VIRTUAL PRODUCTION & BEYOND

SLAYING THE MYTH TO UNCOVER THE TRUTH

CASE STUDY: SHORT FILM

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Cloud computing is a model of enabling on-demand access to a shared pool of configurable computing resources over the Internet, with pay-as-you-go pricing, minimal management effort, and rapid provisioning and release of resources, allowing companies to access technology resources with no need for huge upfront investments in physical data centers and servers.

[**Keywords:** cloud computing, technology, internet, computing resources, data centers, virtualization, ARPANET, TCP/IP protocol, virtual machines, time-sharing, on-demand access, pay-as-you-go pricing, data backup, disaster recovery, software development, big data analytics, and customer-facing web applications.]

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5th Kind is a digital asset management company offering next-gen solutions for distributed teams and high-velocity production workflows with a vision to be a cloud-based media operating system for real-time decision making, with a focus on intuitive and automated solutions for asset extraction and enrichment to maximize investment in creative processes.

[**Keywords:** digital asset management (DAM), single source of truth, libraries of digital content, metadata, teams collaboration, security, hierarchy-based access control, functions and features, workflow preferences, pipeline integrations, naming conventions, best practices, folder taxonomies, 5th kind, Steve Cronan, next-generation asset management, real-time collaboration, distributed teams, and high-velocity production workflows]

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[**Keywords:** Arch Platform Technologies, cloud-based, creative studios, remote workflows, cost-effective, CTO, Edward Churchward, Fathead, virtual production, AWS, user dashboard, automated processes, application stack, hardened environment, and in-house teams]

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[**Keywords:** graphics processing unit (GPU), NVIDIA corporation, real-time 3D graphics, virtual production workflow, gaming, media and entertainment, AI, supercomputing, hyperscale data centers, graphics acceleration, compute capabilities, encryption, network acceleration, simulation, rendering, data processing, ray tracing, RTX]

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[**Keywords:** gaming, film, media, virtual reality (VR), augmented reality (AR), artificial intelligence (AI), digital transformation, version control, git, AWS, ICVR, helix core, unreal engine, digital twins, single source of truth, virtual art department (VAD), Katie Cole, Ryan L'Italien, streaming, visual effects (VFX)]

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Authors: Alan Lasky, Zach Willner, Brian Kenworthy, Jack Wenzinger, and Matt Herson

[**Keywords:** Fathead, AWS, cloud-first, virtual production, game engines, cloud-based solutions, pre-production, on-set collaboration, post-production, executive producer, virtual production specialist, Amazon Web Services, Epic Games, Perforce, 5th Kind, Arch Platform Technologies, Blackmagic Design, Bluescape, pre-visualization, Amazon S3, security policies, identity access management (IAM), and shared responsibility model.]

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Contributors: Production Technologist Dane Brehm, Lead DIT Johanna Salo, 2nd DIT Chris Hosey, and DMT Sherri Miranda

[**Keywords:** production technologist, technician, 35mm film, 8K, data-based acquisition, AWS, senior solutions architect, script, filmmaking, data, mags, backup, shuttle, laboratory, editors, dailies, script supervisor, deliverables, data-based acquisition, digital image technician (DIT), dailies colorist, VR supervisor, workflow supervision, and LED volume]

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CLOUD COMPUTING
Growth Without Bounds

> **"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."**
>
> — The National Institute of Standards and Technology (NIST), a part of the U.S. Department of Commerce [1]

Imagine accessing technology resources on-demand over the Internet with pay-as-you-go pricing and no need for huge up-front investments to own and maintain physical data centers and servers — that is one of the enormous benefits of cloud computing. Companies big and small in various industries already use the cloud for data backup, disaster recovery, email, virtual desktops, software development, testing, big data analytics, and customer-facing web applications. [2]

We all benefit from cloud computing, whether or not we know much about it. Without this one utility, the wide array of applications and solutions at our fingertips may not have existed. Much of its superpowers remain hidden from the majority, but its function in society is undeniable.

The origin story of the cloud has many versions. Some date back to the '60s, linking it to Joseph Carl Robnett Licklider, believed to have originated the concept. Other sources cite it as a natural evolution of mainframe and time-sharing systems from the '50s that led to foundational innovations at the Advanced Research Projects Agency Network (ARPANET), the first wide-area packet-switched network with distributed control. [3]

ARPANET is believed to be one of the first networks to implement the TCP/IP protocol suite. Together, these are foundational technologies that heralded the Internet age. Surprisingly, Licklider is also said to have set the stage for ARPANET. He worked with Bolt Beranek and Newman (BBN), one of the first companies to connect their computers to the ARPANET. [4, 5, 6]

Among other great minds who have contributed to the field, you will encounter these two champions when you investigate the genesis of cloud

technology. Herb Grosch postulated in 1953, "To do a calculation ten times as cheaply, you must do it hundred times as fast," which he called Grosch's Law. [7] John McCarthy proposed the concept of 'time-sharing' in 1955, which enabled smaller companies to gain access to mainframe computing and automation — he also coined the term 'artificial intelligence.' [8]

Several other concepts emerged through the '70s to the '90s that exponentially evolved into the layered and intricate ecosystem for computing solutions that laid the foundation for cloud computing as we know it today. The '70s saw companies like IBM develop virtual machines, and the telecommunications industry introduced virtual private networks (VPN). Cluster computing arrived in the '80s as an alternative to mainframe computing, making high computations affordable. Systems placed in varied geographical locations could be connected via the Internet by the '90s, giving rise to grid computing. [9]

Virtualization uses a method that centralizes administrative tasks and exponentially boosts scalability and compute capacity. Multiple instances of virtual layers of operating system (OS), server, storage device, or network resources over the hardware, help economize overhead, enable automatic backups, recover data or quickly migrate it to an entirely new location significant for disaster recovery, provide a safe environment for testing, and free up resources to focus on productivity rather than system management.

Virtualization is an essential aspect of cloud computing. [10]

We entered the new millennium with advancements such as Web 2.0, which facilitated greater interactivity and dynamic web pages leading to services such as blogs, video streaming, interactive maps, image galleries, social networking, content hosting, web applications, and podcasts. [9]

Finally, let's touch upon concepts that contribute toward productizing and quantifying varied attributes of a complex entity that are just as important for the continued progression necessary to sustain technological advancement.

The goal is to identify customer needs and provide tools and solutions that address those while remaining price-conscious, flexible, and constantly evolving. The computing model that emerged out of this resulted in concepts such as quality of service (QoS), service level agreement (SLA), and software-as-a-service (SaaS). The approach as a whole is known as Service Orientation. [9]

A Databarracks explainer video created by Cognitive Media and narrated by British comedian and actor Stephen Fry, published in 2013, proposes that "Utility is the largest single change to computer thinking this century. A change so great, you can compare it to the computing equivalent of the industrial revolution. A revolution that was fueled by 'utility.'" [11]

Peter Groucutt, managing director of Databarracks, suggests, "We live in a world where we now have the ability to scale memory, processing, and storage at the touch of a button while only ever paying for the amount we use. We really are at the dawn of an exciting era: the era of utility computing." [12]

The term utility computing embodies a computing model that makes the provisioning of services such as compute capacity, storage capacity, scalable infrastructure, and similar needs of clients of any size on a pay-per-use basis. [9] Customers can now access the many benefits of the cloud, broadly characterized as on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service available as three service models (software-as-a-service [SaaS], platform-as-a-service [PaaS], and infrastructure-as-a-service [IaaS]) and four deployment models (private cloud, community cloud, public cloud, and hybrid cloud). [1]

> "WE LIVE IN A WORLD WHERE WE NOW HAVE THE ABILITY TO SCALE MEMORY, PROCESSING, AND STORAGE AT THE TOUCH OF A BUTTON WHILE ONLY EVER PAYING FOR THE AMOUNT WE USE."
>
> — PETER GROUCUTT,
>
> Managing Director of Databarracks

Naturally, most folks prefer to bypass understanding the complex operations under the hood and stick to enjoying the advantages made available through intuitive, easy-to-access mechanisms and interfaces. Hence the need is met with solutions where the end-user may receive the benefits without fully understanding the elaborate set of processes and systems delivering them or having to bear the immense burden of cost to set up and operate a behemoth necessary for such massive scale, speed, and security. Welcome to cloud computing.

The increased operational tempo of modern content production has created the perfect conditions for the rise of AWS in the media and entertainment industry. On-demand media consumption, remote collaboration for content production, and rapid scalability are all essential components for creative workflows in the filmed entertainment space. AWS has an initiative called 'AWS for M&E', launched in 2021, which AWS describes as:

Media and entertainment customers face industry-wide transformation, with companies reinventing how they create content, optimize media supply chains, and compete for audience attention across streaming, broadcast, and direct-to-consumer platforms. AWS aligns the most purpose-built media and entertainment capabilities of any cloud against five solution areas to help customers transform the industry: Content Production, Media Supply Chain & Archive, Broadcast, Direct-to-Consumer & Streaming, and Data Science & Analytics. With AWS, you can select the right tools and partners for your workloads to accelerate production launches and see faster time to value.

Fathead provided a unique opportunity for AWS to work with ETC and Amazon Studios on a state-of-the-art production incorporating several critical technologies including virtual production, remote color grading, original camera negative to cloud pipelines, and more.

According to Zach Willner, AWS senior partner solutions architect for media & entertainment content production and technical lead for AWS on *Fathead*: "Getting to work on the *Fathead* project with top industry talent was an eye-opening experience; by connecting my AWS knowledge with the on-set production team, we were able to streamline production processes such as original camera negative (OCN) to cloud that normally take days and turned it into a real-time process. *Fathead* represents an example for the industry of the future of modern production."

AWS and its partner network provided much of the critical infrastructure for *Fathead's* prototype production model. Partners such as 5th Kind, Arch Platform Technologies, Adobe, Autodesk, Blackmagic Design, Bluescape, Epic Games, and others all contributed to the success of the project.

Of course, no virtual production project could take place without NVIDIA's RTX technology and GPU hardware delivering the real-time graphics that drive the volume.

Willner concludes, "Unlike traditional productions where schedules and budgets create an aversion to risk, the *Fathead* project with ETC allowed us to experiment with workflows and optimizations that would otherwise be impossible on conventional productions. ▪

EDWARD CHURCHWARD is the co-founder and CTO of Arch Platform Technologies, a cloud enabler offering fast and easy ways to move creative teams and workloads to the cloud. The company liberates productions and studios from the additional burden of having technological savviness or upfront expensive infrastructure spending. Churchward pointed out how relevant remote workforces have become since the advent of COVID, and "by enabling AWS cloud workflows, Arch has empowered people to get back to work safely."

Speaking about the times before moving to AWS, Churchward said, "we were hamstrung by the lack of real automation using APIs and on-demand availability at a global scale."

"We have seen large six-figure sums saved on productions," explained Churchward, highlighting the practice of "deploying content creation facilities in tax-incentivized regions" to cut production costs.

Arch supported the *Fathead* teams in Los Angeles and London by deploying virtual machines to enable remote workflow efficiencies.

DANE BREHM is a production technologist at Cintegral Technologies, and, on *Fathead*, he was in charge of the digital imaging technician (DIT) and on-set data management pipeline. Brehm worked closely with the AWS solutions team and championed several pipeline innovations and workflow efficiencies. He observed that "AWS has altered the production and post-production landscape by providing platforms for filmmakers that were traditionally too costly to build on a production-by-production basis, which has unlocked efficiencies that were previously inconceivable."

Recalling how things were done before what was achieved on *Fathead*, Brehm noted that production crews did not have the required technical understanding or know-how to incorporate a camera-to-cloud workflow independent of a proxy workflow as they lacked access to on-set network performance, pre-constructed platforms for moving RAW camera and sound data to object storage soon after the first data offload, or the right partners to assist with the construction of virtual production pipelines. These tools, solutions, support, and access were available on *Fathead* through the ETC partner network and the AWS solutions architects.

Summing up the experience on *Fathead*, Brehm said, "Virtual production has altered what filmmakers perceive of the needs and efficiencies of the cloud — how it has transformed previs, on-set production, and post-production."

Citing a use case for cloud implementation on *Fathead*, Brehm shared, "AWS S3 storage and Arch Platform allowed a first in my experience of a 'true' camera-to-cloud pipeline. AWS's architecture allowed the OCN data, DIT, and dailies teams to work lab-less and LTO-less, creating massive efficiencies in the data transfer, color, transcoding, review, and verification processes between production and post-production in mere moments."

Celebrating the experience, Brehm noted, "As a production technologist and DIT on *Fathead*, this was a big 'WOW' moment for what's possible for the future camera, sound, and DIT teams to develop, process, and deliver the most accurate creative intent before it leaves the set." He reminisces about the excitement he shared on set with Post Supervisor James Blevins, Data Manager Sherri Miranda, and DIT Johanna Salo when they completed the first 800 MBps direct upload of the original color negative (OCN), sound, and dallies to S3, and the near-set editor confirmed that everything had landed in DaVinci Resolve mere minutes after the upload. The team continued the process for five weeks without a single hitch.

Speaking about the results of using the cloud-first approach on *Fathead*, Brehm said, "To say that we were successful is an understatement."

JAMES BLEVINS is a leading industry expert on virtual production pipelines and workflow, having set things up on *The Mandalorian* that got the ball rolling. As post-production supervisor on *Fathead*, Blevins was integral to the directions explored in setting up the cloud-

"AWS HAS ALTERED THE PRODUCTION AND POST-PRODUCTION LANDSCAPE BY PROVIDING PLATFORMS FOR FILMMAKERS THAT WERE TRADITIONALLY TOO COSTLY TO BUILD ON A PRODUCTION-TO-PRODUCTION BASIS, WHICH HAS UNLOCKED EFFICIENCIES THAT WERE PREVIOUSLY INCONCEIVABLE."

- DANE BREHM

Production Technologist,
Cintegral Technologies

workflow efficiencies by centralizing the original camera files (OCF) and providing robust connectivity between the users, the applications, and that data.

"By centralizing the OCF, we created a reservoir of potential," Blevins explained. "We eliminated the need to transport proxies of the OCF, which inspired more efficient collaboration." As a result, creative sessions could be scheduled with more flexibility, allowing the creative to work at their own pace.

Citing the many benefits of the new pipeline, Blevins said, "We no longer needed a copy of LTO tapes. Because we copied our OCF into the cloud, we provided an assembly of the day's shooting as we shot."

Furthermore, he added, "Normally, the conform process requires additional time to consolidate the OCF from the cut," but on *Fathead*, "this occurred on the same OCF upon which we edited."

The color correction session was performed by accessing a cloud instance in Resolve. After the color session, Blevins worked with CineCert to create all IMF and DCP packages from the same data set. Celebrating the success of this cloud-based color grading process performed at Light Iron, Blevins said, "We have created *Fathead* without moving the source material more than once. That is incredibly efficient, and as a result, it has helped us keep the egress fees to a minimum."

Keeping things consistent, Blevins said, "The show was uniquely positioned to get consolidated into an archived asset."

STEVE CRONAN, CEO of 5th Kind, Inc., shared some pointers on how digital asset management is the spine of any production today and where and how their cloud-based solution has added immense value. He said, "AWS allows us to have a high-speed backbone, so once we get the data into the cloud, we can share and scale to meet any need."

Since its inception in 2001, 5th Kind has been used on many VFX-heavy tentpole productions by leading studios. Cronan cited Marvel as the best use case. He said, "They scaled from sharing 15M watermarked files in 2020 to 25M in 2021 without any impact on performance or experiencing any delivery bottlenecks." The teams could ingest, transcode, watermark, and distribute millions of files with limited impact on the user experience. Cronan added that this "allowed maximum creative flow for over 45K users at 4.5K companies."

Naming another example of where the cloud-based solutions provided by 5th Kind have augmented productivity, Cronan shared that it has enabled "Universal to provide a high-quality-dailies experience to some of the most demanding creative pipelines for over 16K users."

At Disney Parks, 5th Kind provides global live streaming at <200ms latency.

On *Fathead*, Cronan noted, "It allowed us to have a unique opportunity to test a cutting-edge pipeline and deliver a range of real-time global collaboration tools. The cloud gave us the framework to integrate and collaborate at the highest performance possible."

MARK REISCH, an assistant professor at the Rochester Institute of Technology (RIT), led a team of his graduates to produce one of the three Unreal Engine environments used at the LED volume. Describing how the multi-user remote workflow in Unreal Engine was supported via the version control system Perforce Helix Core, Reisch said, "Perforce was our main interface, and that was set up for us by Ihar Heneralau of ICVR. We never ran into any hosting issues. All the files we needed were dependably there. We could all connect to the files as if we were in the same building."

NIALL HENDRY, the head of product at Move.ai, a markerless, suitless motion capture solution, said about a major benefit of switching to the cloud, "Frankly, scale. Instead of a world where data, takes, and content gets processed singularly (one at a time), cloud gives you flexibility."

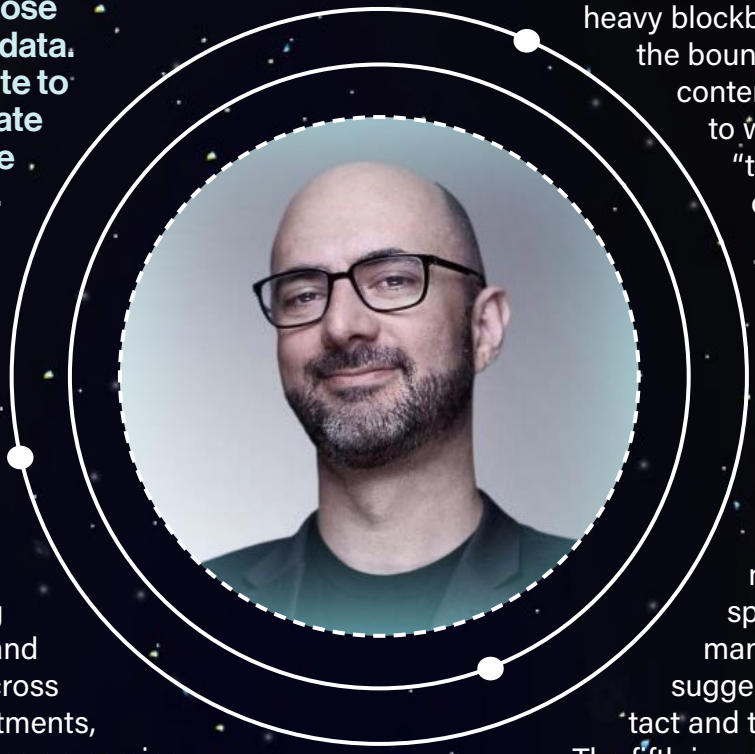
"The ability to operate flexibly rather than be tied to hardware is massive bonus for clients," Hendry added. ▪

Fathead crew shooting at the Amazon Studios Virtual Production (ASVP) LED volume Stage 15, Culver Studios, Los Angeles, California.

5th Kind CEO

STEVE CRONAN

Digital asset management (DAM) systems are designed to facilitate ready access to libraries of digital content from one interface, often termed a "single source of truth." The objective is to catalog all assets acquired, created, or transformed throughout a project and have those populated with metadata. Teams can collaborate to illustrate and assimilate information and value across departments. Security and hierarchy-based access control are prominent features of these systems.



An evolving menu of functions and features attempts to keep pace with the changing workflow preferences and pipeline integrations across multiple studios, departments, and vendors. Discussions on naming conventions, best practices, and baseline folder taxonomies are ongoing, but choices may vary across teams and products.

The founder and CEO of 5th Kind, Steve Cronan, has dedicated nearly two decades to pursuing next-generation asset management and real-time collaboration solutions optimized for distributed teams and high-velocity production workflows. He started as a software engineer and bagged the role of IT manager for *The Matrix* sequels in 2001. His work on the films, a video game and *The Animatrix* project exposed him to a "perfect transmedia reuse scenario of a unified goal." Cronan said of the cutting-edge visual effects creators such as John Gaeta and Kim Libreri, "they understood the data challenge."

Data challenge is a critical component of modern productions, especially where film or television may just be one of the many forms of creative expression and media utilized to embody or productize a concept or intellectual property (IP). Sadly, as Cronan put it, "this is not fully understood by everyone just yet." He was at the forefront of VFX-heavy blockbusters transcending the boundaries of form and content, having the privilege to witness and appreciate "the ripple effects of decision-making."

The early versions of 5th Kind were engineered in Cronan's bedroom. He took the company to Los Angeles, where it was employed for big-budget tentpoles. Cronan named the company inspired by the tiers of human-alien interaction that suggest the third kind is contact and the fourth is abduction. The fifth is collaboration — and his product "centers around the future of collaboration," which Cronan believes has "reached a certain maturity and is looking to evolve into a media operating system in the cloud."

At the start of the journey, everything was done with systems on the premises, with Cronan "flying around setting up servers and VPNs," which he said felt like "attaching to that existing paradigm of department folder structures on the on-prem server." Those early experiences rooted in solving real-world problems directly with physical departmental structures and hierarchies, folder taxonomy, and file-naming conventions have informed the processes embodied in the 5th Kind DNA.

5th Kind CORE assets and usage by Fathead by the numbers

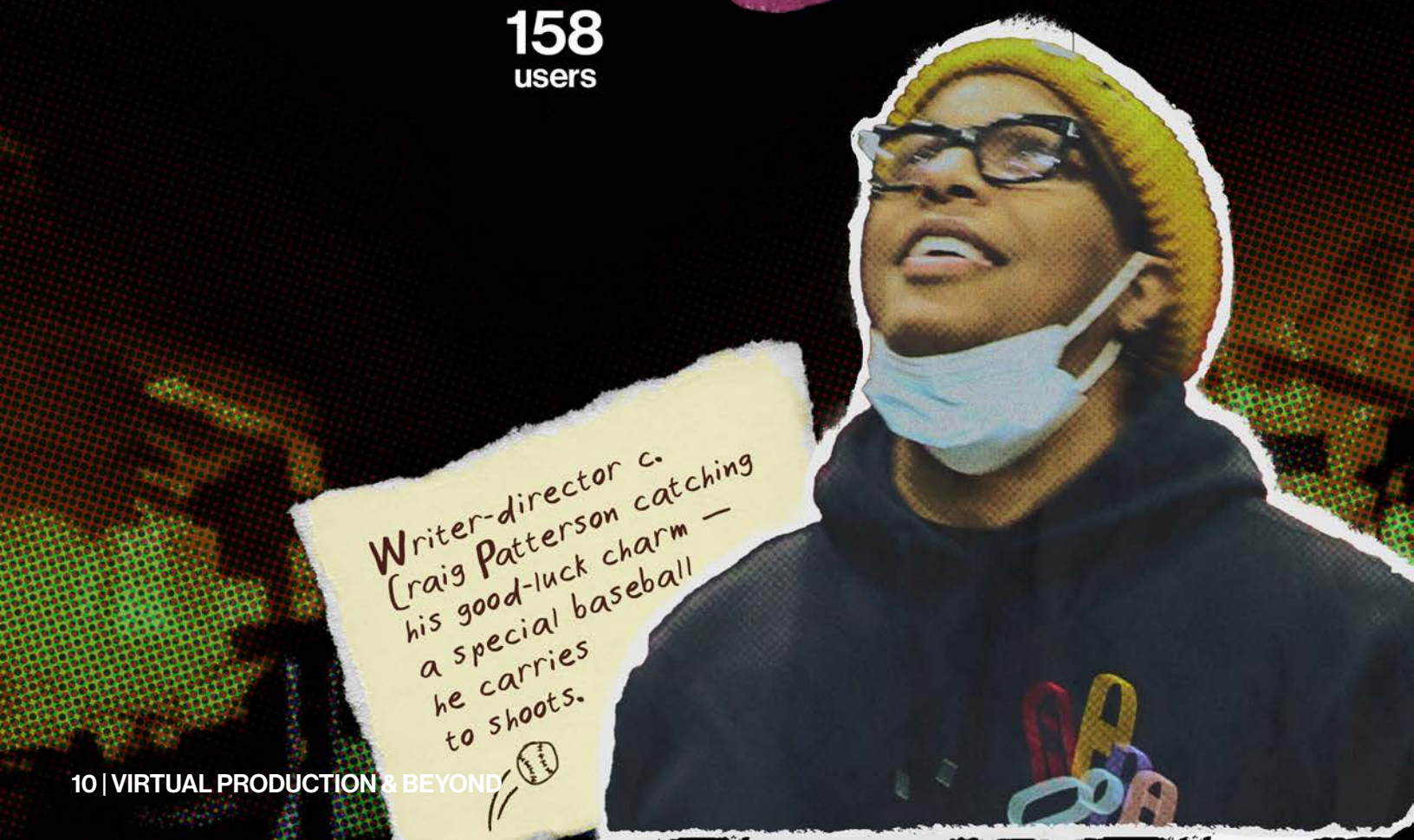
20,294
files shared

7,511
uploads

85
participants in the stage Live Room

3,580
downloads

158
users



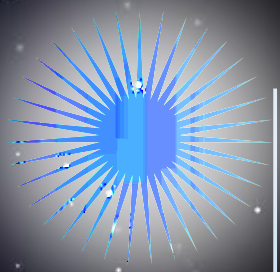
Over the years, however, larger studios and productions have evolved to set up "their own servers deployed in their data centers," while other things are moving to the cloud. These infrastructure updates present "exciting opportunities to scale and accelerate the integration of all these different products in the cloud," according to Cronan.

VFX-heavy pipelines have always required "a file naming convention, because of the complexities of the amount of data they're dealing with," he said. There's great value in "the long-term preservation of this amazing content created" across departments, especially the virtual art department (VAD). Contractors hired for short periods of time cannot be concerned with these challenges. A dilemma this presents is: "How to remove the technical hurdles from that creative process?"

5th Kind, as Cronan put it, is always on the lookout for intuitive, easy, and, wherever possible, automated solutions to "extract and enrich those files to become assets." Useful blocks of information are gathered from the naming convention, extracted from embedded metadata, or acquired by connecting to external systems like ShotGrid or ScriptE. Searchable assets maximize the investment made in creating them. Assets that were either used during production or remain unexploited may now find new applications as NFTs, in the metaverse or 3D web, creating "all sorts of amazing opportunities."

The recent rise of virtual production has forced producers to question: "How do I create the highest quality product as several creative processes have moved into pre-production?" Cronan said, "It provides an opportunity to increase the velocity of decision-making." There's a growing demand for increased feedback, high versioning, and faster turnaround.

On *Fathead*, 5th Kind integrated ScriptE, which is "a source of truth for essentially what's happening on set." Based on the script breakdown, 5th Kind can pull up storyboards for that scene or the previs — it can filter out rejected items and list the approved ones. Cronan felt enthusiastic about "building these collaborations, real-time, live layers on top of this really rich metadata layer instead of the traditional DAM search engine." The 5th Kind vision of "a media operating system in the cloud for real-time decision making for creative, legal, talent, approvals, etc., can be a pretty significant orchestration layer of the organization."



While the cloud can appear to be a limitless resource, there is a cost associated with operating purely in that domain. It is necessary to identify the appropriate workflow that is mindful of the capture resolution and what pipelines may need that source resolution. One must consider transcoding down at the edge. Support from the studio and the right funding is needed to "figure out how to glue this pipeline together to allow all these solutions to start truly integrating."

The ETC projects are a great place to "test the limits on what's next." *Ripple Effect* saw "the initialization of our live products," whereas, with *Fathead*, we've witnessed "an evolution into Unreal integration and building a longer tail to live sessions," Cronan explained. Virtual production brings people together, from being on set with Unreal developers to having a team of engineers working out ideas in real time. Everyone has access to materials from pre-production, especially the virtual art department content, to bring it into the on-set process — a "much richer media experience" and a "deeper reference library," allowing for more accuracy and an automated handoff, pushing information upstream.

"We achieved new features at the tail end of the *Fathead* production timeline that we could not test on the project," he said. "Web protocols have been integrated to stream directly from Unreal into one of the panels — with support for up to nine panels simultaneously, across the main camera, witness cam, etc."

While it feels like "we've got the fundamental LEGO bricks of this media operating system concept, we continually learn how best to implement the system, how to train, how to streamline the usability of the product."

The biggest challenges are "balancing the complexity of the need and all the security requirements and the simplicity of, say, an executive who doesn't even want to log into a system."

Cronan and his colleagues hope that MovieLabs might "set some foundation of standards around the data" to remove a lot of hurdles so "we can all just agree on a naming convention." When there's a constant, that will reduce the need to perennially adjust, allowing for a lot more automation and movement.

The M&E industry is different than most others, as Cronan cited the success of selling his product to $100 million productions that shut down in two years. Each production gets registered as a separate LLC, which disbands when the product is ready for distribution. Building technology solutions for the M&E sector is complex. It is an industry built on trust.

5th Kind addresses localization needs as far as having "the ability, on a per-user, per-role basis, to define what language the UI is presented in, from at least the labeling perspective. But the complexity comes with the data of the database — doing translations on the fly."

When asked whether certain positions need to be instated on teams and at studios tasked with asset and metadata wrangling to maintain protocols and consistency across departments and vendors, Cronan said, "It's funny that you define it as a new role because I've been ringing this digital asset manager bell for 20 years." He feels somewhat relieved that "we're starting to see more and more of that," but in his early days of evangelizing this adoption, "it wasn't even a line item."

While smaller shows may find it difficult to justify a separate role, the larger productions, anything $50 million and above, should see it as a "no brainer," recommends Cronan. While some studios may still believe in dumping it all on a tape and throwing it in a cave, a long-time 5th Kind patron, Marvel, has recognized and capitalized on having dedicated personnel assigned to unifying all media to ensure the accuracy of the data and turning files into assets — maintaining "access to everything they've ever done and reusing at least half a million dollars in assets per production." Cronan asserted, "the savings are significant, let alone what else can be done in this new wave of 3D web." The team at 5th Kind is always looking to address: "How do we connect with the creation process? How do you get concept artists and storyboard artists to engage with the system to get the content there? How do you give them tools that guide them to tag that content correctly?"

The system is designed to leverage file-naming conventions and turn those into metadata — a structural taxonomy that walks creators through it. A further review process by an asset manager will ensure the consistency of every asset across the production. At the top layer, studio-level asset managers will monitor for conformity across the whole studio.

Marvel supposedly has 4,500 companies running through the system where 25 million files were distributed using 5th Kind — that amount of routing and tracking across all of these different facets of the studio from every toy to every trailer and everything in between requires a database — but, "how do we reduce the technical hurdles of this?"

The creative process goes down many paths and continues to branch out and backtrack. Versioning and chronological data to track and correlate pieces of information are critical to identifying issues such as continuity and consistency.

"That's the impetus for our rebuild of the product about five years ago (circa 2017). The data layer, this ability to create these relationships and have metadata about metadata." You can select a shot and identify who was assigned to it. What's the latest status? What's the data type? Is it a date field, dropdown, etc.? "This extensible data model is the foundation that allows us to capture and make it searchable," he said.

5th Kind provided the Fathead team full access to all CORE products, including the DAM (digital asset management) and LIVE tools.

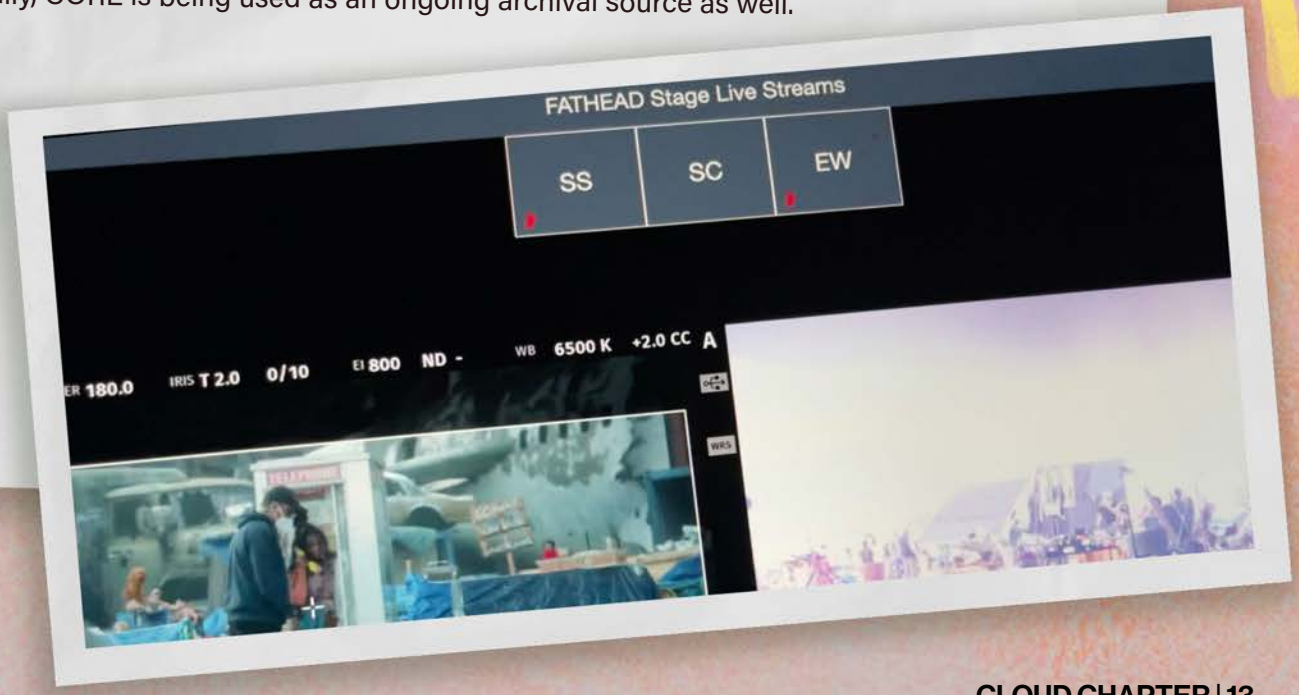
Paige Barnett, VP of client services at 5th Kind shared some anecdotes highlighting how CORE was used on *Fathead*.

- CORE was used in pre-production and post-production for work-in-progress sharing and decision-making between the teams, the director, and the producers.
- Everything from storyboards to set diagrams to character costumes and metahuman designs was shared and reviewed together before production.
- CORE enabled users to comment and annotate files and provide feedback that ultimately led to what was captured on set.
- In pre-production, users also used the CORE LIVE tool for remote live review meetings with vendor companies.

The CORE LIVE workflow continued into production.

- From the set, LIVE was used as a remote video village that crew members could access from tablets and laptops while on set, and offset crew could access from wherever they were based in the world.
- In the evenings after wrap, the editor and the director met via LIVE for remote review sessions of the first cuts.
- On the DAM side, the feeds from the set, main and secondary cameras, and the witness cam feed were recorded and made available for reference and notes in the system.
- Likewise, all dailies for *Fathead* were uploaded and distributed through CORE with an extensive list of stakeholders.

Finally, CORE is being used as an ongoing archival source as well.



Additional layers introduce extra demands on the system. For example, a file layer raises questions about support for video, or the ability to handle 10-bit HDR. Watermarking or even forensically watermarking some clips may turn up as a requirement. Will it play on the Apple TV app or a mobile device or desktop? How many layers of security are available? "There are all these complex layers that have to be dealt with," noted Cronan.

With the complexity of the asset types and the velocity, it's not uncommon to have someone upload multi-terabyte data in a single file. Thousands of stills may arrive from an on-set photographer, all in RAW format. The system may have to handle watermarking a script for 100 people while handling a screening somewhere else. "The orchestration of file processing and data movement needs to be exceptionally optimized because of the velocity."

Since one product cannot satisfy every need and be "everything to everybody," adopting an open ecosystem is desirable. Build integrations and interoperability to deliver the "best quality at the end of the day." 5th Kind has several integrations to facilitate and augment functions such as DRM, live streaming, and production reports. The Dolby On integration supports live streaming, providing a superior audio experience that can deliver spatial audio, background noise cancellation, and low-latency streaming.

CloudFront, ScriptE, ShotGrid, 3D Model Viewer, Adobe Creative Suite, Apple TV and iOS, Box, and Perforce are some integrations either already in play or soon to come. IBM Aspera file transfer acceleration directly through the interface provides the ability to upload and download folders natively. The Autodesk ShotGrid integration helps pull in all that shot information, the elements, and the characters and informs a new feature — the file-naming convention parser. As we create a sequence code in ShotGrid and upload a file with that code, 5th Kind connects that information and makes things more searchable.

Cronan reasserted the goals at 5th Kind as "focusing on what are the most valuable things we can do to reduce friction, either within production or even outside to the vendors working within the production — providing an asset source of truth, that aggregates a lot of information from a lot of different tools, and gives you great experiences for decision-making on top of that."

While several technology solutions originated elsewhere to serve critical functions of society before getting borrowed to facilitate improved production and distribution of entertainment, 5th Kind stemmed from the demands arising out of "a breeding ground of some of the most complex requirements" in Hollywood. Virtual reality is another emerging area with implications far beyond the media and entertainment domain. Cronan is well positioned to handle those demands with "some patents around similar ideas" of "optimizing the right environment to augment creative flow, reduce friction to allow people to stay in that creative space, and deliver their ideas as clearly as possible." ▪

Live camera feed and witness cam from the production stage viewed remotely via 5th Kind CORE LIVE.

Case Study 1: CORE LIVE for remote collaboration with the on-set production crew

Access to physical locations was severely restricted due to COVID-19 protocols. *Fathead* needed a solution that empowered remote teams to deliver valuable support and input during on-set production. A live feed from the stage, which in essence, was a remote video village, was the right solution. Teradek Cube Encoders and Open Broadcaster Software (OBS) were used to send real-time messaging protocol (RTMP) from the Teradek Cube and low-latency Web Real-Time Communication (WebRTC) from OBS directly into 5th Kind's CORE LIVE.

Remote collaborators signed into 5th Kind's Live Room for the stages to watch the camera's main feed via the Teradek and a witness camera feed of the entire volume production environment/stage via OBS and WebRTC.

Room participants could select individual feeds or switch between them. The DIT team set up the witness camera live feed on the first tech day to enable remote teams to observe and provide feedback as the production sets were incrementally built.

The feed was accessible via tablets, and crew members practicing social distancing also used it for review and communication. More than 85 collaborators and crew accessed the stage streams at any given point during physical production.

Case Study 2: CORE LIVE for remote dailies editing and review pipeline

Post-Production Supervisor James Blevins wanted the ability to immediately see each day's content uploads without waiting for DIT transfers at the end of the day or using a lab. Since the files had already landed in high-speed FSx for Zettabyte File System (ZFS) storage in the cloud, the dailies editor (Shawn Carlson) could begin work from home as soon as the upload was completed.

Carlson used Arch Platform to facilitate a connection to an AWS G5 series instance, where Blackmagic DaVinci Resolve Studio 17.4 was running. In this instance of Resolve, Carlson created stringouts (a common way to review multiple takes in a TV production.) Then, sharing the screen of the virtual workstation via OBS back to a 5th Kind CORE LIVE collaboration room dedicated to the production phase editorial team, the director on set, the post-supervisor who was remote, and other key remote collaborators were able to view the content directly from the Resolve timeline, without any transcoding or proxy generation required for playback.

EDWARD CHURCHWARD

Co-founder and CTO, Arch Platform Technologies

arch platform technologies

Arch Platform Technologies provides powerful, secure cloud-based creative studios, offering fast and easy ways to move creative teams and workloads to the cloud. Edward Churchward is the co-founder and CTO of Arch Platform Technologies, who took the initiative with the *Fathead* team to provide the virtual machines used on the project and educate the team on the most effective use cases for its application relevant to virtual production.

Arch provides cloud infrastructure that enables remote workflows, which Churchward said: "brings down the overall cost, and you can spin up in-house teams quicker and more easily." One of the key benefits is that "you don't need to hire a tech team to do this."

Arch Platform is software agnostic. We are always asked, 'But can you run this?' Yes, we can run anything you like. It's a computer. But people think about the cloud like it's not. "We look at ourselves as glue at Arch," explained Churchward.

Myriad AWS products have been productized and commoditized into a simple dashboard. Churchward shared during a brief demo of the dashboard, "Behind the scenes, everything we're doing here is AWS. Do you want to build a new workstation? Click the plus."

"You don't need a tech team to build a new workstation and ensure it is hardened and secure," said Churchward. A user can select one of the templates, place it in a group, and click launch. "And away it goes."

If needed, 50 new workstations can be launched at once. These are built using an image pipeline with a pre-assembled application stack.

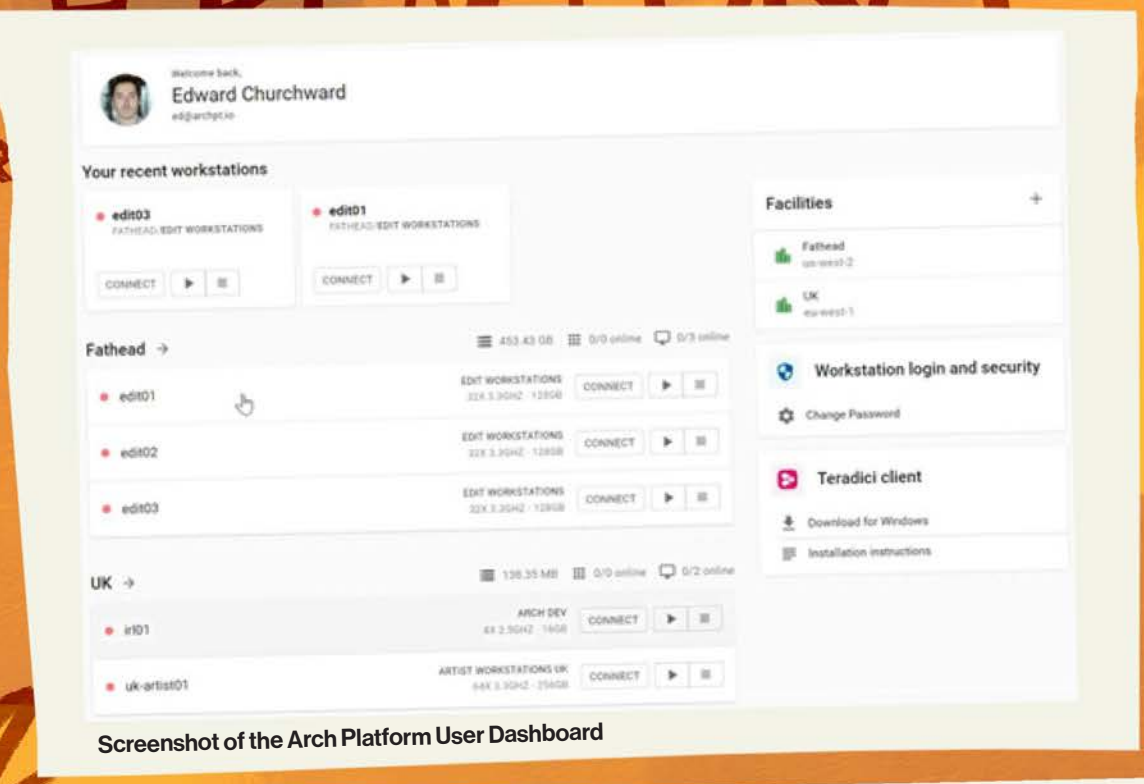
Arch is constantly building out the application stack to include a collection of software that users will need but may not think about while setting up the workstation. Most will focus on the handful of main applications, such as Maya or Unreal Engine but will ignore small yet essential apps like file archiver 7-Zip. "It's all automating the processes," Churchward said.

Arch relies on AWS. When a hard drive fails, "they magically fix it in the background." No one has to worry about IT if a machine's CPU or RAM is not good. "That's the beauty of the cloud."

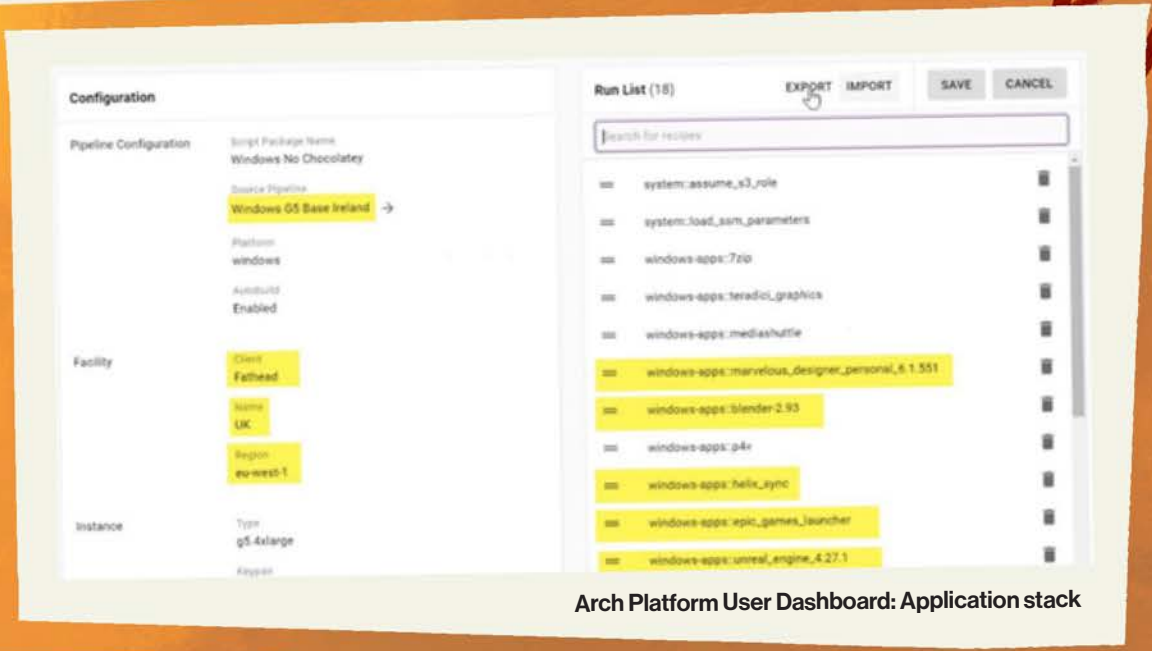
Using the Arch Platform dashboard, it doesn't take much time to build a new facility in any part of the globe. "You'd be surprised how big an infrastructure one can run with access to all the AWS regions and local zones."

Using the dashboard, Churchward set up an artist workstation in Ireland for the *Fathead* virtual humans workgroup supervisor based in London, which took under an hour to build and another hour for the system preparation phase. It requires minimal human effort as much of it is automated.

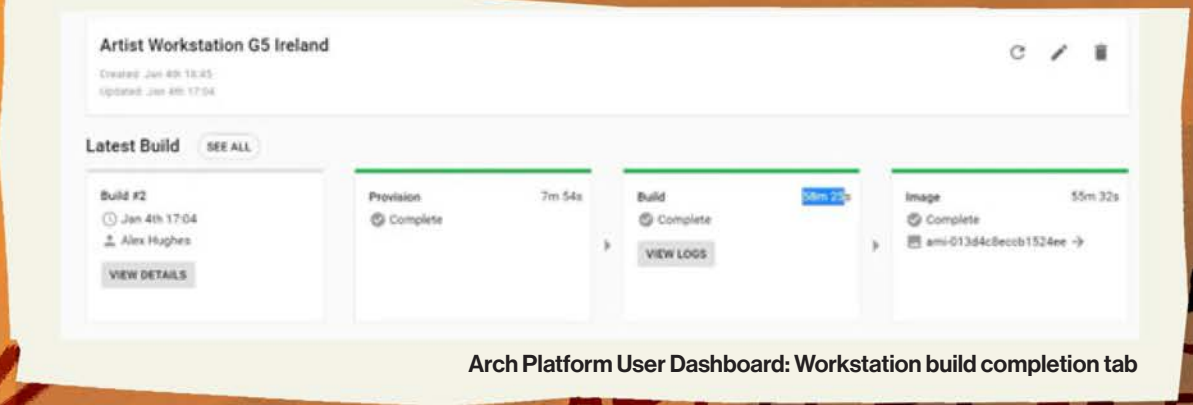
In as little as 45 minutes, it is possible to have a fully-featured facility running with storage, render workstations, license manager, and connection manager for a Teradici or Parsec broker within an audited, secure, hardened environment. Asserting the benefits of this workflow, Churchward said, "That gives us real flexibility and takes anyone just one click."



Screenshot of the Arch Platform User Dashboard



Arch Platform User Dashboard: Application stack



Arch Platform User Dashboard: Workstation build completion tab

START EARLY TO SAVE BIG

Churchward recommended that the best time to engage Arch is "when you're at your budgetary stage and planning out," allowing his team to work with the producers to discover ways to "save a good amount of money."

"We've got case studies where people have gone in with a $1.7 million VFX budget on a movie and spent only $800,000," said Churchward. He attributed these savings to the engagement of Arch Platform at the budget stage. "They used our platform, spun up a team of 10-15 people who did the work for six months, and then shut it all down."

Such savings may get productions greenlit that otherwise struggle to get made.

"Creatives shouldn't be weighed down with the nuance, but they need the right tools to do what their talents let them do," Churchward pointed out. He endorsed that having the producer who runs the budget get on board with this approach is the most powerful shift for a production.

Once there's a buy-in upfront, producers can speak with the team and tell them, "This is how we're saving the money to make the movie."

VFX vendors have huge margins. In-house teams are becoming popular, especially for low-end VFX work like compositing and 2D wire removals. Churchward said, "If you can pay out the rates in a rebate zone, it's a 'super' cheap way of doing it."

The VFX supervisor or show producer will have to decide the direction. Churchward classified them based on approach. "Some are good at budgets, wrangling numbers, and managing vendors. Others are artists and creatives who took on new responsibilities and have to get their hands dirty." It's the latter group that Churchward found "are the ones that love building in-house teams."

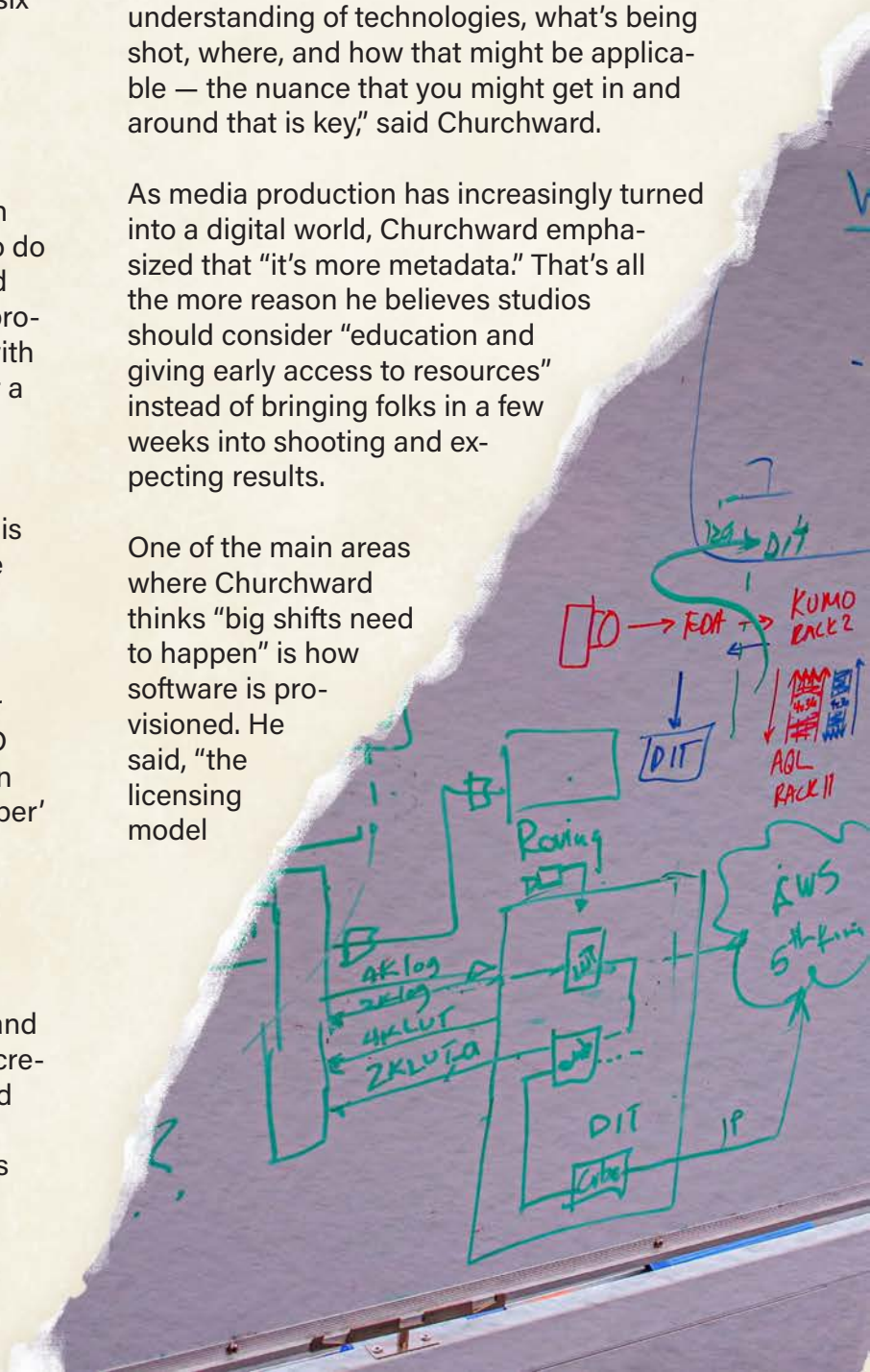
ROLE OF A CTO AT MOVIE STUDIOS

Straining on the importance of a CTO at a movie studio, Churchward sighed about not many studios having them, and the few that do, he said, "are not given the authority." He attributed this to the predominant focus at studios on deciding which movies to make and how to get them made.

"The CTO may not have much input" on the creative aspects, "but the visibility of what is happening, the planning, the foresight, the understanding of technologies, what's being shot, where, and how that might be applicable — the nuance that you might get in and around that is key," said Churchward.

As media production has increasingly turned into a digital world, Churchward emphasized that "it's more metadata." That's all the more reason he believes studios should consider "education and giving early access to resources" instead of bringing folks in a few weeks into shooting and expecting results.

One of the main areas where Churchward thinks "big shifts need to happen" is how software is provisioned. He said, "the licensing model



doesn't fit the new types of workflows for that side of things."

CLOUD PERSPECTIVE

Customers seeking cloud solutions often go directly to AWS with the problem. AWS may educate that customer on how to use AWS solutions, which Churchward said, "is a big challenge because it's complex to do it right."

COMPUTING ECOSYSTEM

Equinix offers global colocation data center solutions that are fairly ubiquitous. Most big enterprise customers need data centers. "One of our future roadmap pieces, which some of our enterprise customers have motivated, is the support of non-AWS computers," explained Churchward.

"Our dashboard will show you not just your AWS cloud computers, but also the computers sitting in your data center — a single pane of glass to manage your resources: human resources and their allocation to the compute resources."

"There is a happy world where you will get edge computers," said Churchward, "which is what these data centers are called that aren't quite cloud."

Churchward differentiated edge computers as systems that may not have the sort of API-level integrations attributed to the cloud. This is possibly why, he said, cloud is "a programmatic way of dealing with things rather than doing it physically." He finds great synergies between all of them.

Accounting for the role of edge and on-prem, Churchward said, "they offer useful geographical data points because AWS can't be everywhere." There are huge swathes of the world where they are not present. The same applies to Microsoft, Google, and Oracle.

These smaller, more bespoke data centers are in great places, which Churchward noted, "could enable workforces that otherwise don't get access to cloud local zones yet." The smaller edge data centers can pop up much faster and are synergistic with the cloud workflow, which is why Arch is making provisions to enable computers that aren't yet part of AWS.

CLOUD RENDERING

"We don't want to move data — that's the key for us," said Churchward, "because moving data is where you get big expenses and security vulnerabilities." Data is stored in the secure virtual private cloud (VPC), where a render farm also exists. "We provide a deadline render farm within the same facility."

When it's cheaper to render in another region, Arch will pair VPCs. If a production can save 30% by moving its render pipeline from Frankfurt to Virginia, it's executable because an S3 to S3 copy of the relevant data is part of the workflow, and it's

all still housed in the same AWS account within the same locked-in environment with the least privilege.

ARCHIVING DATA AND FILES ON PROJECT COMPLETION

Arch extensively uses AWS for archiving as it offers fast ways of getting things onto on-premise. Churchward said, "Most clients prefer to put it into Amazon S3 Glacier."

"The key thing for any film production once work is completed," stated Churchward, "is to work out what needs to be archived." It's not the data they have at the end but what they will have left over after deleting everything that won't be needed again.

VFX shots often have several iterations with multiple versions of the same shot. Most of these early iterations become completely redundant once the shot is finalized.

All of those files can be deleted, retaining only the dependent hierarchy. "Suddenly, you can dramatically reduce your datasets."

"That's the challenge," noted Churchward. "That's an on-premise challenge as well."

"People tend to be slightly lazier on-prem because they're just putting it onto an LTO, which is a one-time cost," he added.

"Whereas with Glacier, you're paying monthly, so people need to be more aware." Arch has great success with the low price point of Glacier. ▪

GRAPHICS PROCESSING UNIT (GPU): Vital for Real-Time 3D

The NVIDIA Corporation has been a major driving force in the advancement of GPU technology and its application across wide-ranging industries. The team at NVIDIA discussed how they continue to make significant contributions to the fields of gaming and real-time 3D graphics, and how these contributions have allowed for a greater level of creativity and efficiency in the virtual production workflow.

QUESTIONS FOR NVIDIA FROM ETC FOR THE VIRTUAL PRODUCTION WHITE PAPER:

1. **Graphics Processing Unit (GPU) — What are some of the industries that have progressed rapidly and impacted lifestyle advancements in recent years with the expansion of GPU processing capacity?**

- All industries are now benefiting from advancements in the GPU, from life sciences and healthcare, manufacturing and telecommunications, to the obvious ones: gaming and media and entertainment. GPUs have ignited a worldwide AI boom. They've become a key part of modern supercomputing and have been woven into sprawling new hyperscale data centers.
- Key advancements in the GPU range from graphics acceleration to powerful compute capabilities for AI, and even tasks such as encryption and network acceleration.
- Simulation, graphics and rendering, AI, projection and display technology are all enabled by the GPU's ability to process vast amounts of data.

2. The penetration of gaming across the globe has been growing exponentially, spanning every age range in the past few decades, with some sources claiming the numbers to be around three billion. How has this demand for faster and improved real-time graphics pushed the innovation cycle at NVIDIA?

- Gaming is important and has always been a part of the innovation NVIDIA is driving. More recently, NVIDIA has innovated around edge computing and the cloud, enabling anyone to have access to powerful GPUs from anywhere on any device.
- NVIDIA's advancements in ray tracing have become an important visualization technology in many industries like architecture and manufacturing.
- NVIDIA has similarly been working alongside our partners and customers, innovating around the most demanding requirements in the film and television industries, enabling key virtual production technologies and workflows.

3. RTX cards are all the rage in the industry. Can you describe the role ray tracing plays in generating improved, real-time photoreal rendering?

- NVIDIA RTX 6000 GPUs have been a mainstay for real-time content for virtual production for LED volumes due to the large GPU memory profile, support for genlock, and display synchronization using NVIDIA Quadro Sync II and Unreal's nDisplay.
- The advent of NVIDIA RTX brought about RT cores, providing additional compute power for real-time ray tracing, as well as tensor cores for accelerating artificial intelligence, such as denoising and super sampling with DLSS (deep learning super sampling).
- Ray tracing allows the user to simulate the path of light, how it bounces, changes color, and illuminates the virtual world with a level of fidelity that mirrors our physical reality. This simulation can provide great accuracy and in the past was only available to high-powered systems working in offline rates, minutes to hours per frame rather than frames per second. NVIDIA's RTX opened the door for anyone to create high fidelity visuals in real time.

4. How have these advancements in gaming-related real-time graphics rendering led to a revolution in the movie production workflow — methodologies that have collectively been termed virtual production?

- Epic Games has invested heavily in the professional use of Unreal Engine in the film and television industries and these investments formed a strong foundation for virtual production. Epic was early in the reinvention of VR, and they hardware-accelerated their engine to take advantage of the latest innovations in GPU computing. Epic continues to invest in training and customer projects through Epic MegaGrants and Unreal Fellowships.
- Similarly, NVIDIA has invested heavily in research, SDKs, hardware and software for the media & entertainment industry for decades, continuously breaking boundaries in terms of graphics performance, ray tracing, and AI. These investments allowed all of the ray tracing goodness to be exposed that were developed for the professional market. Technologies such as Quadro Sync II also allow multiple computers to render a single picture and allow a camera to capture the complete picture without "tearing."

5. What do consumers and creators need to know about identifying use cases for their line of work in the virtual production pipeline and how should they go about finding the right GPU to address those needs?

- In some cases, less is more, but in virtual production, less is less. Less memory, fewer systems, lower pixel counts all lead to lower quality, lower frame rates, and less usable footage in the end. The NVIDIA RTX 6000 series of professional GPUs provide the power and memory required by virtual production stages. By using Quadro Sync II technology, you can expand the system cluster as large as you need to accommodate the rendering requirements of your production's assets for the number of wall controllers and total number of pixels you are supporting.

6. How has the consumption pattern changed in recent years as game engines like Unreal Engine and Unity have become free to use?

- Many software companies have learned that making your product free to use allows individuals to learn the product, create online learning videos, and ultimately grow the community. Waiting to monetize the software has attracted development to come in and invest their time to even build new workflows in nascent industries.

7. The LED wall has become a ubiquitous phenomenon somewhat overshadowing other applications and workflow methodologies involved with virtual production. The hype around it has seen rapid growth in walls of all sizes and shapes popping up everywhere, which needs powerful computing that goes with it. How early in the discussion do the entrepreneurs, creators, and technologists involved in designing and operating these pipelines reach out to NVIDIA to discuss solutions for real-time graphics processing as a prominent facet of this process?

- NVIDIA is involved in all phases of development quite early through a dedicated Developer Relations team, as well as industry experts including solution architects that came directly from the industry. As a global leader in graphics and AI, NVIDIA is frequently brought into the discussion early on projects that have never been done before. Many of these collaborations with partners and customers have helped the pace of innovation for all involved.

8. What are the questions groups involved ought to ask early in the game to better equip the infrastructure to maximize what is possible in the virtual production workspace?

- There are a variety of different wall setups including small floating panels that can float into specific positions needed, to general use caves which cover three sides and a roof while using practical set pieces for the ground, to custom shapes like tunnels for specific shots. Breakdown the use cases you want to cover and design a stage that fits. A gargantuan cave isn't going to be used if it's so large it demands a high price tag while productions can get their work done with smaller flexible panels. The industry is still moving fast. Panels are maturing quickly, so design for flexibility and short equipment lifespans.

9. To upskill and build capacity in this burgeoning field, the need for structured and segmented education protocols is being recognized as the gap to be filled most urgently. Does NVIDIA have education curricula and workshops catering to this industry and workforce?

- NVIDIA actively works to educate the market at events such as NVIDIA's GPU Technology Conference (GTC), SIGGRAPH, NAB, IBC, RealTime Conference, Infinity Festival, and others. NVIDIA has also partnered with customers on videos and blogs to showcase how AI can help with virtual production. Additionally, NVIDIA recently partnered with Epic Games and Microsoft for a two-day summit that allowed attendees to get hands-on with a virtual production stage (https://productionsummitla.com/).

10. In 2021, *TIME* magazine listed NVIDIA Omniverse among the year's top 100 inventions. What does this innovation deliver to users and what are the different use cases that have earned it this distinction?

- Based on Pixar's USD (Universal Scene Description) format, NVIDIA Omniverse acts as a hub to interconnect your existing 3D workflow, replacing linear pipelines with live-sync creation, letting artists collaborate across the art department, the VAD, or on-set across Unreal, Maya, and 3ds Max. This allows artists to use their favorite DCC tool while enabling a common viewport across all apps through NVIDIA's multi-GPU-enabled RTX Renderer.
- Omniverse allows industries such as architecture and manufacturing to create digital twins and simulate them before they are ever built in the physical world.

11. Will Omniverse replace our dependence on game engines to power virtual production pipelines?

- NVIDIA Omniverse is not a game engine. While it is game-changing technology, it will not replace game engines in the virtual production pipeline. NVIDIA Omniverse will enhance the content creation process by connecting artists with different disciplines and different DCC tools to all collaborate on the same scene file in real time. ▪

PERFORCE SOFTWARE

Fathead Executive Producer Erik Weaver learned during the Unreal Fellowship (Spring 2021) that Epic Games preferred Perforce as its go-to version control software for Unreal Engine. He reached out to Ryan L'Italien, director of solutions at Perforce.

"Sure, we'll donate some licenses for this good cause," L'Italien responded. In addition to the free licenses, he made time to attend meetings about structure, content, and workflows to help the *Fathead* team set up and use Perforce Helix Core on the project. "It was a solid fit that made the workflow smoother," he added. The *Ripple Effect* white paper covers the Perforce use case for virtual production, but on *Fathead*, there was an opportunity to carry that involvement further.

Ryan L'Italien, Director of Solutions at Perforce Software, at the Amazon Studios Virtual Production volume stage during the *Fathead* first unit shooting schedule.

SINGLE SOURCE OF TRUTH

As the single source of truth, it is best to get everything into Perforce and start using it from the beginning, so all your assets are there. Citing one of the game studios that separated from a major triple-A group to start their own thing, L'Italien said, "Before they had an idea or started writing any code, they bought Helix Core licenses." The goal was to put everything in Perforce to maintain that consistent traceability. L'Italien wanted to help ETC on *Fathead* to support the growth of this new vertical.

ROLE OF ICVR

On *Ripple Effect*, ICVR played a much bigger role in streamlining the shoot by helping maintain the environments, workflows, pipeline, and content. They helped with art and VFX. They didn't have enough time around *Fathead*, so they worked with AWS directly to set up a server and maintain the Perforce environment for users across the project and streams. They played the role of an administrator, and L'Italien helped get users connected, syncing files, and checking out files. L'Italien said he operated more as technical support. "As much as possible," he noted, "without changing the project settings, depots, and streams." That's where ICVR would step in to help orchestrate it from a top level.

ICVR has a strong footing in mobile gaming and is familiar with the concept of version control. They'd been using Plastic SCM, and on *Ripple Effect*, when they had some errors on the platform, they reached out to Perforce for some trial licenses. Once ICVR started to build a workflow around it, L'Italien said, "They went full Perforce, bought licenses, and migrated from Plastic onto Perforce."

VERSION CONTROL LEGACY IN OTHER INDUSTRIES

Perforce has been around for decades. Traditionally, it served software developers. For all types of application development, it became the go-to source control. The focus was to help industries with some element of scale with projects having thousands of users all over the globe, using lots of massive files. Katie Cole, the gaming & virtual production evangelist and director of product marketing at Perforce stated, "There were no other source control solutions available on the market that could seamlessly handle those elements of scale."

The transition into more specific industries like gaming was natural — as game development involves software

development. The humongous binary assets wouldn't work with Git (a competing version control system). "That's how we got into gaming," explained Cole. Then with the migration of game engines into other verticals, like virtual production on the media and entertainment front and digital twins in manufacturing, Perforce entered those new environments.

Digital twins were adopted by retail during the pandemic to cut costs. Cole said, "I can make digital replicas of the things I'm selling to people. But how are those digital replicas created? We're recreating them in game engines, not some old, antiquated digital twins' technologies." The game engines moving into these other verticals is a primary driver for Perforce to support those industries.

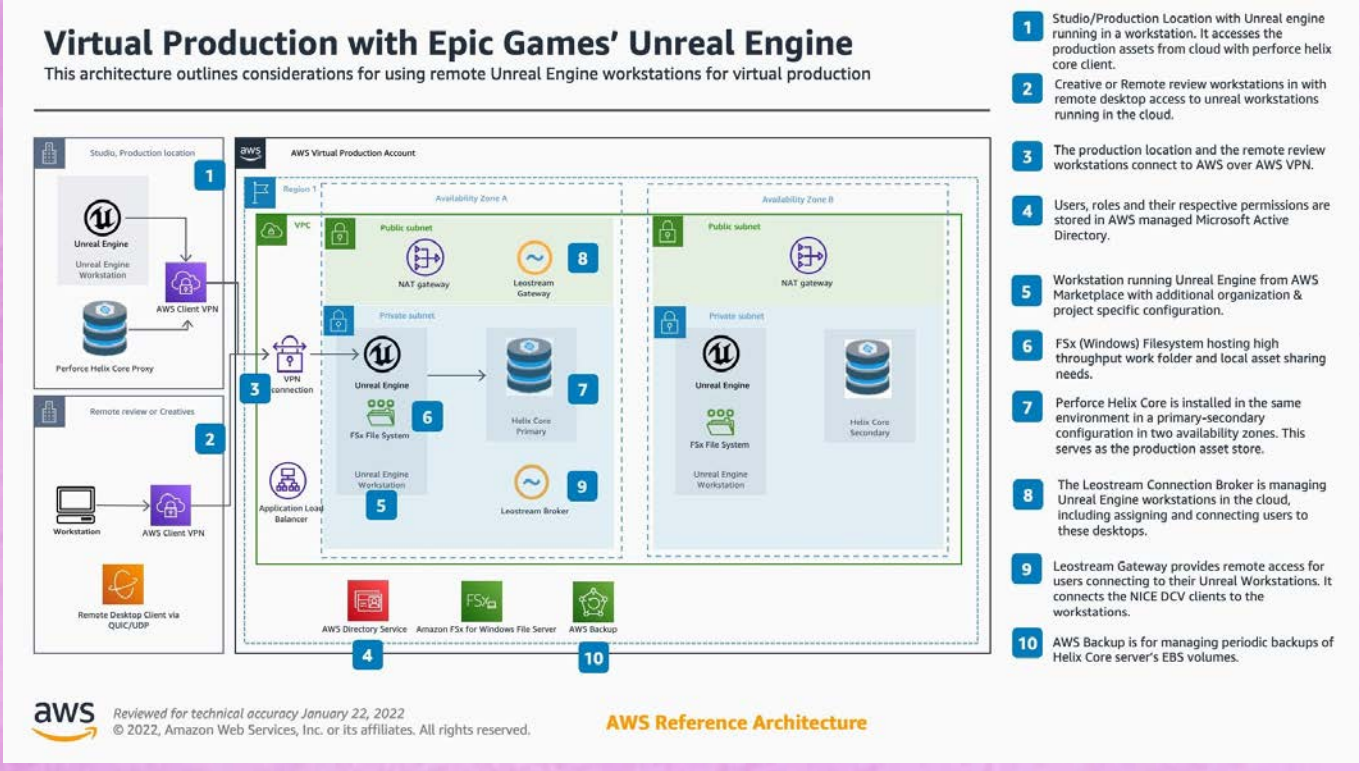
"Game developers historically worked in silos," L'Italien added. "They're being pulled out of the game industry and are asked to change how they look at content for other verticals. They have transferable skills." The movie industry is open and shares its processes, which increases the demand for artists and developers from the game industry.

ASSIMILATING INTO OTHER VERTICALS

Moving into different verticals has required building specific tools for those new industries. "It was probably about a decade ago when game development became a big focus for us," Cole observed. That didn't change much from their previous model as the ratio of coders to creative individuals. The gaming pipeline was still heavily reliant on individuals being able to write code.

The Perforce toolset was built to serve developers who write code. In some of the new verticals beginning to adopt Perforce, where there's less reliance on developers and greater dependence on creative people who are less technical in nature, Cole said, "We're adjusting and have been in the process of continuing to adjust our tools to be friendlier for the people who aren't developers by nature."

The goal is to build user-friendly workflows for less technical people. Cole also noted that the



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https://aws.amazon.com/blogs/media/virtual-production-reference-architecture-with-epic-games-unreal-engine/

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types of assets they're storing in the depot are more visual. While storing files was never an issue, the new paradigm is: "How do we make it friendlier for them to find those assets and preview them?" These are just lines of code, so the question becomes: "How do they compare those assets to each other?" These other verticals have led the team at Perforce to venture into the next frontier of visually aware source control.
The product management team is hard at work. Cole said, "It will be a long process to interact with enterprise-level software to get there."

Continuous improvements have been made in recent years to upgrade the usability to make things more accessible and findable at any level instead of relying on a subject matter expert or getting into the documentation. The user interface (UI) will be simplified with safeguards and prompts to help people understand things in regular English instead of technology speak — for example, error messages that tell you what's happening. It is 30 years of development that the team has to gloss over and modify.

"How do you jump from code to pretty pictures?" L'Italien pondered. "It may take us a little while." To expedite the process, Perforce is partnering with others in the industry to work out integrations — those coming up soon will include Blender, Houdini, ftrack, and ShotGrid. Epic Games has changed the UI for Unreal Engine 5 for 'change lists' and checking files in and out using the Perforce concept.

Perforce organizes customer advisory boards, where they have learned that versioning has to be made almost invisible for the less technical users. "That's the idea with all these integrations," said Cole. "You don't even have to think about versioning. You do the workflow you're used to, and all the right stuff will happen on the back end to secure it." That is the concept leading the movement forward.

HIERARCHY IN FILMMAKING

Virtual Production Producer Tom Thudiyanplackal brought up the nature of filmmaking that is wildly different from game or software development. "The director, producer, writer, and DP are folks who come in, and their time is very limited on many projects," he said. "You get them for two hours here or there because they're in about 20 meetings."

Thudiyanplackal highlighted that these key contributors "put their fingerprint on something, and it's important to get that across the board for everybody." At that level, they are not dealing with assets or working with fine details. It's all about broad strokes that have an implication all the way down because it's coming from the top.

"Filmmaking has a hierarchical structure for how content is dealt with, and that needs to be reflected in how we interact with software," said Thudiyanplackal.

Perforce deals with this top-down approach by setting up streams and workflows based on how users and content creators interact with the files. "We originally had a flat hierarchy," said L'Italien. There was a mainline with several different streams. The problem with merging is determining who has access to what — separating streams based on the content that was being edited and not the persona or the stages of approval.

L'Italien said, "The new way marks it out, but it couldn't be implemented in time on Fathead." It mirrors how code is developed. There are development branches, integration streams, and release streams. That now provides a solid way of thinking about how to promote content through a workflow.

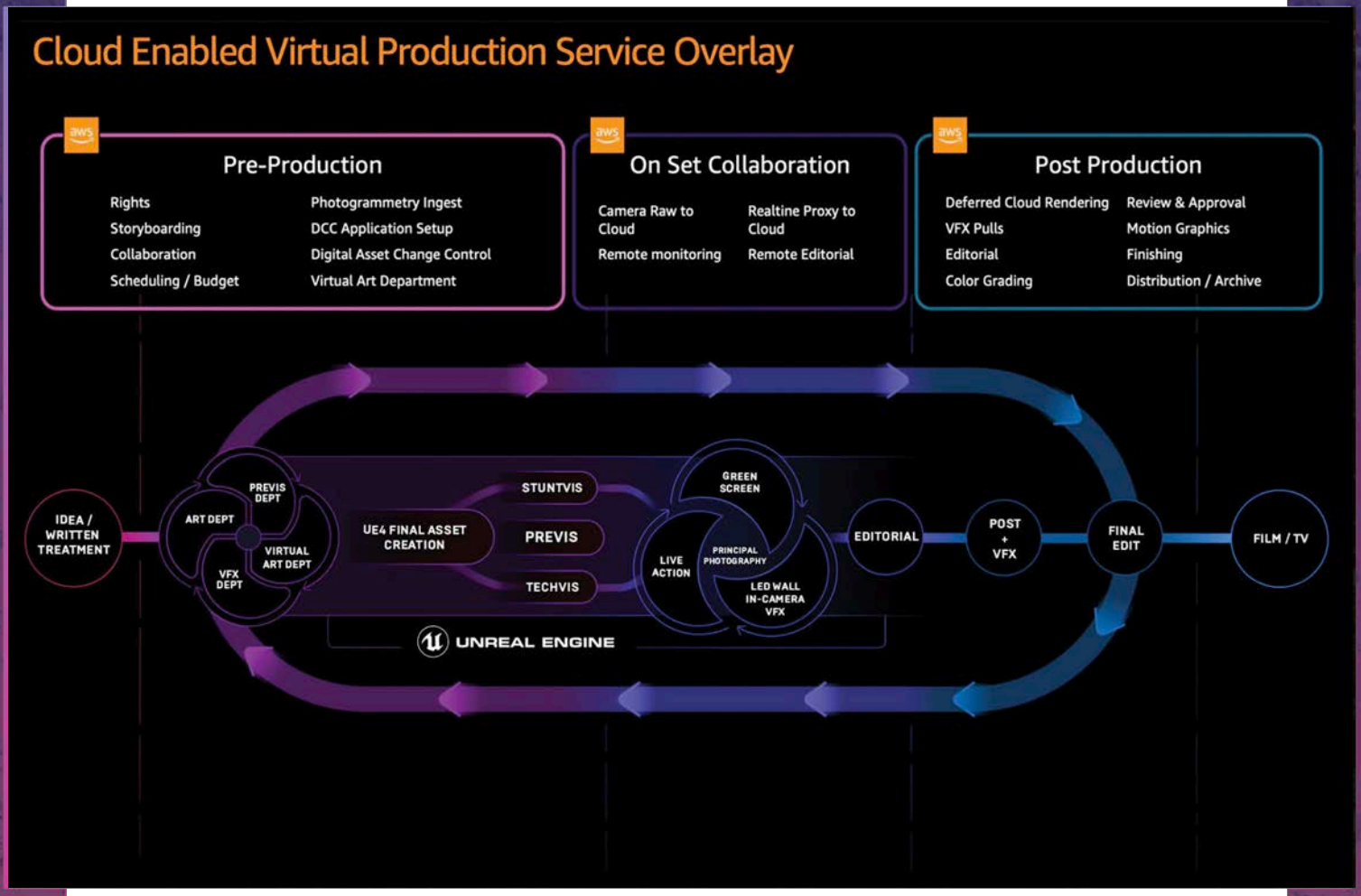
"We're still in the process of figuring out how to best work inside of these different industries," explained Cole. One approach being explored is to create a tab for virtual production. Cole is working with Application Engineer Cassidy Pearsall with Systems Solutions at ARRI to put together a customer advisory board to learn the right process for filmmakers better.

"We have a way of doing it now, but is that the most optimal way?" asked Cole. She and her colleagues at Perforce are interested in discovering what improvements will make the product simpler for creatives. She added, "Maybe there are things we need to add on that don't exist right now." Industry feedback is key to preparing better tools for the future. ▪

FATHEAD AWS WORKFLOW

Fathead was designed to be a cloud-first production and serve as a testing ground for new virtual production workflows. Anchored by real-time game engines and cloud-based solutions, the project's workflow enabled a small team to create a high-quality deliverable.

Fathead Executive Producer and virtual production specialist Erik Weaver enlisted the help of Amazon Web Services (AWS) to work closely with *Fathead* creatives for leveraging AWS services from beginning to end, supported by partners, including Epic Games, Perforce, 5th Kind, Arch Platform Technologies, Blackmagic Design, and Bluescape.



[Image source: Epic Games]

As with most virtual productions, the process was broken down into three phases: pre-production (before camera), on-set collaboration (camera capture), and post-production (services after camera).

PRE-PRODUCTION

In pre-production, critical ideation, planning, and budgeting are paramount. Efficient scheduling, pre-visualization, and line producing during a project's early stages determine how smoothly production will function. For *Fathead* pre-production, the team selected cloud-based security, artistic, and scheduling tools suitable for remote collaboration from anywhere in the world.

Fathead production designed the project's workflow and chose Amazon Simple Storage Service (Amazon S3) as the foundational content lake where all created assets could be stored. To protect the content, the team created Amazon S3 security policies to tier access privileges for the crew. Using Identity Access Management (IAM), the team generated individual credentials and delivered them to the recipients.

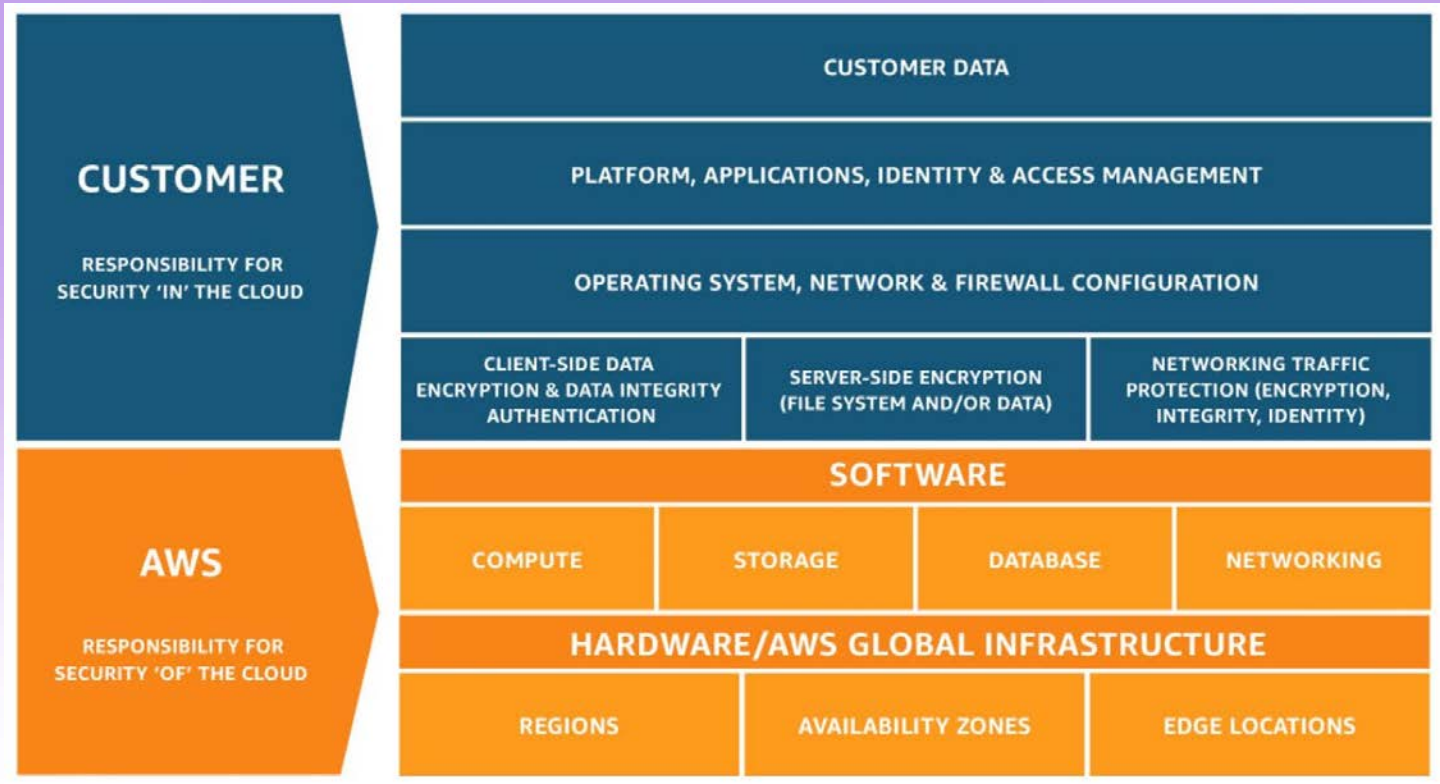
Amazon S3 enabled encryption to secure the assets, without creating an extra workflow step.

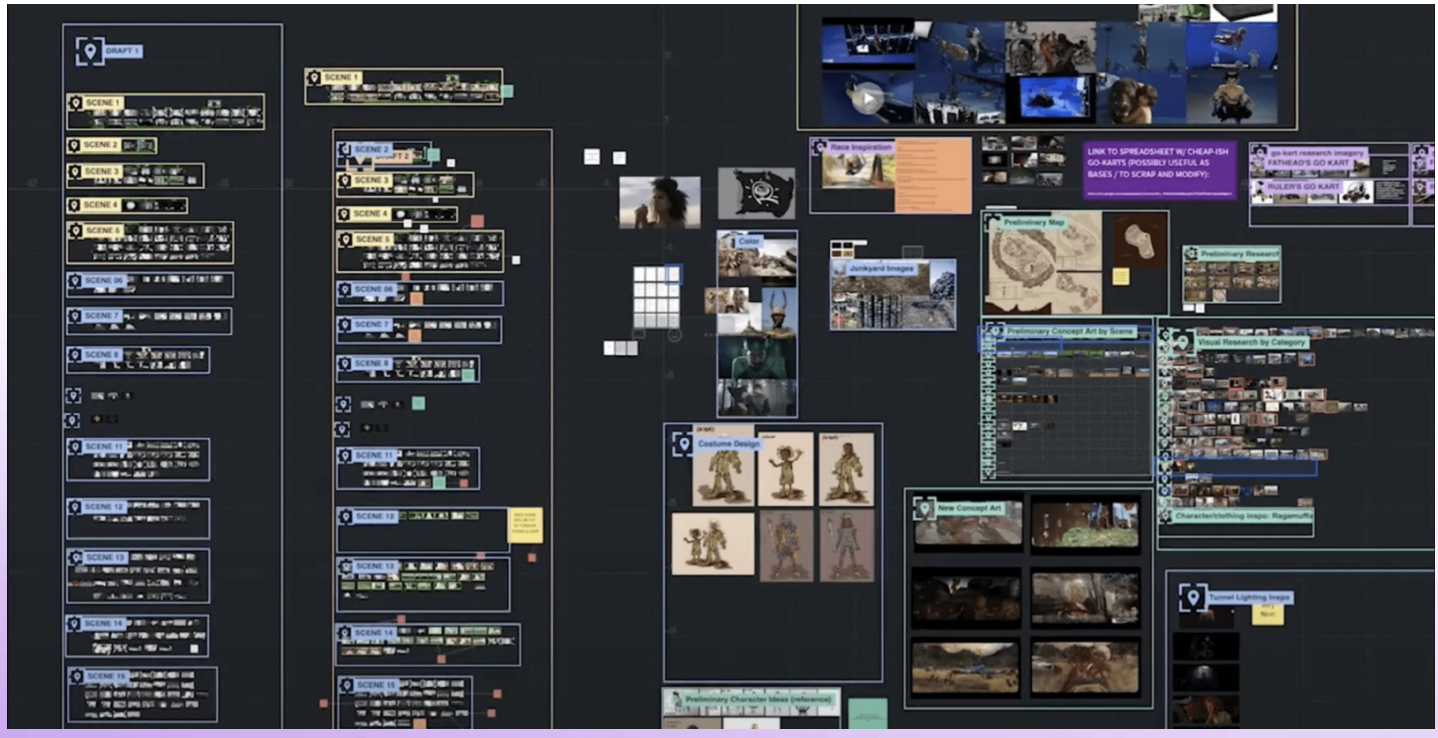
The project also followed the AWS shared responsibility model for security. AWS operates, manages, and controls the components from the host operating system and virtualization layer down to the physical security of the facilities in which these services operate.

The AWS content lake enabled the *Fathead* team to establish a cloud-based collaborative management framework capable of handling personnel activity, script tracking, scene tracking, digital environments tracking, asset management, camera shot planning, physical and virtual assets procurement, shot lists, pre-visualization, and scheduling.

For the production infrastructure, *Fathead* Executive Producer Greg Ciaccio and Post-Production Supervisor James Blevins consulted with AWS to develop a design using the AWS content lake architecture. This system provided photogrammetry ingest support, virtual art depart-

The nature of this shared responsibility model is outlined in the following diagram:





Screenshot of Bluescape interface

ment services, on-set collaboration, Original Camera Footage (OCF) to cloud ingest, remote-on-set editorial, and post/visual effects (VFX) pipeline services.

The virtual art department collaborated on designing the digital environments using Perforce Helix Core, which tracks and manages changes to digital assets, including code, video, and large binary files. They also used Hansoft — a tool for team collaboration, workload management, assignment tracking, and real time. Perforce provided an AWS CloudFormation template, which was used to launch these tools.

Throughout the project, the virtual art department collaborated on more than 60,000 UASSET files stored in Perforce, totaling over 576 GB. To create these designs, the team leveraged Marvelous Designer and triMirror's 3D Draper for clothing creation and design in 3D.

Photogrammetry — the process of extracting 3D information from photographs to create 3D models of real-world objects and locations — played a crucial role in creating many 3D scenes displayed on the LED walls during in-camera capture on the virtual production stage. Epic Games' RealityCapture photogrammetry tool primarily supported asset capture.

File transfer service MASV, an AWS Partner, helped accelerate the ingest of the photogrammetric assets to Amazon S3. Once the assets were uploaded, the photogrammetry team used online image viewing tool PhotoView to view them.

AWS partner Bluescape helped to streamline production planning for *Fathead*. The virtual collaboration platform equipped the team with an actionable grid of storyboards, which allowed for the dynamic review of concept art as if it was a fully articulated animation.

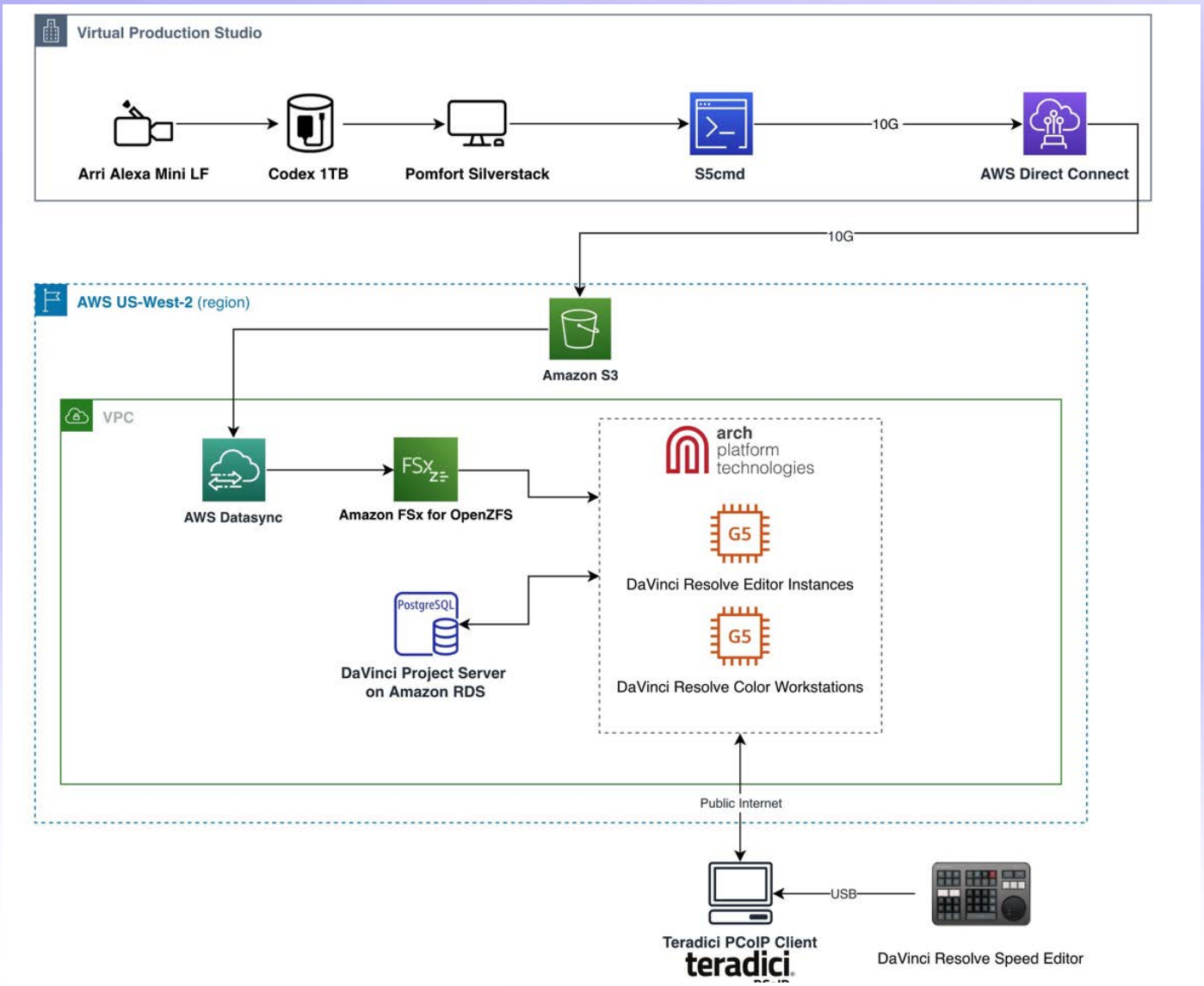
Using the tool's virtual whiteboard functionality, multiple departments collaborated remotely. The production designers could review costume designs, see reference imagery, and evaluate storyboards all in a shared virtual environment, comprising 51 users, 18 workspaces, and 2,172 files throughout production. For the entire project, Airtable enabled activity scheduling and tracking from a single source of truth to keep teams aligned and due dates on track.

ON-SET COLLABORATION

To optimize production time during principal photography, the team established a robust network, including a 10 Gb AWS Direct Connect, from the virtual production stage into AWS Region US West 2 (Oregon). This connection enabled the team to upload OCF files directly into an Amazon S3 bucket and keep network traffic on the AWS global network versus public Internet to reduce bottlenecks and prevent latency issues.

With this approach, *Fathead* production sustained ~800 MB/s as it sent content directly from the digital imaging technician (DIT) cart to Amazon S3. The accelerated upload speed was significantly faster than the camera's OCF bitrate (500 MB/s for 4.5K Open Gate at 24 fps), and about 40 percent less network load with CODEX High-Density Encoding (HDE) lossless compression enabled. Once the OCF upload was complete, the setup triggered AWS DataSync to move the files into Amazon FSx for OpenZFS high-speed shared file system for online editing. Using Amazon FSx for OpenZFS enabled workstations to connect regardless of operating system and delivered up to 4 GB/s and up to 160,000 IOPS for smooth RAW playback.

Using CODEX HDE with an ARRI Alexa Mini LF also helped to reduce file size and transfer



times. The footage could be played back natively in Blackmagic Design's DaVinci Resolve 18 editing, color effects, and audio post software without transcoding, so clips appeared immediately in the timeline playback post-upload. With COVID-19 protocols limiting on-set crew, *Fathead* production collaborated with AWS to deliver a secure, live feed for remote stakeholders via a virtual video village setup achieved using 5th Kind's CORE LIVE. Main stage camera feeds were sent via RTMP streams from Teradeck Cube Encoders, while a witness camera of the entire volume was transmitted via open-source Open Broadcaster Software (OBS) and WebRTC.

Remote collaborators could sign into the *Fathead* Live Room on 5th Kind to view activity in real time and switch between the streams. The DIT team set up the witness camera live feed on the first tech day so that remote teams could observe and provide feedback on production operations as they created the project's sets. Project members could access the live feed via tablets used 'near-set' by social distancing crew members. More than 85 collaborators and crew accessed the stage streams at any given point during the physical production of *Fathead*.

POST-PRODUCTION

Since captured files were automatically sent to Amazon FSx for OpenZFS storage, *Fathead* Dailies Editor Shawn Carlson began work on the footage from home as soon as the upload was complete. He used the AWS partner Arch Platform to facilitate a streaming connection via Teradici Cloud Access Software (CAS) to an Amazon Elastic Compute Cloud (Amazon EC2) G5 instance, a virtual machine designed to handle demanding graphics workflows. A local screen streaming solution was created for producer reviews with the project's post professionals using OBS. Leveraging the AWS global network and 5th Kind CORE LIVE, review sessions could be conducted remotely, and notes could be shared live with little latency.

Upon completion of the story edits, Colorist Arianna Shining Star color finished the project with Blackmagic Design DaVinci Resolve 18 on an Amazon EC2 G5 instance, with a live stream of 10-bit 4:4:4 HVEC footage sent from AWS to her desktop. She worked on the project out of Light Iron's post-production facility using the Blackmagic Advanced Panel.

ARCHIVE

Once the project wrapped, the team leveraged an Amazon S3 lifecycle policy to move *Fathead* production files from Amazon S3 Standard to Amazon S3 Glacier Instant Retrieval, a more economical storage class for archiving content that is still accessible. With all the assets in the cloud, the production's data and metadata are efficiently preserved, removing the worry of disappearing drives. ▪

AWS Senior Solutions Architect Zach Willner and Post-Production Supervisor James Blevins photo-bombed by Writer-Director c. Craig Patterson.

James Blevins is a media and entertainment consultant with extensive experience in stem-to-stern data flow management from the first day of shooting to worldwide distribution. Blevins had shouldered diverse responsibilities as a post-production supervisor for Lucasfilm and led pipeline innovations and implementations at major studios, including Netflix and Disney.

As a VFX industry veteran, Blevins continues to look for efficiencies and makes meaningful contributions toward defining new processes, standards, and workflows. He is the current chairman of Networking Education Technology (NET) at the Hollywood Professional Association (HPA).

WHY DO *FATHEAD* AFTER *THE MANDALORIAN*?

Blevins arrived on *Fathead* after a stint as post-production supervisor on presumably the largest and most popular virtual production venture, *The Mandalorian* (*Mando*). It is natural for one to wonder what could have attracted him to a project less than a hundredth of that scale.

"I love collaboration," said Blevins. "But collaborating at the level of *The Mandalorian* is not on your terms. At that level, everyone is risk averse." Professionals are expected to deliver tried and tested solutions. The mantra is simple: "Don't fix it if it isn't broken."

The demanding nature of those enormous jobs drove Blevins "to see possibilities for innovation." On *Fathead*, he'd known of ETC's experience with previous productions such as *Ripple Effect*. The experimental nature of the project and the opportunity to test novel tools, processes, and integrations made him consider joining the band.

"Having taken the entire Mandalorian team to their remote workspaces — into their homes or wherever they wanted to work — we had to do it in a hurry," he explained. Given this list of resources available to ETC through industry partners and patrons, Blevins wanted to try some new ways to do things better.

"It was a no-brainer," he noted. "I had my experiments to try." Blevins liked the diverse innovators on board the project and joined them to enable the collection of ideas and innovations lined up to push the envelope for virtual production.

Blevins pondered, "what can be done with premature technologies," since some of the products and processes arrived at ETC well before an official beta release. Manufacturers and technologists hopped on board to generate a proof-of-concept by plugging them into a real-world simulation of a live production environment.

Speaking about the larger motif and the experimental goals on *Fathead*, Blevins said, "I only had my own experience to draw from and what we had brought on to *Mando*."

Reminiscing about his time on Disney's maiden venture into a full-on virtual production series, Blevins said, "We realized some things between season one and season two were real 'gotcha' moments for newcomers to the virtual space."

On *Fathead*, he wanted to get in front of those

problems and point them out. He categorized the key challenges into two conversations affecting production directly: The role of post-production in ensuring that the color pipeline is intact and the importance of on-set editorial.

Now we have a new color producer for the LED volume. On *The Mandalorian*, Blevins collaborated with the DP, the VFX supervisor, and ILM to ensure it was all intact. Everything shot was as intended in terms of color.

"When things are fast-moving and expensive, you need to have an on-set editorial because there's very little chance we're returning," emphasized Blevins. Everyone has to know what they've shot.

FIX IT IN PREP

On *Fathead*, when Blevins joined the show, previs was limited, and there was no shot-by-shot breakdown for all the sequences. He said, as soon as he introduced editing directly in the cloud, "it became the spirit of the project."

One of the advantages of virtual production is heavily investing in visualization early — doing previs, virtual scouting, VCam sessions, and being able to investigate, iterate, and start editing to see the film evolve.

There weren't any edits of the storyboards, animatics, or previs. Going into production at the LED volume, the team did not have techvis in place to help with intricate planning. If this is something to be expected from traditional filmmakers and whether only tech-savvy directors like James Cameron will embrace it, Blevins said, "I don't know what goes through the mind of the filmmaker."

Filmmaking involves a creator and a camera conveying a story through a unique lens. Blevins shared that sometimes there's a 'predator' problem. It's a blend of one person playing the producer, editor, and shooter. The execution remains locked in the head, and they don't feel the need to collaborate. Blevins believes predators will fail to scale.

Previs promotes communication. Creators can use it to pitch ideas and render a proof-of-concept. Blevins reckoned, "If we don't democratize the process and tools, we may wind up with these boutique studios that cannot scale to satisfy the demand." There were only about six places that Blevins could recommend for previs (circa 2022), but they're always busy.

Blevins suggested that if you're doing virtual production, you "absolutely" need to prepare for the day. In his opinion, to move forward without previs and techvis is risky.

"If the content creator doesn't see it as a useful tool and has never collaborated that way, it's a horse and water situation," said Blevins. Producers should ask for the storyboards as a yardstick to identify what kind of creative group is involved.

Storyboards translate into previs. Blevins said, "If a team can't even manifest storyboards, then it's all in their head." That's a risk. A script is a good starting point, but you should be able to take it and translate it into a storyboard.

The conversation about turning storyboards and animatics into an edit happens in the editorial. "You get storyboards, line them up against the script, and paste them," he suggested. "Then you take whatever previs you can get from the Unreal team and the Virtual Art Department and layer that. The editors can then provide input."

For virtual production, Blevins believes, "It's important to make editorial a part of the previs process because on-set editorial is just an assembly process, and the editors don't get to make an impactful decision." But if they are forced to, as no edit exists before production, that's an expensive place to say, "Stay a little later and get that extra shot for coverage."

Previs edits can be beefed up with dialogue from the table read. When a recorded line is

unavailable, we can insert text into the frame for reference. Blevins read some lines for a character on *The Mandalorian*, which made it into the show because the creators fell in love with how he did the lines.

Some filmmakers may use previs edits as a place to experiment with a scratch soundtrack and sound design. However, previs doesn't need any of that. The real purpose of previs should be to get the coverage of the shots right. "That's the key," said Blevins. "Where will the cameras be, and what sets will be used on what day? What has to fly in, fly out, and when? Where do the dolly tracks go?" These are some questions you can answer during the previs and techvis processes.

NEW ROLE OF PRODUCTION TECHNOLOGIST

Blevins took on greater responsibility as a production technologist by going beyond what he has traditionally delivered as a post-production supervisor. The tasks previously exclusive to the post-production pipeline occurring after the conclusion of principal photography have now moved to the start of a project and remain equally relevant during the shoot.

It's helpful for people to ask themselves, "If we are going to produce a movie with a substantial budget, would we do it without a transportation department?" A sizable production will never do that. They need that expertise to fully understand the logistics of moving whatever needs to be moved around quickly and efficiently. A production technologist fulfills that same mindset applied to technology.

It's logistics — the logistics of technology slathered over production. It allows production to scale. "You can look at Netflix and see what amazing things focused technology will do for your content creation," observed Blevins. On a show level, it requires that you understand where you're going from point A to point B regarding the tools you're using and whether you're well supported to accomplish that. A production technologist gets the technology part out of everyone else's way and makes things move smoothly.

Blevins noted, "If you've done your job correctly, you will have your plan B ready and know who to tell what and why." Productions need stability and consistency, and a production technologist provides that for an entity that has become tech-heavy.

SUPPORTING THE CREATIVE VISION

Traditional filmmakers can get acquainted with technologies like cameras, lighting, and related tools to get an immediate response to their creative impulses. It's mostly intuitive, and you can see how any of those will allow you to reach your vision.

Today, we're not always capturing a finished frame in-camera because we are engineering parts and components separately and then piecing them together at various stages. In some ways, on-set virtual production (OSVP) and in-camera visual effects (ICVFX) may allow us to get close to the final image in-camera.

But we still need to get into post-production to piece additional layers onto it to make it more believable and congruent. Filmmaking has become a parts acquisition process. Blevins pondered how someone in his position may empower a filmmaker who is probably not familiar with these technologies but is a great storyteller.

"It's about trust," said Blevins. "You must be someone people trust to handle each situation appropriately." How things are managed is often more critical than what is done to manage them. "You must be very targeted about communicating with the people needing your help."
Technology can cause anxiety. When the risk

is high, we get less comfortable with the tools, leading to panic. The situation demands de-escalation, education, and troubleshooting. Blevins recommended, "We must allow the client to make an informed decision."

Producers should ensure that the right group of technologists are in the mix by considering their resume and track record. You may even foster someone with potential and encourage them to grow into the role.

Producers are required to bring costs down and extract value. Because some of these things are new and they've never experienced them before, they may have to take a leap of faith.

VFX supervisors are now turning to Blevins to help create virtual production build-outs or set up a virtual art department. Blevins pondered that a VFX supervisor generally knows enough to put these things together. However, production should not expect this person to be the integrator for technologies that enable their work.

"The infrastructure needs to be in place so that people can collaborate," said Blevins.

DATA MOBILITY AND DATA GRAVITY

When you're moving data around, many folks become fascinated with the idea that everything can be cloud-based. But practically, everything cannot be cloud-based because you still have something happening on-prem. Some things will happen in the edge. A new term is floating around: 'fog' — compute happening somewhere between the edge and cloud. The cloud is beyond that. There are economical and practical use cases for each.

The show needs to be tracked. Where does all tracking take place? Historically, it's editorial where the metadata has been occurring for 100 years. Go to keycode and timecode. On productions, there's all this data moving around. The movement cannot happen unless it's registered into the central database — the codebook.

It's important to have centralized data about the data — metadata — to know where all the assets are and how the proxies relate to the original material. Centralization of data is convenient because the data itself is centralized. The codebook is the centralization of the information of where the data is.

The codebook is a complicated thing. It references where certain assets sit relative to others in the timeline. But there's convenience in having all data accessible in one place. Blevins was able to centralize the project efficiently. Everyone gets to work on the material. Codebooks exist because you need to tie back the vision to other assets housed in different places, and hence, "it's going to exist for a while."

"There's no straight answer because it all comes down to time efficiency," he said.

"What is the path of least resistance?" Blevins is still analyzing the centralized cloud for how much it would have cost if ETC had to pay for the service. But he agrees that it's convenient: "It's like having a nexus for the entire process. Everything is just there and accessible. There is no proxy."

Every show is still going to be a snowflake. "I will not be able to tell you that centralization is the only way for your data," noted Blevins. "But certainly, centralization of the metadata will continue." As long as that's clear and concise, he believes we can make decisions on the fly about where we need to keep those assets to make them most efficient for the show.

DATA MANAGEMENT AND INTEROPERABILITY

On *Fathead*, data spanned from one phase to the next, and numerous people accessed much of the information remotely. Multiple users worked within Unreal Engine, accessing projects stored in a centralized depot managed by Perforce software. Artists could

access assets they were working on and push those back to the depot after they finished. Others continued to work on distinct portions of the project and could subsequently get the latest version of those files.

People working on other assets such as photogrammetry, storyboards, concept art, and videos published those to 5th Kind, a centralized repository for previewing, reviewing, and collaboration. In editorial, users accessed virtual machines remotely to take advantage of the computing power and software licenses needed to execute the tasks. The whole architecture was set up for groups working on different aspects of the project.

Ben Baker, executive producer on *Fathead*, used Airtable to meticulously collect metadata across departments and break it down, correlating it with the script and the production timeline populated with notes for all the stakeholders. But the disproportionate amount of data and the innumerable places to access them soon became overwhelming.

Blevins explained how all of that was integrated. Where and how did each of these environments come into play? 5th Kind provides a family of proxy-based tools that enables administrative communication — approval and kill processes — suitable for allowing state-of-the-art access to the content review process.

The editors and mixers need some quiet space to work, which is often written into their contracts. "That's why there's a punch through into a review process because people need to be able to work internally and then present," Blevins said. The 5th Kind tools present an administration layer to the producer while augmenting internal communication to get the job done.

Blevins had seen these tools being used from previs through final delivery. He thought the Airtable use case for *Fathead* was an experiment and that people mistake the spreadsheet database hybrid for an Excel spreadsheet killer when it's really more of a FileMaker Pro killer. And much in the same way that teams created FileMaker Pro templates in the past, Blevins predicts Airtable template-based workflows will become commonplace.

"Airtable was used to capture as much as possible to tie it back to the timeline," explained Blevins. "We were creating a template filled with tons of useful information as a stopgap." He acknowledges that the metadata ocean boiled over on *Fathead*. "That was the nature of this project. It's hard for me to think of anything unique about how we used Airtable. But I'm glad we did it."

Can all that metadata between what was being collected through notes on 5th Kind, Airtable, and ScriptE be tokenized somehow and turned into a sidecar file that gets linked with the relevant shots?

"Some tools do that," said Blevins. "If the tool can't do it, then you've got editorial. They're the ones who line up those elements." But the editorial team will be busy cutting the show. They still contribute to the conversation by sharing the updated cut and adding that information to whichever tool is used to track the individual shots in an edit and how that relates to the assets used to make those shots. It's a job that requires oversight. But that level of support gets expensive. It ultimately comes down to: "What are you trying to do?"

NUMEROUS FIRSTS ON *FATHEAD*

Blevins had not used 5th Kind before as he was only familiar with the Lucasfilm suite of tools from earlier productions. He had never seen a live streaming room plugged into the dailies delivery, review, and cut services before, and the live aspect intrigued him, which he thinks is novel.

Blevins introduced color grading in the cloud, wanting to push the envelope. He discovered the stage had 10 gigabits of connectivity. "I was able to record and copy the data from the card and get the bonded copy process going because you need a copy in case something goes wrong," he said. Once the data went to

S3, the bonding was complete. "You knew that the data got saved to nine nines."

Blevins and the AWS senior solutions architect set up the quick automatic copying of all the S3 to the FSx in a day and a half. The DIT received a small batch file script to copy the material. The editorial system surrounding it did not rely on DNX or Apple ProRes but could interpret camera data expertly in DaVinci Resolve.

The workflow became effortless as Blevins eliminated two or three different processes. "We still created ProRes for the dailies," he explained, "but the DIT took that on. We could have easily done that in the cloud."

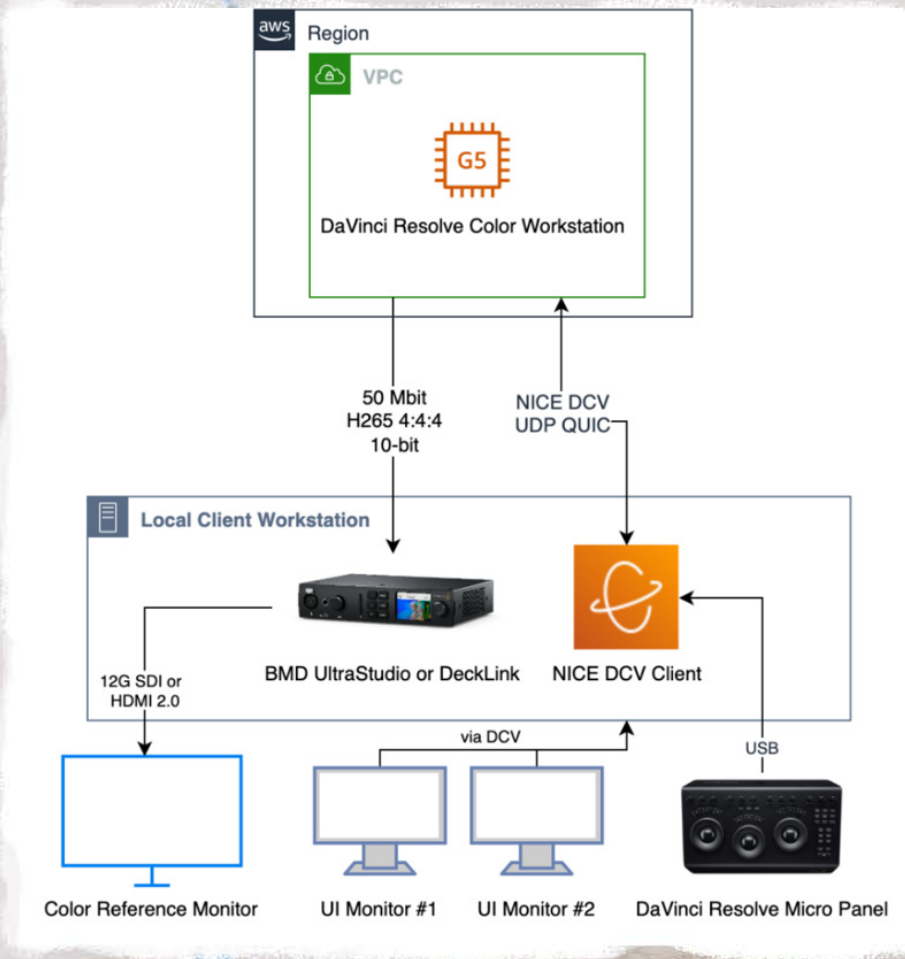
Blevins asked to find if anyone was color grading in the cloud. No one had that figured out. Using DaVinci Resolve 18, the team accessed a 4:4:4 HEVC solution that made it possible. "The amazing thing was — the remote protocols to control surfaces worked. I was most worried about that and the low latency." Those machines with the data weren't even in the same state. They were in the same time zone but over 1,000 miles away.

COLOR GRADING IN THE CLOUD

No one had to write a special script to facilitate the inclusion of the HEVC codec for the color grading session. It was turnkey, out of Resolve, and only needed someone to deal with the firewall. When you go to wherever the colorist is, they will need a clear path from the cloud to the Blackmagic DeckLink card driving the monitor. You have to keep an eye out to identify any problem if one arises. A 100-megabit bandwidth is more commonplace today, and Blevins believes more and more people can now use this pipeline.

The data first goes to local storage, then to S3, and 15 minutes later, after the last file gets copied, AWS Senior Solutions Architect Zach Willner's script automatically copies those to FSx. Everything gets in sync. Whatever was in S3 will show up on FSx. Blevins said that's not a tough script to write if you know the protocols.

Once the files are on FSx, Arch Platform Technologies mounts the Y Drive, which is the FSx volume. Those policies allow certain people to connect to it. The emulated machine gets spun up, and the



The DaVinci Resolve Remote Monitoring application combined with a high-performance remote desktop solution, such as NICE DCV, enables live 4K video streaming to system monitors. It also allows users to connect a DaVinci Resolve Control Surface, such as a Micro Panel, and get a color-accurate HDMI or HD-SDI video feed delivered via a compatible UltraStudio or DeckLink Card on the client workstation. Editors and colorists can then work in their preferred ways.

A detailed explanation of this workflow can be found in the related AWS Blog Post.

user profile relates to that emulated machine. Roaming profiles were sometimes observed as the slowest part because of some form of disconnection between an emulated machine and a profile. You'd then have to spin up another one.

Co-founder and CTO Edward Churchward at Arch Platform Technologies has supposedly taken what used to be around a 10-minute delay down to about two minutes. Timeouts may happen at times on Windows machines running Resolve. Blevins had a hunch that while the HEVC processing works on Resolve to send that signal on the fly, it may be causing these issues. Next time, he hopes to try out a Linux machine. There are not many things a Linux box does besides what you ask it to do, whereas, with the Windows boxes, you commonly need to monitor background processes.

The colorist on *Fathead*, Arianna Shining Star, worked from Light Iron, where a local machine with Resolve was used to hook up to the interface. The local Resolve has a daemon with the sole purpose of capturing all the color control interface inputs and sending them to a daemon with an IP address.

It looks up an IP address and runs the same queries on the remote machine as on the local machine. The remote machine recognizes these inputs as information originating at a control surface and moves the mouse or any other corresponding response to inputs from the local interface. Shining Star did not notice any lag in these responses.

"It's a zero client," noted Blevins. A Teradici signal returned to Shining Star's operating screens and provided her a view of the emulated machine. A studio version of Resolve 18 was needed at the emulated machine to integrate with Dolby Vision. The picture was graded in the Rec. 2020 color space and conformed to SDR later.

"It's pretty straightforward," added Blevins. Once you are logged into a remote machine, the only complicated part is ensuring the HEVC gets transported to a DeckLink card.

Blevins is fascinated by the role of the colorist, and noted, "It surprises me how much they bring to the final product." He was thankful for the challenges presented by the pandemic that has altered how we work and made us more aware of the options available. "We always knew various options were there, but we didn't trust them until we were forced to use them."

Blevins in discussion with director Patterson at the Amazon Studios LED volume stage

EXCITING PARTNERS ON *FATHEAD*

Blevins dealt with the underlying technologies and processes in addition to the interfaces on the client side. Most folks on the project are only dealing with the client user interface.

"We're at a place where it's all about options," observed Blevins. It's difficult to succeed when some of the greatest supporters of the new technology have already spent capital on internal hard drives, internal storage, and internal machines. For this to grow, it needs to mesh with the cloud aspect. "The future is hybridized. It's about interoperability."

Blevins believed it will help us find efficiencies by going "everything" into the cloud because everything's then in one place. Achieving true efficiency is about having an ecosystem that allows you to use whatever storage is most suitable for your situation.

"It is happening now." There are clunky solutions to things when shooting in Europe and finishing in Australia. Blevins thought that editorial departments drove this shift because they have to ensure it's part of the checklist: "We moved everything, and everything's still here."

Blevins emphasized that it's important for this interoperability of cloud storage to happen efficiently. Egress fees need to be revisited. He believes providers are analyzing this because that's part of the stumbling block: a subsidized viewpoint. Cloud services should reconsider applying the same egress model for M&E as what is applied to other industries. "It doesn't fit us because we're not that big of an industry," he clarified. "But we use unprecedented data for how big we are."

If you're a content creator, Blevins said, "you're driving the business for Amazon, Google, and Apple because people are consuming that stuff. It's about interoperability — and we must encourage these cloud vendors to work together."

METADATA FOR THE VFX PIPELINE

A significant amount of data is captured during production, ranging from camera and lens metadata to tracking data from the OptiTrack motion capture system and Preston remote focus control system. The belief is that we are acquiring the final pixel in-camera by using virtual production. There will be little or no need for VFX or other visual modifications during post-production, substantially compressing the post timeline. But did we achieve that on *Fathead*? If we had to fall back on a plan B, did we gather all the necessary range of metadata to pull that off?

We have the source data, and editorial can recover that from everything. As long as we capture what we want to do in-camera, there's nothing we can't do. "That's a pretty powerful position," said Blevins. "We found efficiencies when rolling out infrastructure. We spun up a machine. It only took 15-20 minutes for someone like me, some of the editors, and assistant editors." You can have all sorts of machines spun up for different reasons.

The efficiencies that you need are at your fingertips. You don't have to requisition a machine to have it in the corner in case you need it. "None of that exists," said Blevins. "I don't have to look for yellow lights on hard drives. I do need support, but it's a certain class of support." All that goes with ensuring your nexus is healthy has now gone away.

"There were efficiencies to be found as we integrated sound and VFX into this centralized way of working," said Blevins, who continues to hunt down more efficiencies wherever and however he can deliver them. ▪


"THE BIGGEST THING FOR US WAS HAVING IMMEDIATE ACCESS TO AN AWS SENIOR SOLUTIONS ARCHITECT."
- DANE BREHM
DIT & Production Technologist

Dane Brehm has operated as a freelance technician for over 18 years and transitioned from 35mm film to 8K+ data-based acquisition within the last decade. Brehm started as an apprentice under the best image-makers in the world — Roberto Schaefer ASC AIC, Paul Cameron ASC, Phedon Papamichael ASC, Hiro Narita ASC, Josh Bleibtreu ASC, Bill Coe, John Chater, Jay Farrington, DIT Jim Rolin, and gaffers Mike Ambrose, Peter Thomas, and Steve Condiotti.

Brehm wears many hats on projects ranging from commercials to $200M studio features, performing as an ICG digital image technician (DIT), Phantom tech, stereo 3D specialist, dailies colorist, drone operator, and VR supervisor handling workflow supervision from large data capture, on-set color, near-set dailies, and 8K and 4K spherical deliverables.

On *Fathead*, Brehm stepped in as a production technologist, delivering his in-depth working knowledge of lighting units, camera preparation, lens design and character definition, large data footprint management, on-set color, high-end studio monitoring, and a wealth of strategies to enable capture systems for DPs, ACs, DITs, VFX, and post-production.

The project also benefited from Brehm's relationships with several manufacturers who stepped on board to solve hardware- and software-related research and development, delivering a wealth of tools and know-how to facilitate the innovative workflow.

UNIQUE FEATURES OF *FATHEAD* STAGE PARTNER

The ETC attracts participation from the biggest and newest technology innovators. On *Fathead*, the team secured access to an LED volume comparable to or larger than the one used for *The Mandalorian*. Lux Machina engineered the LED volume, and a small group of technicians from Lux remained present to watch over and guide the process.

Brehm joined *Fathead* after working with Marvel and James Cameron. Though *Fathead* is a short film, the stage and tools were on par with those used to produce the biggest shows in the world. The brain bar or volume control and data connectivity outdid what most stages would afford.

Asked to quantify some of the benefits of working in a robust virtual production environment, Brehm said, "Walking into a stage that's already well developed, there's little that I had to come in and ask for, like a piece of hardware or software required to do my work."

"How do I plug into a pre-existing infrastructure?" wondered Brehm, reminiscing about the abundant access to 40 GbE worth of band-

width, "which we couldn't even leverage."

For most productions, Brehm noted that teams interact by physically exchanging media containing the data, which consumes time and involves some discussion to solve any issues that may arise. The infrastructure at the stage allowed each specialized workstation to remain connected to the network and cloud services to exchange huge amounts of data.

In an ecosystem like this, Brehm appreciated the ability to network with everyone around to share data seamlessly, even anticipating what someone might need down the line. Brehm thought the most transformational part was having all of the production designer's data to look at and perceive where to put the camera and the lighting.

The team could access the review process, color management, viewing HDR and SDR simultaneously, and broadcast that data to gather real-time feedback. Scott Squires, the virtual production supervisor on *Fathead*, remotely accessed the content and communicated with the team at the stage.

As the production technologist, Brehm examined department by department and conveyed to the teams, "Here's how we're going to interact with each other because we don't have to think about all these difficult things that have already been decided and put forth for us to be able to plug in and start working."

Brehm attributed the team's success to these advancements that helped them quickly launch the processes of testing, evaluation, real-time filmmaking, and sharing across the board. Data was relayed and accessed in real-time, and for the editors, camera footage was uploaded as raw files and proxies.

For the remote teams, Brehm streamed a witness camera that captured the activity at the stage alongside the film's primary camera. He thought, with all that data, "there's no lack of stimulation." The only question filmmakers need to ask is: "How do I use all of these streams to the benefit of the story and to tell what this picture wants to be?"

Having everyone available to make decisions on behalf of the story is extremely powerful. Normally everything is approached via silos, but now it's possible to address en masse.

THE MANY FIRSTS OF THE PROJECT

On *Fathead*, the Cintegral Technologies team started with the question: "What are the significant issues we want to handle that may accelerate the workflow for the filmmakers and bridge any gaps within our profession as digital imaging technicians to shorten the distance between thought to execution and back?"

"The biggest thing for us," said Brehm, "was having immediate access to an AWS senior solutions architect." The film was shot on an Alexa Mini LF shooting 4.5K open gate ARRIRAW, where the camera records around 750 megabytes per second. This value of 750 MB/s became the performance benchmark for Brehm from capture to the media and wherever else it needed to go.

Brehm worked with the AWS senior solutions architect to create a script that enabled uploading and verifying everything. In traditional filmmaking, the data is received via mags and downloaded locally, where a backup is main-

A 12-hour turnaround is considered normal. But in this case, that entire process was accelerated and condensed to a 45-minute window. "That's a first for me," noted Brehm.

tained on the set. A shuttle carries the mag to a laboratory that downloads the data and sends it to the editors.

Usually, a dailies laboratory works on the footage around 9:00 p.m. because they wait until all the day's footage arrives. A 12-hour turnaround is considered normal. But in this case, that entire process was accelerated and condensed to a 45-minute window. "That's a first for me," noted Brehm. "Where can I get that level of verification? We could push that and work directly with our post-production supervisor and editor."

On *Fathead*, the script supervisor also happened to be the editor. Brehm had yet to experience that situation and said there was an unanticipated positive outcome — a real-time conversation with the editor. The editor/script supervisor incorporated more information into the ScriptE program that was uploaded to the 5th Kind and DIT teams.

The deliverables for the day included camera footage, lens metadata, and camera tracking data. The first phase happens at the Data Management Center, managed by the lead data management technician (DMT) or loader, Sherri Miranda. She ingests that data. On *Fathead*, the DIT team used an additional shared storage device.

The additional shared storage was a new device, and *Fathead* was the first project to use it. The iodyne Pro Data is a powerful Thunderbolt storage solution that supports speeds up to 5 GB/s, allowing it to perform as a fast, central storage repository for all the footage to be immediately shared across the on-set pipeline.

Johanna Salo served as the dailies processing colorist and lead DIT, and Chris Hosey was the fourth member of the Cintegral team who stepped in to lend additional support. Brehm arrived at the stage on some days to operate from the command center to set up a bridge between various teams: sound, virtual production, art department, and script supervision/editorial.

"I've never had so much of a feedback process," said Brehm, "where you can shoot something, see it, download it, process it, and upload it in a proxy or an editorial format. Simultaneously, we're uploading that directly to 5th Kind."

Brehm also installed a set of streaming devices, Teradek Cubes, which work directly with 5th Kind's CORE to broadcast the information and the camera's perspective. A feedback loop went into that, and things got complex quickly. "There are a lot of moving parts. It's like a spider web of spider webs."

"How to safely reuse the camera media?" was another unaddressed challenge Brehm chose to examine. In a normal filmmaking workflow, as of 2022, there's usually a 24-to-48-hour quarantine period. This restriction limits the quantity of media available for the camera. You are not allowed to erase anything until feedback is received that the editorial has seen it and there aren't any issues.

The main problem in an LTO/lab list environment is: "How do we check ourselves? How do we verify that we've done our job? That we haven't passed on anything with issues in the data?"

"That's a big problem," said Brehm. "There's a reason we had Zach Willner, the AWS senior solutions architect, help us build that, so we could upload a one-to-one of what the camera sees without building in corruption."

The data was split into multiple streams, which is called parallelizing information. Instead of just going up one pipe, which can only go so fast, if you combine 10 x 10 GbE individual pipes, all the data can go through that sync process with the cloud and replicate correctly.

On the DaVinci Resolve team, Assistant Editor Shawn Carlson was there to say, "I received it." Or, on occasion, he'd say, "We received frames one to 10,000, but we don't have 10,001 to 10,404." In this case, the DIT team would hit sync again. The cloud has to sync to what you have locally. That first copy was a big part of the process Brehm wanted to achieve.

Brehm collaborated with Post-Production Supervisor James Blevins, supported by ETC and

AWS, to authenticate: "How do you create that verification process so that our editor can say they received it and it's in the cloud? It's been replicated many times." Once this was possible, what Brehm calls the biggest achievement, he could reliably decide to keep that data locally, just as a supreme backup, without needing three or four backups.

"I can have two solid backups of our project knowing that we took care of everything on that side of things," said Brehm. Willner from AWS developed some scripts "to allow us to do that." Cintegral used Seagate Lyve Mobile, a 92 TB encrypted storage solution system, to archive everything.

Blevins shared how the team achieved much higher bandwidth for low latency playback for the review pipeline, including color grading in the cloud. "That's a big thing in its own right," said Brehm. "That's a closed loop at that point."

You can get all this high-quality footage and upload and maintain everything in a raw-quality pipeline. You can then move that over to a review process, which includes color grading, visual effects, and everything that needs to be acutely reviewed, contributed to, and previewed with notes. "That's so incredibly exciting," explained Brehm. "A whole company would be tasked to try and do that."

FLOWCHART OF DATA TOUCHPOINTS

In post-production VFX, starting with the camera, there's the lens metadata, which is a list. The ARRI Lens Data System (LDS) contains lens data and camera-related information. All the lens data was carried through the pipeline and embedded in the original camera negative files for use in VFX.

The system was offloaded from the mags. The metadata was pulled and sent to an Airtable spreadsheet for VFX. The raw files were available for the effects team. The LDS was on the camera, but another part of this was the streaming — a real-time on-screen display came through the stream using the Teradek Cube that went to the remote teams, including the VFX team. They could see where the camera was in real time, streamed via Teradek to 5th Kind.

Next, there's Silverstack reporting, which built a Pomfort Silverstack database where everything went through the Pomfort Silverstack Lab. This database was referenced later for how many gigs were shot, which involved terabytes per day. Sound files would be assigned an MD5 checksum, a 32-character hexadecimal number computed on a file. When two files have the same MD5 checksum value, it suggests a high probability of both being identical.

Where does it all go? The database is a cataloging of the camera footage as raw files, its metadata, and sound files delivered by the Production Sound Mixer Brandyn Johnson. In addition to all that data, the script supervisor's notes were also included. The metadata can be pulled directly from Silverstack to 5th Kind for visual effects. "That's the first copy on the data management station," Brehm explained.

More data gets created inside of Resolve. Initially, there's data management. Then it's dailies. That's the first Resolve database origination point — because of ingesting. The Pomfort Silverstack Lab was our data management database. The Resolve system was the SQL database that covered the color pipeline, dailies pipeline, editorial, and VFX — it created the point for everything else to be processed and delivered in post-production.

The whole point of this is to stay in the same program and have the same language between what DIT is doing with what the editorial team is using to review the files, put eyes on that footage, and guarantee that it comes across. It's not missing any frames, not going to another program, and then creating another set of logic that has to be attributed to the pipeline. Only then does that get distributed to remote teams, which becomes another thing in its own right: The color and the effects review.

The color pipeline used Resolve's color science. "We combined everything into one large command center," said Brehm. Beyond that, a


miro
G.Ciaccio 2021
Z.Willner 2021
D.Brehm 2022
Sony X300
Konvision 4K 3240
ScriptE iPad
Return to Set
Who?
What?
When?
Where?
How?
AJA Image Analyzer
AJA FS-HDR
OCN if Network is not capable
OCN to USWEST-2 (800M
CF engine
On-Set Color Livegrade PRO
Dailies + S3 Push
ASC-MHL Silverstack LAB
Data Management
Silverstack / XXH64
/ASC-MHL
LyveDrive Mobile Array
OCN, Metadata, LUTs,
ProresLT Dailies, H265
Primed for DC Injection
Zoelog Camera Reports
Cintegral
OCN Verification, Metadata,
+ Offsite Archive mgmt
Attach/Handoff
Attach/Handoff
IODyne PRO
DATA 20TB

video village was inside the volume linked to the art department's review station. That was where the production designer and art director, with the script supervisor/editor, would notate what things were working and what was not, or whatever feedback they had.

The DIT managed the video review pipeline and the video village. It forked into what the remote teams were viewing and what was on-prem, the video networking backbone of the stage. "We could ingest 1080p (HD) and 4K, which is 3840 x 2160 pixels. We were returning that feed to a color pipeline with our color decision list (CDL) data that allowed us to draft the look," said Brehm.

The art department, director c. Craig Patterson, and DP Kat Boyd-Batstone could see, as Brehm's team was transmitting through cable and wireless Teradek Bolt 4K's, what the footage looked like with the color applied.

"We took a feed from the camera directly into the video pipeline, into the backbone, essentially," said Brehm. It ran through DIT, was color processed through the pipeline, and sent back to the router. That was broadcast to everyone on set.

The DIT is the hub of information and connection to post-production, visual effects, archive, cloud, and the center through which information flows before it goes to anyone else. It operates like the central nervous system of production at one phase. If a failure happens at that level, then everything after that is essentially corrupted at some level.

At a different phase, DIT dailies get pushed to the cloud for the editor, and there it functions more as the arms and the legs translating into movement.

Brehm, Blevins, and ETC's Erik Weaver (executive producer of *Fathead*) leveraged industry relations to acquire all the storage used on the project. The team tested many new devices, pipeline integrations, and interoperability on the project — some of these technologies and devices include iodyne Pro Data and Seagate Lyve.

"We had a pure SSD version this time," said Brehm, having used Lyve once before for the previous ETC project, *Ripple Effect*. "It's $100 million worth of goodwill we received. As you know, goodwill is a quantifiable metric." The entire list of benefactors of the production is listed in the white paper.

On an ETC project, Brehm said, "I don't have anyone saying 'No, you can't do that, or we can't afford that.' It's where my expertise meets the road for leveraging my team's ability and mine."

The only limits Brehm faced were his own or when the cinematographer said, "No, we don't need that because it's not part of our process or the language of the film." That's a creative decision, but on a budgetary level, Brehm went to where those relationships exist and explained how it would benefit the process. And most of the time, they agreed.

"These USC graduates received a master class in virtual production," suggested Brehm, pointing to the immense resources and industry support garnered by the ETC to manifest the production. ▪

3.4 TB
in the 5th Kind bucket across 330,000 Objects

14.4 TB
in the S3 bucket* across 1,696,439 objects

*includes camera raw

576 GB
in Perforce

"We offloaded using Codex HDE, so it's about 40% smaller than it would be if we used regular ARRIRAW."

!!! DISCLAIMER!

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While there are several providers for any category of technology integrated into the pipeline, we partnered with certain brands and companies who stepped forward to back the production and offer the necessary resources and personnel. It warrants a disclosure that our findings are limited and may have unintended bias, which results from our exposure being restricted to only one service within each category. Our resources were limited on this short film, hindering our ability to explore and compare these to a broad range of competing brands in those categories.

Moreover, we state that the context for this exploration is singularly focused on the processes involved with the implementation of numerous tools and services that, in combination, are termed virtual production, which the participating teams across the diverse pipelines ranging from development, pre-production, production, and post-production accessed to produce a final product, a short film, with the intent to augment traditional practices and currently established visual effects methodology by economizing and enabling efficiencies and collaboration between all contributors to agree on creative decisions from early stages and iteratively progressing toward cohesive goals to achieve in-camera results requiring little or no post-production fixes.

The feat would have been highly improbable without heavily relying on the combined force of several volunteer contributors and a significant number of establishments assigning valuable resources toward the project. The participating companies have supported the short film (*Fathead*) by providing resources and expertise and encouraging their business allies to partake.

The generosity and genuine interest of our partners on this project in exploring the evolving field of virtual production to understand where, how, and why specific needs remain unaddressed and how they may each shape services and tools that alleviate the pain points for all the professionals in the field has been a vital force for this opportunity to exist. The effort in supplying the white paper follows a similar intent to share our learnings for communal good and see more rapid innovation and adoption in the space for the tools and services that may solve authentic challenges, making a greater creative expression more attainable.

ETC makes every effort to provide a neutral setting that does not endorse technologies, products, services, or vendors. Participation in ETC activities is not an explicit or implicit endorsement of any technology, product, service, or vendor. ▪