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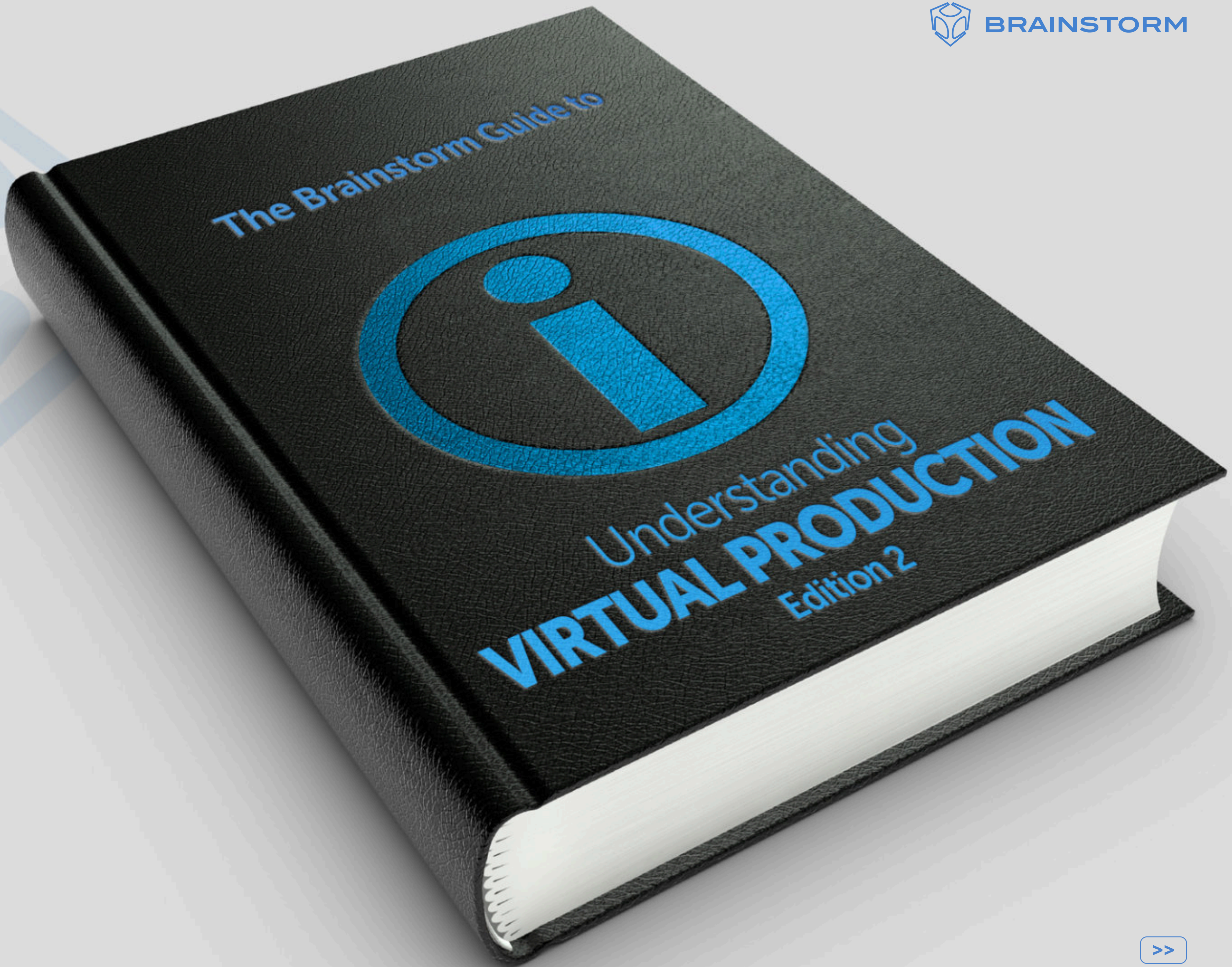

Being at the cutting edge in technology for two decades, allowed Brainstorm to define the foundations of many technologies.

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ABOUT THIS WHITE PAPER

Since we launched the first edition of this White Paper two years ago, virtual production (VP) has become not just a reality but a common technique now widely used in film, broadcast and live events worldwide. The industry agreement is that Virtual Production is here to stay, and responds to the profound changes the digital age has driven to content creation. Broadcasters and production companies are most aware of the opportunities virtual production brings to improve audience engagement, content quality and flexibility in creation.

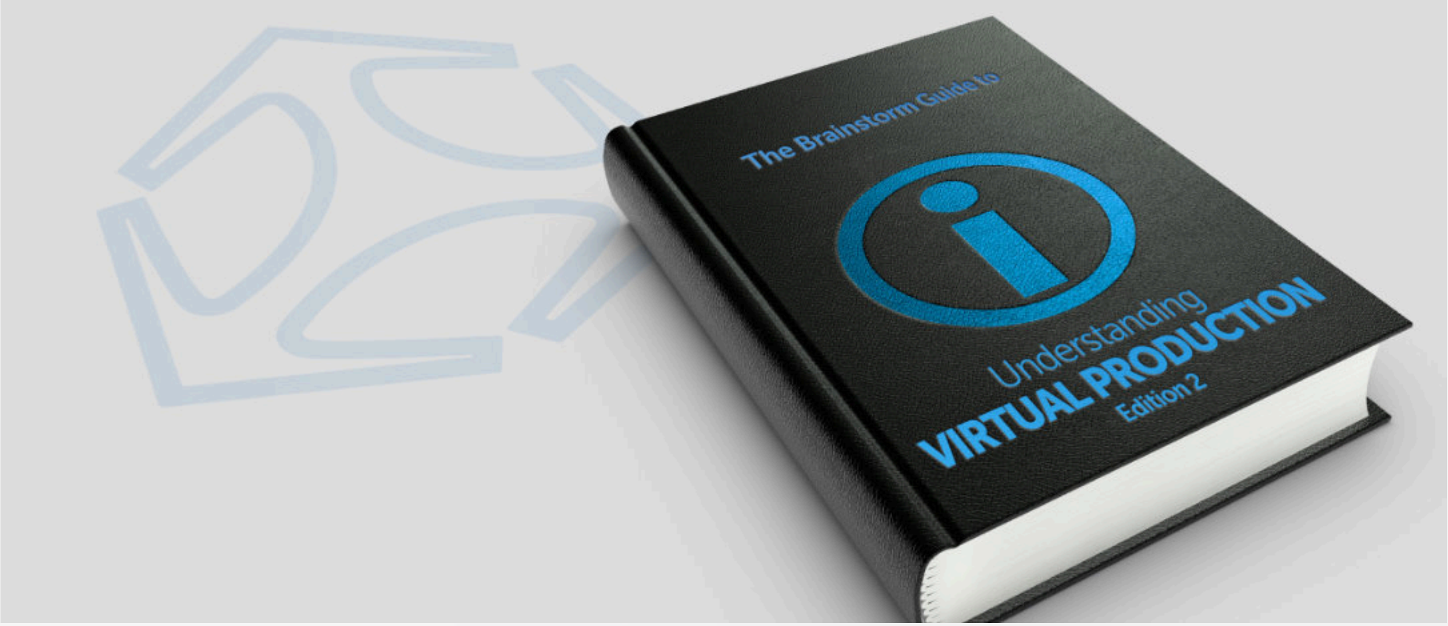
Although virtual sets or augmented reality (AR) have been around for decades now, the new developments on rendering technologies like PBR, real-time ray tracing, or the arrival of game engines such as Unreal Engine, brought a new era to virtual production. However, the concept has also diversified with the arrival of new display technologies like LED volumes, that provide alternatives to the traditional chroma keying.

The increasing popularity of virtual production marks a significant turning point in the filmmaking and broadcast industry, blending the physical and digital worlds to create a seamless and immersive storytelling experience. Unlike traditional filmmaking methods, virtual production leverages real-time rendering technologies, LED volume stages, chroma sets and sophisticated motion capture systems to bring creative visions to life with unprecedented precision and flexibility, and making them indistinguishable from reality.

Also, one of the balancing acts that broadcasters and content providers have to manage is that of costs versus capabilities, and nowhere is that currently more evident than in the use of virtual reality (VR). Virtual studios become more appealing because of the democratization of the virtual technology, and the availability of powerful enough hardware at a price point that a wider range of content creators can afford.

As the demand for more visually stunning and narratively complex content continues to grow, virtual production stands at the forefront of this evolution, enabling creators to push the boundaries of what is possible in visual storytelling. Through this exploration, we hope to shed light on the transformative potential of virtual production and its role in shaping the future of the filmmaking industry.

Amazingly enough, semantics are important in this matter, as many authors and vendors are including concepts that often only describe partial aspects of VR. This White Paper, therefore, continues with its objective of shedding some light on the concepts, the possibilities and the pros and cons of each approach (LEDs and chroma sets).



You will also find some QR codes in this document, which lead to additional sources of information, most of them videos. You can access the information in the QR Codes by scanning them or by clicking on them, which will open your web browser to access the material. Also, clicking on some of the images the will open up the original video they were taken from, displaying further information.

So, thank you for downloading this paper, and we hope the information in it will be useful for your future productions. Of course, please feel free to contact Brainstorm with any queries you may have about virtual production, XR, augmented reality or motion graphics, we will be glad to help with your requirements.

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THE VIRTUAL REALITY: WHAT IS XR?

The terms "Virtual Reality" or "Augmented Reality" have been used to describe ways to enhance visual perspectives or views in a variety of media such as PCs, headsets or mobile phones, adding data such as advertising or cultural information on pictures or maps.

Virtual Reality, in its vast variety of flavours, is a great tool for enhancing the information displayed in a broadcast program, while adding spectacularity to such content, and also for creating artificial worlds that can be assimilated as real by the audience. Moreover, the availability of enormous amount of data to be displayed require visually attractive ways to present these data to the audience at home, which can be done by combining real and virtual images.

Let's start by assuming that all the **synthetic** or **virtual** "realities" we will mention in this document are the result of **combining 3D computer-generated (CG) imagery with real feeds**, and not just standard chroma keying over images or video. By using 3D CG imagery, the resulting camera views display a fully immersive world where cameras move freely in **3D space,** compared to the relatively constrained camera movements of typical video compositing.

So, we can start by defining **Virtual Reality (VR)** as the method to display **computer-generated images along with real feeds**. Therefore, by extension, we can say that traditional Chroma Keying could represent a form of Virtual Reality, as the resulting image is obtained by compositing different images, but in this document we will not consider it VR as we established the requirement of using 3D environments.

It is also interesting to introduce the concept of **Virtuality Continuum**, as defined by **Paul Migram** and **Fumio Kishino** in 1994. They defined it as a **continuous scale** ranging between the completely **real** (reality) and the completely **virtual** (virtuality). The *reality-virtuality continuum* therefore encompasses all possible variations and combinations of real and virtual objects.
If we apply this concept to the audio-visual content creation, we can then consider **VR as the "container"** for all the rest of the synthetic realities, from virtual sets to AR, ER, XR or IMR, which we will detail and classify based on the mentioned virtuality continuum concept.

The term **Augmented Reality (AR)** has been used to describe ways to **enhance visual perspectives** or views in a variety of media such as PCs, GPS devices or mobile phones, adding data such as advertising or cultural information on pictures or maps. We will use this term to describe **information graphics applied** to any content in television or apps, or when 3D virtual elements are added, in context, on top of real footage.

As the original content is "enhanced" by computer-generated information or objects, some use the term **Enhanced Reality (ER)** instead of AR, however this is becoming **obsolete** and has not been widely adopted. We can also define **Mixed Reality** as the result of c**ombining real and virtual imagery**, specifically **CG objects** which are "enhancing" or "augmenting" the real footage, however we may use a **wider approach** and include the 3D virtual sets here. As a side note, some authors assimilate AR with **Digital Signage**, bringing confusion to both terms.

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Digital Signage is a method to display advertising in public spaces using digital media such as screens, tablets, etc., that of course, can feature AR to capture its audience, if required.

When **in-context content** is added as AR elements over **3D virtual sets** or environments, and not over real footage, we talk about **Immersive Mixed Reality (IMR)**. Some consider this a special case of AR, because the virtual environment can fill in the whole scene or just a portion of it -meaning the virtual background could be considered yet another AR element.

AR and IMR require **interactions** between sets, talents, and virtual objects, often created out of **external data sources**, such as statistics, charts, bars, and many other. These data driven objects allow for **visually engaging** representations of the data which can be better explained by the presenters on the set. As an example, during Election nights, News, Sports or Entertainment shows, data bars and other statistics can interact with the talents creating an **attractive AR environment** that is more appealing to the audience.

So, **extended reality (XR)** can be understood as the concept that englobes most of the above, and can be defined as the **combination of real and virtual environments**. If we include interactive content consumption in the equation, we should add any human-machine **interactions** generated by computer technology and wearables.

About the term itself, some assume the “X” stands for “eXtended”, while other authors maintain that 'X' represents a variable for any current or future spatial computing technologies. In practical terms for broadcast and film content creation, XR is normally understood as the combination of virtual environments **projected in a LED wall**, and sometimes LED floors, in combination with real characters on stage, sometimes including other graphic elements in a sort of IMR. When using LEDs as background/floor, the camera captures the combined image of the background rendering and the characters.

However, there is no technical reason **why the LEDs can't be replaced by a Chroma set** so, using one method or the other will depend on what users want to achieve and the available workflows, as we will see later in this document.

Reality | **Virtual Reality**

Extended Reality / Mixed Reality

Real World

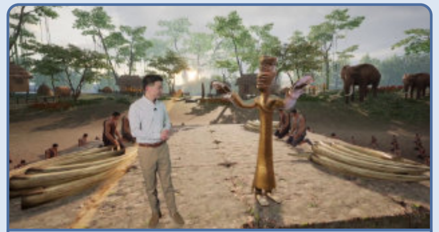
As captured from camera.

Virtual Set

A 3D digital background with real talents integrated in it.

Augmented Reality

Digitally generated elements (objects, graphics, data...) placed on top of real images captured from camera.



Immersive Mixed Reality or “Augmented Virtuality”

The combination of AR and virtual sets, including talents that interact with AR elements.

Synthetic Reality

A fully virtual world, in which all the elements have been digitally generated

AT A GLANCE

Remember that XR does not imply the use of LED volumes, and that there is no technical reason why LEDs can't be replaced by a chroma set, and vice-versa. It will depend on our requirements for each production to decide which method will be more suitable for achieving the desired result in an easier and more effective way.

In any case, regardless which technology we use in our VR projects, the perfect integration between real and virtual objects and environments is essential, so any VR project must take into account the following aspects:

- **Real-time** performance, regardless the complexity of the scene.
- Seamless, realistic, and accurate **integration** between the different real and virtual elements. Both the background and the additional elements must be indistinguishable from reality.
- Precise perspective **matching** between the different elements with regards to the camera view, even when it moves, for which camera tracking is required.
- **Photorealistic** render quality when possible.
- Properly **delivered** and set up data.

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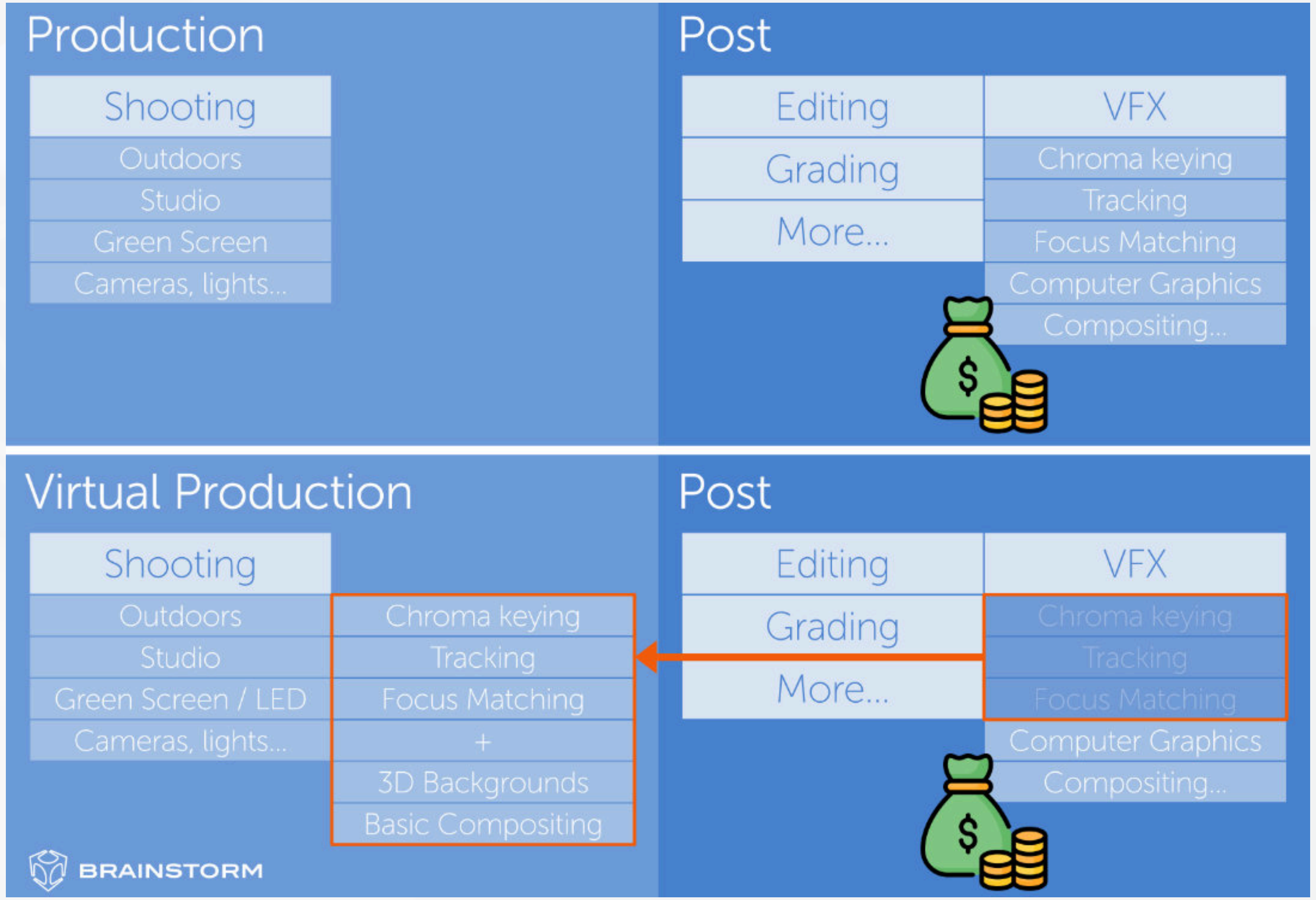
WHY VIRTUAL PRODUCTION

With the increasing popularity of real-time hyper-realistic rendering, virtual production has evolved from a decades-old technology into a mature and highly sought-after tool in the filmmaking industry. Today, the results achieved in real-time are often so realistic that it is impossible to distinguish between actual footage and rendered scenes. Virtual production not only delivers high-quality results but also reduces costs, enhances industry sustainability, and opens new creative horizons for filmmakers.

A growing number of producers, content creators, and production crews are leveraging this technology. This democratization is driven by a broader and more affordable range of solutions, making budget less of a barrier to achieving excellent results. As a result, creativity becomes the key differentiator. Brainstorm, with decades of experience in virtual sets, real-time 3D graphics, and film pre-visualization, recognized the benefits of virtual technology from the outset. Today, its product range and expertise encompass all aspects of virtual production, from large blockbusters to corporate presentations.

The introduction of advanced rendering technologies, such as game engines and real-time ray tracing, has significantly enhanced the quality of real-time renderings. This allows content creators of all sizes to produce photorealistic content, making high-end results accessible to a wider range of creators. Real-time virtual production offers additional benefits, primarily cost reduction, enabling the production of diverse scenes, including outdoor environments, on set. This optimizes staff and actors' time, reduces travel costs, and improves overall efficiency. Directors, DOPs, and art directors can perfect scenes as desired, shooting a car scene without closing a city or capturing a sunset all day with ideal lighting conditions. While many associate virtual production solely with large LED volumes, it can also be achieved with smaller LED videowalls or even chroma sets of any size and shape. Although LEDs have recently overshadowed chroma keying, the latter remains a valuable tool for virtual production. The choice between LED-based production and chroma sets depends on production requirements and budget. Both approaches support smaller, more compact setups, utilizing set extension techniques with LEDs or the capabilities of 3D virtual sets with chroma studios. This flexibility demonstrates that while larger setups are beneficial, they are not essential for achieving excellent results.

Virtual production allows to bring into the production stage some tasks that are now typically done in the post production stage. The traditional workflow (or "fix it in post") shots the



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scenes to send them to postproduction for compositing and VFX, and of course editing, grading, etc. Once the shots enter post production, the chroma shots can be tracked for the required compositing, adjust the digital background and the final scenes, focus, color correction...

But, what if we are able to transfer some of these tasks into the production phase? With virtual production, it is possible to do real-time chroma keying, tracking and focus adjustments, while including the virtual backgrounds and some basic compositing, all in real time, and even record all the above as separate layers for further refinement. Combining chroma keying with tracked cameras and recording real-time chroma keying and tracking information in simultaneous layers streamlines post-production and ensures accurate VFX integration, saving valuable time and resources. So, this workflow allows to save significant time in post production as tracking and talent/scene adjustments are already done, so instead of dedicating operators' time to manually track and composite scenes, we can use their skills to fine tune the shots. In many occasions the composite output from the production will be good enough to broadcast (News, Sports or live shows, for instance), but we will still have the flexibility of using the recorded pieces for further adjustments.

Virtual production's flexibility is especially evident indoors, allowing creators to unleash their creativity with locations, environments, and timing. Directors can "travel" to any location, from fictional settings to real but inaccessible or restricted places. This technology allows filmmakers to shoot in made-up places or protected environments, which would be impossible or impractical with traditional methods. Specialist production houses like MR Factory have pioneered real-time virtual production using chroma sets, achieving results indistinguishable from reality. They demonstrated this by emulating a short film shot in real locations with real-time chroma sets, showcasing the technology's potential.

Producing perfect scenes indoors saves on actors' time, travel costs, and logistics by bringing the scene to the set rather than the crew to the location. Real locations remain an option, but virtual production offers the flexibility to choose the best scenario based on budget and requirements. And, when locations are inaccessible or even non-existent, virtual production is there to save the day.

The environmental benefits of virtual production cannot be overlooked. By reducing the need for extensive travel and location shoots, the technology significantly lowers the carbon footprint of productions. This aligns with the industry's growing commitment to sustainability and responsible filmmaking practices. Additionally, virtual production reduces the need for physical sets and props, further minimizing waste and resource consumption.

In conclusion, virtual production delivers excellent results with various setups and workflows—LED volumes or chroma sets—suitable for content creators across different budgets and requirements. It also contributes to industry sustainability by reducing travel costs, construction needs, and post-production resources. By enabling filmmakers to create highly realistic and visually stunning content in a controlled environment, virtual production is revolutionizing the filmmaking process.

Brainstorm's product range for virtual production, led by InfinitySet, offers extensive possibilities for content creators and producers in film, high-end drama, sitcoms, news, sports, and entertainment shows. As the technology continues to evolve, its impact on the industry is poised to grow, setting new standards for creativity and efficiency in visual storytelling, while expanding its reach to live events, corporate presentations or even education.

SCAN ME

Why virtual Production?
Because it is possible to create, in real-time, photo-realistic scenes that can't be distinguished from reality

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VR / AR / XR WORKFLOWS AND SETUPS

As we've seen, virtual production does not imply the use of LED volumes, as it has rely traditionally on chroma sets. In any ase, the different types of virtual reality content require **specific setups**, which can differ for each of the different workflows. Following you will find some of the typical setups and workflows for the most common VR applications.

VIRTUAL SETS

A virtual set is a **3D digital background** on which we place/ integrate a **real talent captured from camera** on a chroma set, and then keyed out using a chroma keyer, which can be internal, created on the same workstation, or using an external hardware such as Ultimatte.

Virtual sets can be **trackless**, **TrackFree™** or use **tracked** cameras, with one or multiple renders per camera (one workstation rendering the inputs of all cameras) or a render per camera (a workstation rendering only the input of the assigned camera). But, in all cases a camera captures the feed of the talent(s) on a chroma set and sends it to a computer, which will render the feed keyed over a 3D virtual set.

VIRTUAL SETS WITH FIXED CAMERAS

Trackless virtual sets are those that use **fixed cameras** to capture the talent, so the position of the real camera in space is always known and can then be recreated in the 3D scene. This excludes the need to calibrate the camera and lens, as opposed to tracked environments, but **limits the camera views**.

Brainstorm's **TrackFree™** technology was designed to take fixed camera setups to a different level, allowing the seamless **mix** of tracked and trackless environments. This **patented** technology takes the signal of fixed or tracked cameras, creates virtual camera views from it, and includes features that provide additional freedom for virtual camera movements that can resemble real PTZ cameras or even cranes.

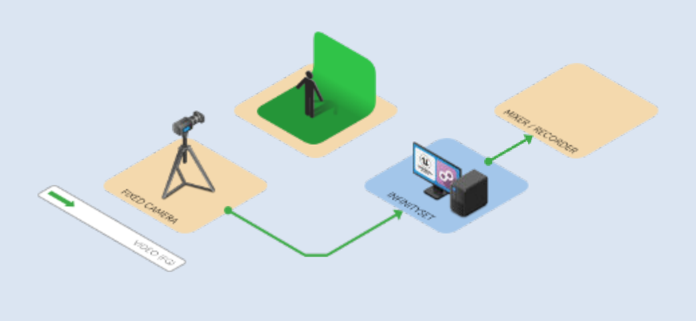
The virtual camera views are **independent** from the live feed, and can **move freely in 3D space**, just as pedestals or cranes do in live production environments, expanding the limits of the physical chroma set, also allowing the virtual cameras to virtually detach themselves from the real camera view and position in 3D space. Of course, is is possible to use LED walls and floors instead of the chroma screen, however the workflow is more complex, and the results may not be as expected, as we will see later in this document.

VIRTUAL SETS WITH TRACKED CAMERAS

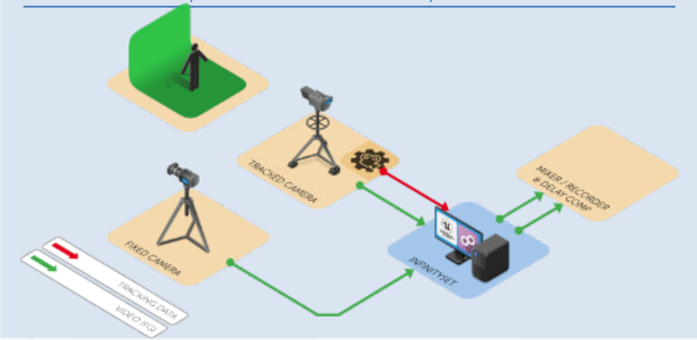
By using tracked cameras, the tracking device transmits the camera's **position in space** to the workstation, which serves to render each frame accurately from the perspective of the camera. Hence, if the camera moves, the render will move accordingly to **match the camera view**, and this is applicable to spatial movements, focus and zoom, depending on the capabilities of the tracking system.

Simple PTZ cameras do not change the camera position in space, although can track **Pan & Tilt** movements and also provide **Zoom** information - however by using Brainstorm's TrackFree™ technology users can expand these camera

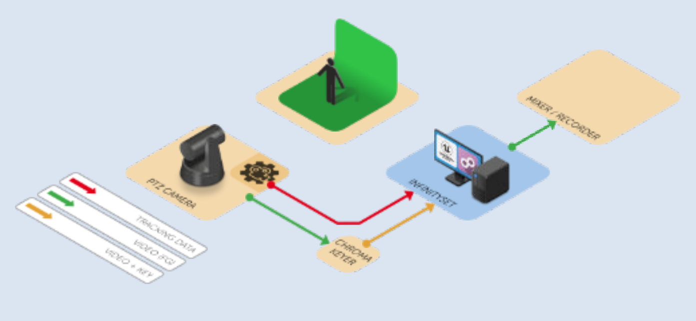
Virtual set, fixed camera, internal chroma key



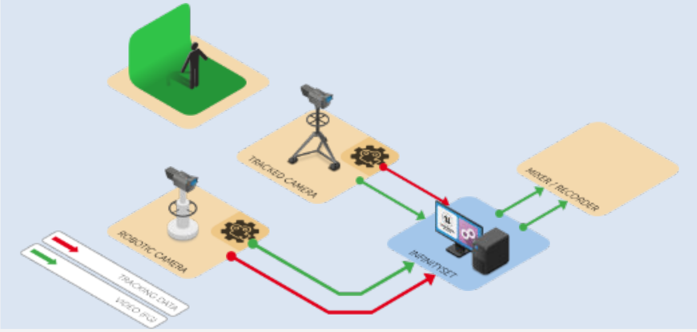
TrackFree™, fixed+PTZ cams, one workstation



Virtual set, PTZ camera, external chroma key



Multiple tracked cameras, one workstation



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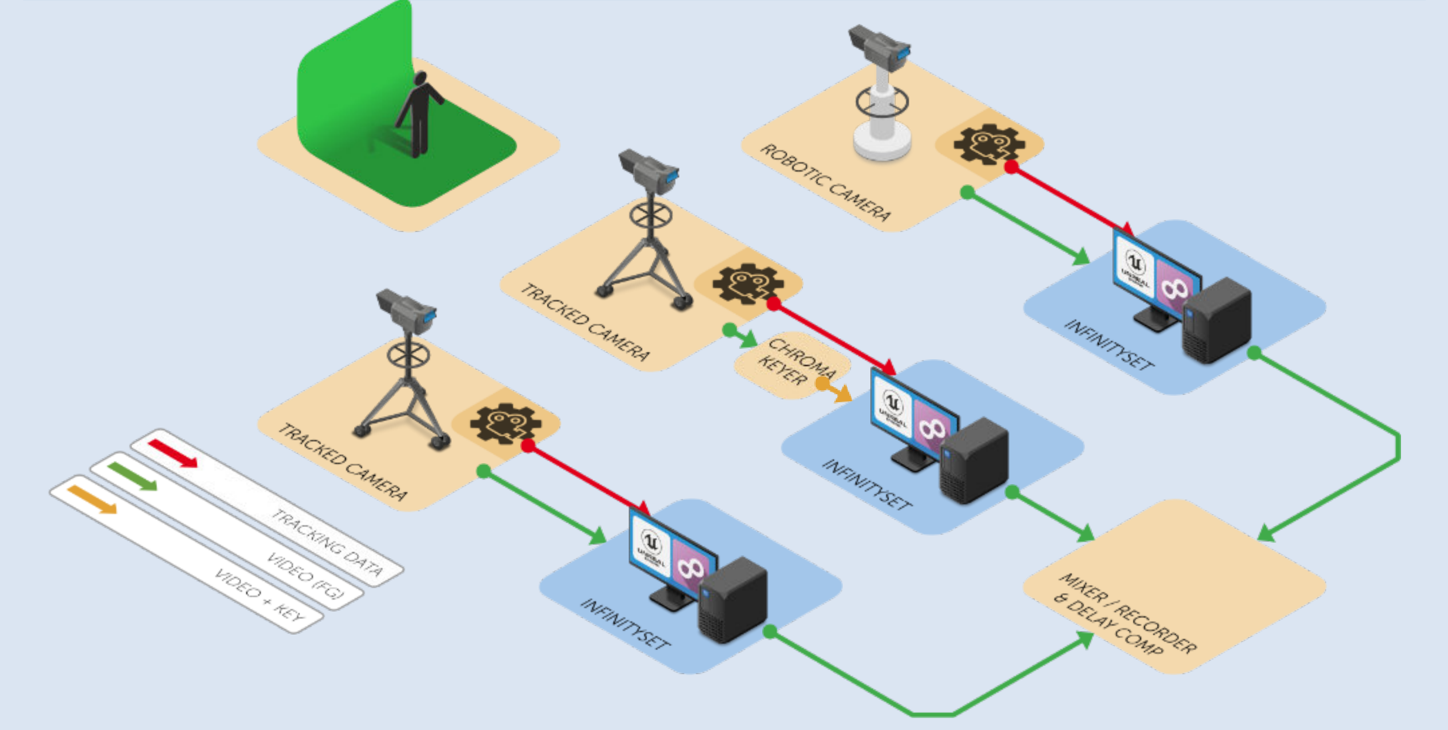
Virtual set, multiple tracked cameras, render per camera

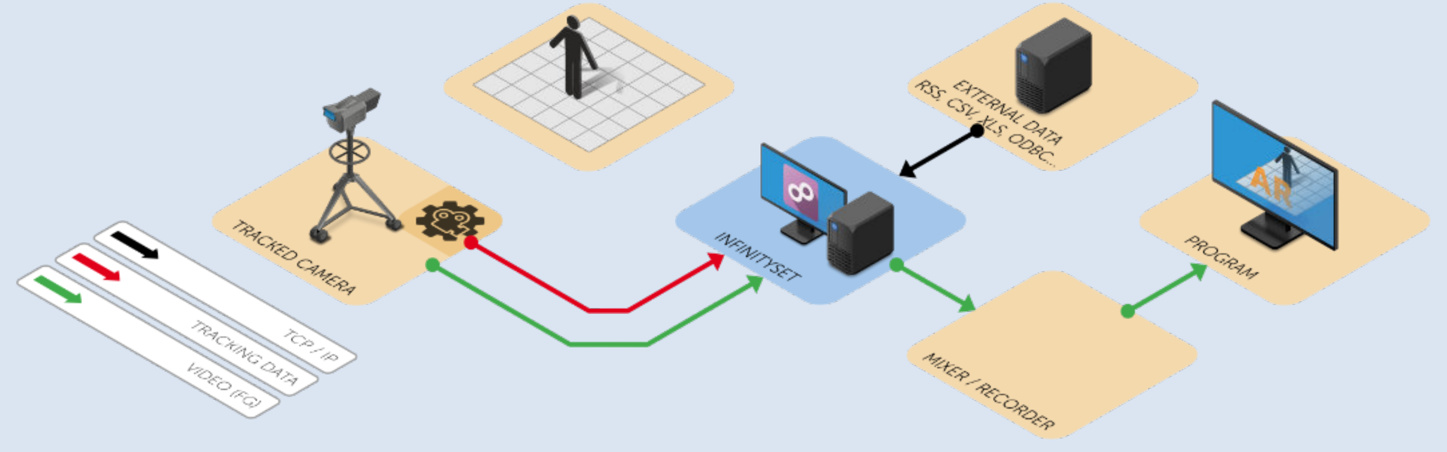


movements into space to simulate the movement of the cameras on the set. More complex tracking systems can also be integrated in pedestals or cranes, allowing for free three-

dimensional camera movements in space, along with zoom and focus information, when present. Tracked virtual sets can use one or more cameras, and as each camera has a different framing, this allows for more complex productions with different camera vieww. As mentioned before, using TrackFree™ technology makes it possible to mix fixed and tracked cameras for increased production flexibility.

One workstation may support multiple camera inputs (Brainstorm InfinitySet can also create **multiple simultaneous renders**), but for better performance each camera can be assigned to a single workstation, which will then send the render to a studio mixer for live production or recording. In any

Basic augmented reality workflow



case, the camera will send the feed directly to the workstation to use an internal software chroma keyer, or to a dedicated chroma keying hardware, which will send the video+key image to the workstation. Brainstorm technology allows for **any combination of the above**: workflows combining single or multiple cameras, tracked or fixed, multiple renders in single workstation or render per camera, internal or external chroma keyers, etc., all of them are possible.

AUGMENTED REALITY

As defined in Chapter 1, augmented reality (AR) is the **in-context integration** of information and/or graphics on any television content (or apps), or when 3D virtual elements are added, in context, on top of real footage captured by camera.

As cameras will move freely around the set, **camera tracking is mandatory** to ensure the added graphics are perfectly integrated in the original footage, both in movement, perspective and looks. Advanced AR applications such as InfinitySet can add real reflections or shadows to the synthetic graphics, resulting in a better integration with the real scene. Of course, the AR graphics can be created as bespoke elements or can also be data-driven templates that can be updated live as data changes. For instance, in Sports or Elections shows, the automatic update of the graphics' data is essential.

The basic configuration for creating AR content starts with a **tracked camera** that feeds a computer with video and tracking data, so the graphics can be rendered on top of the real images but with correct perspective matching and movement control.

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IMMERSIVE VIRTUAL REALITY: COMBINING VIRTUAL SETS WITH AR

Sometimes the real environment is not enough for our content creation requirements, so we must enhance the real scene with **virtual imagery**, along with the AR elements.

These enhancements can be just the inclusion of a virtual set for the talent to be placed on, or the usage of larger virtual elements that can be displayed on top of the real content. The basic configuration for an immersive mixed reality (IMR) workflow is similar to an AR setup, but we must take into account that increasingly complex scenes and objects may require, in most cases, a render per camera approach rather

than a multi-render approach with a single workstation, due to the rendering requirements of complex hyper realistic scenes.

XR USING LED VOLUMES

When using LED volumes for an XR project, there is no need to use a chroma screen, as the background image is directly **rendered** and **displayed on the LEDs.** Then, the camera captures the "composite" scene of the LEDs plus the real talents in the set. The render of the virtual background is previously sent to the LED walls based on the camera tracking information, to ensure its **correct perspective** based on the camera position and parameters.

This, of course, needs **careful calibration** of the whole setup so there is no noticeable lag between the render and the current camera view/position. If we need to add AR elements on top of the scene, they can be included in the background scene in some cases -rendered "inside" the LED volume taking into account the camera position. However if the AR elements are to be displayed in front of the talent or real elements, this will require an additional render on top of the real camera feed, and this additional render must be created depending on the position of the camera in space. All the above may result in a number of issues that need to be considered, as it will be detailed later in this document.

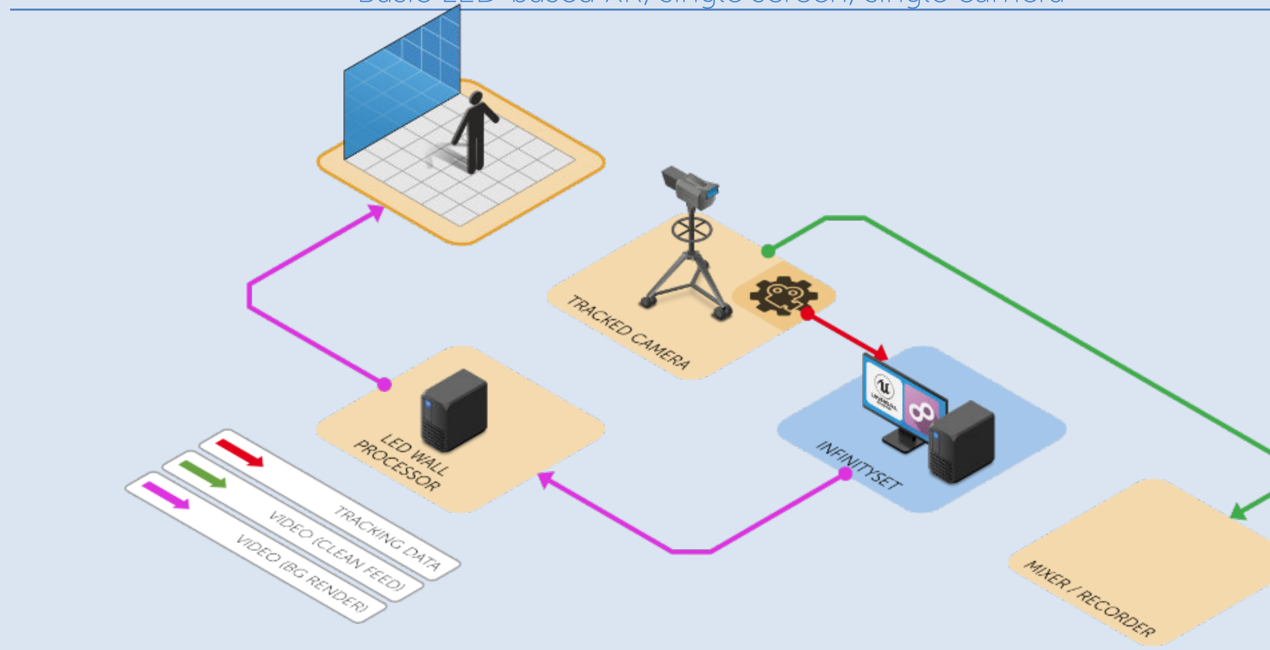
The basic configuration for a LED-based XR setup will require a tracked camera, most likely with a render per camera setup, and the workstations to take care of these renders, including the AR elements, if present. It is the complexity of the scene and the possible in-front AR graphics which will define the final hardware requirements, so careful preparation is required to ensure real-time performance.

Many other complex scenarios can be set up, and are detailed in the next chapter **LED-based XR workflows.** These workflows may involve several LED volumes, LED floors, curved or angled LEDs, and many more, including other requriements as set extensions or combinations with chroma sets.

The workflows detailed in this chapter are just some examples of what it's required to setup a virtual production environment. The possibilities are endless, only limited by the content creator's imagination and the resources available.

However, as mentioned, every setup has its own particularities, so the pre-production analysis and work is essential to ensure we achieve the expected results.

Basic LED-based XR, single screen, single camera



SCAN ME

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LED-BASED XR WORKFLOWS

First of all, we need to understand that XR or virtual production using LED volumes is much more than just playing a video on the LED as a background. This will only work if the camera does not move or if its movements are simple enough that do not imply a change in perspective. For instance, a traveling following the actor in a straight line, and even this will only work in certain circumstances. Camera shots are normally more complex, involving zoom, variable depth of field, close in/outs, tilts… So, we'll need to render a hyper realistic 3D scene to cover these requirements when shooting, to start with.

On top of that, as mentioned before, we need to render the background scene according to the camera position and parameters, as provided by the tracking device, and send it to the LED volume so the camera can capture the composite scene to make the shooting behave as a real life shooting would. So, we'll need to add depth, parallax, depth of field and adjust the perspective taking into account the tracking parameters, so the rendering in the LED volume will replicate what real life shooting would provide as a background.

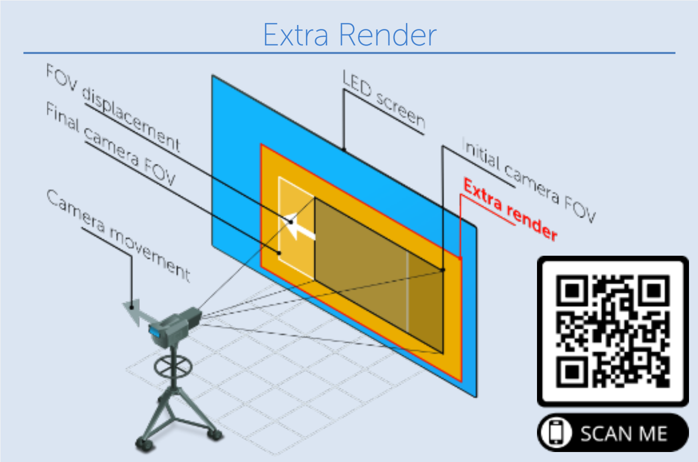
That is, providing the LED is flat and large enough to cover the complete field of view. If the LED volume is curved, composed

of angled screens, or smaller than the camera frustrum, we'll need to take this into account and render according to the geometry of the LED volume, adjust it depending on the lens distortion and parameters, or even use set extension techniques to compensate the lack of LED surface. So, let's take a look at the basic workflows when using LED volumes for virtual production and their requirements.

The simpler application is the display of a virtual set using the LED screens, a setup that can increase its complexity by including virtual set extensions or in-screen AR, and also include additional AR graphics on top of the scene, as mentioned above.

LED-based XR uses a similar basic workflow for any of these applications. The basic setup requires a camera with **tracking** to provide the camera position in space and lens parameters, workstation(s) for the rendering and LED videowalls to display the render of the virtual background or scene created out of the tracking position. The cameras will capture the live scene as it is, which becomes the final content. This workflow may include several cameras, workstations or LED walls depending on the applications and requirements.

In some cases, the camera does not capture the whole screen, but just a portion of it; in other cases the camera sees the screen as a "window" that displays an "external" world. In any case, one of the obvious issues of any LED-based XR workflow is the **delays** resulting from the time difference between the capture of the tracking data, that is, the time required for rendering the image and displaying it on the screen prior to the camera capture. If the camera only captures a portion of the LED screen, we will just need to render an image that fills in the



field of view (FOV) of the camera, with the resolution of the camera capture. But, in any real situation, the camera moves while the rendering is being done and sent to the screen, so we will need to render a larger image than the required for the camera FOV, to fit a "safe projection area" which will prevent the camera to see a blank, non-rendered image when moving.

This is called **"extra render"** and can be created either as a larger than the camera capture (HDTV, 2K, etc) render, or as an interpolated image (extra FOV), an image with the same resolution of the camera output but stretched to fit the "safe" larger projection area.

SINGLE SCREEN & SINGLE CAMERA

This workflow is the simplest one, and just requires a **single LED wall** fed by a **single workstation** and a **camera** with a **tracking** system (see diagram in page 10).

The tracked camera sends its position in space and other data (zoom, focus…) to the workstation, which renders the virtual world to be displayed on the LED wall with the correct and

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precise geometry and FOV, based on the tracking information. Then, the resulting scene is captured by the camera.

MULTIPLE LED SCREENS & SINGLE CAMERA

LED screens can be configured in different **shapes, size and geometries**, including curved walls or corners configurations with or without floors. This means it is possible to create immersive environments in which anywhere the camera moves, even with pan/tilt and head rotations, there will be a part of the LED available to render the virtual environment.

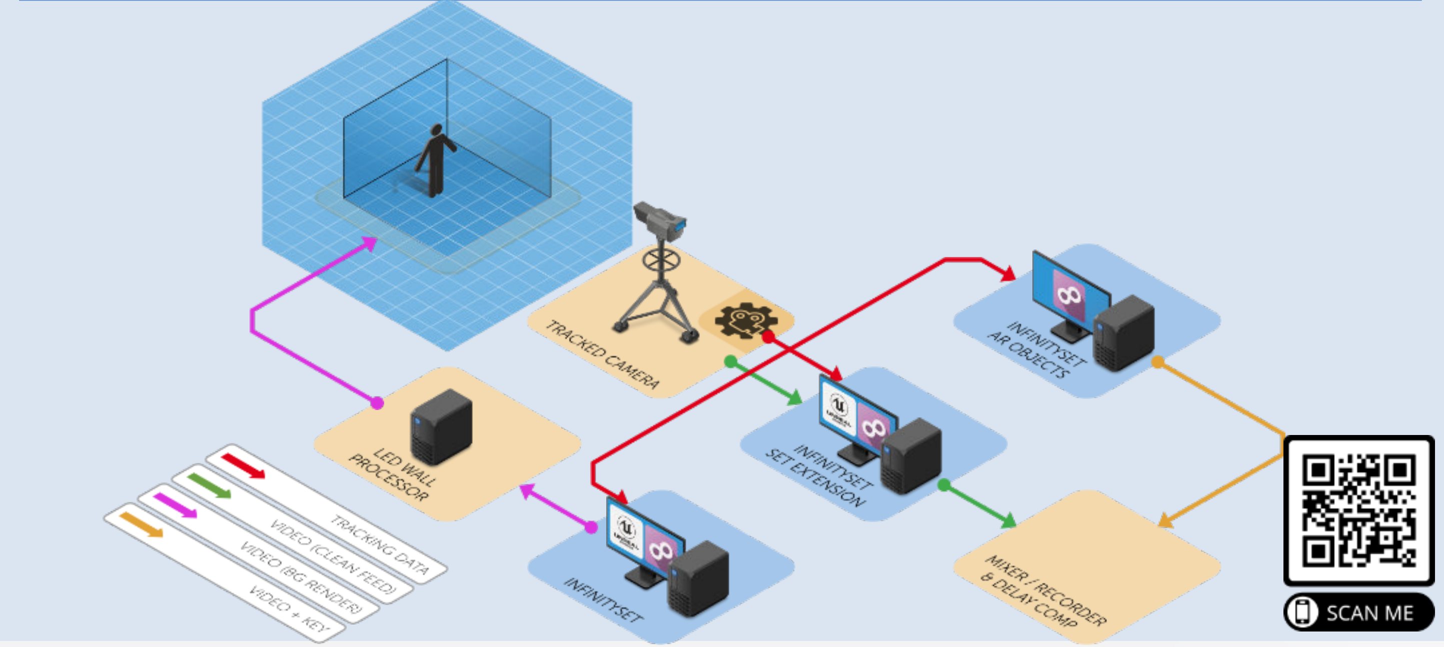
Brainstorm's InfinitySet includes a variety of tools that allow for creating several renders simultaneously, so a geometrically correct render can be displayed in several screens, even if they are configured as corners or even floors, regardless the screen configuration, for the required camera view. InfinitySet establishes the position of each screen in the real world, as measured from the origin point specified by the tracking system prior to rendering. This will allow users to create, for example, an optimized corner with two LED walls and floor **which requires only one render**, that is correctly mapped onto all configured screens.

Brainstorm InfinitySet provides users with comprehensive tools to adjust the shape, dimensions and resolution of the LED volumes to the render is correctly mapped on the LED.

SET EXTENSION

A set extension is required whenever we need to **display the background beyond the limits of the screens** as seen by the camera, which is achieved by creating a **continuation** of the background environment beyond the edges of the LED screens. This is similar to what we are used to with chroma keying. However, this has limitations on the camera views and positions compared with chroma sets, not to mention the required **color calibration** or tone mapping to match the different renders and displays.

LED-based XR - Set Extension with multiple LED screens



Also, image differences between the LED display and the additional render may be noticeable due to image degradation, pixel pitch differences, etc., as the extra render is **created on top of the image** captured by the camera, which displays the output of the LED screens. Tracking, video delays and lens calibration accuracy play an extremely important part in this setup, as we need to blend the set extension render with the camera capture, and any inaccuracy would cause a discrepancy between the camera image and the set extension.

To achieve this, set extensions may require to **model** a 3D object to represent the **location** and **shape** of the real world LED screens. This 3D model can be used to mask the screen area in the final composite. Conceptually, we will end up with a 360 environment where part of the render would be the LED screens, plus an overlaid image around the screens that displays the rest of the virtual environment "outside" the LEDs. Once again, InfinitySet has plenty of tools to achieve this effect.

MULTI-CAMERA WORKFLOWS

Although in film production this is not essential, broadcast workflows normally involve multiple cameras. Also, multi-camera setups for LED-based XR provide better production options and advantages, but result in some **limitations** that are important to keep in mind. They will require one render

(workstation) per camera, providing a continuous render image for each camera's point of view. When using several LED screens, it may require one render per LED screen as well.

Most importantly, this setup requires careful planning while in production, because when changing between cameras on the video mixer, the image on the LED walls needs to change to the corresponding camera **at the same time** as the video mixer cuts to any camera. Or, more accurately, the render corresponding to each camera must be visible at the exact moment we change cameras.

Since LED screens or video walls imply processing delays, the synchronization can be done by constructing **macros** on the video mixer/switcher, so the device can execute two

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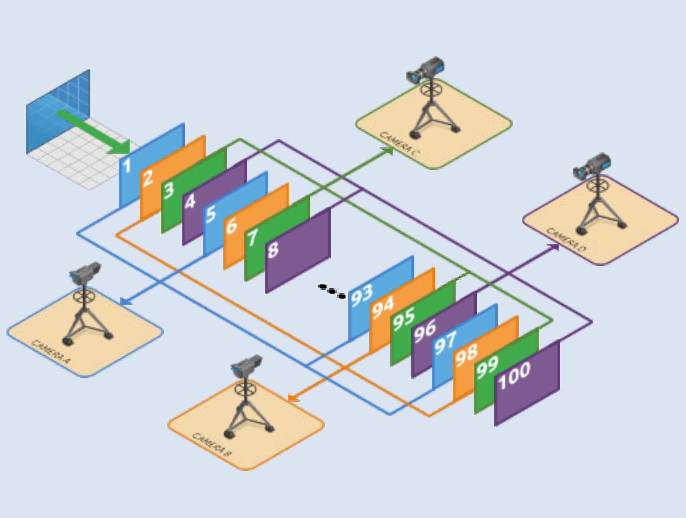
commands when switching between cameras. The first command switches the signal (render) going to the LED walls to display the correct signal of the camera that we are cutting to, and the second command, accurately delayed in relation to the first one, switches to the image captured by the camera. This makes operation more complex, often causing problems when video mixers are controlled by automation systems.

A more realistic approach for this situation is to implement a video wall controller capable of **displaying all required camera signals simultaneously** on the video walls, giving the option for each camera to always see its own unique point of view on the LED screens. This is the case of Megapixel's **Ghostframe** or Brompton's **Frame Remapping** technologies. These processors are capable of sending signals at 100 fps, or even a higher **multiple of the camera frame**, rate to the LED volume. Then, we will need to adjust the cameras shutter so it captures only one of the signals in the video wall, discarding the other signals, which will be captured by other cameras, by using shutter and phase adjustments.

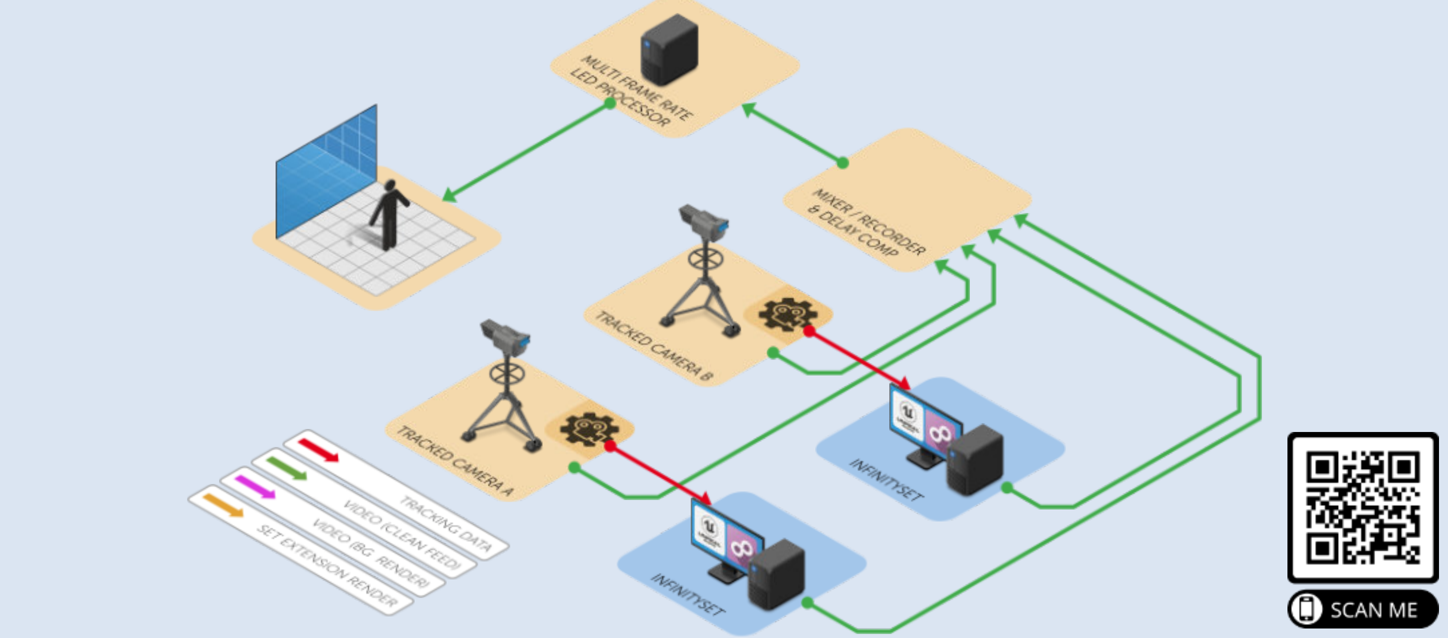
Each camera's unique point of view would be sent to the LED walls continuously through the controllers and based on the tracking information, as usual. Images would then be displayed in succession on the screen, and each camera will capture the background depending on its own phase and shutter angle adjustments. This technology creates flexible setups in which it is possible to not only display alternative backgrounds, but also use one of the signals to display a green background, providing one of the cameras with a green screen which can then be sent to post production or keyed directly; or displaying a tele prompter directly on screen, allowing the talents to read it live while the text is not visible to on-air.

Multiplexing setups allow for a more traditional multi-camera workflow by reducing the complexity at the production switcher, so, as a result, fading between camera sources is technically possible. The system may, however, set certain technical requirements and limitations, like using **progressive** signals, cameras with shutter angle and phase adjustments, and, most importantly, the camera sensor most likely should use a **Global Shutter** instead of the usual Rolling Shutter type. In any case, the LED wall **controllers are a separate issue** within the LED-based XR workflows, which must be discussed with the manufacturers / integrators to ensure they meet the

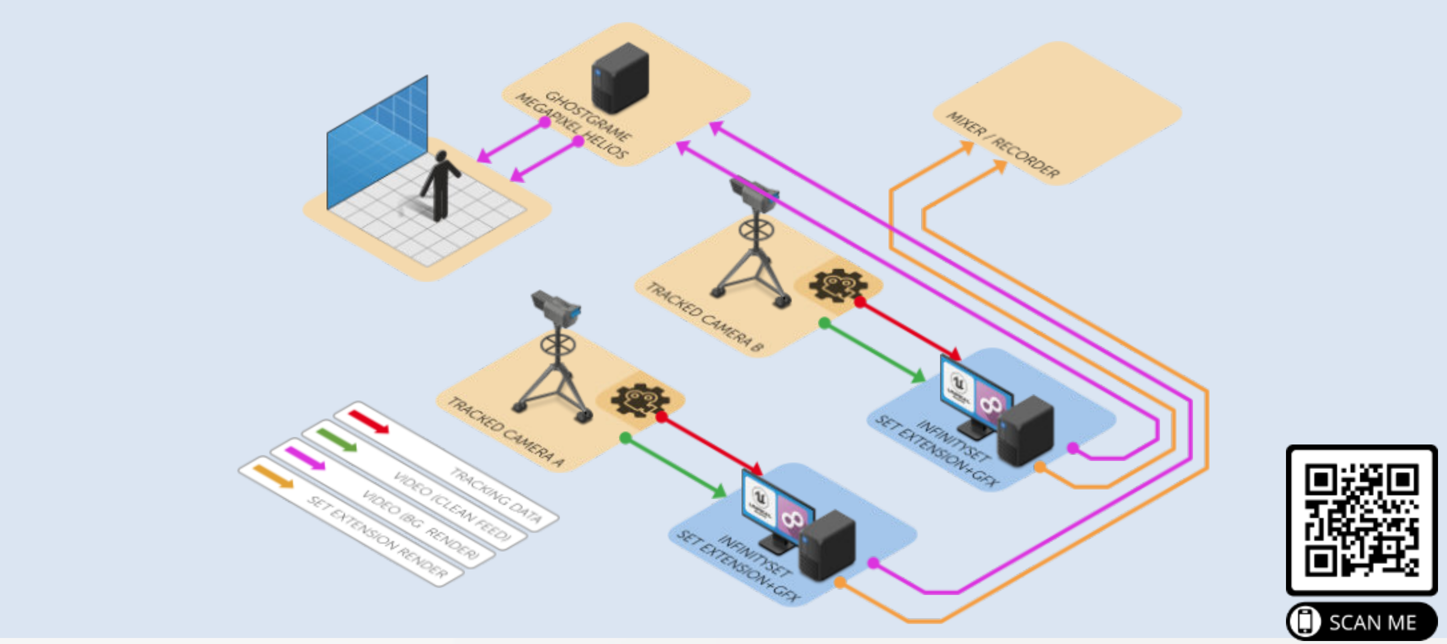
Capturing multiple frame rates



LED-based XR - Multicamera Workflow, mixer driven



LED-based XR - Multicamera Workflow, multiplexing images (Ghostframe, Frame remapping)



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requirements of the setup and content production, or to be aware of their limitations.

IN-SCREEN AR

This application features objects that appear to be ***outside*** of the screen even though they are **rendered *inside*** the LED screens. They are rendered in the same scene, but because the camera position and FOV are known, a workstation, with InfinitySet for instance, can render such objects in the same scene, and they will be displayed with the correct perspective with regards to the camera view. For obvious reasons, these AR objects cannot exceed the screen boundaries and will inherently be behind the real-world talent or any other element in the world in front of the screen.

With in-screen AR, all the 3D elements within the screen are obviously **"behind"** the presenter, as if the camera was looking through a window. If the 3D elements are arranged within the 3D set "in front" they will appear as if they were *out of the screen* **from the camera position**. So, it is essential to choreograph the movements considering that the talent can't be in front of the AR elements, or the result will not be valid.

XR WITH AR GRAPHICS ON TOP

Both in Set Extension or In-Screen AR applications, **AR graphics** can be **rendered in front** of the real-world people located in front of the LED screens, and **on top of the rest of the elements** in the scene. This requires an additional rendering after the composite scene has been captured by the camera, which may imply an additional workstation and careful calibration of the tracking, scenes and applicable delays to ensure that all elements work together in co-ordination. Within the Brainstorm environment, if this AR graphic is an Aston graphic it might be rendered within the same engine but if this AR graphic is an Unreal Engine render, it is strongly recommended to use an additional render engine for performance reasons. This additional render will allow for placing AR graphics in front of the real-world talent.

FILM AND DRAMA PRODUCTION

The use of LED walls to display the background environments rather than using chroma keying techniques is increasingly common. There are important advantages and time-saving benefits when using LEDs.

With cinema style productions we refer to productions where just one camera and a **background scene** are used, and only the area of the LED screens seen by the camera frustrum are rendered in full quality while the rest of the LED volume don't receive such render. But we must also bear in mind that the background, the unrendered area not seen by the camera, is extremely relevant in a cinema style production, as it provides additional lighting and content for real world reflections. This could be a typical film production setup, although it is also used when shooting drama or sitcoms, especially those of higher quality or that need additional refining after shooting.

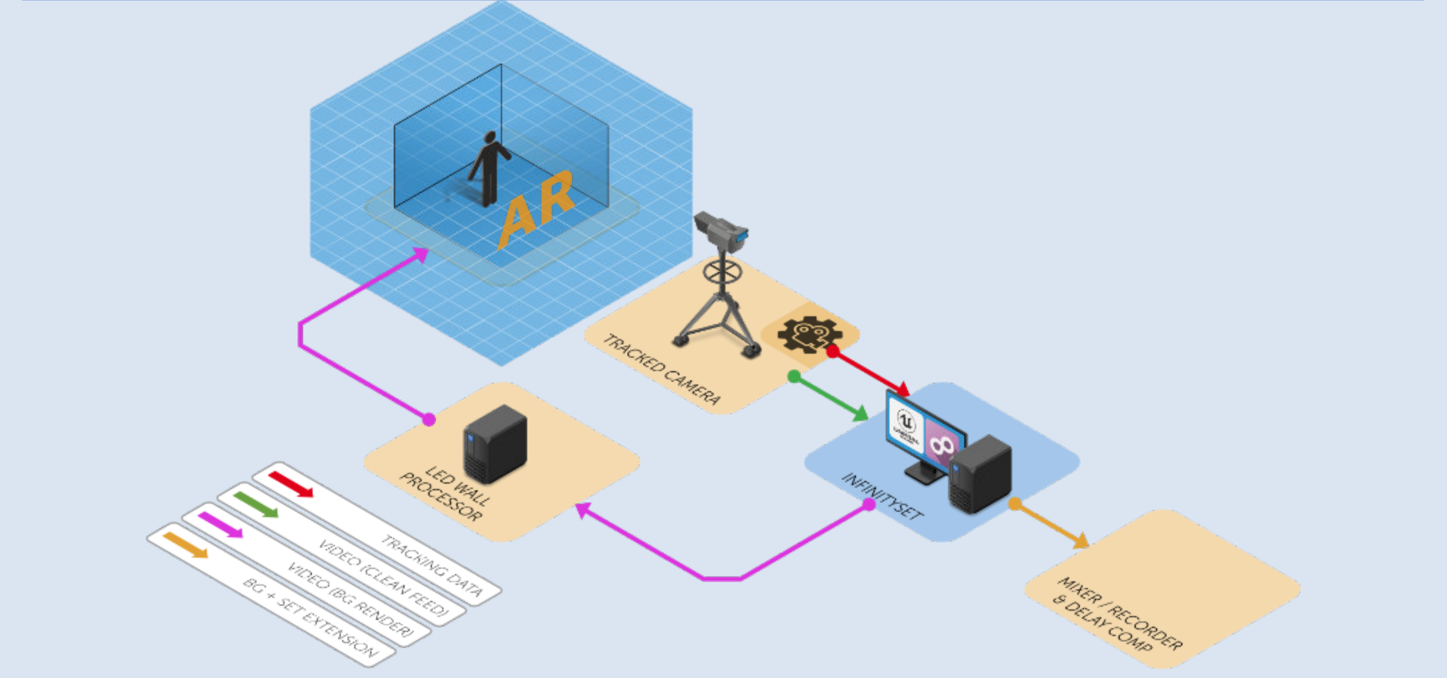
So, in a film workflow, all background screens need to stay active (display an image or a render instead of black) at all times, regardless the field of view of the camera. Other possibility is using LEDs for projection of reflections, lights, etc, to avoid post-production time. Also, LED ceilings are increasingly common in these workflows, as they provide organic lighting and environmental light, not to mention the common usage of advanced lighting technology like Image-Based Lighting, that can also be used with multiplexing signals, even dynamically changing the lights according to each camera requirements.

Film productions can use a variety of different approaches to fill in content on the screens **that are not seen** by the camera.

Screens may simply display an approximate still image or video of the correct content, a colour, or a live geometrically correct render. We must keep in mind that film productions are not easy to setup, and there is no single correct workflow, or set of technical tools to use.

Film productions inherently spend significant time in pre-production, prototyping and testing workflows, which in many cases imply going through possible issues that can arise while in production. Other uses for this approach to film production is to complement chroma key or live shooting by using LED screens or projectors to simulate a background, which can be quite useful to achieve correct reflections in cars and similar shiny of reflective objects.

LED-based XR with set extension and AR objects in front of the talent, using one workstation



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LED OR CHROMA? CHOOSE WISELY!

As we've seen before, there is no technical reason why the results obtained for XR applications using LED screens or chroma sets can't be similar. However, although we can reach a similar result with any of these methods, both have their own advantages and disadvantages, due to their own nature. Most importantly, we've also seen that we can combine both technologies to achieve the best results.

As there are many factors that affect the results and which we must consider when one technology or the other, let's see them in detail.

COMPOSITING THE SCENE: BACKGROUND INTEGRATION, SPILL, GRADING...

One of the most relevant benefits of LED-based XR is its ability to create a "real" environment in which the virtually generated background is seen as a real "world" from the perspective of the camera. This technique, then, updates the traditional filmmaking techniques that used other display sources such as projectors or painted walls, which has been common since the very early days of cinema. Capturing the scene as a whole means that chroma key compositing may not be required as the background is directly captured by the camera(s). This brings in significant benefits because, as compositing is not required, the scene is captured "as is", which, in essence, avoids the need for compositing the scene after it is captured. Also, real-time chroma keying can be applied when using virtual set technology, which saves costly post production time, or even avoids post production completely.

However, not everything is as nice as it may seem. Since we are displaying the environment directly as a background, the scene is as "fixed" as it could be in a typical shooting, which implies that making further adjustments in post will be as complicated as it will be in any standard shooting, therefore it will not enjoy most of the benefits of virtual production. XR works best when shooting medium or close-up shots, because when shooting wide or full-body scenes the size of the LED walls increases significantly or requires a virtual set extension -which has its own issues as we have seen before- and requires carefully installed props.

In any case, LED-based XR is likely to be used in studio, and it is not practical, or even impossible, to use it for remote outdoor shooting. Chroma keying can be easily transported and used outdoors with little or no problems, taking advantage of the real location environment for the floor, lighting, etc.

For studio shooting, real-time virtual set technologies allow for real-time chroma keying, even using photorealistic backgrounds rendered using PBR or based on game engines like Unreal Engine. When using advanced chroma keying software / hardware, there is no delay in compositing, and recording the layers independently allows for straight-forward post production, if this is required. On top of that, new chroma keying techniques, under development, that use Vantablack or

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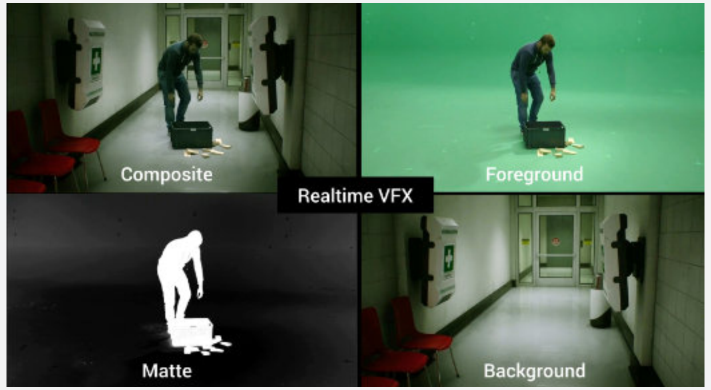

similar non-reflective “superblack” backgrounds instead of green/blue sets do not have spill or color contamination issues. Lately, we’ve seen how multiplexing techniques allow for displaying a chroma background on the LED volumes (see page 18, Chroma Set Displayed by a LED Volume), which provides further flexibility to these setups.

On the other hand, color grading is an essential process in the finishing of any video and film production. It is always a required step that provides the desired look and feel to the final product in postproduction. And the better the integration of the different elements in the image, the easier the process will be, so the colorist will focus on the creative and finishing side of the process rather than on fixing color issues. So, when using LED-based XR, it is likely that color corrections may not be required, as the lighting and environment can be matched together for the scene.

With multi-screen and/or multiple camera setups, colour calibration becomes extremely important as different physical screens might have distinct colour reproduction characteristics. Also note that the lighting of the real-world set may also require for independent colour calibration of screens as studio lights will affect how a camera sees the colour reproduced on individual screens. This is even more complicated when doing Set Extensions, as the output will be displayed with two different media (virtual render and captured screens), so the extra render pass created by the set extension will require grading the input of the camera coming into the workstation. Otherwise, it will not be possible to match the colors of the graphic elements on the screen “cave” effects, compared to the set extension method.

On virtual set environments, the grading can be approximated by dynamic lighting, which can be adjusted directly, for instance, from InfinitySet via DMX protocols. This allows for adjusting the color and intensity of the light as the background changes. Most often this requires fine tuning in postproduction to ensure the best possible integration, but if the scene has been recorded in layers this is not much of an issue, as the elements can be easily isolated prior to composting.

LIGHTS, REFLECTIONS, AND SHADOWS

With LED-based XR, most of the issues of chroma keying like spill correction or fine details like hairs or transparencies are not a problem. Also, reflections of the background environment in shiny or reflective surfaces (glass, metal, etc) are captured live and represent real reflections/refractions of such environment. Then, no postproduction is required to apply them.

Managing light spill in XR environments can be more difficult, as studio lights may illuminate on different LED walls from different angles and with different intensities, making it more difficult to match the color of the different LED displays. Also, the camera angle will affect the way reflections from studio lights on LED screens are captured.

When integrating the talents and the background, shadows are an issue with LED-based environments, and what benefits reflections now makes shadow management difficult. For virtual production using green screens, the industry has spent decades refining chroma keying to ensure the light drops the shadows correctly as per the requirements of the scene, and that these are captured with enough detail and quality to be used in the virtual environment. Also, props and green elements were often placed to ensure shadows are correctly applied over virtual walls, etc. Brainstorm TrackFree™ technology, with the 3D Presenter feature, helped to further refine this workflow by allowing to drop virtual shadows over virtual object.

But LED walls are light emitters, which means that shadows, especially when using LED floors, are quite difficult, or even impossible to manage in these environments. When using prop dressed floor the studio lighting surely helps, but in any case, the light emitted by large LEDs can interfere with the studio lighting, which must be taken into account. Also, if we have a real object in which the talent drops a shadow, we need to ensure that the shadow on the floor has the same radius and intensity, which can be quite complicated. That is why in some cases LED productions use real floor and props or do not show scenes with actors’ full bodies.

Some productions try to create virtual shadows in the LED floors, but this adds another layer of complexity and hardware requirements, not mentioning the requirement of an additional tracking for the character and the fact that the shadows may not match the talent’s real shadows.

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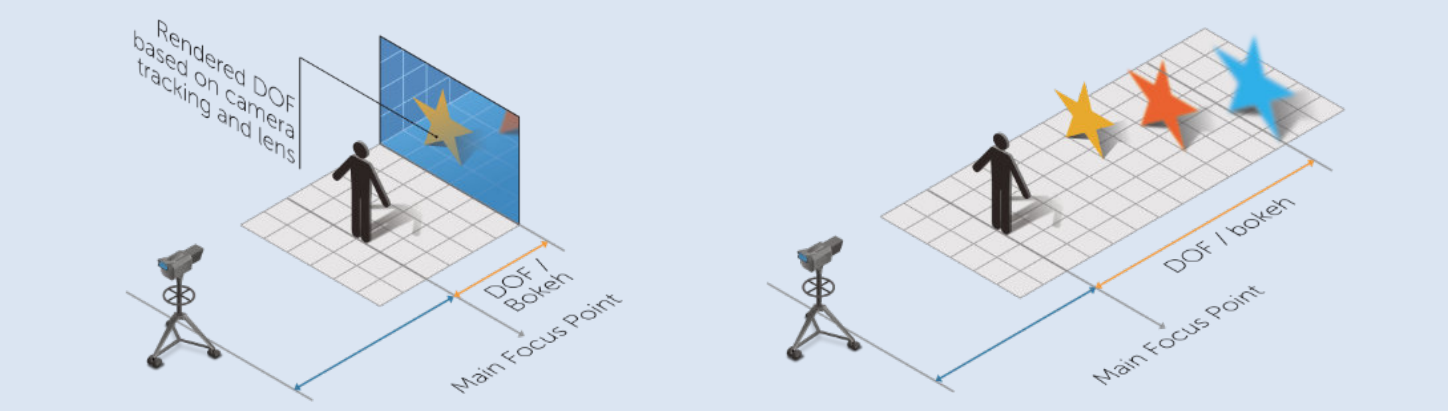
Depth of field and focusing issues with LED videowalls



PIXEL PITCH, DEPTH OF FIELD, FOCUSING

Pixel pitch defines how large individual pixels are on a screen, so the smaller the pitch the higher the pixel density in a given screen and therefore better resolution. LED screens' pixel pitch affects how the background image resolution will be perceived, and as such can cause "resolution issues" when focusing in on screens with the camera.

Sharp images with not enough shallow depth of field may result in a visible moiré effect in the background when shooting the scene. When the end user wants to do close-ups with a CAVE screen in the background, resolution and pixel pitch require special attention. Also, when the wall is not flat and its distance to the camera(s) is variable, the moiré can affect just parts of the image due to depth of field and focusing differences, which may result in an unusable scene. This must be considered in pre production to avoid unwanted artifacts.

Often the background is not perfectly sharp, and because the combination of the DOF of the background image and that of the lens used, the resulting composition will feature a somehow blurred background, which, on the other side, looks natural. However, if we need a sharp background, the pixel pitch, size and resolution must be carefully taken into account.

Just as with tracking, please note that pixel pitch issues will be more visible on multi-camera setups, as operators will use the full zoom range of their broadcast lenses.

Defocusing, or bokeh, can be more challenging when using LED volumes. In the real world focusing from near to far elements is simple, but in XR "far" is beyond the LED volume, while the LED volume must maintain a certain focus. To solve this problem additional hardware and software solutions are required, but this workflow should be thoroughly tested beforehand in real world environment.

Chroma key production allows for applying, in real-time, whatever focus and DOF we require depending on the scene and camera lens/zoom. In non-live productions, the background image's focus and DOF on the LED wall cannot be changed after shooting, while in chroma keying production we have room for any improvement in postproduction if the shooting has been recorded in layers.

VIDEO DELAYS, CAMERA TRACKING, CALIBRATION AND MULTI-CAMERA

When working with real-time renderings, delays are inherent to live operation. Even the fastest processing requires information to build the scene, so in any setup, including single camera ones, the image displayed on a real-world background screen will always be slightly out of sync with the camera movements.

This is because the computer needs to firstly generate a background image (which requires a variable time depending on the complexity of the 3D scene, use of Unreal Engine, etc); this background image then is transported to, and displayed on, the LED screens, then the camera captures the image and sends it back to the workstation for composition of the final image. And this process goes on and on.

Even if each process takes milliseconds, the delays are incremental and may even get close to a quite noticeable delay, depending on the complexity of the scene. So, the image that the camera captures shows a 3x delay compared to the camera position captured by the tracking device, meaning that it is not possible to fully synchronize the image displayed on the screens with the movements made by the camera.

This can only be somehow hidden with smooth and slow camera movements and careful zooming. On top of that, when we need to place AR elements in front of the presenter, we must add yet another delay.

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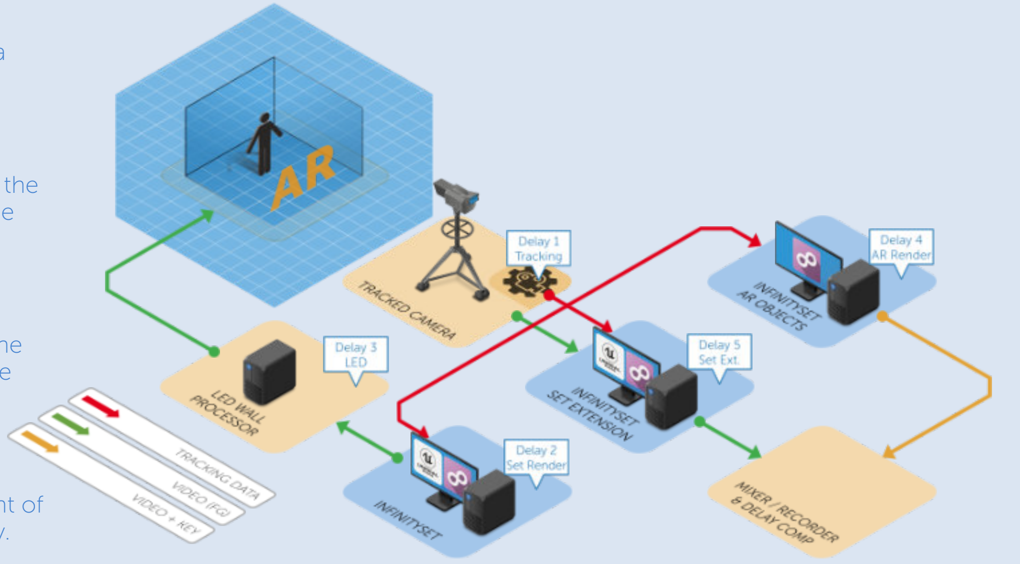
Incremental delays using LED walls

Delay 1
The tracking device reads the camera position in space and sends it to the workstation for rendering the scene.

Delay 2
Once the tracking position is known, the workstation renders each frame of the scene. This may take a variable time depending on its complexity.

Delay 3
Each frame needs to be mapped in the LED wall, so its processor receives the signal, prepares it for the different modules and displays it.

Delay 4
If AR elements must be placed in front of the presenter, this adds another delay.



On the other hand, virtual production based on chroma keying only feature a single delay, which is controlled automatically when rendering the composite image, and regardless the speed of the camera movements, the synchronization in the composed image is fully guaranteed.

When dealing with set extensions, the delay on the background screens will be different to that of the virtual set extension, while all screens must reproduce their images with exactly the same timeframe. This may limit the camera movements that can be done without breaking the illusion of the XR effect.

XR effects are only visible when moving the cameras over large areas, which provide enough parallax for the viewer to fully see the required depth. So, tracking is mandatory, as tracking and quality of the lens calibration play a pivotal role on how functional an XR effect will be. Also, as multi-camera setups tend to use larger tracking areas, it means that tracking quality requirements are more stringent. All tracking systems need to be calibrated to use exactly the same origin point to achieve the required accuracy. Also, any problems in tracking quality or accuracy will be more visible in a multi-camera setup.

Delays also need to be considered in multi-camera productions with LEDs, as cutting between cameras may become extremely complex, and sometimes tricky. As the cameras have, most likely, different FOVs and perspectives, live cuts from one camera to another imply sending a different render to the LED wall, and sync the whole operation accordingly, as we've seen in Single or Multiple LED Screens / Multiple cameras.

Film productions will most likely be shot in single camera mode so this issue should not be that important here, but in live or live-to-tape productions multi-camera is widely used for time savings. This needs to be considered when choosing the right tool for our productions.

CHROMA SET DISPLAYED BY A LED VOLUME

The ability of some LED volumes and processors for displaying multi frame rates in sync with the cameras provides an additional alternative, which is the display of a chroma key image inside the LED. When using Ghostframe or Frame Remapping (see page 12, Multi-camera workflows), one of the images displayed on the LED can be a flat green or blue image, that can be captured with a camera which can then provide the talent in a chroma set for further editing or post production.

As the camera(s) can capture the talent on the green background or the composite image at the same time, this makes possible to include the chroma sequence independently, which brings in additional possibilities for easier post production. However, we may need to lit the scene accordingly, or take into account the potentially higher spill coming from an LED green image.

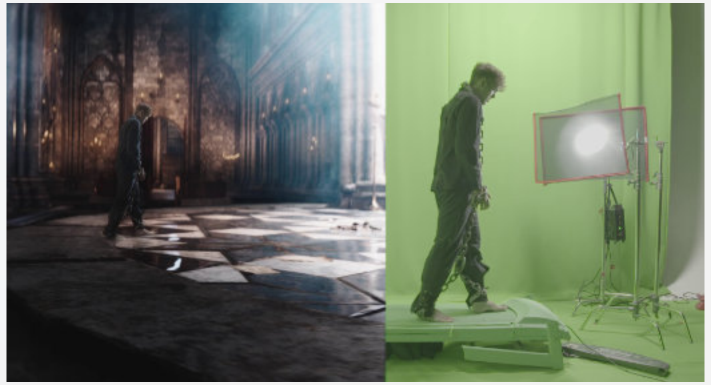
HARDWARE REQUIREMENTS

Larger walls need more hardware, and the workstations must

be co-ordinated accordingly, not mentioning that large or higher resolution outputs may require significant computer power. But chroma key-based production does not require feeding large videowalls, only the final rendered image, and if we use a render per camera approach, each camera's output should display the best possible signals we can get.
In any case, real-time hyper realistic production pushes the boundaries of the hardware as it requires significant resources due to the rendering quality that is required, so in most cases vendors need to create workflows with several workstations, a render per camera approach and additional machines to add set extension, AR and so on. This implies that being able to optimize the combination of hardware and software to reduce the hardware requirements can vastly improve the workflows. For Suite 6, Brainstorm introduced technologies such as Dual GPU compatibility, in addition to other optimizations.

FIXING IT IN POST

This may be one of the biggest issues for LED-based XR. For live productions (events, broadcast, etc) involving rendered backgrounds (videowalls), this approach is possibly the best option, as the results will always be played live, although there is no room for mistakes!



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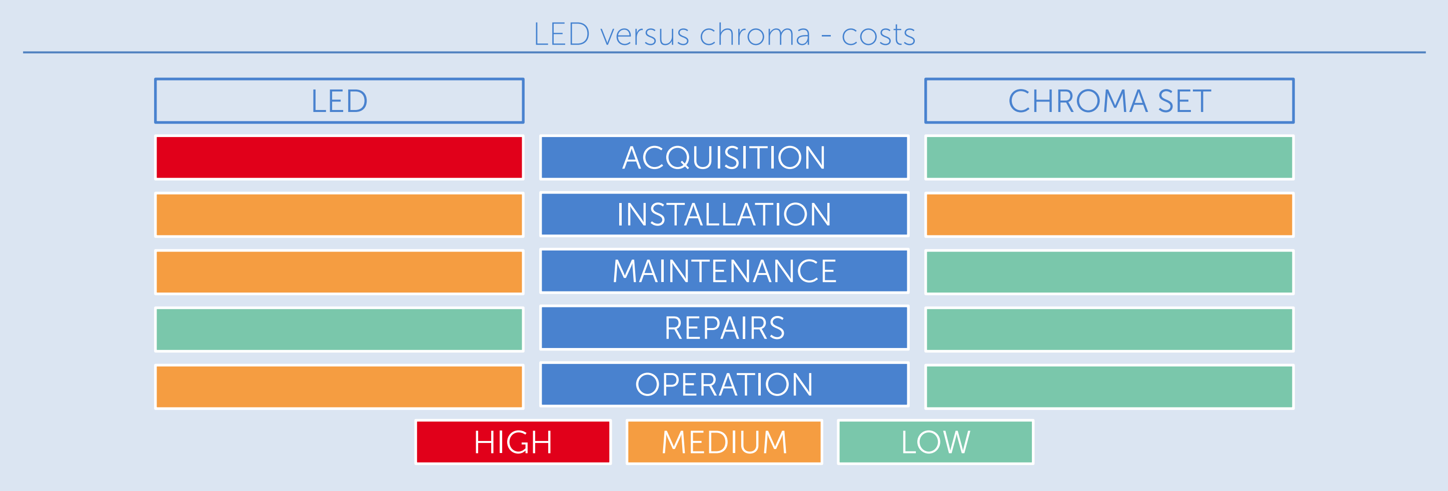
However, for film and drama productions, shooting the background “as is” may lead to a significant loss in flexibility when postproduction is required, such as adding compositing, VFX, environmental grading, particles, etc. As the image is “fixed”, or “baked”, rotoscoping or other techniques may be required to isolate parts of the image prior to apply effects, which makes no sense in complex productions, whereas using chroma keying will allow VFX operators to easily achieve all that is required, as the elements are already shot separately and stored independently for post. This can be solved by using a chroma background in multiplexing modes (see page 18).

Once a scene has been recorded, regardless the method,it may often require changes. Many can be done while in production, just reviewing the shots and reshooting if required, if the actors and crew are still available. But, if such changes are required later, as the LED-based scene is “baked” or already composed, we may have to re-shoot or enter in longer and more complex postproduction processes, meaning all the time and cost savings of virtual production disappear.



As mentioned, if a scene shot in a LED needs changes, we have the alternative of using a chroma plate in a multiplexed LED volume, as mentioned in the previous chapter. In this case it is possible to record both the composed image and the talent with the green background at the same time, even using the same camera -latest cinema cameras allow for this kind of shooting- ensuring the same POV, and maintaining the ability to change, edit or adjust the scene at any time while saving post production time.

Of course chroma keying, when used with tracked cameras and multilayer recording of the shooting, can perform any changes in post with total ease. In essence, we see that in many cases combining LED and chroma results in a winning combination. It is required, then, to carefully review the production requirements so any eventuality is taken into account.

FLEXIBILITY AND SUSTAINABILITY

Shooting live without chroma keying has its advantages and challenges, impacting production workflows. While it offers immediacy, it sacrifices the flexibility often needed in complex productions. In this context, LED volumes, especially those using multiplexing technology for chroma backgrounds, may be the perfect choice and provide additional possibilities, however, as we’ve mentioned, we need to take into account the possible changes to the scene.

One major benefit of virtual production is the cost reduction in areas like actors' time, props, setup, travel, and outdoor shoots. However, content creators must invest in pre-production to fully capitalize on these savings. LED-based XR retains these benefits, but scene changes or background adjustments might still require reshooting -or using more complex setups such as multiple frame rates and embedded chroma backgrounds. This can also be mitigated by thorough rehearsals, though some changes may need post-production due to scheduling conflicts or last-minute decisions.

Chroma sets, in contrast, offer more flexibility for outdoor shooting, which is more challenging with LED volumes. For outdoor shooting, obviously fabric chroma screens and structure can easily be transported to the required location.

Chroma sets also provide cost savings and creative flexibility for smaller productions while supporting complex visual effects for larger projects. They cater to diverse production needs, ensuring both small and large-scale projects benefit from this technology’s versatility.

Last but not least, sustainability and flexibility are crucial considerations. LED volumes, especially large ones, are expensive to acquire, operate, and maintain, involving costs for LED tiles, processors, structure, and electricity consumption.

AT A GLANCE

Both technologies, LED and chroma sets, have their own pros and cons, and it is the nature of the production we are planning, and its requirements, that will define which technology fits best with what we want to achieve. Of course, LED volumes and chroma sets can be mixed together in the same production or used for different scenes of the same content.

When using live production for events, LED-based XR seem to fit better as the audience on site will also see the production as it was designed, while with chroma key-based production it is most likely that only the audience at home will enjoy the final content. Also, there are certain situations in which the LED will outperform the chroma sets, while other situations will face the opposite.

However, chroma keying still has significant benefits in workflows and flexibility, not to mention time savings in production and postproduction, cost of operation and sustainability.

So, it is up to the specific requirements and budget of each production to decide whether to use chroma sets, LED volumes, or both.

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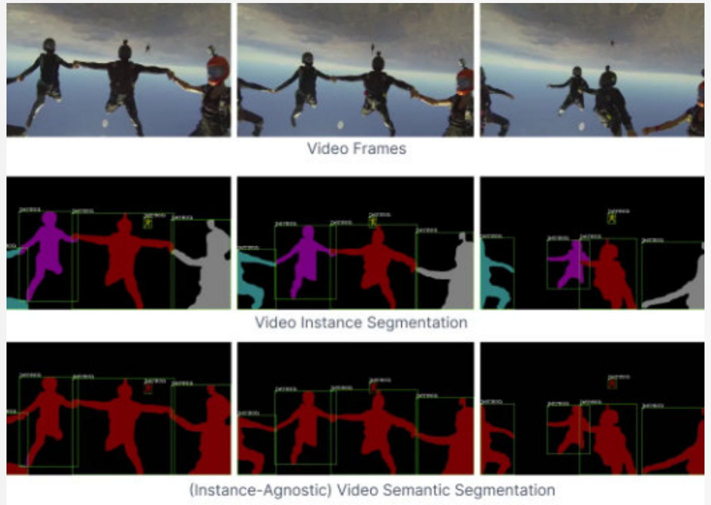
WHAT'S COMING? THE FUTURE AHEAD

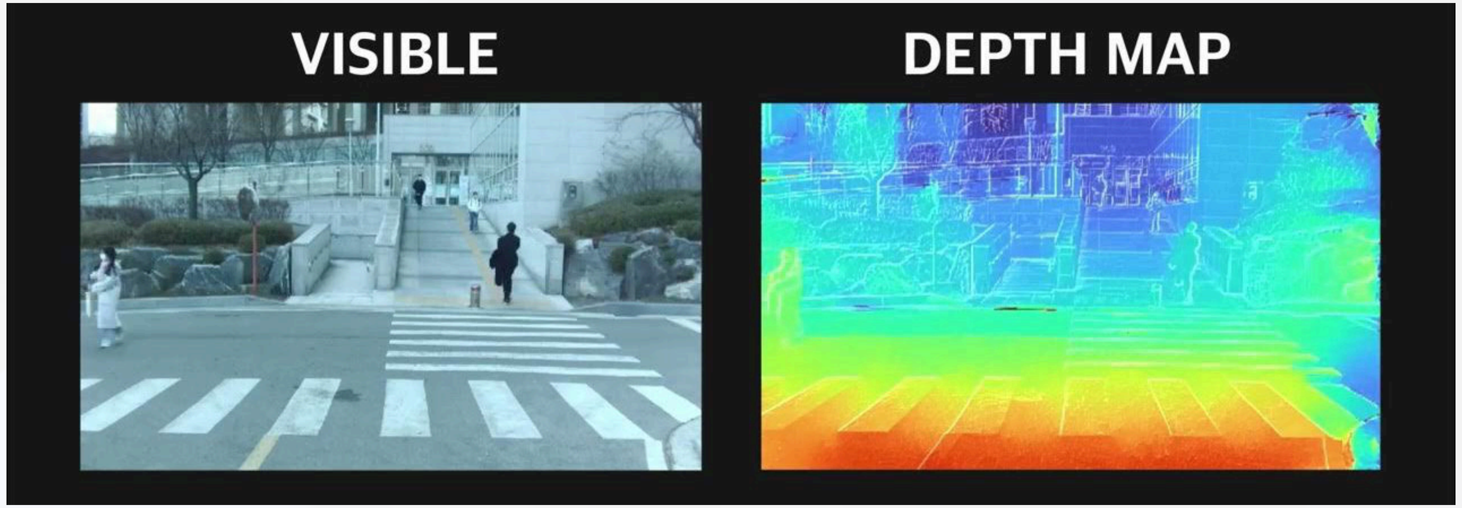
Predicting the future of virtual technology is no small feat. While certain trends may seem clear today, even predictions made just a year ago have often proven surprisingly inaccurate. Nonetheless, some emerging market trends are worth exploring. In this final chapter, we'll delve into developments like new rendering techniques, AI-driven keying, markerless tracking, and the transformative potential of Generative AI for creating 3D content.

KEYING USING AI SEGMENTATION

This technique could potentially render chroma keying obsolete: it partitions an image into segments (groups of pixels), employing complex neural networks for sophisticated pattern recognition. It effectively separates elements from their background or the other way around, opening the door for AR elements inserted onto real footage features for virtual advertising for instance.

A simpler way of achieving a similar effect can be done through just depth mapping: where talent stands in regards to the





shooting camera. As talent walks back and forth the depth map varies, sending out those changes to the real-time engine which uses this information to position them in depth within the 3D space. It typically requires a stereo camera rig, but some algorithms solve it over the lens.

MARKERLESS TALENT AND DEPTH TRACKING

By using deep learning neural networks, an accurate human body pose estimation can be achieved without markers. This is a more cost-effective way of learning where the body and some of its parts are in the 3D space. It typically requires an array of fixed cameras looking at the shooting area where the talent(s) are, although some techniques employ just a couple of cameras or even a sinfle PTZ camera.

Knowing where the talent's body is in the 3D space expands the interaction possibilities between the real and the virtual world: certain hand gestures can trigger on an animation, a walk on the studio space shows and hides AR elements automatically, based purely on the position.

GENERATIVE AI FOR 3D MODELS & OBJECTS

Generative AI (Gen AI) refers to a type of artificial intelligence that creates new content based on the data it has been trained on. Unlike traditional AI, which focuses on recognizing patterns or making predictions, generative AI produces entirely new outputs by using advanced machine learning techniques, particularly deep learning and neural networks. Today's Gen AI tools are capable of creating impressive outputs such as realistic images, videos or 3D models. However, challenges

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such as maintaining coherence, achieving photorealism, and adapting to specific artistic or professional standards remain. Text-to-image tools like MidJourney and DALL-E can generate visually striking artwork, but achieving precision for commercial-grade projects often requires human intervention or fine-tuning.

As these tools become more reliable and sophisticated, they are set to play a central role in content creation across a number of fields, including 3D modelling.

CAPTURING REALITY IN 3D

Usually, capturing reality in 3D has relied on **photogrammetry**, a technique that scans an environment and converts it into a 3D model. This process has been widely used in industries like gaming, architecture, and film production to recreate real-world with high levels of detail and accuracy.

However, photogrammetry's reliance on creating detailed mesh and texture data can be resource-intensive and time-consuming. While it remains an important method, a new approach has emerged in recent years that challenges traditional techniques by offering an alternative way of visualizing 3D data.

Latest advancements in 3D capture technology focus on generating point clouds instead of meshes and textures. Unlike traditional models, point cloud-based methods represent a scene through a collection of points, each with its position and color, distributed across the 3D space. This approach sidesteps the need for heavy polygonal meshes, simplifying the rendering process and reducing the computer power required, while maintaining spatial accuracy.

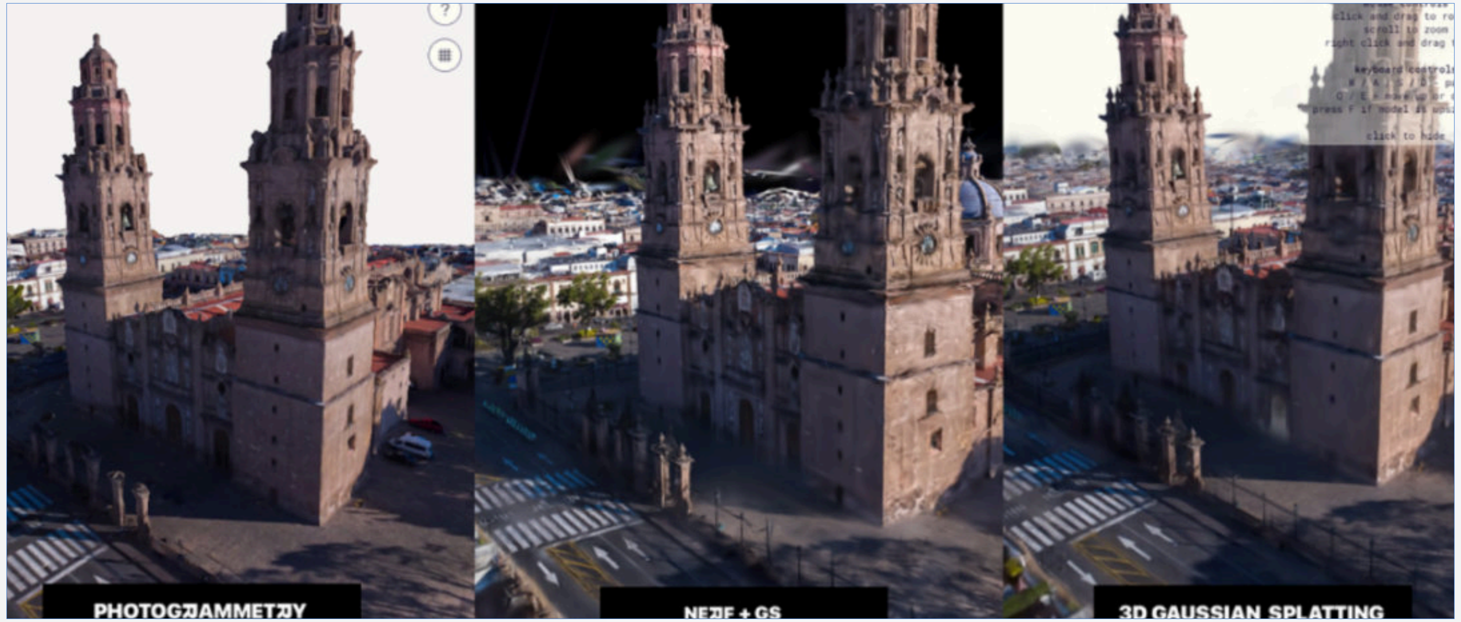
Two key techniques are at the forefront of this revolution: **Neural Radiance Fields (NeRFs)** and **Gaussian Splatting**. Both rely on 2D inputs—typically a set of images taken from different angles—to produce 3D representations. However, the way these methods approach the problem differs significantly, offering unique advantages depending on the use case.

NeRFs use a neural network to encode the 3D structure of a scene, allowing it to reconstruct the environment for multiple viewpoints. This method captures fine details and complex lighting interactions, making it particularly useful for applications requiring high-fidelity visualizations, such as virtual production or realistic 3D reconstructions. However, NeRFs are demanding, as rendering often requires significant processing power and time, which can be a limitation in real-time scenes.

In contrast, Gaussian Splatting simplifies the process by focusing on rendering from a single point of view. It relies on creating Gaussian "splats" (soft, circular points) to represent the 3D scene, which are faster to generate and render compared to NeRFs. This method trades off some visual complexity for efficiency, making it ideal for real-time applications such as live broadcasting, AR/VR experiences, or projects with limited computational resources.

NeRFs are being explored for creating ultra-realistic digital twins of real-world environments, enabling immersive virtual tours or simulations. Meanwhile, Gaussian Splatting is gaining traction in AR/VR development, where quick rendering is critical, such as interactive applications or hyper realistic live virtual production.

As these techniques evolve, as hardware accelerates and Generative AI models become more sophisticated, the possibilities for capturing and rendering reality in 3D will surely expand, unlocking creative opportunities.



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