finished. Next, we're deploying the volume, doing camera and color calibration. Then we're starting to shoot. The process runs in phases, from design to engineering, installation, and operation.

What are some of the challenges of integrating LED volumes?

Galler: People assume you can go out and buy any LED but it's a very specific set of parameters we're looking for when choosing an LED product. We also have to take into account the complete system design. It's a holistic solution, including how are we rendering everything, is it being scaled, what's the latency, and what are the color metrics?

Can you explain a little more about latency?

Galler: We're talking about the latency that's propagated through the entire system and achieving the lowest latency possible while also maintaining the rest of the system's structural stability. You also need to be striving for genlock, proper color, and timing delay throughout the tracking system. These things may add more latency, but they're also required to meet the rest of the deployment's technical parameters.

Is there an optimal shape for an LED volume?

Galler: The reality is that it's back to the design process. We do techvis and have tools built for Unreal Engine and Houdini that let us quickly analyze LED deployments. People often think *The Mandalorian* was an excellent solution for in-camera backgrounds. The reality is we were solving more for the reflections. The backgrounds are great, but they could have been achieved in any number of ways. The reflections would have been very expensive and challenging to do in any other way.

So, the shape of that volume was driven by the need to fill in a bunch of reflections on the Mandalorian's mask, which was completely chrome. There are going to continue to be many shows that don't need that amount of LED product. They may only need a deployment like *First Man* or something like *Solo*, where they only have a small arc behind the camera because they're trying to solve for the backgrounds and not worry as much about reflections.

Can you talk about the actual hardware pumping out the imagery?

Galler: We custom spec our machines pretty rigorously. We have some very specific parameters for why we do that. Part of it has to do with how much hardware we want to have on-set at any given time. Imagine if we get ten computers, and we need eight render nodes and two control nodes. It's easier to just spec one machine that fits all the needs because then if I have a failure, I know that I can grab any machine and put it in the place of any other machine.

Image courtesy of Gabe Tiano

Who is in your typical crew for on-set operations?

Galler: It depends on the parameters of the show. Is there simulcam, object tracking, actor tracking, and/or mocap? Is it pre-rendered plates or real-time? A full-blown staff could be anywhere from 8 to 14 people. You might need camera tracking people, a couple of people to run the computers, a supervisor. Then there are the LED techs to run the LED screens.

How do you interact with nDisplay to feed Unreal Engine content to the screens?

Galler: It's getting easier every day, and Epic has done a really good job making it more straightforward. It becomes a challenge as you push the boundaries toward HDR and 120 hertz. nDisplay can scale and do all these great things, but it can't be taken as an isolated approach. It has to be the whole system that can handle and do those things. There's still a difference between deploying it for a show at your VFX house or a small studio versus a large episodic production.

Are LED manufacturers developing products specifically for virtual production?

Galler: We've been working with the manufacturers at a component level for six years now on the LED side to push the products to the place they are right now. There's another round of products that will come out later with even more improvements. Megapixel and ROE are currently the two market leaders for virtual production. ROE for LED and Megapixel and Brompton Technology from a processing point of view.

How challenging is it to get consistent color across all the tiles in a large LED installation?

Galler: We have to deal with it very specifically and buy tiles with the same batch of LEDs in them to get matching color. We buy them in what's called bins, which dictates the color of the tile. Then you need someone who knows broadcast engineering, someone who understands AV, and a networking specialist. On the Unreal Engine side, you may need someone to write Blueprints as we did on the Golden Globes a few years back. It's never just plug-and-play.

Image courtesy of Gabe Tiano

Do you focus more on features, episodics, theatrical, or all of the above?

Galler: We see everything from an independent comedy feature about bodybuilders to people trying to adapt feature films into episodics at large studios. Then there are the $100-$200 million features who want to use the technology but aren't sure how to engage with it.

Where people generally understand it, the easiest is actually around car work. People have been putting LED and projection screens around cars to view pre-rendered imagery in camera through the windows for years. The real-time version of that will eventually replace what we're doing now.

How have your projects been affected by the current need for remote collaboration?

Galler: You need to have all the infrastructure in place, and then determine how comfortable people are working like that. It's easier from the asset creation side because those artists are used to working in a connected pipeline. But the delays propagated via Zoom and a VPN can cause issues for someone like a director calling out specific actions.

I see people remoting to a trailer parked outside with a direct cabled connection. Then people aren't in the room, and that helps make it safer and reduces the overall footprint. That's going to be the way forward with isolated

brain bars and engineering rooms, and then personnel designated to go between those areas who understand how to fix things on both ends.

How is IP security handled?

Galler: The reality is a lot of people will have to put secure networks in place and contract with secure fiber. That's what most larger groups will do, but maybe you can't afford that for smaller feature production. So when you open up a connection to the outside world, perhaps you're only sending OSC and lighting data and not a complete scene feed.

What would your career advice be for someone interested in on-set projection and integration?

Galler: We have people from all backgrounds. Some went to film school or have animation or visual effects degrees, and we have some people with no degrees at all. It's more about dedication and passion for storytelling in some capacity, whether it's filmmaking or broadcast. It's also having a deep understanding of technology and at least some basic knowledge of networking. The best thing to do is not be afraid to reach out to people and have a conversation with them about what you want to do, and get one-on-one advice.

Where do you see the technology evolving over the next few years?

Galler: I see a convergence of better display technology; perhaps it's OLED. And also, the convergence of real-time volumetric capture and playback with better tools and new tracking solutions. That will be combined with AI, deep learning/machine learning models of some kind. That's probably the five-year goal of what we're looking at now, and trying to figure out how it can improve the work we're doing.

Interview
Directing - Rick Famuyiwa

Rick Famuyiwa made his feature film directing debut in 1999 with **The Wood**. His directing credits include **Brown Sugar**, **Our Family Wedding**, and **Dope**. Famuyiwa also directed two episodes of the first season and one episode of the second season of **The Mandalorian**.

**How did you come to be involved with
The Mandalorian as a director?**

Rick Famuyiwa: I had some development meetings at Lucasfilm and met Carrie Beck, who was co-producing the show. She later called and asked if I'd be interested in meeting about *Star Wars* on TV. And I said, "Of course, I would love to."

I met with Jon Favreau and might've been the first person other than Dave Filoni he was talking to about this. He was interested in bringing in different points of view and a diverse set of voices into the world of *The Mandalorian* and *Star Wars*. Jon took me through the world and showed me artwork. We just started vibing on our backgrounds in film, and at the end, he asked me to jump in.

Jon started talking about the things that he had been doing on *The Lion King* and expanding it to its furthest potential. I had no clue what this was going to become. But I was excited to jump in and go for the ride.

**How challenging was it to get up to speed on
virtual production and the LED volume?**

Famuyiwa: It was a crash course and immersion in visual effects. When I started, my understanding was at a "see spot run" elementary level in terms of visual effects. Jon uses visual effects as a big part of his storytelling, which also remains personal and character-driven.

Jon took me through the entire process, starting with VR scouting, setting up shots, shooting, and everything else. At the first meeting, he took me into his world of VR, and it was Pride Rock because he was working on *The Lion King* at the time. It felt familiar because I had grown up playing video games. It felt natural there, and it was an incredible tool.

So, we built out the worlds, both through the virtual art department and then moving into those environments. I learned how to tell a story with it and use extensive previs. It was an incredible education in visual effects.

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Everything got demystified in the process. It became fun to create in a way where your imagination can take you anywhere.

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Everything got demystified in the process. It became fun to create in a way where your imagination can take you anywhere. I'd say my skills are maybe grade school or middle school level now.

Can you describe the virtual scouting process?

Famuyiwa: You'd go inside these locations with your DP, but unlike four walls around you on a traditional scout, I can go, "Okay, what really would be great is if I can get a camera here." [Production designer] Andrew Jones would say, "Okay, what if we move the wall over here?" And it's like okay, perfect.

I come from relatively small films where you constantly have to figure out solutions to problems. To have some of the solutions built beforehand was certainly great. It took some time to get completely comfortable in the environment because a lot of the language was still new to me. Once you see how you can use your imagination, it becomes easier to grasp and use it as a filmmaker.

**Did the technology leave room for you
to interact with the actors?**

Famuyiwa: The most practical benefit of this environment is that you're in your location when you walk into it. Now you're just on a set. On the day when you're shooting, you're working as if you would on any film in any location. Once the actors got over the trippiness of how the wall moves when the camera moves, it was just great.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

It became completely liberating for actors who were very familiar with visual effects. You can work with your actors in such a detailed way versus 10 percent or 15 percent of the time saying, "Well, here's how the world's going to look and here's what going to be over there." Now, that can be, "Let's get the scene, make this work, and make it all feel right."

How did the volume affect your working relationship with the cinematographer?

Famuyiwa: The work starts earlier in the prep process than it would on a typical shoot. We're thinking about the lighting, even though a lot of that is going to come from the interactive light from the screen. The DP and I are very conscious of where the light is coming from, the shape and direction. We would look at the photogrammetry and think about how the clouds and light are coming through.

For example, in Chapter 2, when we're in the caves, we spent time deciding where the sun was going to be in relation to the cracks in the ceiling, and how it reflects off of his helmet and everything else. The conversation happened very early, so when you're on set, you're really thinking about where the cameras should be and the best way to get the action. You're able to move in a freeing way. Jon's calculation is that it's a lot of work to set up, but once you're in production, you move at a much faster pace than you would on a typical film set.

Does going into post with more shots completed in camera make editing easier?

Famuyiwa: About 70-80 percent of the shots started at a final level, and then there's still a lot of stuff that has to be tweaked. A significant amount of this show is shot traditionally with blue or green screen. So, in your cut, you still think about how those things are going to come together and how many shots you're going to use.

As a director, you got your way on a lot of different things, because everyone knew how important it was to get the first *Star Wars* series right and feeling cinematic. For me, having everything in place made it easier to fine cut the episode before having to turn over and get more specific for VFX. I could just cut the film as I would anything else because I had most of the information already there.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

Do you see virtual production as a useful tool in this era of social distancing?

Famuyiwa: I've thought about that a lot. I'd just wrapped my second season episode a week before everything went into quarantine, and it was the last. Post-production happened remotely. It wasn't as disruptive as it could have been, but at the same time, it got me thinking about the technology and how the volume can enable us to move forward with production.

The ideas behind it minimize your footprint in a way that's going to be advantageous, particularly in how we prep the show in the VAD in VR. We don't need a ton of people to get the process going. Then, on the day, you need less of a footprint to build out worlds.

There are still times where we're in there with tons of extras. But as the animatics or animations on the screen get more interactive, you could use it for deeper background players. We tried to play around with that and see how we could use the sprites in the background. There will be tangible benefits, especially if the cost starts to come down as the technology spreads around the globe.

What should people interested in a career in virtual production study?

Famuyiwa: I've gone back to my film school and said this is the future of filmmaking. I'm a lover of film, cinema, and the process of making films. I also love technology and knowing what's happening or going to happen to help tell a story. I want to continue to dive into this and see how it can be pushed in a lot of different ways.

It puts you in a place that's so familiar once it's all done, I feel like it's approachable. Many filmmakers, once they get involved in it, are going to find value in ways to be creative with it. I've been preaching to anyone who will listen is that this method is the way. We shouldn't be afraid to embrace it. It gives the tools back to the filmmaker in a very cool way.

Where do you see virtual production evolving next?

Famuyiwa: We think about virtual production in terms of larger-budget film and TV projects, but the value could also come from mid-budget and low-budget films that couldn't afford to be in a lot of different locations. This technology gives you a way to be somewhere too expensive, or where you wouldn't want to take a crew.

I was developing a project about this hacker. When he hacked into different computers, you would go to these different server locations around the world and see his journey from New York City to Ukraine to Japan. After I did *The Mandalorian*, I started thinking this was the answer. We could have built those worlds and sent a small crew to each location, do the photogrammetry, and bring it back in and shoot on a stage.

I also got excited about where this could go once it's less cost-prohibitive. Even as I start to think about my next projects, I think about how to use it in other ways. I'd also love to see other directors get their brains on it.

Interview:
In-Camera VFX - Richard Bluff

Richard Bluff of Industrial Light & Magic served as the production visual effects supervisor for Lucasfilm LTD's Emmy-nominated series **The Mandalorian**, for which he received a Visual Effects Society Award and an Emmy. Bluff also leveraged real-time technologies as one of two visual effects supervisors on the **Smuggler's Run** simulator ride for Disneyland and Disney World. His film credits include **Doctor Strange**, for which he received a BAFTA nomination for Special Visual Effects, **The Avengers**, **Above and Beyond**, **Lucy**, and **Unbroken**.

How did the first season of *The Mandalorian* come together?

Richard Bluff: Initially, Kim Libreri from Epic and I discussed the technology and its capabilities with a number of others.. No one had attempted these kinds of real-time set extensions and in-camera finals at this scale before. We each came to the table with certain ideas of what we thought would be achievable by using a game engine, either in post-production or on the LED screens.

Jon Favreau pushed us on what was possible. He was instrumental in its success by seeing the potential of the LED screens and helping to birth the technology, and most importantly, by bringing all the right people together to make it happen. The technology effort that went into making this possible was massive, but what isn't often spoken about is how important it is to have a reliable production workflow.

It's all well and good having all the best visuals that ILM can create. But if the workflow isn't solid and the tools to load the content are not reliable on the day, if there are technical issues, then the workflow is never going to be adopted. Every day that we intended to shoot in the volume, it simply had to work.

I always had faith in the team at Epic and at ILM to produce the required technology. One of the biggest challenges was how it completely changed prep and the way visual effects interacted with every department. The volume is a stage with set pieces that involve every department. It happens to require visual effects at its core, but it is an immense collaboration that exceeds the purview of traditional visual effects. The visual effects department has been in a privileged position for many years, where its involvement in prep is vitally important, but it doesn't get to roll its sleeves up and stretch its legs until post. At that point, it becomes a very linear process building on what's already been shot.

Due to the need for visual effects to generate content for the shoot, visual effects were now front and center at the beginning of the process, which allowed every department and key creative to contribute directly towards them. All of that collaboration helped us to not tear anything down in post-production. Anything that was going to be displayed on the LED screens had to have the buy-in of every department. The lighting adhered to what the DP wanted to see in that environment. The production designer had control over how the environment looked and how it interacted with the physical sets.

Amanda Moss Serino, the set decoration supervisor, could decorate the background and move crates and other props around. Normally, the art department would be more like a viewing audience where they would get to see how a visual effects environment was decorated in post. In the volume paradigm, they were a big part of the process. I thoroughly enjoyed collaborating with all the different departments and finally getting involved in their specific craft, in a virtual way, with our digital set extensions.

How does the process compare to a more traditional visual effects pipeline?

Bluff: Ultimately, what we execute is effectively the same—what's different is how we get there and which tools we use. One of the frustrating parts about working in traditional visual effects is dealing with post-production issues that are a result of not being able to visualize the CG work earlier in the process. If a DP is not able to frame up on a set extension, creature, or ship flying in during the shoot, and then you need to bend that plate to tell the appropriate story in post, it's not to anybody's benefit. If they can't see it, then they can't frame or light for it without guessing.

My career began in video games, building hundreds of environments for a PlayStation game. There was a budget for what that environment could be to ensure that it performed well for gameplay. It was a restriction, but by the same token, I think that the best kind of creativity comes from restrictions because you have to be thoughtful and intentional in your decisions.

If you talk to anybody involved in the original *Star Wars*, they talk about being limited in how they could shoot.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

However, it was through all those limitations that the charm, the craft, and the creativity developed. It was the same thing for us as we were building environments for the screen. The conversation became: what is the most important thing, and what story are we trying to tell? Once we understood those points, the set extensions and environments would be optimized to serve the story rather than serving as a distraction.

Can you talk about the challenges of keeping assets performant for the screens?

Bluff: We hit limitations every single day of production and left nothing on the table. You can assume that the scenes in hyperspace and regular space were the only environments where we had a lot of headroom left. One of the last things we shot in the volume on Season 1 was the Roost hangar from Episode 6. All the ideas we had through prep and shooting, and everything we were learning,

came to a head with that environment. It was one of the most challenging and also one of the most successful environments on the volume.

The Roost was the size of a football field. Across three different days, we would shoot in three very different locations. We had crane arms, a vat of molten metal sparking and producing steam, and digital doubles walking around. Any one of those ideas could max out the memory footprint we had.

It required compromises, and the filmmakers had to become educated on what was possible. ILM did various benchmarking tests on the scene to see what would tip it over the edge. We would figure out where it was most important to feature some of these animated elements.

We shot real actors against a green screen for placement on cards, but the textures of the footage of those characters consumed more memory than using 3D digital doubles. So, we went back to using digital doubles when you would think it would be the other way around. With real-time game engine technology, many traditional filmmaking and visual effects rules are different.

Was the volume more immersive for the actors versus a green screen stage?

Bluff: I heard they all appreciated and enjoyed it. Everybody had the same feeling: you would walk into the main stage and be wowed by the level of technology. Then, you would walk into the volume itself and, again, be wowed by how the technology works. But, very quickly, you simply forgot about it and went about your business of shooting the day's work.

How challenging is it to have environmental assets ready on the shoot day versus deferring to post-production?

Bluff: We were very fortunate that Jon fully understood those challenges and that new paradigm from the very beginning. He spoke to all the heads of departments, the filmmakers, and the actors about his vision. He took pride in explaining how we were doing it differently on our show, what this new technology was, and why we were

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

embracing it. When that messaging comes down from the top, it's very clear how we have to be on the same page and make all those decisions ahead of time.

After that, it was understanding the schedule and being able to measure the amount of time each set would need before it had to effectively get to the point where it was approved. Then we could do performance testing to make sure it would work on the stage on the day of shooting.

What are the limitations of working within an LED volume?

Bluff: The lighting, because you can't currently use the LED panels to simulate the sun or get parallel light rays. So, whether it was Jon with his writing, Doug and Andrew with the environment design, or the DPs with their lighting, everybody crafted the scenes to support the lighting that we were comfortable we could reproduce.

Also, the way that the camera focuses on LED screens is vitally important. You have to avoid the moiré pattern you get when focusing at just the right point on the screen. By the same token, the falloff we were able to achieve with the lenses chosen by Greig and Baz allowed the screens to fall off in focus most of the time, which helped with the illusion.

It reminds me of when I first joined ILM back in 2003 in the matte painting department. Back then, the majority of the movies we did were on film. Whenever I would create a matte painting to what I felt was like a 90 percent level, someone like John Knoll had the experience to say, "That's good enough." Just the transition of going from digital to film provided that extra creaminess and the lines would be slightly blended, slightly softer, and with film grain. That, for me, was a eureka moment of a magic trick working by having the filming process take the work over the line.

Will ILM use the volume technique on other productions?

Bluff: I can confidently say that there is a place for this technology for every show and every movie. It has exceeded our expectations both for Season 1 and

subsequently in Season 2. There are limitations, but it's amazing how, when you read the pages of a script, you can quickly start to break it down for the screens or bend the concept slightly to make the screens work.

Do you see the advantages of this technology in the current era of increased remote collaboration?

Bluff: Definitely. There's less of a need to move a crew out on location and travel. People can stay home or on a stage, which is easier to control. With all the advancements that we've had in remote working, we can move some of the brain bar operators off the stage, for example. We already close the volume doors, so no one has a line of sight into the stage because we need the wraparound 360-degree light. We also use walkie-talkies for communication, and witness cameras.

What pleases me is the interest people already had in StageCraft [ILM's virtual production solution] as a viable filmmaking tool. We didn't build it as a reason to avoid going on location—we built it because it was the best way for us to tell our story. The current high level of interest validates the choices we made with this technology.

Where do you see LED stages evolving in the future?

Bluff: We have a lot of ideas to continue to push this technology. We're interested in making it more modular, so you're not resigned to one size of LED stage for all your scenes. If it becomes more portable and you can construct walls, shapes, and corridors with the LEDs, then it becomes incredibly flexible. The quality of the LED screens is something that we are also very keen to watch advance, as is being able to weatherproof some of the finer-pitched LED modules.

Imagine you have the deck of a ship, for example, and you surround it with LED screens—you can convincingly have a water sim playing on that screen in real time. Then you put the boat on a gimbal and then start splashing real water around. You begin to look back at how films were made over the years and how those scenes could have been improved with this LED technology.

Interview
In-Camera VFX - Charmaine Chan

Charmaine Chan is a lead compositor and virtual production technical director at ILM. Her credits include **Harry Potter and the Half-Blood Prince**, **The Avengers**, **Jurassic World**, and **Black Panther**. She also served as the on-set, real-time compositor for Season 1 of **The Mandalorian**.
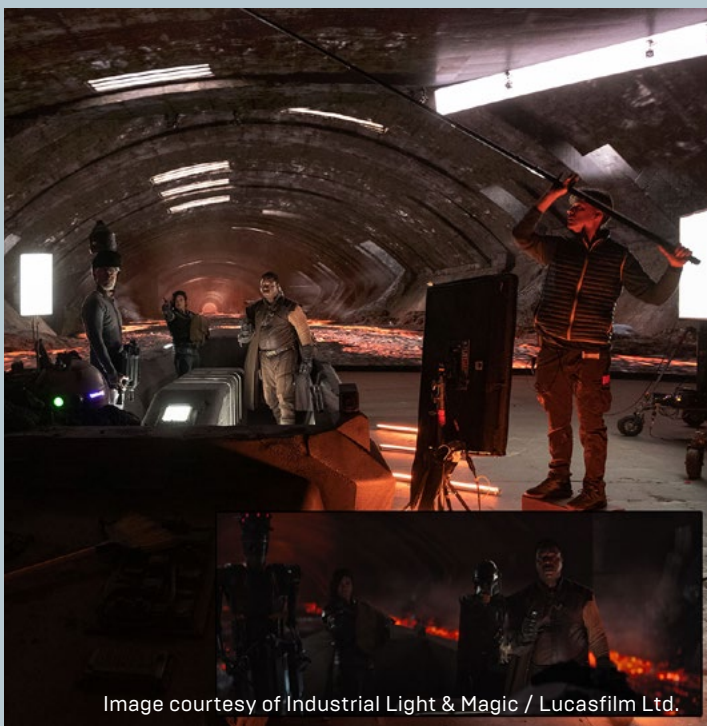
Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

What are the differences between virtual production and traditional compositing pipelines?

Charmaine Chan: Virtual production finally brings visual effects into production as opposed to post-production. We're used to being the end step and not having much say over what happens during shooting. Being on set makes a huge difference in getting the director's or showrunner's immediate feedback and makes the process a lot more efficient.

With traditional compositing, you can sometimes work on a single shot for months. On set, you're constricted by the time and trying to get the best picture as quickly as you can. Real-time gives you a more immediate result, as opposed to waiting for renders of your final shot.

Does real-time compositing require fewer layers than traditional compositing to maintain performance?

Chan: Compositing is often treated as a "fix it in post" solution. So, we're layering so much because none of it existed during production, versus real-time compositing where you're looking at your whole picture. We try to find the final imagery in camera.

What are your on-set responsibilities?

Chan: We get our 3D scenes and assets in Unreal Engine from the talented artists at ILM, then we bring them onto the giant LED screens. There may be things that don't work right out of the box. For example, we might need to color correct a specific rock in an environment to match a practical rock that's on set. Or there's a giant sand crawler, and half of it is practical and the other half is in Unreal Engine. It's a matter of blending the digital scene with the practical set so it looks flawless.

There's also a lot of general compositing, coloring, and lighting cues that you can modify in real time. Let's say we bring up a desert scene with a mountain and a sun, and the DP decides the sun being on camera right doesn't quite work for the look we want. So, we'll move that 3D sun to light the scene the way the DP wants. It's not that different from what I do day to day in post-production.

Which software applications do you use?

Chan: We're using Unreal Engine to real-time render out the scene, and other software such as Nuke, Maya, 3ds Max, and Photoshop to make the polished real-time scenes that are completely photoreal.

Is post-production easier on real-time shots versus pure green screen?

Chan: Yes, when we knew that certain assets wouldn't hold up or were too big for the screen, we would plan for post-production replacements. I was surprised just as much as everyone else on Season 1, where we would set a complex shot and look through the camera, and it was pretty much finished. That's our end goal—to get as many in-camera finals as possible.

A lot of the issue with green and blue screen shots is the green or blue spill on your actors and set. When we de-spill that via compositing, you can lose a certain quality and sense of natural skin tone in extreme cases. With the LEDs and a limited, small green screen path, you don't have that spill and you're getting great interactive light. Those reflections and interactive lights, especially on a character like the Mandalorian, who is like a giant chrome sphere, make a huge difference.

Does seeing so much more imagery in camera lead to a greater sense of engagement for the crew?

Chan: Definitely. I remember when we were shooting the iconic cantina from the original *Star Wars*, everyone wanted to replicate exactly how it looked in the movie. We cheated quite a lot, but we completely nailed it. Everyone who was acting on that set said it felt like you were in the original cantina even though more than half of that set was entirely digital.

There's a moment, when you've been doing so many takes on one scene for so long, where you completely forget it's an LED wall. Or, where the floor ends and the walls begin. If we're in the Razor Crest cockpit and the galaxy rotates around, you do feel like you're out in space.

Does the technology have applications outside of *The Mandalorian*?

Chan: Absolutely. Even pre-lockdown, there was a lot of talk about how we can take this to the next level. I'm seeing all these people who are interested in the industry, gaming, VR, and more. There's also a huge community push for doing more, whether indie or large-production scale—people are really seeing the potential.

How has remote collaboration affected your workflow?

Chan: When it comes to creating the imagery and assets we need to do a production, it's very similar. We have video chats for check-ins and dailies per usual. From the virtual production side, it's cool that the studios allow us to work remotely because you can tap into talent across the world to get what you need.

There isn't a mandatory physical requirement to be on set, and virtual production can happen via streams and via cameras. Virtual production has made it more accessible for companies and individuals to work collaboratively in a remote way. COVID-19 has pushed virtual production further as a need for general film and TV production versus a nice-to-have.

The thing about people working from home is that you have access to them at any time. Sitting around for long days on set waiting for the next scene seems like an inefficient use of time. People can now just remote in when they need to, and then remote out and work on the next scene. I'm a huge fan of multitasking, so I feel this will speed up our efficiency and processes.

Where else do you see virtual production evolving?

Chan: If you look at our primary use of the LEDs, it was mainly static 3D set extensions. I can imagine scenes where we can go crazy with the cameras and animations. People are finding very innovative ways to create moving imagery and scenes that look like a giant world, but it's all in one small space

There have been times where there are a lot of digital characters that actors need to work with. When the actors can put on a VR headset and see the digital characters, there are endless possibilities. The more we can bring all the different disciplines together, the more we'll see what develops in the future.

Do you have any advice for someone looking to start a career in virtual production?

Chan: We're all trying to be visual storytellers. With the accessibility of technology like Unreal Engine being open and free, people can so easily download the software and learn it. You don't need to have a 75-foot LED set—you can use Unreal on a laptop and make a stop-motion animation. It's nice to scale up and use it on a giant production, but it's always best to start small. There are plenty of tutorials online regarding how to use Unreal Engine.

There's no one formula to get into this, but it's still filmmaking at the end of the day. You're using cameras and lights, so the fundamentals are there. People need to keep on making content, no matter how big or small. It's very possible with the technology and communities we have.

Interview:
Visual Effects - George Murphy

Visual effects supervisor George Murphy spent years at major visual effects companies including ILM, Weta, and now, DNEG. His credits include **Jurassic Park**, **Forrest Gump**, **King Kong**, **Constantine**, and **Murder on the Orient Express**. Murphy earned an Academy Award for his work on Forrest Gump and an Emmy for his work on **Black Sails**.

Is it challenging to design visualization assets that can be used for final imagery?

George Murphy: You've got a certain budget set aside for asset builds and various other things in that realm. And you're going to spend a pretty good amount upfront before you finish designing the movie. You have to be careful because the whole point is not to do work as a throwaway.

One of my goals working with the crew at DNEG has been getting visualization as the first step in building the real assets. The bar is going up on the fidelity and the complexity that you can run in real time in the engine. If you can do that development up front and get feedback, then you can make real decisions with a minimum penalty.

In my perfect world, you're starting in production design standing around a virtual maquette of the set. There are pre-baked animations, or you can grab an asset and move it around with a hand gesture in Unreal Engine. It's great to bring those technologies together so you can do asset design, production design, and set scouting in a more fluid, integrated way.

How have workflows evolved due to the era of increased remote collaboration?

Murphy: A silver lining from the world pandemic is that all of the security issues around remote collaboration have been solved—because that's the only way we could all move forward. For my current project, the teams I'm working with are remote. I'm in London, many are in Montreal, and others are in Los Angeles. And because everybody is already working within that mindset, we're actually able to do more.

Everybody is getting on the same page about it. VR, AR, and mixed reality are coming together more cohesively so that the process doesn't get in the way of what we're trying to accomplish. As the process matures, we can just focus on the work and it becomes much more viable.

It all portends a vast re-envisioning of the way we approach projects. The goal is ultimately to empower creators so they can refine their vision on projects with more confidence and efficiency. And do that in ways that offer greater creative freedom and collaboration as they

craft the stories, performances, designs, and imagery that must all come together for these works. It's getting back to when we could just grab a camera and a few people, go out, and shoot something. But now, you can do that at a production level that once would've been a Steven Spielberg movie.

Do real-time engines encourage more experimentation when compared with traditional VFX?

Murphy: Yes, because in a typical pipeline a lot of your post schedule is working everything out at low resolution, with important pieces of the visual puzzle missing. You're going to spot check a few high-res frames, but you can't afford to render all the shots all the time at full resolution. That was the rule for a long time.

With tools like Unreal Engine, you can get very close to the finished feel and make real decisions. I can't tell you how many animations I've seen that look great in grey-shaded, low-res but once you get to the final render, you discover the eye line is not quite right. Or once you light the character, it doesn't feel the same. Now, you don't have to delay that understanding.

There's also the added bonus that if you're doing mixed reality setups, you can be outputting near real-time renders on the side, and by the end of the day, you've got footage that goes into editorial. Now, they're cutting in something that looks like the movie and not a bunch of blue screens waiting for the turnaround of the effects editorial's mockups.

The irony is the audience views a movie spontaneously and might not consider it's the result of years of work.

Murphy: If it feels that way then you've succeeded, because sometimes you can feel the labor that went into a production. But we're also looking to these new tools to keep it spontaneous for at least the key parts of the development process. The tools for modeling, texturing, lighting, and animating are improving.

I think about that really stunning Unreal Engine 5 demo. You look at that playing in real time and just go, wow. But consider how much time was spent designing and building that environment, the character, and everything else that

went into the scene. Through all of that advance work, you've created this world where you can do something really responsive.

Understanding that concept in the early stage of development means you're not locked in. There's a lot of naturalism built into these tools. For example, there are effects simulations so when you need a rock to fall a certain way, you don't have to spend a month setting it up just to explore the concept interactively.

Do you see an uptick in real-time workflows within the effects industry?

Murphy: My colleagues and other facilities have been making great progress. Everybody has got different things that they're doing, but there's a pretty broad consciousness that this is ultimately not only going to be an integral part of the workflow, but eventually will probably become the workflow. It can't happen soon enough for me.

Vendors are in an interesting situation because they can't put unlimited resources into something new. If there isn't a production driving it, the resources you have available for assets or development move at a much slower pace. The hard part is actually finding the people with the skills to do this work. There are traditional skills from the effects side, but you also need game developers who have more experience with this kind of workflow and who are able to more quickly integrate a tool like Unreal Engine.

It almost goes back to the old days of CG visual effects where one person would both model and texture, then somebody else could animate, and someone else could light, render, and comp. While artists still had their areas of focus, artists with the ability to own more of the process were incredibly effective. For real-time workflows, the more versatile an artist can be, the better. You can be more responsive and flexible in how you come up with answers to move things forward.

It reminds me of my time at ImageMovers, shortly after we had finished working on *A Christmas Carol* with Robert Zemeckis in 2010. We were in the final stages of production on a digital screen test for a new project, racing toward

Image courtesy of 20th Century Studios

final delivery with a small core of about a half-dozen or so artists. Without the complexity of a full, traditional pipeline, you could do a massive amount of exploration very quickly.

Sometimes you need the aircraft carrier, but sometimes, early on, you really want a bunch of little speed boats and cruisers to get it all sorted. Real-time technology allows that to happen in a strong way. You can be collaborators and be in touch with the core creatives. And they feel like they have control because it's not just these rooms full of bodies working on disconnected pieces of the puzzle, maybe even in another country, within a traditional structure where one thing has to go to one department before it can go to another department, and tasks are stuck in departments and teams. When everything is collaborative and in real time, you can cross those lines.

The things I want to dive into are the things that we can drive from the production side, and they will push things on the vendor side. So, I sit on both sides of that fence. I am DNEG's client on projects, even as internally I'm a vested collaborator in the process and talking to the team about what we can do next.

DNEG is focusing a lot on LED screen technology right now because there's a lot of interest in it and it's a viable service. Companies see that for many productions, these setups are too expensive to do as one-offs. From my side as a visual effects supervisor and creative director, I'm looking to bring an even more holistic approach to projects. The use of screens is just one part of a growing portfolio of tools and techniques that will allow us to help productions succeed in new and exciting ways.

Interview:
In-Camera VFX - Sam Nicholson, ASC
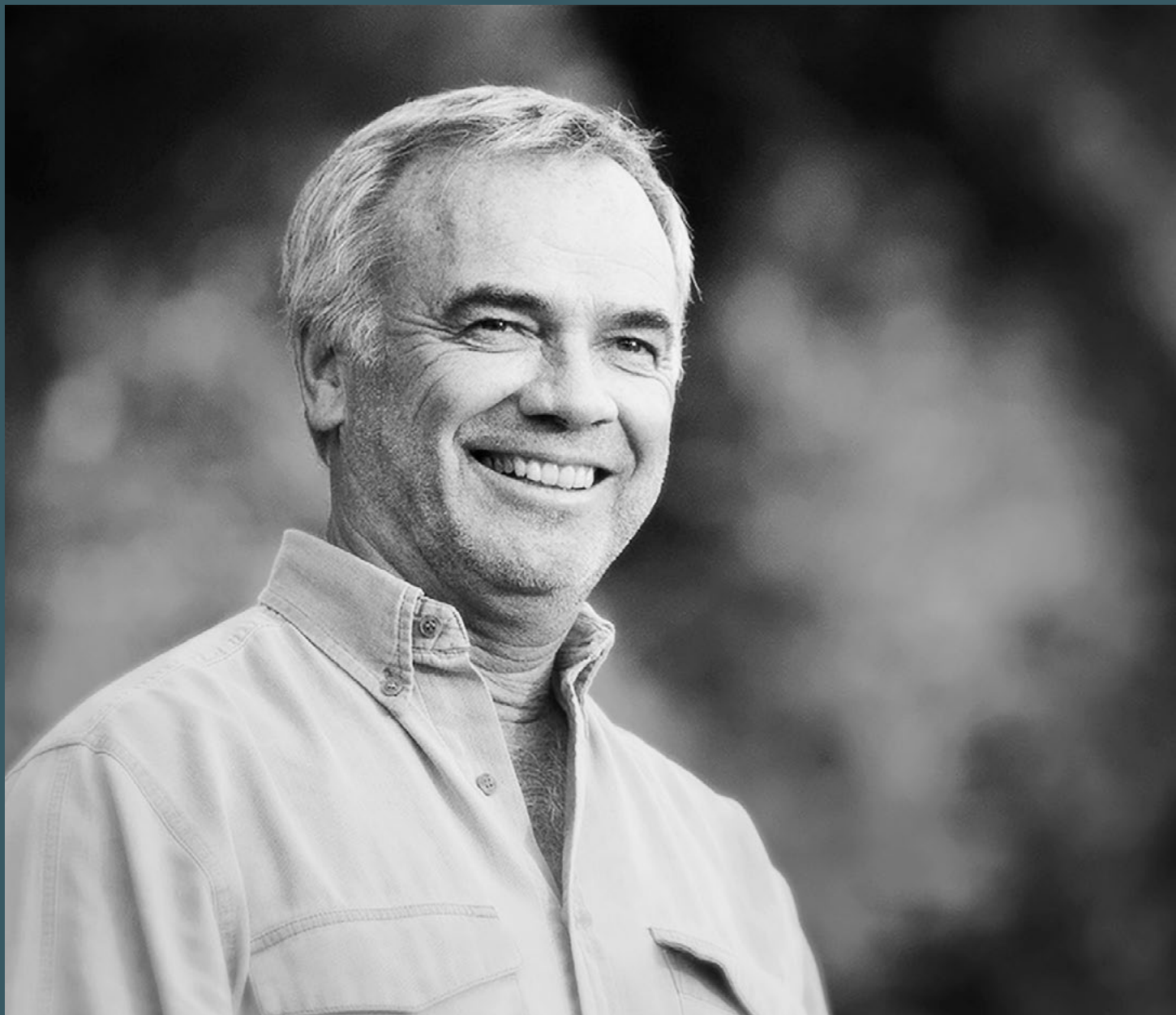
Sam Nicholson, ASC is a veteran cinematographer and a visual effects supervisor. He's also the founder of the visual effects company Stargate Studios. His credits include **Star Trek: The Motion Picture**, **The Running Man**, **Heroes**, **24**, **Pan Am**, **The Walking Dead**, and **Run**.

How has the global pandemic affected interest in virtual production from your perspective?

Sam Nicholson, ASC: Our last experience like this was right after 9/11 when nobody would fly. We converted shows like *ER* and *Grey's Anatomy* over to virtual production. *Grey's Anatomy* didn't have to go to Seattle anymore, *CSI* didn't have to go to New York, *ER* didn't have to go to Chicago.

We created a virtual backlot, which meant capturing a bunch of locations and creating a footage library. Producers can peruse the library and reverse-engineer a scene in London or Paris or Moscow. We're sitting at about 300,000 mostly multi-camera circular clips now, and still growing.

That converges with new technology like LED walls, NVIDIA's GPUs, and Blackmagic's 8K DeckLinks streaming 8K that you can quad split. Now you can push a lot of pixels in real time. It changes the business model away from green screen because no producer wants to deal with a thousand shots coming out of post. Editors don't like it, directors don't like it, and actors don't like acting on green screens. They'd much rather sit on the steps of the Capitol Building than stare at a laser dot.

The remote collaboration that Zoom has brought is incredibly efficient because we don't have to travel. We can have a great, intense discussion, and you can have another one right after with a completely different set of people. Everybody's concerned about spending so much time online, but nine-tenths of the effort of shooting on location is just getting everything planned.

You recently completed the first season of HBO's *Run*, which used OLED monitors outside of train car windows to set the scene. How did that turn out?

Nicholson: We estimated 3,000 effects shots at 300 shots per show, times 10 episodes. We shot a little bit less than that, but 95 percent of the final shots were captured in camera. To do that, we used 40 very high-resolution 82-inch 4K monitors. You could look directly out of the train window with no moiré and shoot it as real.

If you're shooting a tiny little piece of a 100-foot 2.5 mm pitch LED wall, it will moiré. So we thought *Run* through and had a considerable amount of time and prep to shoot the pilot. Then almost a year went by before we shot the series. Doing your homework is a big part of surviving virtual production.

We built a section of the train at our studio in Los Angeles and tested it for months before the pilot. When HBO decided to go to series, we just kept working out all the code and the theory as part of our ThruView process. We designed our own trackers, which are markerless and wireless because shooting inside a train, you can't put markers up or run a cable to the camera.

We're also controlling Arri SkyPanels and pixel-mapping them to the footage in Unreal Engine. So when you go into a tunnel, the whole train goes dark and yellow lights go by. Everything is automated, which is one of the big time savers. You overlight with three times more fixtures than you need, and then activate them when they're needed.

How does the experience of virtual production compare to a traditional visual effects shoot?

Nicholson: It's much easier with real-time, in-camera production because everybody from craft service to makeup to the grips can just walk over to the video village and see it with their own eyes. In fact, the whole crew would sometimes go onto the train to eat their lunch because it felt like you were taking a ride somewhere. By comparison, shooting green screen can be like getting a lobotomy, and everybody winds up over at craft service, disinterested.

Once you get into the real-time realm, everybody gets on board and can see it. The level of enthusiasm goes way up. The actors can look out the window and have a good time. The camera operators can frame based on what they actually see. The knowledge and the playfulness that you get is enhanced because once you see the reactive light and everything working, you take risks that you would never take shooting green screen.
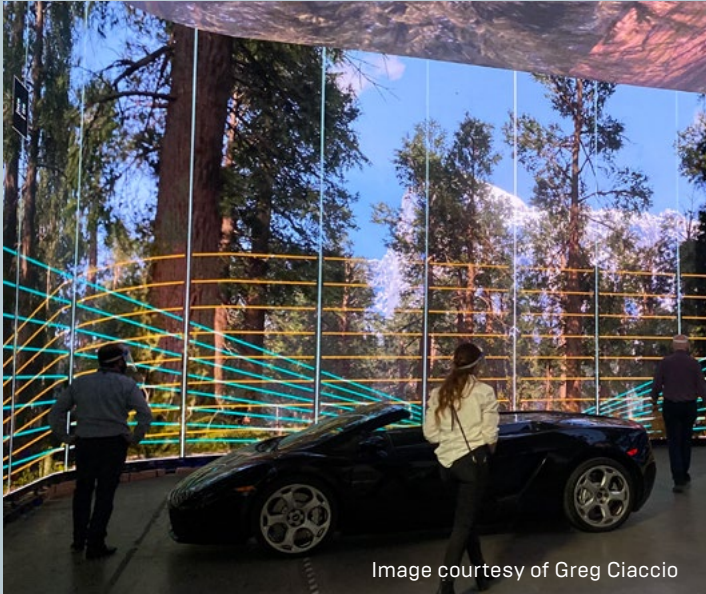
Image courtesy of Greg Ciaccio

What's a good background for a career in virtual production?

Nicholson: This is going to open up new territory and many new opportunities for people. If you're a colorist and tired of being in a dark room, you can now be on set. DITs [digital imaging technicians] are an excellent crossover because many already have some compositing capabilities. Being fluid in computers is never going to hurt anybody.

I would recommend anybody going down this path to learn Unreal Engine. Conceptually, it's about what you can accomplish in real time, and the GPU mentality is different from CPU rendering. Young people gravitate naturally to this because they don't have pre-existing norms of the way things are supposed to work.

What's your reaction to the upcoming capabilities of Unreal Engine 5?

Nicholson: It's going to change a lot, and I love not having a polygon limitation. But there will still be optimizing and fitting the puzzle together with other components, like a hot-rod car that suddenly got a lot faster. We're excited to work with Epic very closely on what we can do with it.

Where do you see the workflow evolving in the future?

Nicholson: The process needs to start with writing. It's one thing to be handed a template at the concept level. It's another to have a creative partnership where we're brought in early enough to influence how the script is written.

For example, scale is no problem. I'll never forget when we did *Helen of Troy*, they built a set in Malta that was so big and they spent so much money on it that they didn't have enough left to put enough extras around it. So when the Greeks invaded, there were three people down there. Virtual production can offer certain creative freedoms, and the writers need to know what those are.

If you want to do a one-page scene in a phone booth in London, well, the producer is going to come by and rip that page out. But if it's virtual, you can do a half-page scene in London easily. We just happen to have some great phone booths in London in our library. Shows like *The Lost Room* and *Dirty Sexy Money* took a look at our library and reverse-engineered scenes based on the virtual environments we already had.

One day we'll look back on the cameras that we're currently using and say, "Can you remember when we used to shoot flat, and the camera didn't understand anything about depth?" The next wave of cinematic imagery is cameras that can see in depth. LiDAR, edge control AI, all these things will get us to the next level. Green screen isn't going away, reality is not going away, but virtual production is a new creative tool that everyone should learn.

Some directors feel very comfortable in this space, and others don't. The more it can be real-time and convenient, the better. You can touch and see it without putting glasses or a headset on. Once you've shot real-time, seen it in-camera, and know it's finished pixels, you really can't go back.

Animation

The state of the art in real-time workflows, virtual production lends itself well to animation. More to the point, games are built upon real-time animation. Whether the animation is controlled procedurally through an input device, keyframed, or performance-captured, real-time technology can make the process more interactive and efficient. And these same animation virtual production workflows can also be applied to animated elements for live-action movies.

Animation not only applies to characters and objects, but it also applies to the cinematography itself. For example, the virtual cinematography of *The Lion King* is CG driven by a traditional camera crew using the same tools they would on a live-action set—like dollies, tripods, pan/tilt geared heads, cranes, drones, and so on.

The Call of the Wild and *The Jungle Book* feature live-action performances combined with characters animated via both performance capture and keyframes. A real-time platform makes the process more akin to traditional filmmaking. Finally, fully CG films without any direct physical input can also be created with real-time animation. For more information about the latter, see our interview with Dane Winn from Blue Zoom Studios.

During the pandemic, animation had the potential to be one of the least disrupted production areas because so much of it can be done remotely and asynchronously. Many aspects of remote collaboration are perfectly suited to distributed animation workflows. For example, remote sessions involving an entire crew—including actors in mocap suits, cinematographers, directors, editors, and set designers—could be conducted from home with shared sessions.

In this section, we'll examine the common components and workflows for various animation pipelines including virtual camera capture (vCam), performance capture, remote collaboration, and traditional keyframe animation. We'll also share interviews with heads of studios, directors, and animation supervisors.

Components

Unreal Engine

Unreal Engine has evolved in recent years to include a number of essential animation tools. Although it is capable of interoperability with other DCCs, a significant amount of work can be accomplished completely within the engine. Later in this section, we'll go into more detail regarding these specific strengths.

Tracking Solutions

Whenever a virtual production calls for performance animation—whether camera, actor, or object—a tracking solution is required. Tracking solutions come in many flavors, with the choice of tools dependent on the type of input and desired outcome.

For camera movement, the vCam virtual camera plugin in Unreal Engine is a simple solution. This plugin accepts real-time movement data and connects it to a virtual camera. The plugin's flexibility means the input isn't restricted to movement from a physical camera—an iPad meeting ARKit requirements can also be used to operate a virtual camera from real-world input.

Many body tracking solutions are available for use in performance capture, typically optical tracking or inertial sensor suits. Optical trackers use special infrared cameras arranged in a volume to track high-contrast markers placed on bodysuits. Examples of optical tracking solutions include OptiTrack and Vicon. These systems are generally more complex and expensive than inertial sensor suits, but are also highly accurate and flexible.

Inertial sensor suits are self-contained body tracking solutions that do not require external tracking cameras or a volume to capture a performance. One well-known example is the Xsens motion capture system, a self-contained system that wirelessly streams live data to Unreal Engine. Another example is Rokoko, which is a cost-effective solution for body motion performance capture.

In addition to full-body capture, facial capture can also be deployed to control virtual characters. These systems typically include facial markers in combination with special tracking cameras or head-mounted cameras. Head-mounted facial tracking solutions include the venerable Technoprops Facial Capture system, which was used on movies like *Avatar* and *The Adventures of Tintin*. Another
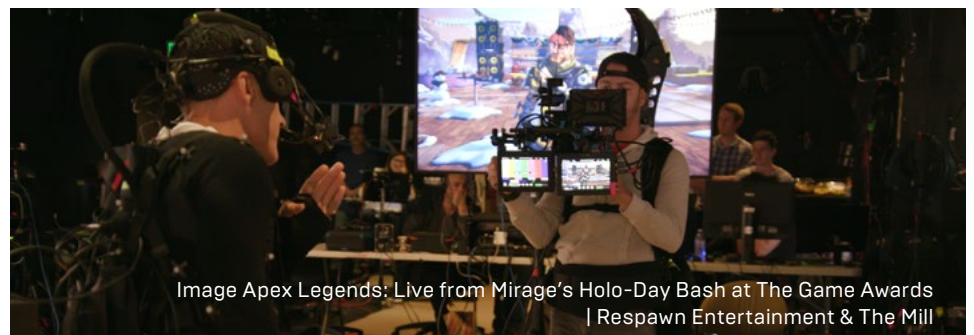
Image Apex Legends: Live from Mirage's Holo-Day Bash at The Game Awards | Respawn Entertainment & The Mill

head-mounted system is Faceware Technologies' Mark IV Wireless Headcam System, which is optimized for movie/TV production and live facial animation.

Epic Games recently joined forces with 3Lateral and Cubic Motion. 3Lateral develops technologies that enable digitization of human appearance and motion with a high level of realism. Cubic Motion offers highly realistic facial animation techniques with Persona, a complete real-time facial animation solution that captures human actor performances and translates them onto digital counterparts. It uses advanced real-time markerless tracking and solving to create animated characters that engage with real-world events immediately. For more information about Cubic Motion, see our interview with Nathalie Bergeron.

It's also possible to experiment with facial capture techniques without a significant upfront investment. New applications leverage phone and tablet cameras to deliver highly affordable facial capture. Such applications may not be as accurate as more advanced systems, but can be very useful for creating proxy scenes and visualization. Epic offers the Live Link Face app for iPhone and iPad, which uses these devices' depth cameras to create live facial animation and stream the data to Unreal Engine.

Character Animation

Unreal Engine includes many character animation features including digital human tools, hair/fur simulation, and cloth simulation. You can learn more about digital humans via the Digital Humans project in the Epic Games launcher. Recent improvements for digital humans include improved lighting models, realistic skin shaders, and eye detail.

Hair and fur simulation are also important aspects for character animation. Unreal Engine 4.24 introduced a preview of real-time hair rendering with dynamic support, which became more robust by version 4.26. For maximum realism, the engine renders hair accurately by individual strands. Hair simulation is also deeply integrated with Unreal Engine's Niagara visual effects editor. For more information on hair and fur simulation, see this blog post, and learn what's possible with the system with a look at Weta Digital's real-time hair and fur short, Meerkat.

Cloth simulation plays another important role in realistic character modeling and animation. Clothing in Unreal Engine is simulated via a physical particle simulation. Clothing can be painted directly onto characters via their skeletal mesh with the Cloth Paint Tool. For more information about cloth simulation, see the Unreal Engine Clothing Tool documentation.

> **"**
> We're building a world where digital humans will appear to be part of our society to a point where it will be difficult to differentiate.
> **"**
>
> Nathalie Bergeron
> Vice President of Operations and
> Business Development
> Cubic Motion

Physical Simulation

Physical simulation leverages the strengths of game engine technology to bring programmable real-world physics directly into animation. With physical simulation, objects within a scene can interact and collide with one another as they would in the physical world. Complex interactions can be achieved procedurally through Blueprints instead of painstaking keyframing. Physical simulation has many uses for virtual production and animation, especially when a realistic style is desired. For more information about physical modeling, see the Chaos Physics documentation.

Visual Effects Animation

In Unreal Engine, visual effects animation generally refers to a subset of particle animation, including water effects, electrical effects, fire, explosions, and other physical phenomena. Unreal Engine's Niagara visual effects editor is used to create and adjust visual effects animation. For more information, see the Niagara documentation.

Blueprints

Unreal Engine's Blueprint visual scripting system powers complex interactions within a scene. Although Blueprint's node-based, object-oriented interface was initially designed for games, it also has plenty of uses for all types of animation. Characters and objects can be given specific logic with Blueprints, making them interact procedurally during a scene based on user-defined rules. For example, a character can be scripted to turn and face another character as it gets closer.

You can also use Blueprints to create dynamic and adaptive visual effects, or connect real-world cameras and other tracking inputs to virtual cameras. Blueprints can be defined for an entire scene and/or per object or character. To learn more, see the Introduction to Blueprints.

Sequencer

Sequencer is like a nonlinear editor, but one that goes far beyond setting in and out points of static clips. Sequencer forms the backbone of the animation workflow by defining the parameters of characters, visual effects, objects, cameras, and even sound effects across a timeline. It is highly interoperable with external non-linear editors (NLEs) and digital audio workstations (DAWs) for maximum flexibility.

Image courtesy of Bild Studios

Compared to a traditional animation workflow that deals primarily with individual shots, Sequencer can be used to take a far more holistic approach to animation. Because each camera, character, and object is always editable both as an asset and in relation to the rest of the scene, complex refinement can be performed across an entire scene. And because rendering is typically performed in real time or near real time, there is little penalty of time or cost for deep experimentation and iteration. To learn more, see this Sequencer Overview.

Finishing / Render Management

Because Unreal Engine is designed to work at high quality in real time, the pressure of render management and finishing is much lower when compared to a traditional animation workflow. Although Unreal Engine's real-time render quality is often sufficient for most applications, sometimes even higher image fidelity is desired. In these cases, the Movie Render Queue feature of Sequencer delivers a more traditional, non real-time, render farm export workflow. You can also split scenes into custom render passes to optimize for external compositing. Some specific benefits of the Movie Render Queue for virtual production animation include higher-quality anti-aliasing and motion blur along with reduced ray-tracing artifacts. To learn more, see the Movie Render Queue Overview and the documentation on Exporting Custom Render Passes.

Workflows

Virtual Camera Capture

Virtual camera (vCam) capture can bring a human, real-world touch to otherwise completely computer-generated animation. By connecting human film crews' movements with their virtual counterparts, a best-of-both-worlds solution can be delivered. *The Lion King* is a recent example of a virtual production that transferred both the artistic eye and instinctual physical camera operation of veteran cinematographer Caleb Deschanel, ASC into the virtual world. See our interview with director Jon Favreau for more insights about vCam for virtual production animation.

The main components of a virtual camera for animation workflow involve the connection of physical camera controls to the virtual world. In *The Lion King*, the physical camera controls included tripods, dollies, cranes, and drones to provide the point of view and physical interaction for a virtual camera. No actual cameras were needed because the resulting imagery was computer-generated.

In addition to the camera controls, a system of tracking is required, either sensor-based or marker-based. The tracked camera moves can be captured directly into Sequencer. See our interview with Jerome Chen for more information about virtual camera capture.

Performance Capture

Performance capture brings another element of real-world movement into virtual production. Human body and facial movement can make digital characters look more realistic. It's also often more efficient to capture desired movements for characters via performance capture than it is for keyframed or procedural animation.

Like vCam, performance capture requires a level of infrastructure to capture and translate the real-world movement into the virtual world. Body movement can be captured via worn sensor suits or tracked via motion capture cameras within a volume. Facial movement is typically captured with facial markers and often with a head-mounted camera or a mobile device. For more information about performance capture, see our interview with Christopher Sanders.

Remote Collaboration Animation

During the pandemic, virtual production teams leveraged remote collaboration tools to record motion capture sessions without being in the same physical location. Owing to the multi-user capabilities of Unreal Engine, a level can be easily shared between several users, each assuming the traditional roles of camera operators, director, actors, production designer, stage operator, editor, and more.

In this way, animation can be created entirely remotely. Though multi-user workflow was originally developed for use within a LAN environment, it can also be adapted for use across a mesh VPN (peer-to-peer virtual private network). Epic added specific improvements to this remote workflow in response to observations and requests made during lockdown periods. Unreal Engine is also well suited to integrate into pipelines with other DCC applications such as Maya and Houdini, and other Alembic and FBX-capable applications. For additional information regarding remote collaboration and animation workflows, see our interview with Edward Quintero as well as the one with Jason Chen, and this blog entry about new production workflows.

Traditional Animation

Real-time rendering and a centralized hub for all aspects of a scene make Unreal Engine ideal for traditional animation workflows as well. Unlike DCC animation applications, Unreal Engine offers the advantages of high-quality image rendering and real-time game engine technology throughout the development process, which encourage experimentation and iterative development.

Shifting from a traditional animation pipeline to a real-time pipeline may not require major personnel or equipment changes. In general, Unreal Engine requires a reasonably powerful desktop CPU with a modern GPU to deliver peak performance. Many animation studios have discovered that they already have the necessary technical infrastructure.

While you might already have the equipment, additional training is often necessary for animators transitioning to a real-time workflow. However, the conceptual basis and workflow can feel familiar to most 3D artists, though with less compartmentalization. Instead of focusing on a specific area such as modeling, layout, look dev, lighting, or compositing, Unreal Engine artists can be generalists and take on more shot production. There is less time waiting for renders and more time working with high-resolution assets full of detail, much earlier in the process. For more information about traditional animation and Unreal Engine, see our interview with Mark Osbourne and the one with Dane Winn.

> **"**
> As our filmmakers and artists have moved to at-home environments, virtual production has allowed for a whole new creative collaboration level.
> **"**
>
> Girish Balakrishnan
> Director of Virtual Production
> Netflix

Interview
Real-Time Animation - Jerome Chen

Jerome Chen is an Academy Award-nominated senior visual effects supervisor at Sony Pictures Imageworks. His credits include **The Polar Express**, **The Amazing Spider-Man**, **Suicide Squad**, **Fury**, and **Jumanji: Welcome to the Jungle**. Chen also directed "Lucky 13," an episode of the Netflix animated series **Love, Death & Robots**.

What projects are you using Unreal Engine for?

Jerome Chen: We're using it for an episode in the second season of *Love, Death & Robots*, the Netflix anthology produced by Tim Miller and David Fincher. The episode is all CG in the style of high-end game cinematics with human characters and creatures. Our front-end workflow involves Maya, ZBrush, and Houdini, but the commitment is to try to stay in Unreal Engine as much as possible and break out where it makes sense. This is our first foray into Unreal, and we're very excited about the possibilities.

What led you to Unreal Engine versus your more established visual effects pipeline?

Chen: I've had an interest in real-time technology for decades and tried to introduce it into visual effects for features and animation. I've known Epic's David Morin for a few years, and we just started talking more and more. When *Love, Death & Robots* came around to me, it was a perfect opportunity to try Unreal Engine and see what it offered. I had no experience with it before this, other than seeing some very compelling demos and videos.

And has Unreal Engine lived up to your expectations?

Chen: It's definitely lived up to the hype as a very powerful and deep set of tools. The project we're doing is pretty ambitious, even for Unreal Engine. So, we're going to finish it first and then do a postmortem and find access points for the engine in our pipeline. Ingesting Maya animation into Unreal for high-quality lit dailies is one of the first things that comes to mind. There will be many opportunities that will make themselves available after we've delivered and performed a postmortem of the process.

**Did you need Unreal Engine specialists, or was it possible to work with in-house artists?**

Chen: Given the time frame, we did a poll of our in-house artists to see who had used Unreal Engine before. It turned out we had probably two dozen people with experience using it at other companies for games and animation. They're now on the team for the project, and we also have very close support from Epic to help us along our journey.

Did you need any significant equipment upgrades to implement Unreal Engine?

Chen: We assessed with Epic and our systems and engineering group, and luckily, there were only a couple of minor changes needed. We updated our graphics to RTX cards and added some larger, solid-state drives. It wasn't that different from what the systems group was already intending to acquire.

How does the real-time mindset compare to traditional computer animation?

Chen: The techniques and the knowledge set are perfectly applicable, but the workflow is completely different. Everything works in parallel and then merges itself into the engine, which helps each step of the production be much more successful. In a more traditional serial pipeline, you do your animation before assets are fully done, and you do lighting after you approve animation. Your effects come after you approve animation.
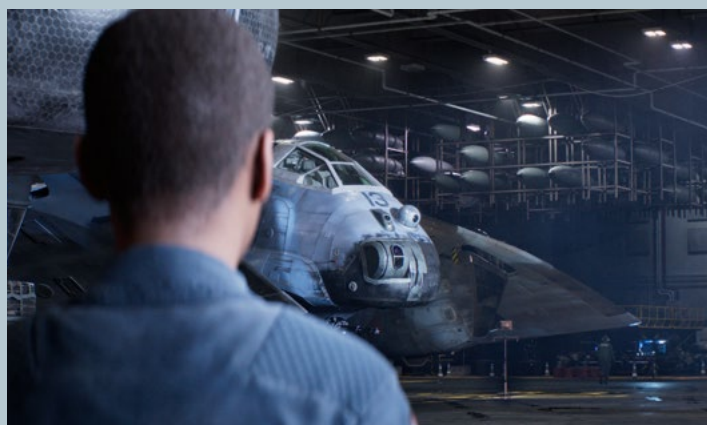
Images courtesy of Sony Pictures Imageworks

We become myopic at each step in a traditional pipeline. In the Unreal Engine real-time workflow, things merge much earlier. You're able to see animation in your environment with lighting happening at the same time. For creative collaboration and decision-making, that's one huge difference.

What do you see driving the increased interest in Unreal Engine for visual effects?

Chen: It has to do with a curve of maturity. Everything that Epic has done through the years, culminating with *Fortnite*, has given them a tremendous amount of resources and allowed them to reinvest back into the engine and now really make it available to people. I also see a concentrated effort to get knowledge about it out there.

Do you have any career advice for aspiring artists?

Chen: The traditional fine arts and theories about cinema will always be true. This technology enables you to do amazing things, but the roots come from the traditional core understanding of composition and light and all the theory dating back to the Renaissance days. You can't shortcut that when you begin your foray into the creation of synthetic imagery using digital tools. These tools always evolve, but your core artistic understanding needs to be based on tradition.

Has the need for remote collaboration affected your workflow?

Chen: Absolutely. I started this project during lockdown, so pre-production was all done virtually. I'm in Los Angeles, my team's in Vancouver, and yet I'm in the engine with them eight hours a day. Whether we're doing modeling or environment review, I go into Unreal Engine with the artists. If I need to move something around inside the engine, I can manipulate objects and adjust parameters. The collaboration has been almost transparent and very productive.

You can also give a client or any person an executable file to review, and they don't need Unreal Engine. They launch the executable, log in to an IP address, and we're in an environment together. The studio gets a very immersive experience reviewing an asset, and they love it. That level of collaboration is very interesting, involving the remote participation of reviewing work in progress.

Do you foresee sticking with Unreal Engine and real-time technology for future projects?

Chen: I don't intend to go back. The speed you can work at in terms of visualization and decision-making is world-changing for me. It's easy to embrace, and comes down to how inventive you are about designing new workflows embracing Unreal Engine. If you're not using real-time, you're behind the curve.

The render farm workflow is not going to go away, but having real-time in parts of your process is going to become a necessity for a variety of reasons. We're going to be adopting new habits and workflows. Because everyone's not able to work together for the time being, not implementing real-time will slow down your decision-making process. It's not just the real-time tools that make Unreal Engine so powerful, it's also the collaboration tools that allow us to work virtually.

Our project also involves performance capture, and we're recreating the likenesses of some of the actors. For the performance capture sessions, I'm going to be driving the real-time characters so we can visualize it with the sets for the actors. They'll be in a performance-capture volume, but they'll see themselves as soldiers in an Afghan tunnel system.

That type of visualization will enhance their performances and give them ideas they might not have thought of otherwise. That's very powerful and compelling. It's going to have a significant impact on how we do things in ways that we're not even fully aware of yet. People may not be able to articulate exactly how it will affect the way we work.

I compare real-time to a finely tuned hot rod. It runs great, and it's amazing, but when it breaks, it's often due to something obscure. By comparison, the images Unreal Engine makes are amazing, but it can also be technical. For me, that's balanced out by its performance, the results you're getting, and the shortcutting in the creative process it offers.

Interview
Performance Capture Animation - Edward Quintero

Edward Quintero is the owner and creative director at Mold3D Studios. Mold3D focuses on real-time virtual production, animation, VR, and video games. He also worked at DreamWorks Animation and Industrial Light and Magic. Quintero's credits as a digital artist include the **Matrix** sequels, **Iron Man**, **Transformers**, **Hellboy**, **The Croods**, and **Avatar**. He worked remotely during quarantine on **Slay**, an in-house short animation project for Epic Games.

Describe the development process for your animation project.

Edward Quintero: I became involved with virtual production at Fox VFX Lab, where I headed up their virtual art department. We used virtual production with Unreal Engine to drive animated characters and help the director visualize scenes. I saw the vision and opportunity of studios using Unreal to create animated shots from start to final pixel.

I wanted to push more in learning, so I pitched Epic an animated short combined with educational training. It's a challenge to find experienced UE generalists, so the idea was to inspire artists and kick-start their Unreal Engine experience.

The final version is not much longer than a minute, but we're doing the whole pipeline, including concept art, storyboarding, previs, lighting, effects, and motion capture. There are two main characters and some keyframing and cleaning up with mocap. We're also talking about using the new hair system.

We're designing the sound from the foley effects to the music, so it's a self-contained, animated, short cinematic. It features the character from the Lumen demo for UE5, which Mold3D had a hand in developing. We created many of the statues, buildings, and props, and helped out with some of the design work. It was nice transitioning from that project to continue the adventures of the same character.

Is it challenging to optimize complex models for real-time performance?

Quintero: The approach is very similar to how 3D models are optimized for video games for current-generation workflows. First, the artist creates a high-resolution sculpt, which must be optimized into a lower-resolution mesh. The details are baked from the high-res model to the low-res model in the form of normal maps.

This workflow could soon be changing. Everybody online is buzzing about the UE5 demo and how it could be a game changer for creating assets. The hope is a shift towards flexible workflows where the artist worries less about polygon counts—enabling more focus on the artistry.

Are you also modeling within Unreal Engine?

Quintero: We do some of our modeling work in Unreal Engine, mostly environment / landscape work. For characters and props, we use third-party applications and photogrammetry. Our photogrammetry team scans real-world objects and cleans them up for set-building in Unreal. Photogrammetry-based asset libraries such as Quixel are also essential in helping us create convincing environments.

Can you describe your mocap workflow?

Quintero: It starts with a storyboard and then previs, which informs the mocap team. However, the beauty of virtual production is giving the director the freedom to create new shots on the fly or come up with happy accidents while you're on set. You are visualizing a shot, but you're able to make changes and discover things that you might not find otherwise if you're constricted to locked-down previs.

What's the typical hierarchy of a virtual art department (VAD)?

Quintero: The VAD is in charge of all the assets that create the environments and characters. It's usually a combination of asset builders and Unreal Engine generalists who have experience in video games or visual effects and animation backgrounds.

The hierarchy is still evolving, and our team is continuously learning new tools. For artists who want to be involved with new, upgraded technology, this is a good place to be. I've been working in the 3D entertainment industry for 20 years, and this feels like a new and exciting chapter in my career.

Do you get the sense that more visual effects studios are incorporating a real-time pipeline?

Quintero: If you go online and look at job postings, you see most visual effects houses are looking for real-time artists. They are actively researching and getting involved. At the very least, they're doing R&D or experimenting with short projects to help them figure out how to implement Unreal Engine into their film VFX pipelines. They're using it in different contexts, such as AR or VR games. There are many different avenues to add Unreal into existing toolsets.

How has the need for remote collaboration affected your workflow?

Quintero: Our animation project wasn't intended to be done remotely, but COVID-19 hit a couple of weeks before we started production. It seems like we're going to finish production while still in lockdown. Creating content remotely and virtually in Unreal Engine is possible, and this project is proof.

Unreal Engine enables a remote pipeline that we wouldn't have tried to attempt for another couple of years. We're pushing it now out of necessity. This shift to remote work is helping to fast-track the groundwork for collaborative 3D projects that can be done outside the physical studio workplace. Necessity is the mother of invention.

How do you see real-time animation evolving in the future?

Quintero: The next logical step, in my opinion, is building assets that can be utilized in more than one medium. Take our project as an example—we're building assets for an animated short, but in theory, you could leverage those assets and use them to create a mobile game or an interactive VR experience. The goal is to be smart in how you build content to leverage it in different media.

Remote Collaboration Animation - Jason Chen

Jason Chen is Head of Digital at BRON Digital, a feature animation studio leveraging virtual production and remote collaboration. Chen's credits include **Avatar**, **Jojo Rabbit**, **Real Steel**, **Star Trek: Into Darkness**, **Bumblebee**, and **Thor: Ragnarok**.

Where does Unreal Engine fit into your workflow?

Jason Chen: On *Fables*, our current project, we have a virtual art department based mostly in New Zealand. We have our animation lab and environment design team in Vancouver. Then all the creatives, the director, myself, and a lot of the mocap performers are in Los Angeles, and we're all working cohesively in one little virtual box.

We're embedding Unreal Engine from the early stages of asset creation, look development, and character design through final render and delivery. We're taking experience from live-action virtual production workflows and traditional animation workflows, and combining them into this fantastic pipeline. We're also bringing live-action industry professionals such as Ra Vincent, the production designer of *Jojo Rabbit* and *Thor: Ragnarok*, and having them guide a virtual production team through their prep.

Virtual production and game engine technology have been in my blood since the beginning of my career when I worked on *Avatar*. It's really exciting to see how it's progressed, and I can't wait to see how it progresses for the future. Just seeing what's possible in UE5 is remarkable.

And everyone works from home, even the mocap performers?

Chen: The performers we hire are veterans in motion capture and also technical people who understand the medium. We're able to send them an Xsens mocap suit in a Pelican case with a laptop. They're capable of putting everything on, calibrating, and syncing up. I'm doing virtual cameras in my living room and able to cover an entire scene in two hours.

We're also working within Perforce and able to update assets on a 24-hour basis, with teams all around the world. It's almost more efficient than just a singular team in one spot. Work is consistently getting updated, things are being built, and you notice new updates every day.

What is causing the industry to push into real-time animation?

Chen: I worked at ILM for a while and was there when Kim Libreri transitioned to Epic. He has such vast experience in visual effects and the techniques that create stunning visuals, that his contributions to the engine have really brought it to the next level.

My goal is also to integrate motion capture techniques and get that base layer of performance because it's so valuable. The tools are getting better and better. We can do virtual cameras in our own home now, and thinking back to 10 years ago, we would need hundreds of thousands of dollars to get a system up and running. It's really an exciting time to be in this next wave of content creation.

How do you manage assets to be performant in real time but still have high image quality?

Chen: There's a balance. You could have millions of triangles in a single model, but with a combination of materials, shaders, textures, and displacement maps that the engine provides you, it doesn't matter. You can optimize and make it still look fantastic, where you can't perceive the difference between a model with a billion polygons or a hundred thousand.

Skeptics are trying to find the catch with real-time. The engine is living, breathing, changing, and evolving. It's on its way to being the be-all-and-end-all solution, but you have to work at it. The iterations happening now are a combination of so many people in the user base, all contributing to it and helping it to grow.

Is it challenging for creatives who are not highly technical to contribute to virtual production?

Chen: It's intimidating the first time around, but once you bridge the gap and say, "This is a location scout, this is a camera, and this is a lens," you can make them feel comfortable. On *Fables*, one of our directors had used his first green screen a month before quarantine, and now he's directing an episodic show entirely within Unreal Engine.

> **"It's an open-source community where you can find people pushing the limits of Unreal on a daily basis."**

As the supervisors and producers, we need to help guide them, because at the end of the day, filmmaking is filmmaking. We're still going to have a medium shot, a close-up, and a wide. Unreal Engine gets us back to the core of filmmaking and allows the creatives to be more exploratory.

How has the need for remote collaboration affected your workflows?

Chen: There's a massive shift in mentality because of the state of the world. The idea of choosing remote collaboration seemed too good to be true, but now people realize it works because they are literally forced to understand it. Now that we're able to work from home, it opens up an entirely new thought process because we can pick the best people from around the world to contribute to a project. We're in three countries right now, and we're pushing through a pipeline that's never been shaped in this way before.

Is real-time a paradigm shift for visual effects, or more of an evolutionary step?

Chen: It's a combination of both. Within the visual effects industry, it's a monumental shift, but our job as professionals is to make the transition seamless for the general public. The images will get better because it's been happening for a long time, but always in the background.

Once gaming technology and virtual reality become cool, the public will feel the shift more directly. For the longest time, computers were not seen as something cool until the iPhone came out. Now everyone, whether they like it or not, is a tech person.

Do you have any suggestions for someone interested in a career in virtual production?

Chen: The beautiful thing about Unreal Engine right now is that everyone, from 20-year veterans in the visual effects industry to college students just graduating, is on the same level field. People who want to get into this industry should go online and start learning. Epic has done such an incredible job of making information available. It's an open-source community where you can find people pushing the limits of Unreal on a daily basis. So, my advice is just to do the homework, because we are all doing that right now.

Where do you see Unreal Engine evolving in the future?

Chen: I feel that the engine will evolve into not only a tool that is used by technical artists, but one that creatives of all ages and skill sets can utilize to help realize their unique visions. World creation is the next step, and when creating worlds, it's important to remember the 100-plus years of filmmaking skills and tools that helped shape the visual language of film and television. Preserving these looks will be extremely important as we move forward in this digital world.

We would love to incorporate distortion maps and lens grids from all types of lenses (anamorphic, spherical, macro) that were around since the *Ben-Hur* days and are still consistently used on movies like Scorsese's *Goodfellas* and J.J. Abrams' *Star Trek*. We need to preserve them for the engine so we can replicate those looks. Having my roots in traditional VFX, I understand the importance of those distortion maps because each lens is unique and has its own character. Unreal Engine will allow us to capture the best practices of traditional filmmaking and push them forward for the new generation.

Interview
Animation - Mark Osborne

Writer, director, producer, and animator Mark Osborne's stop-motion animated film **More** won a Special Jury Prize for Short Films at the 1999 Sundance Film Festival. His credits as a director include the live-action sequences of **The SpongeBob SquarePants Movie**, **Kung Fu Panda**, and **The Little Prince**. Osborne is currently using Unreal Engine to develop a new and versatile collaborative virtual filmmaking pipeline called CoLAB.

What sparked your interest in real-time animation?

Mark Osborne: Before I fell in love with stop motion, I was doing live action. I was making a lot of films quickly on video just to learn, and was learning animation at the same time. Now, I'm falling in love with virtual production as a way to bring spontaneity into making animated movies.

We're building a process where we can bring in traditional animation and see it within a virtual set. We can iterate lighting and just keep building a movie. I want to create the kind of creative collaboration that's hard to achieve in animation but comes easily in live-action filmmaking.

Your film *More* packs such an emotional punch. How did you create that intensity?

Osborne: It starts with the storyboards, and the music really does a lot of heavy lifting in that case. There's a certain amount of planning put into everything. When I found myself animating on set in super slow motion, I was able to get into the performance aspect of it. I had to reconceive shots and ideas because of technical limitations.

I learned a lot in that process that I can apply in other areas, like what we're doing now in the collaborative virtual environment. Making a movie is a very fluid process of discovery. You have to build on what you're learning.

As you've worked on larger projects, did you use virtual production tools such as previs?

Osborne: When I joined *Kung Fu Panda*, I'd never worked in CG before and I wasn't sure if it was going to be a fit for my process. I found I didn't actually have to get my hands dirty in the tools of making that movie. I was able to just think and work like a director and it was quite liberating.

As we got deeper into the process, I learned more and more. I loved previs, storyboarding, and anything that allowed us to explore the cinematics and editorial, where the movie really comes together. We rewrote the movie as we played with the actors' voice improvisations and constantly evolved it. New ideas popped up from all the different artistic points of view to help solve problems with the story.

> **"**
> It's all about collaboration and cross-pollination with as many departments as possible, as early as possible, so everybody's working together in an inexpensive and low-risk environment to help tell the best story.
> **"**

The Little Prince was very complicated because I was essentially thinking about CG in the mornings and stop-motion in the afternoons. It was two entirely different processes, but that got me ready to want to do more of a mixture. I wanted my CG keyframe-animated characters to show up virtually in real sets so I could look through the lens and see them.

That's now evolved to where we're bringing keyframed animation into Unreal Engine and developing the environments and the lighting as we're developing the cinematics. We're in a very low-risk environment that is incredibly versatile and allows for a lot of collaboration. I'm also a huge gamer and am so in love with how amazing games look these days. I'm looking to combine all those things to allow that creative process of discovery.

We're now talking about building sets, scanning them at super high-res, and simulating them in a virtual environment. Then we can have even more freedom and not be tied to a plate shoot. We're talking about using Unreal Engine to fully achieve our background plates. Depending on how the characters develop, if we can render everything in-engine, it would be unbelievable.

Lip Comarella (L) and Mark Osborne (R) collaborating in Unreal Engine. Image courtesy of Rhea Fischer

How does this compare to traditional animation development?

Osborne: The traditional way that CG animation is done is based on the 2D process. I think that's really hampered things and created a siloed situation. Unreal Engine provides an environment where creativity can flourish in a unique way. This is giving us an opportunity to bust open and reconfigure the traditional CG pipeline. It's all about collaboration and cross-pollination with as many departments as possible, as early as possible, so everybody's working together in an inexpensive and low-risk environment to help tell the best story.

There are so many learning experiences I've had along the way, like the last sequence we animated on *Kung Fu Panda*. An animator came to me and said, "When I saw this sequence fully lit, I realized I would've done something different emotionally with the character, had I known what it was going to look like." And that always killed me because if that animator had that information, the sequence could have been even better.

How has the current era of remote collaboration affected your process?

Osborne: We were already stressing out about the logistics of building our sets and doing plate photography when COVID-19 hit. Then we started talking about going virtual, but we were more practical in how we approached it. A single model maker can build a model on their own and we can scan that in and make a digital duplicate.

This process we are working on will allow people to safely and collaboratively plan any kind of movie. If we can fully execute within the same environment that we're planning in, that's a dream come true. It used to be when you previs, you'd throw it all away and start over again when you moved into production. I want to be able to rough-make the movie quickly and have it come more into focus over time. This is a great opportunity to develop these tools so that if we have to be working from home, we can do it effectively and efficiently.

Is it challenging for creatives trained in traditional art to transition to virtual production?

Osborne: It's definitely not for everyone. I love being in a headset because it's the closest that CG ever has felt to being on a real set, but where I have much more flexibility to navigate in my set and change scale. Not everyone has to go deep into virtual space to use this pipeline.

I've been working with Ken Duncan, who was a traditionally trained 2D animator, and he does phenomenal work in CG. I don't know if he ever wears the headset, but that doesn't matter because I can bring the work that he's doing into Unreal Engine. We've also got model makers physically building models and they'll never have to look at the virtual version.

Do you find yourself working more with visual effects artists or game engine developers?

Osborne: My producer Jinko Gotoh and I have been dreaming about this for a while, and we started talking about it with all the different animation houses and visual effects companies that could potentially partner with us. I was really inspired by how they made *The Jungle Book*. We started talking directly with Girish Balakrishnan, who was the mastermind behind that. He was the first one to make us feel like we weren't crazy. I was pitching that we could bring a lot of how *The Jungle Book* was made into CG in an interesting way.

Then we started working with Rhea Fisher, who was coming off all the amazing development that was done for *Mouse Guard*. We weren't interested in the mocap aspect but we were interested in everything else. Rhea immediately lit up and started pulling in the coders and sandbox developers we needed. We started working with a New York-based company called Parallux, which was breaking ground in the field. We've held to this idea that the best pipeline development is going to come from the actual creation of a story. Now we've got all these really interesting thinkers and geniuses helping us, and it's great.

Do you have any career advice for someone interested in animation?

Osborne: The most important thing is to find your voice as an artist because tools are going to change. When I started out, I was able to tell a story that was strong enough and it gave me the opportunity to work with artists that were way better than me at every aspect of all the other crafts necessary. A voice is what I look for most in any artists that I'm hiring.

I treat everybody on the team as a filmmaker because we're all working together and making the film come to life. If I look at an artist's reel and see them having a point of view and telling a story, then I know I can engage them on more than just a technical level. I want to talk about story with everybody.

When I made myself vulnerable and made the process of telling a story like a sort of therapy for myself, I was able to connect on a human level with my work. I discovered that you can be universal by being very specific to your own feelings. Allow yourself to be vulnerable and find those things within your own experience that are important to you.

Where do you want the technology to evolve next?

Osborne: The more it can engage the free flow of ideas between creative artists, the better. We were working with this amazing tool called Gravity Sketch where you can quickly build out an environment and characters. We got this incredible artist, Emanuele Pavarotti, doing amazing things with it. Then, we discovered you can have ten users at once in a session and I was salivating at this idea that we could go a step further and collaborate together.

I'm excited about the future and feeling this tremendous growth as the tools get smarter. When I saw the Unreal Engine 5 demo, I became so excited about the possibilities. I never knew that I wanted billions of triangles and now I'm so happy that it's within reach.

Interview
Animation - Dane Winn

Commercial animation director and 3D generalist Dane Winn works at Blue Zoo Animation Studio in London. His credits include commercials for **Pup Hero Adventures** and series work on **Tree Fu Tom** and **Miffy's Adventures Big and Small**. Winn also recently directed **Ada**, a short film rendered entirely within Unreal Engine using an evocative graphite pencil sketch style.

What led to the creation of *Ada*?

Dane Winn: It was born out of the short film initiative at Blue Zoo. The brief was to tell a true story using a real-time game engine. I was also interested in telling a survival story and found there weren't many true stories like that about women in animation. I came across Ada Blackjack's story and it was pretty amazing.

What was the impetus behind creating in Unreal Engine versus a traditional animation pipeline?

Winn: We were really keen to experiment and see how fast you could iterate in real time. The appeal was we could manipulate the lighting and not have to wait for overnight renders. Our concept art was quite 2D and in a graphite style that felt appropriate for the story. That was a real amalgamation of comping, lighting, and shaders. Unreal Engine let us dabble with all the different areas at once and see the images in a way that we can't normally.

Did you achieve the style via built-in parameters or did it require external plugins?

Winn: We wrote a lot of tools using Blueprint and I think also some C++. It was really interesting because I had no idea how much we could do in camera. Most of the shots are designed in a static way and we used focal lengths to add a more two-dimensional feeling. We could also create

smudge masks around the edges of the character and do all this interesting stuff that I don't think we could've really done in Maya.

Do you expect to use Unreal Engine on future projects?

Winn: Yes, we've already started using it on some client projects and we're trying to use it more and more. New features like ray tracing have changed the game because we're now getting the same results that we could get with an offline renderer. Every time we get a new production in, we're trying to see whether Unreal Engine is right for it. It's more about being prepared pipeline-wise before we go too big with it.

Does having everything available in real time cause a shift in mindset with artists accustomed to traditional animation?

Winn: Totally—we changed our mentality from being lighters, compers, etc., and we started referring to them as Unreal artists. It was really a case of being more of a cinematographer and using all the different artistic aspects at once. Traditionally, we would be rendering passes and handing those off to a compositor who wouldn't necessarily be working with the lighting.

With real-time, you're seeing it all at once and whatever you plan to composite, you're integrating it right then and there. We were also really keen to restrict ourselves to just using Unreal Engine to produce the final frames. We didn't even color grade externally. It was entirely captured straight out of Unreal to test how far we could take this pipeline.

We still did the animation and asset creation in Maya, but as soon as we were up to polishing shots, we'd go into Unreal Engine and deal with all the materials and produce the final frames and effects. Everyone felt like it was very liberating to see how each element was going to affect the next. We'd change textures on characters and see how that's going to affect the post-processing of the comp stage at the same time.

Image courtesy of Blue Zoom Studios

### Were you able to take advantage of multi-user access to the same project?

Winn: We used Perforce, so we could all be working on the same Unreal project at once, even if we weren't all in the same scene. You could be working on the lighting and someone across the room has just updated the snow and now you're seeing it in your scene. That was really exciting and it was very nondestructive. Normally, there's a lot of communication within the pipeline just to know what stages people are at. Whereas Unreal Engine is more like, "I'll just keep working on these textures and I'll publish them." Then suddenly your textures just pop in for the lighter—it was nice having that kind of workflow.

Unreal Engine, as a game engine, comes from the software development concept of parallel contributors. Does that translate well to animation?

Winn: Normally we are in more of a linear pipeline. Whereas with this, we can start lighting as we start animation. Budget-wise, it may be about the same, but time-wise, you probably cut it in half because you're working on top of each other. That's quite a nice benefit.

Were you able to leverage existing hardware?

Winn: Yes, we had quite a lot of decent GPUs to start with because we have been using Redshift for rendering. We've invested in some of the NVIDIA TITAN RTX cards to handle
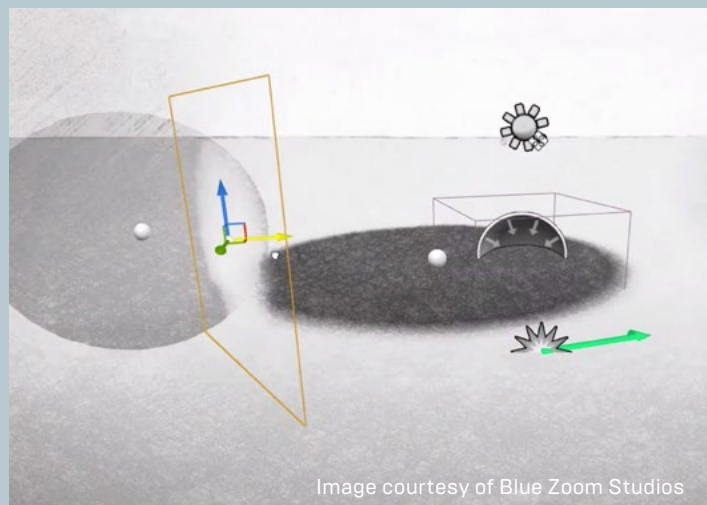
ray tracing on current projects. For *Ada* we used features like cascaded shadow maps, and we were able to get way more with the graphics cards we were already using.

What sorts of additional tools would help you in Unreal Engine?

Winn: Rigging is the main thing. Epic's already started introducing their own tools for rigging and for animation, which is exciting. Rigging is the main thing I think about because you can model in all sorts of programs and you can animate in different programs, but that stage of creating tools and controls for the animator that translate is so crucial.

Do you expect to have both real-time and traditional animation pipelines for a while at Blue Zoo?

Winn: The commercial area is probably going to get real-time first because the projects are on a shorter turnaround. For major productions, everything's got to be airtight and the assets have to work perfectly across a whole year's worth of episodes. For commercials, we've got a little bit more room to experiment and try new tools and not worry too much about the greater pipeline. That's why we're trying to introduce it in those projects. Then slowly, maybe that will leak its way into a major production when we feel like, "Okay, we've got enough understanding now of what goes into this and we know what we need to change."

CHAPTER III

Additional Applications and Opportunities

If you've read the guide this far, you should have a thorough understanding of the many different kinds of virtual productions and have gained insights from a lot of firsthand experiences. We hope you've found this intriguing and eye-opening in terms of the scale and breadth of opportunities. All of this is to state the concept: there's nothing to it but to do it.

Anything you can imagine, you can make with a game engine. Everything is made possible by an engine's flexibility when you treat it as a creative nexus instead of a simple render portal. Because you can see your vision at high quality from inception and within a shared, open environment, you can live in the image instead of just planning for it.

In this chapter, we'll look at some of the additional applications and opportunities created by the Unreal Engine virtual production ecosystem. These opportunities include companies that support virtual production needs, such as systems integrators and on-set service providers. The opportunities also include complementary services such as indie plugin and app developers, virtual backlots, and asset creation and optimization services.

Application: Virtual Production for Indies

When we talk about indies, we're referring to both independent game and app developers, and to filmmakers. They are creators coming from the same basic background of working on their own creative time without a major studio or investor's financial backing. It's often challenging to be an indie because you have to support yourself, but you also get the satisfaction of calling all the shots.

Many successful game developers and filmmakers were indies at the beginning of their careers. They ultimately earned the support of a game company or filmmaking studio based on the merits of their indie efforts. If you're looking for a way to break into the gaming industry or the movie business, being an indie is a great way to start.

Components

Unreal Engine

Unreal Engine itself is well suited for both indie developers and indie filmmakers. Because the software is free to download, it's easy to learn and experiment with. Epic offers a free, 15-hour online learning path called the Virtual Production Primer. Furthermore, the Unreal Marketplace contains high-quality assets and Quixel Megascans you can use to quickly start projects. The ecosystem is cost-effective and there's a vast community of fellow indie developers and filmmakers whose brain trust you can tap into.

Departments and Roles

Indie Developer

The developer world for Unreal Engine is truly vast because it includes an indie game and app development community in existence for more than twenty-five years. You'll find plenty of resources and examples of games and other apps made with Unreal Engine. Recently, the world of virtual production and indie app development has overlapped. Filmmakers have developed their own applications that leverage Unreal Engine to assist with some aspect of filmmaking.

Indie developer examples include Matt Workman's Cine Tracer app, which is designed as a cinematographer's storyboarding and planning tool. Another recent indie developer example is Pathfinder from The Third Floor, which offers virtual scouting based on real-world locations. Glassbox's Dragonfly is a third example of an indie developer tool designed to leverage Unreal Engine for virtual production workflows.

Indie Filmmaker

As a tool for indie filmmakers, Unreal Engine effectively levels the playing field by providing access to technologies previously available only to high-end filmmakers. The impact is arguably even more profound than the widespread availability of digital cameras and editing technology. When factoring in all of the available creative content and assets, you're only limited by your imagination when creating with Unreal Engine.

Some recent examples of indie films created with Unreal Engine include the award-winning student sci-fi short film Adam and Eve Mk.II directed by Sebastian Kuder. Another example is The Pantheon, a fantasy action short film directed by Han Yang. You can see more work in the Spring 2020 Student Showcase. Indie filmmakers can leverage all of the traditional cinematic techniques—including lens choice, depth of field, camera movement, lighting, sound effects, music, and dialogue—to create indie movies without even stepping foot on a set.

Interview:
UE Developer - Matt Workman

Matt Workman is a cinematographer and founder of the Cinematography Database. His credits include a variety of music videos for artists including Justin Bieber, 50 Cent, and Diddy as well as commercials for clients such as Google, Facebook, and BMW. He developed Cine Tracer, a planning and visualization tool built in Unreal Engine. Workman also explores and teaches virtual production and Unreal Engine workflows via his YouTube channel, Cinematography Database.

What are some of the key developments in Unreal Engine for the indie developer world?

Matt Workman: We're building from the ground up with the context of trying to determine the lowest entry point to get into virtual production. Something that really helps is the HTC Vive and Valve SteamVR ecosystem, which essentially is doing tracking for us. We're able to get it up and running using just consumer VR equipment. That's the cornerstone tech piece that allows pretty much anyone to get into real-time camera tracking without it costing an exorbitant amount of money.

I also consider Blackmagic Design as a key partner moving forward with affordable cinema cameras like the Ursa Mini Pro G2 and 12K. They also make video I/O cards like the DeckLink 8K Pro, which are necessary to get footage into Unreal Engine, and the Ultimatte 12, which is the industry standard real-time hardware keyer. Blackmagic Design also makes control panels, which is a big deal, as I see virtual production for DPs and directors where you never touch a mouse or keyboard.

Lens data protocols like Zeiss eXtended data are also going to make everyone's lives much easier. The manufacturer calibrates them, and we get real-time data regarding focus, iris, zoom, lens shading, and very importantly, distortion values.

What about the software side?

Workman: The render quality of Unreal Engine is what sold me on dedicating almost three years of my life into this ecosystem. When they updated the circle bokeh in 4.20, the images started to look like they were photographed with real-world lenses. The ray tracing is really fast with reflections and bounce lighting since 4.25, which makes the lighting feel more realistic as well.

How has the need for remote collaboration affected your work?

Workman: In 2020, the film industry had more time at home to learn both Cine Tracer and Unreal Engine. The quality of work from both user groups have increased quite a bit, which is amazing to see.

Images courtesy of Matt Workman

I've also been working with Art Directors Guild (IA 800), who have fully embraced Unreal Engine as the place to collaborate with VFX and the camera department. They're developing their standards when working in Unreal Engine and I'm in touch with them to make sure Cine Tracer and my Unreal systems stay in sync. Developing industry standards is especially important for remote collaboration, so everyone can work on the same project seamlessly.

What are the challenges in remote workflows?

Workman: Unreal Engine has a feature called Multi-User Editing where we can have multiple computers working on the same Unreal project. It's like a big *Fortnite* game, but within the full Unreal Engine. We can have an actor in a mocap suit broadcasting their actions, a cinematographer finding the camera angle, and the art department tweaking the set all at once.

Doing this remotely requires a VPN and it's currently a very technical setup process. I believe this will get easier over time and it's the direction where a lot of virtual production is headed. Professional remote virtual production crews will need fiber internet connections to be able to make this workflow viable.

What are your biggest challenges as an Unreal Engine developer?

Workman: Unreal Engine is lovely, and it's updated and improved so quickly that sometimes I can't keep track of the changes. One of my jobs is to keep Cine Tracer up to date and getting better, which means rolling in the newest updates, like the ray tracing and the new sky system. That's a good issue to have, just implementing the new features into my software and learning them.

One of the things I've done throughout learning Unreal Engine and doing software is to be very open about it. I share what I'm working on and the issues I encounter on YouTube. I have a Facebook group where I specifically surround myself with people who know more than I do about different aspects of Unreal Engine. For example, DMX lighting recently got enabled with a plugin, so we can control real-world lights from Unreal Engine. I don't know anything about that, but others in the group do.

Do you have any suggestions for someone interested in a career in virtual production?

Workman: Virtual reality is a fun way to get into virtual production. Get a gaming PC and an HTC Vive, and you can get started with Cine Tracer designing 3D scenes and doing virtual camera work. It's a great way to get your feet wet in virtual production if you have no 3D background.

If you have a 3D background, learning how to get assets from Maya / 3ds Max / Blender into Unreal Engine is the first step, and then learning how real-time rendering works to get good-looking images.

As you progress, you'll want to jump into Unreal Engine and start to learn the more professional and advanced workflows for previs and mixed reality. I'd start by getting some free content off the Marketplace and joining the Unreal Engine Virtual Production Facebook group.

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How do you see virtual production evolving over the next few years?

Workman: I'm personally interested in making Cine Tracer a prosumer virtual production platform for filmmakers and creators who want to do previs, mixed reality, and performance capture. Cine Tracer is already being used in film schools around the world and I believe that it will bring more "non-3D" creators into virtual production.

From there, I believe Cine Tracer users will start to learn Unreal Engine for more customization and advanced features that are used on professional film sets. A great example of this already happening is a short film called *Nemosyne*, which is on YouTube. This stunning Unreal Engine film was created by cinematographers Kevin Stewart and Luc Delamare. Kevin was an alpha tester of Cine Tracer and a user of Cine Designer, my earlier Cinema 4D plugin.

In 2020, the film industry really embraced virtual production for its ability to produce content with a smaller on-set footprint as is now mandated in the US. Producers and VFX companies are also looking for ways to virtualize and enable remote collaboration, and virtual production checks that box as well. Whether it's green screen virtual sets or LED walls, we're going to see virtual production in the film industry evolve rapidly over the next few years.

Application: Virtual Production Service Providers

Although the core of virtual production still involves a traditional film crew, it adds new layers of on-set roles and responsibilities that create new opportunities. Virtual production service providers include on-set technical and creative support, virtual art departments, virtual backlots, and virtual asset development and management services.

Components

Asset Management

Much of the work for virtual production service providers involves the creation and dissemination of digital assets. These can be models of characters and environments that may start their lives as development artwork. They might be used again in various visualization forms. Later, the assets might live on an LED wall and be captured in camera or used in live compositing. Finally, the assets may be used again for final animation forms, and even repurposed for ancillary uses such as location-based entertainment, theme parks, social channels, and interactive experiences and video games.

Another important aspect is production data management. Because virtual productions often revisit scenes and environments at different points in their schedule, careful organization and tracking of assets, environments, and settings is critical. Recalling and reactivating these assets and parameters gives a virtual production a level of agility and flexibility that a traditional production could never achieve due to all the logistics involved. As long as you are tracking the production data, you can exactly replicate any scene or environment for reshoots or pickups.

Because each asset has such a potentially long and useful life, there are many new opportunities for service providers. For example, virtual backlot services can offer environments and assets for reuse across many different productions, just like a real backlot. Production designers can also offer digital support services, which extend their traditional set design expertise into the virtual realm. In addition to all the on-set and support roles, there are also opportunities to sell assets directly to end users. Online stores such as Epic Games' Unreal Engine Marketplace and Turbosquid are just a few examples.

Departments and Roles

Virtual Art Department

The virtual art department, or VAD, is an essential part of the virtual production workflow. The VAD's primary role is developing real-time assets from initial look development to production-ready models and environments. The VAD also assures consistency and high quality across all real-time models. It acts as a liaison between creatives and artists to ensure all stakeholder feedback is fully incorporated into the assets.

The work of a traditional art department is generally focused on visual development and pre-production. The VAD is no different in terms of emphasis. The main difference is that the VAD is sometimes tasked with delivering complete, camera-ready assets for production instead of handing off to set building or visual effects departments. With this in mind, the VAD's work may be more involved and intensive than a more traditional workflow and will ultimately handle a larger share of the final imagery.

The VAD is usually one of the earliest departments to begin work on a virtual production. It must account for not only each asset's visual quality, but also for its optimization so that it performs as needed for any on-set workflows. As assets are developed and utilized throughout the project, the VAD is involved in virtual scouting, production, and post-production.

The preparation of assets often involves a cross section of different disciplines. Assets may begin their lives as LiDAR scans or photographic textures, or they may be modeled entirely virtually from scratch. Kitbashing, or the combining of existing models to create new ones, is another popular modeling technique popularized by traditional model makers working with real miniatures. Epic's recent acquisition of Quixel and their Megascans library offers another starting point for creating natural, photoreal environments and assets.

See our interview with Andrew Jones for additional insights into how the VAD collaborates with the other departments in a virtual production environment.

Virtual Production Supervisor

The virtual production supervisor acts as the primary bridge between the physical and virtual production teams. They coordinate both the content and technology to be used by the production. For in-camera visual effects workflows, the virtual production supervisor is responsible for coordinating and delivering high-quality, camera-ready assets as required by the production team.

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The DP will say, "Somebody will walk through here and they're going to need to have a light on them for the story point. So, could you do that?" And we're off to the races right there.

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Andrew Jones
Art Director

The virtual production supervisor also oversees any virtual production technologies such as tracking, performance capture, virtual scouting, or any custom techniques necessary to pull off a specific shot or look. Before principal photography, the virtual production supervisor coordinates the various teams to ensure that once on stage, the filmmakers' time is used efficiently and their creative needs are met.

Once on set, the virtual production supervisor manages both the deployment of virtual assets for in-camera visual effects and the production team's ability to interact with and art direct the content displayed on the LED wall. As production wraps, the virtual production supervisor is responsible for coordinating the handoff to the visual effects teams.

Developer

Out of the box, Unreal Engine includes many features that make virtual production possible in all of its various modes. Sometimes, additional customization or specialized tools are desired to augment what Unreal Engine already offers. The developer service provider role fulfills these requirements.

Developers can interact with Unreal Engine directly through the creation of plugins and visual node-based Blueprint scripts. They can directly edit the C++ source code of Unreal Engine to create modifications or enable new features. Workflow automation can be accomplished via Python scripting or with Blueprints. Developers can also send backend requests into a running instance of Unreal Engine via the REST API.

For example, the director of photography might request the ability to manipulate an LED wall environment's visual aspects, such as the positions of the skies or the overall color tint. These could be controlled manually within Unreal Engine. Or a developer could create a simple, user-friendly iPad app that the cinematographer could manipulate directly.

See our interview with Matt Workman for an example of the developer role in virtual production.

On-Set Service Providers

Elaborate virtual productions involving live compositing, in-camera VFX, performance capture, dynamic scene manipulation, and so on, typically require on-set service providers to operate equipment and supervise stage operations. These support services may include systems integration, IT services, video assist, project management, and performance tracking.

The work includes configuring the stage's display, video I/O, networking, storage, scene manipulation, camera support, and playback needs. It can also involve day-to-day staffing and technical support to keep the stage operating at peak performance and delivering all the on-screen content the creative team needs. Staffing of these support services depends on the specific needs of each production.

See our interview with Philip Galler for more details about the on-set service provider role in virtual production.

Virtual Backlot

Virtual assets are reusable across the various stages of production and from project to project. This gives rise to an industry of virtual backlot services. We've already discussed some of the existing providers, such as the Unreal Engine Marketplace and TurboSquid.

Visual effects studios also have additional bespoke offerings for specific digital backlot needs. For example, Stargate Studios has a growing library of 360-degree footage from a variety of world locations, which can be repurposed into convincing backgrounds for virtual production. Production studios such as Netflix and Lucasfilm have also begun to aggregate assets that can be reused within productions and shared as needed.

Just as prop shops continue to add to their inventories, virtual asset teams continue to build assets. Libraries will grow, and virtual storage costs are less of an issue than with physical assets. As this trend continues, the opportunity for virtual backlot services will expand.

In addition to virtual backlots and asset libraries, opportunities for asset management and optimization also arise. Although a degree of asset optimization can be performed programmatically, there is an art to bringing complex assets in line with the specific performance parameters necessary for real-time performance while preserving their rich visual detail. Interoperability between different DCC applications is another essential part of asset optimization, and is facilitated by emerging and scalable interchange formats such as the Universal Scene Description (USD).

For more information on the prospects of virtual backlots and asset libraries, see our interview with Sam Nicholson, ASC, and the one with Girish Balakrishnan.

Interview:
Virtual Art Department - Andrew Jones

Andrew Jones is a veteran of several virtual productions as an art director and as a model maker. His credits include **The Last Samurai**, **The Polar Express**, **Beowulf**, **Avatar**, and **The Jungle Book**. Jones earned an Emmy Award for his work as production designer on Season 1 of **The Mandalorian**.

Describe the production designer's responsibilities on *The Mandalorian*.

Andrew Jones: *Star Wars* is a known property with its own visual language, aesthetic, and history. We want to take it to new places, but we don't want to change its DNA. We're tasked with creating new worlds and environments, and we're also revisiting places. We reconstructed the Mos Eisley Cantina and tried to be extremely faithful to the point where 20 minutes before shooting, the art director ran in and gashed a big crack in the wall that we'd forgotten. It's an interesting approach for a designer to be faithfully reproducing an existing property.

How do you determine what will be physically constructed versus virtually projected on the LED volume?

Jones: I work with Doug Chiang, the lead designer at Lucasfilm, who's generating the artwork. He's worked with George Lucas for so many years and been part of that whole story. As soon as he touches it, it looks like *Star Wars*, which is cool.

I'm trying to allow the designs to be whatever they want to be. That's a bit easier with the technology we're using. It reminds me of our early motion capture projects, where we imagined what's beyond, and trying to figure all that out in advance.

How do you determine when to texture an asset procedurally versus via photogrammetry?

Jones: Photogrammetry works amazingly well if you do a really good, clean capture and solve. It also captures nuance you wouldn't necessarily build into a bespoke model. Assets made from scratch in the computer still often rely heavily on photography to get good textures.

Do conventional design tools translate well into real-time workflows, or do you need a different approach?

Jones: On this show, it's difficult to work with pencil drafting because of the speed at which we're going back and forth between different levels of design and stages of production. It has to be a swift, fluid process. So, we're trying to use the same tools that the visual effects team is using to go back and forth easily, and lose nothing in translation.

We always had a virtual art department looking back as far as *The Polar Express*. We didn't call it that before, but it's this merry band of creators putting together the virtual worlds. Now we're using Unreal Engine, and our goal is final pixel, so we're very quickly getting right into the film look. I see the VAD just like my physical construction department, which we have running concurrently. We've got painters, sculptors, plasterers, carpenters, special effects, and props in the construction department. In the VAD, we've got Substance painters and ZBrushers and polybashers, and it's all the same workflow.

The two fields cross over quite a lot. The painter, for example, will create a sample for the VAD to match. Or the Substance painter will make a really nice texture, and the physical painter will try to match that. Or the plasterer has some tips for how to get a really good transition from rocks to sand. Both groups can advance in interesting ways and it's very collaborative.

How does Unreal Engine impact your work?

Jones: It feels very natural. I worked on a production in Ireland set 20,000 years ago out in the wild landscape. You'd just go out into the moorland, and there was your set, and you got on with doing the show. *The Mandalorian* feels kind of like that. You get imagery so quickly and so realistically that you're very quickly into storytelling and other late-stage processes without batting an eyelid.

Then there's the mutability of the whole environment. You can relight it, and you can move mountains. And that's kind of an interesting place to be—working with the kinds of concerns we rarely have the luxury of dealing with.

In a physical set, you're building, and you're probably going to deliver the day before you shoot and hope for the best. But now, we're scouting months in advance, and we're saying, "You know what? Wouldn't it be great if we did this?" You work through that stuff, which is cool.

How does your work overlap with the cinematographer's role?

Jones: I've found it to be very collaborative and in a good way. Opportunities arise, and the ability to make
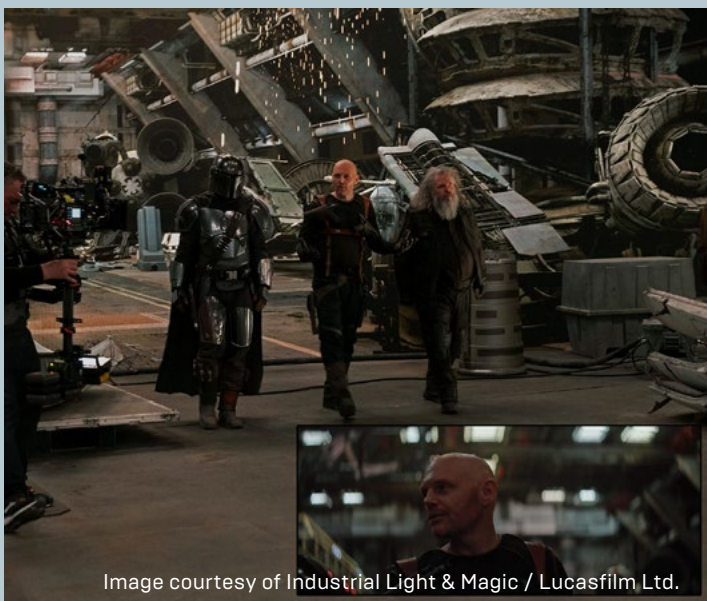
Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

then you had to process the film. So, there was a limit to what you had access to. And now, everybody's got an amazing cinema tool right on their phone with software to process it.

It becomes about the ideas, and that's what virtual production should do at its best. It should make all of these things possible, and if anyone has ideas they can turn them into something.

It's necessary to become fluent with the tools of the trade. Anybody starting out should just jump into this and find out what they're comfortable with. You just need to learn these programs and become good at learning. Once you've done that a few times, you recognize that point where you are having a hard time learning and you know that you just have to push through.

big changes, or even subtle ones, on the stage is great. We're working with the DP so much earlier than we would otherwise, right in the early stages of prep when we're designing a set.

The DP will say, "Somebody will walk through here and they're going to need to have a light on them for the story point. So, could you do that?" And we're off to the races right there.

Rick Carter told me something about Steven Spielberg. Rick designed a number of shows for him and would put lots of things on set for Steven to come in and interact with. He'd see a mirror on a wardrobe, and a whole sequence of shots would emerge from just this chance encounter.

That happens in virtual scouts if you have it built correctly and have the right tools. You see these opportunities, and you're riffing. And it's happening early enough for it to actually be put into the process and really benefit the production.

What might someone interested in virtual production design or art direction study these days?

Jones: When I was in college, a film camera was a tremendously complicated, expensive thing to obtain, and

So much of *The Mandalorian* was groundbreaking. Were there unexpected challenges along the way?

Jones: Yes, it was absolutely all a crapshoot. The one thing we had was Jon Favreau telling us that we should always be pushing forward, finding ways to make it happen, and not tapping the brakes. There were lots of leaps of faith, and there were a lot of smart people. ILM, Lucasfilm, Epic, and all the other production partners were great confidence builders.

The technology is still evolving, which is why I find it so appealing. A lot of new territory will open up. You just need to be prepared to jump into the unknown and see where it goes.

On an artistic level, where would you like to see the technology evolve next?

Jones: The resolution is getting to be extraordinary, and Unreal Engine 5 is going to be a game changer. The fidelity is improving, and all of the things that are going to make this amazing are being developed and getting better, cheaper, and faster. Animated content, whether that's driven by keyframe, motion capture, or volumetric capture—that's the next grail.

Interview:
Virtual Production Supervisor - Clint Spillers

Clint Spillers has experience as a production manager, production supervisor, and virtual production supervisor at Weta, Digital Domain, DreamWorks, and ILM. His credits include **Avatar**, **The Adventures of Tintin**, **Maleficent**, **The BFG**, and **Ready Player One**. Spillers was the virtual production supervisor and oversaw the virtual art department for Seasons 1 and 2 of **The Mandalorian**.

Can you talk about your role on *The Mandalorian*?

Clint Spillers: Our goal was to set up a virtual art department, which would serve as a digital construction department. It's under the guidelines of the production designer regarding the design and the aesthetic. You have people that were building sets on stages and determining how the set would be decorated.

Then we would do virtual scouts with all of the departments coming together, including the director of photography, the visual effects supervisor, set decorators, construction department, art department, and key creatives. We'd make very informed decisions on blocking, lighting, staging, set dressing, etc. based on a host of variables and utilizing all the latest technology that Epic has been developing with our virtual production partners.

We're not just making decisions for things that will be in the LED environment; we're also making decisions on practical sets. The methodology decisions are a collaboration between the production designer, the DP, and the visual effects supervisor, who each weigh in on the approach to the volume work.

What kinds of artists fill out the virtual art department?

Spillers: A lot of them come from visual effects-heavy backgrounds. They're model makers, they understand Substance and understand many 3D applications to build assets. We also get many people from the games industry who know how to build and design for games. They know how to optimize those heavy assets and get them to run in real time, at a high frame rate within the engine, so we can scout them.

We also have a dedicated assistant art director who works within that unit. The crossover between the digital build and the physical build has to marry one-to-one because you're doing something physical and extending it virtually within an LED environment. The department also consists of people who are good at photogrammetry.

We rely a lot on the set decorators to lay out the physical space that needs to continue virtually. So, we need to capture it with photogrammetry and make it a virtual asset and get it into our scene and turn that over to visual effects. We have all these amazing artists at ILM who create the content for the LED screens using the proxy VAD models as building blocks and a guide for the final content. They also finesse the environments with a *Star Wars* aesthetic.

What does pre-production look like for the virtual art department?

Spillers: Typically, the production designer and I come on anywhere from 30 weeks before shooting. We're trying to identify key talent to make up our VAD. And then I'll build out the schedule for that virtual art department and previs department, which we also call our virtual blocking department. We try to have the front end fully staffed from about 26 to 28 weeks out. We aim to start getting stuff over to ILM about 15 weeks out.
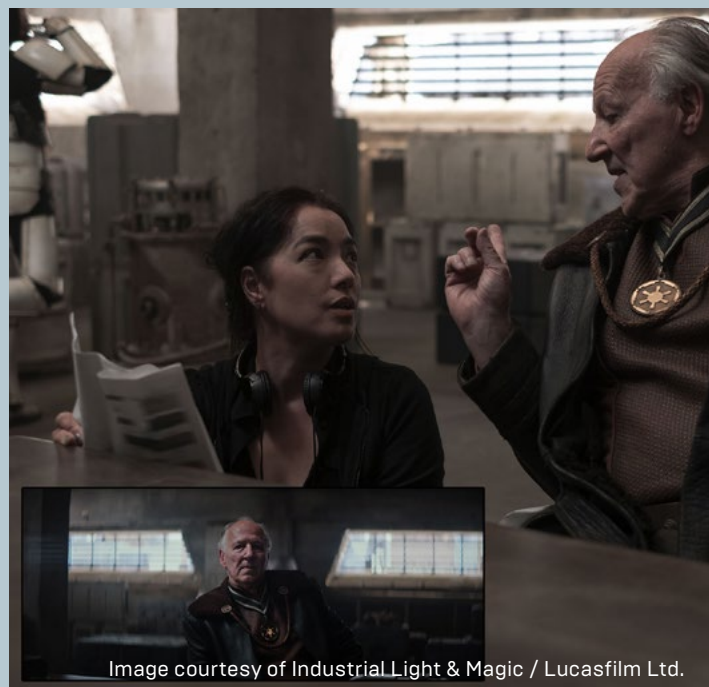

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

Do you take into consideration the camera optics when designing specific environments?

Spillers: We utilized Perforce servers to get everyone connected in the pipeline and share assets between the departments. The previs team knows the layout of the volume or the physical set. So, simultaneously as we're scouting within the VAD, we're also blocking within the virtual blocking department.

Then we have a one-on-one with the DPs, so if they're lensing something in the VAD, we're making sure that it works with the blocking. The whole thing is more or less techvised in this process. We're literally on the same floor in one big bullpen, so there's a line of communication that is constantly going.

How do you manage the seam between the screen and the physical set?

Spillers: Everything that we're building is dialed in to the inch, or the millimeter, in terms of the physical piece and how it ties to the virtual extension. What are the decks and raw trims that need to be brought in? How big is that stairway? If there's a catwalk, how does it connect to the virtual catwalk? The earlier we bring people on, the more decisions we can make up front in partnership with the visual effects supervisor, ILM environments supervisor, the DP, and the more successful we are in providing all that guidance to ILM, who is responsible for creating those final assets and making sure that that marriage is one-to-one.

How do you optimize environments for performance on the LED wall?

Spillers: At the front end of the show, we're trying to make sure that everything is optimized. So, when you're scouting, it is running in real time and at a good frame rate. Once packaged up and given over to ILM, their team optimizes those assets to work within their engine, which is how the final pixel environments are rendered in real time on set.

Do the tools lend themselves to the current era of remote collaboration?

Spillers: Absolutely, and building teams with Unreal Engine gives us a huge leg up. We lean heavily on Perforce servers for this type of work, but we can also do remote scouts. If I have workstations and headsets deployed to the key creatives, we are 100 percent able to do live sessions successfully, and everyone is remote.

What advice would you give someone looking to start a career in the virtual art department?

Spillers: I tell everyone to get involved with Unreal Engine and look at the tutorials. Get familiar with Maya and Substance Painter and start getting those assets into Unreal. I refer interested people to Epic Games' website and the Virtual Production Field Guide. Also, study past virtual production projects like *Ready Player One*, *Tintin*, *Avatar*, and *The BFG* to understand how these workflows have evolved. On top of the tutorials, how-tos, and reading everything you can consume, get into Unreal, and muck around with it under the hood.

Where do you see virtual production evolving next?

Spillers: *The Mandalorian* is a very technically ambitious show, but you could use virtual production to do something as intimate and low-budget as an indie or a short film. Anyone can get their hands on Unreal Engine. So, instead of sending 20 people out to a location to scout, we can get them scouting in engine remotely and make the decisions in real time.

When we were doing *Ready Player One*, we would prep scenes that we were building physically on a set. We needed to understand how many pods we needed to build and how many we could extend. We could virtually scout a location and make critical decisions. If we're never going to see a part of a set, we don't need to build it and can move that money somewhere else.

More traditional departments are going to step into the virtual art department world. Productions will continue to lean heavily on it. Other filmmakers are contacting me, and they're not necessarily trying to do an LED wall. They want to build a VAD to help make these decisions upfront, and they want to use the engine to do that. I just see more people getting involved, which is going to start creating more ideas.

Image courtesy of Industrial Light & Magic / Lucasfilm Ltd.

Interview:
Visualization - Alasdair Coull

As a longtime VR and AR visionary, Alasdair Coull presented the first major Unreal Engine / Apple ARKit integration during Apple's 2017 WWDC keynote. He was formerly Vice President of Special Projects at Weta Digital. Coull has a long history in film visual effects, with credits including **Planet of the Apes**, **Avatar**, **The Avengers**, **Iron Man 3**, **Man of Steel**, and **Furious 7**.

Can you describe your role while at Weta?

Alasdair Coull: My official title was Vice President of Special Projects, which means I was involved in everything from theme park rides to virtual production, and a lot of our work involved Unreal Engine. Weta Digital has been active in virtual production for many years, way back even before the original *Avatar*. *Avatar* was the landmark film for virtual production and Weta built up a lot of tools, processes, and techniques to execute that film with James Cameron. Weta has been evolving and improving them ever since.

It's become really interesting over the last few years, seeing the evolution of Unreal Engine and what's possible to do in previs and live on stage. Previously with a green screen setup, you just had to imagine how something was going to look. Now, you can do it in camera with an LED wall and see it live.

In fact, Weta just recently partnered with Avalon Studios and Streamliner Productions to set up a real-time LED stage in New Zealand. Based on the flood of interest we saw, it's clear that these workflows are great for large big-budget films as well as lower-budget, small-market projects that are looking to protect their budget but still put something special on screen.

Real-time is super interesting to me, because I love fast feedback and I think that's one of the reasons filmmakers are adopting this workflow. It opens up the creative process in new ways. The more iterations you can do of anything, the better the result will be. As workflows become quicker and easier, that helps people get more creative and improves the final quality.

Can you think of an example where visualization tools changed the creative trajectory of a project?

Coull: Yes, this happened on *The Hobbit VR Experience: Thief in the Shadows*. We took the dialogue of Smaug the dragon from the *Hobbit* movies and put it into Unreal Engine to rapidly block out the experience. We were pulling things around, trying to find the right pacing and narrative flow. Being able to quickly drop in animations, slide things

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around in the timeline, and visualize different assets and character motions—all in real time with the dialogue—was critical to our ability to find the story.

There were a lot of interesting processes, and the final result was very much not what was on paper. Seeing it in VR as we tried out different ideas, and actually standing in that world and seeing how different motions and FX looked from any angle, meant that we could make iterations rapidly because we were truly immersed in the audience experience. We knew exactly what we needed to do to nail the audience experience, because we were there.

VR and AR visualization tools are also now commonly used throughout the filmmaking process. From VR virtual location scouts to accurate augmented reality visualization of CG content on location during filming, we've built up a broad range of tools to help the creative process.

Image courtesy of 20th Century Studios and Weta Digital

Is it a change to the overall mindset to see provisional imagery much closer in fidelity to final renders versus a traditional visual effects pipeline?

Coull: It's more a different part of the pipeline than it is a mindset change. Usually, plates come into the facility ready for VFX work to begin. Now, that happens at a different point in the process. There's still a lot of work to prepare assets for an LED shoot, for example, and you're investing a lot of time building something up front. You want to make sure you know you're building the right thing.

That building process would still have happened in a traditional visual effects workflow—it would just happen later in the process. This change definitely affects the director's overall mindset because some creative choices are going to be pulled forward; this inevitably has a flow-on benefit to everything that follows. Real-time enables a new way of working, and most creative people are genuinely excited about having the latest tools and being able to explore many different creative directions early on in the process.

How has the need to work remotely affected your pipeline?

Coull: Over the years, we had people directing mocap shoots from other countries, and that's worked well. Perhaps because Weta is based in New Zealand, we had more experience with this than someone in Los Angeles who's used to saying, "Come around to our office and we'll all look at it." We've built up a lot of tools and techniques for collaborating with people in different time zones.

Unreal Engine's multi-user collaboration workflow works very well for this. LED walls also help satisfy some of the health and safety requirements of not having everyone in the same room together. You have people in different places, but they can all see the same scene moving in real time simultaneously. We used this technology for a lot of international collaborations, and the evolution is accelerating rapidly.

Image courtesy of 20th Century Studios and Weta Digital

Do you have any advice for someone looking to start a career in virtual production?

Coull: What's possible out of the box with Unreal Engine now is phenomenal. It's been interesting to see the number of experienced industry people simply trying Unreal out and putting incredible stuff together. So, download it and start making something. You can make a short movie with the Marketplace and Quixel assets.

You can use an HTC Vive to track your camera, or even your iPhone. All the pieces exist for someone at home to create. It used to require very high-end tools and complex workflows, but we've seen a shift in the tools that are accessible and still work well. Really impressive stuff is coming from people at home now. Just showing enthusiasm and initiative, and learning the tools, is important.

Where do you see virtual production evolving next?

Coull: I would like to see these tools become more ubiquitous and streamlined for the filmmaking workflow. That will open up a lot of opportunities and empower more people to dive in and use them. As workflows and interfaces evolve, we will see more of a true filmmaking toolset evolve. For us, we're excited to leverage two and a half decades of expertise creating groundbreaking imagery through combining our tools with the power of Unreal Engine.

As we see developments like Unreal Engine 5, it'll push much more detailed real-time assets, and that opens up some other exciting opportunities. When you can use the same core assets for previs and final render, that will change how we work. It's about empowering creatives to make fast decisions and try out crazy ideas.
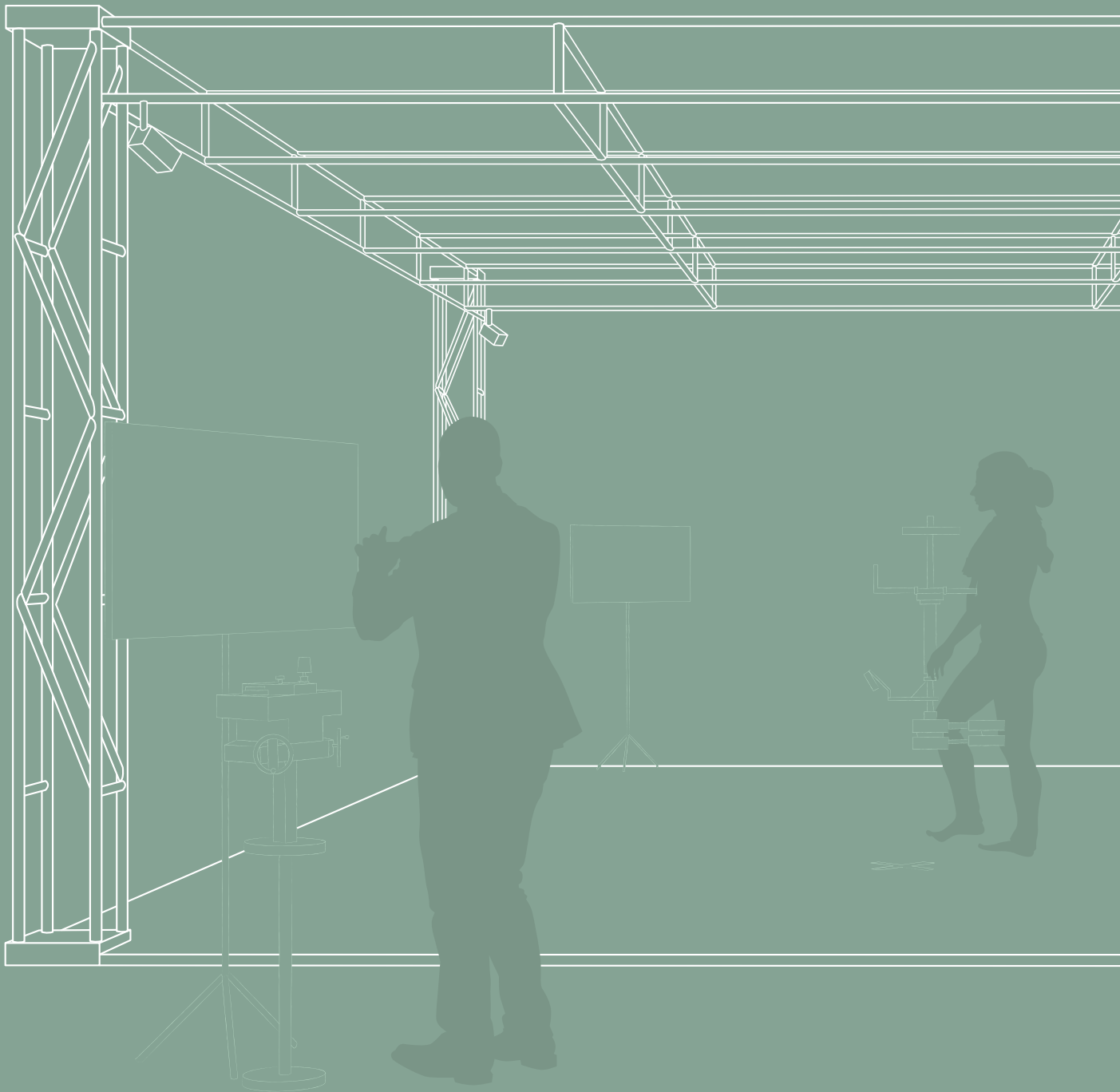
CHAPTER IV

Conclusion

What's next for virtual production?

In 2019, when we published the first volume of the Virtual Production Field Guide, we knew about a lot of great projects in the pipeline—many of which we were not at liberty to discuss at the time. The same holds true this time around. Virtual production's only constant is continuous innovation and reinvention. If you lean into that paradigm, you'll enjoy great success.

What has altered filmmaking and its relationship with virtual production has been the unprecedented disruption of the worldwide pandemic. Although the pandemic brought an undeniable level of loss to the world, it has also caused massive changes in how we interact and work together. Many of these changes will be felt in filmmaking forever. Remote collaboration went from a nice-to-have to a must-have for all filmmakers, and humanity in general. And as fortune would have it, virtual production technology is perfectly suited to remote workflows.

Image courtesy of MELS Studios

But we want to peer even deeper into the crystal ball and ponder further into the future, when the necessities and challenges caused by the pandemic are no longer present. Many of the visionaries we spoke to in this guide's interviews have strong opinions about what's next. Consider anything from volumetric cameras to hybrid game / theatrical experiences.

We think of today's collective experience of the internet as a combination of emails, texts, social media, video calls, and online conferences. But that's just the tip of the iceberg. The metaverse, a mixed reality distillation and remix of all of those experiences, is on the horizon.

As human beings, we're wired to listen to a story and apply its meaning to our own experiences. The metaverse will bring us shared, overlapping experiences as reality and the virtual world mix. It will also engage us at a more subconscious level through visual computing.

The cool thing about all of these possibilities is that tools like Unreal Engine can transform to fit whatever we humans can imagine. If you've seen the demonstrations of Unreal Engine 5, you know that the horizons of imagination are becoming more and more infinite. And it's just getting started.

A Sneak Preview of the Next
Virtual Production Field Guide

We hope you've enjoyed this second volume of the Virtual Production Field Guide. We've concentrated mostly on feature film and television production for these first two volumes. But if you're familiar with virtual production solely in those areas, you're in for a surprise, because Unreal Engine is used in many other forms of entertainment that would fall into the same category of virtual production. So, for forthcoming volumes, we'll expand the scope of the guide to those other forms.

Unreal Engine is, first and foremost, an engine for game development. We'll look at some game-specific and crossover case studies. We'll also look at the rapidly evolving in-engine and in-game sports and events market. Over the past few years, several pioneering special events have taken place in *Fortnite*, which is the best-known game powered by Unreal Engine.

Recent examples include the Travis Scott virtual concert, which attracted over 12 million concurrent viewers, and one for Marshmello, which was attended by more than 10 million fans. In addition to music events, *Fortnite* has also hosted filmmaker events. Examples include the *Tenet* preview and Christopher Nolan screening series, which screened movies directly within *Fortnite*. Director J.J. Abrams appeared virtually in the Millenium Falcon in *Fortnite* to introduce the trailer for *The Rise of Skywalker*. These special events involved many of the same tools used in feature and TV virtual productions to pull humans into the game engine for live virtual events.

We'll also look at how Unreal Engine enhances live venue events with real-time virtual production techniques. In one example, Andy Serkis created performance capture for a virtual character used in The Royal Shakespeare Company's stage production of The Tempest. Musician Childish Gambino also made extensive use of Unreal Engine to deliver a real-time fantasy environment for the live production of his "Pharos" concert experience.

We look forward to diving into these workflows and speaking with the creatives bringing unique projects to life. The feedback we received from the first volume of this guide told us that it was useful both as a reference and as a selling tool for new virtual production initiatives.

The community around virtual production continues to grow, and we're excited that you're a part of it. Please let us know, on the Unreal Engine forum, what you'd like to learn about next and who you'd like to hear from in future volumes. Thanks again for your time.

Image courtesy of Bild Studios

Image courtesy of Media Apparat

Resources For Further Study

Virtual Production Resources

Virtual production is a constantly evolving ecosystem. Here are some recommended additional learning resources from Epic Games and other sources.
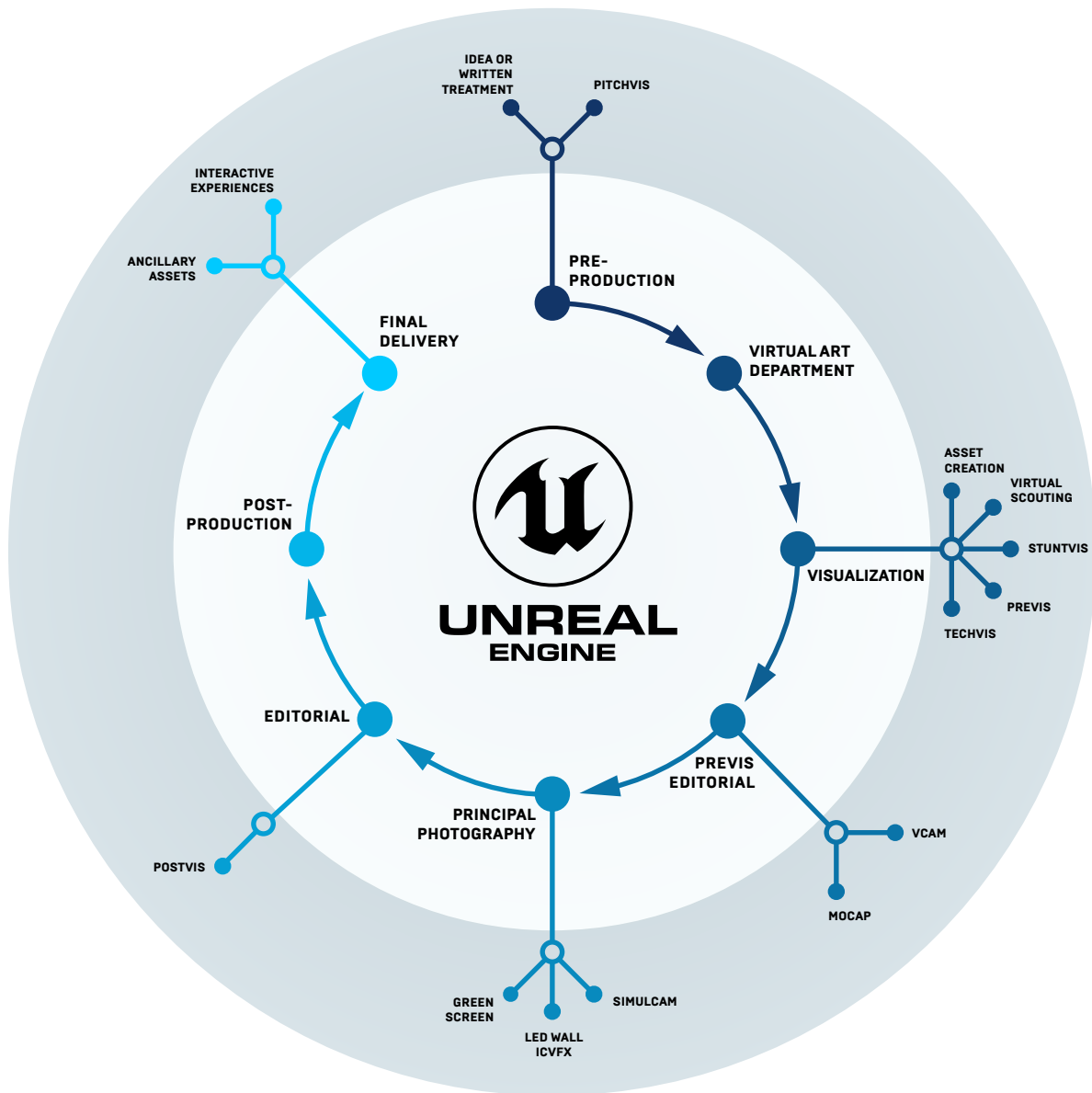
Epic Games Resources

- The Virtual Production Field Guide: Volume One
- The Virtual Production Hub
- The Unreal Engine Blog
- Unreal Build: Virtual Production 2020 Sessions
- nDisplay Technology
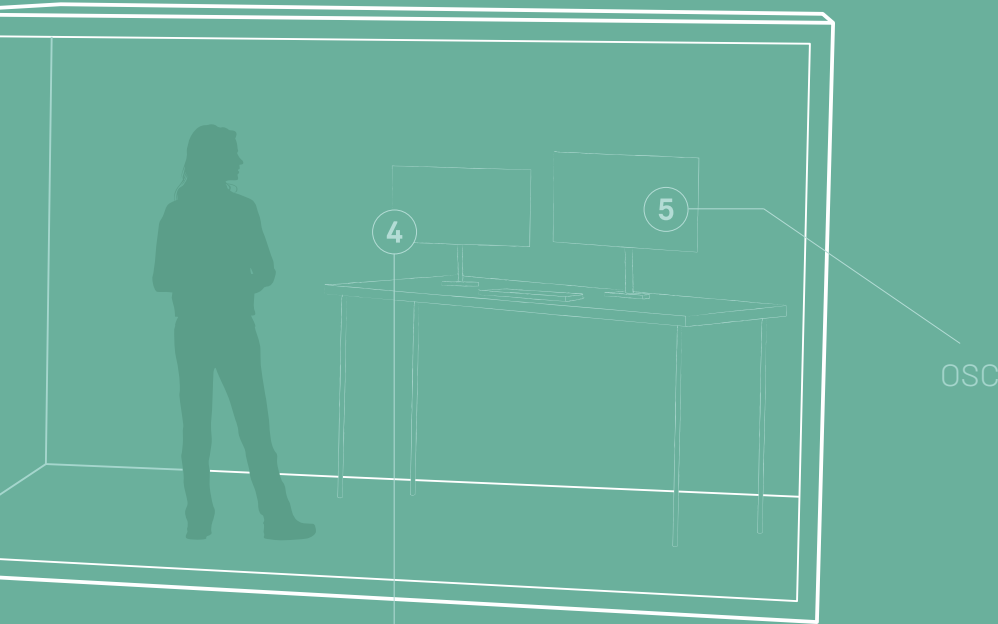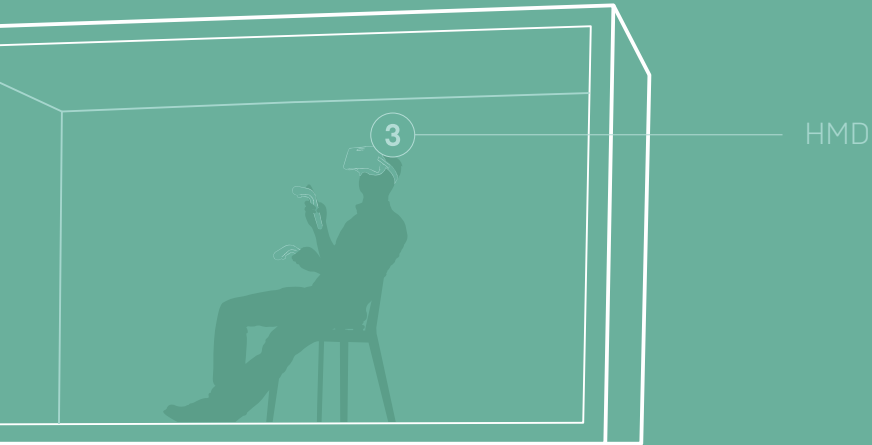- Choosing a Real-Time Performance Capture System

Other Resources

- The Visual Effects Society
- VFX Voice
- Virtual Production Facebook Group
- Befores & Afters
- fxguide
- Deloitte: The Future of Content Creation
- On-Set Facilities Blog

Example of a Virtual Production Workflow

IDEA OR WRITTEN TREATMENT

PITCHVIS

INTERACTIVE EXPERIENCES

ANCILLARY ASSETS

FINAL DELIVERY

PRE-PRODUCTION

VIRTUAL ART DEPARTMENT

ASSET CREATION

VIRTUAL SCOUTING

STUNTVIS

PREVIS

TECHVIS

VISUALIZATION

POST-PRODUCTION

UNREAL ENGINE

EDITORIAL

PREVIS EDITORIAL

POSTVIS

PRINCIPAL PHOTOGRAPHY

VCAM

MOCAP

GREEN SCREEN

SIMULCAM

LED WALL ICVFX

Game engine

① 𝔲

②

Smart stage

Glossary

HMD

3

5

4

OSC

Color science

Action design
A special form of previs, this uses 3D assets to plan and design live-action stunts. Also called stuntvis.

Aspect ratio
The ratio between the width and the height of an image or screen. Common film/TV production asset ratios are 1.85, 2.35, 16:9.

Atmospheric
Fog, smoke, fire, or other physically based visual effect rendered in real time by the game engine.

Augmented reality (AR)
A technology that integrates CG elements into a physical environment.

Bit-depth
The number of binary digits used to store a value, such as a pixel's color. Higher bit-depths offer greater accuracy. An 8-bit image can display 256 color values for each of red, green, and blue, equaling ~16.7 million colors. A 16-bit image raises that number to ~4.3 trillion colors.

Blueprint
Script created from the Blueprint visual scripting language in Unreal Engine— defines how an asset interacts.

Brain bar
The central nervous center of a virtual production, where real-time hardware and software are controlled.

Central processing unit (CPU)
A collection of millions of transistors that can be manipulated to perform a wide variety of calculations.

Cinematic
A pre-rendered, noninteractive sequence in an otherwise interactive experience. Also called "cutscene".

Color science
The capability of a camera sensor to capture a portion of the color spectrum.

Cutscene
A pre-rendered, noninteractive sequence in an otherwise interactive experience.

Data capture
The capture of important details during principal photography such as photographic reference, lighting reference, LiDAR scans, camera metadata, etc.

Decimation
The reduction of detail to optimize an asset's real-time performance; a key difference between assets created for real-time vs. post-production animation.

Depth of field
The range between the nearest and the furthest objects in focus in a camera.

Distributed rendering
Multiple instances of an engine processing the same scene in parallel to achieve much higher total resolution.

Extended reality (XR)
An umbrella term for VR, AR, and MR, and all future realities such technology might bring.

Eyetracking
A component of facial capture in which the eye movements / gaze are recorded.

Field of view (FOV)
The extent of the observable world that is seen at any given moment by a person or camera.

Frustum
The region of a virtual world that appears as a viewport to the camera.

Final pixel
The ability to achieve final image quality live, in-camera, without the need for additional post-production.

Game engine
A software-development environment designed for the creation of real-time interactive content, initially for video games, but now used in many other applications.

Graphics processing unit (GPU)
A specialized type of microprocessor optimized to display graphics and do very specific computational tasks. Modern real-time engines rely heavily on GPUs for performance.

Haptics
Technology that recreates the sense of touch by applying forces, vibrations, or temperature changes to the user.

Head tracking
The method used by a head-mounted display to project the correct image by tracking a user's head movements via gyroscopes, sensors, cameras, etc.

Head-mounted display (HMD)
A device used to display CG content for VR, AR, or MR.

High dynamic range (HDR)
Reproduction of a greater dynamic range of luminosity than is possible with standard digital imaging techniques. HDR images retain detail in a fuller range of lights and darks than standard images.

Immersion
The sensation of feeling present in a digital environment.

Judder
Shaking or stuttering experienced inside of a VR headset.

Latency
The delay between when a signal is sent and when it is received at its destination; experts consider under 10 milliseconds of latency to be critical for real-time camera operation.

Level of detail (LOD)
A lower-resolution representation of an object that can be used to improve performance when an asset is distant from the camera. Typically, several different levels of detail will be produced, each at a different resolution.

Look up table (LUT)
A mathematical modification table that translates between a RAW camera image and the desired display appearance.

Map
What a game engine calls a "map" is called a "set" by filmmakers.

Mixed reality (MR)
The process of anchoring virtual objects to the real world and enabling users to interact with them.

Moiré
An interference pattern caused by focusing a camera directly on an LED screen.

Motion capture (mocap)
The process of recording actions of human actors, and using that information to animate digital character models.

Motion match
A process that creates much higher realism by matching animations to desired poses.

Nit
A measurement of how much light a display screen sends to your eyes within a given area.

OpenColorIO (OCIO)
A system that enables color transforms and image display to be handled in a consistent manner across multiple graphics applications.

OSC
On-screen controls used for controlling real-time game engine attributes via tablets, etc.

Performance capture
An advanced form of motion capture that includes faces and/or fingers, and captures subtle expressions.

Photogrammetry
The automated construction of a 3D model from multiple 2D photographs.

Pitchvis
The visualization of a script or sequence prior to production, used to get investors and studios onboard by demonstrating a concept before it's greenlit.

Postvis
The process of visualizing and designing the visual effects of a film after the live-action elements have been shot. This enables you to design your shots, form your edit, and test screen your film before investing in final VFX.

Previsualization (previs)
The process in pre-production of visually mapping out scenes in a movie, commercial, or music video before principal photography.

Props
Same in both worlds.

Ray tracing
A rendering technique for generating an image by tracing the path of light as pixels in an image plane and simulating the effects of its encounters with virtual objects.

Real-time rendering
The translation of a scene into display pixels fast enough for instantaneous playback at real-time (live) speeds. In contrast, traditional offline rendering may take minutes or even hours to produce each frame, with 24 frames required to display a second's worth of animation.

Refresh rate
The frequency with which an electronic display is refreshed, usually expressed in hertz (Hz). Higher refresh rates can make motion appear smoother.

Retargeting
Application of mocap data to a CG character of a different body geometry.

Set decoration
In film, part of the set. Not used in video games.

Smart stage
A stage purpose-built for virtual production including LED walls, tracking systems, and real-time capabilities.

Stuntvis
A special form of previs, this uses 3D assets to plan and design live-action stunts. Also called "action design".

Techvis
Using 3D assets to perform technical analysis on scenes: camera type, lenses, distances, set requirements, stunts, and any other information needed to physically shoot your story before you get on set.

Universal Scene Description (USD)
Pixar's open-source scene interchange and assembly format, widely adopted in the film industry.

Virtual art department (VAD)
Produces all asset materials—such as characters, props, and sets—in low-resolution for traditional previs, VFX post-production, and virtual production.

Virtual camera (Vcam)
A camera in the game engine that can be driven using a device such as an iPad.

Virtual green-screen cards
Green screens created directly on LED walls for compositing.

Virtual lighting
Use of an LED screen to directly light a scene or act as interactive/reflective lighting.

Virtual production (VP)
The cross section between physical and digital worlds. VP lets directors work on a physical stage but use real-time technology to view and interact with virtual environments and characters.

Virtual reality (VR)
An immersive experience using headsets to generate the realistic sounds, images, and other sensations that replicate a real environment or create an imaginary world.

Virtual scouting
Use of VR technology to share a model of a set for shot planning and production design purpose.

Witness camera
Camera(s) placed on set to provide alternate perspectives on a shoot and provide a comprehensive understanding of the action within a scene.

The **Virtual Production** Field Guide

Filmmakers such as George Lucas (*Star Wars: Episode I*), Steven Spielberg (*A.I.*), Peter Jackson (*Lord of the Rings*), Robert Zemeckis (*The Polar Express*), and James Cameron (*Avatar*) initially embraced virtual production enhanced by real-time rendering.

In 2009, members from the ASC, ADG, PGA, ICG, and VES formed the Virtual Production Committee. The committee shared case studies about film and television projects leveraging virtual production and produced many of its initial definitions.

This field guide builds on the committee's work along with recent advances in real-time computer graphics, which are making virtual production even more accessible to filmmakers today.

EPIC GAMES

UNREAL ENGINE